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Herder Observations of Rangeland Change in Mongolia: Indicators, Causes, and Application to Community-Based Management

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Abstract

Local observations of ecological change are important in developing tools for rangeland management and filling in gaps where quantitative data are lacking. Traditional ecological knowledge (TEK) is a potential source of information that can complement scientific knowledge. It may also allow policy makers and scientists to suggest responses that will be locally relevant, and therefore effective on the ground. We conducted 40 surveys with the use of closed-ended questionnaires followed by open-ended qualitative questions with herders in two *soum* (administrative districts), located in the steppe and forest steppe of Mongolia. Respondents were asked about their observations of rangeland change and its causes in the last 20 yr. Across the study areas, a strong majority (75%) of all herders reported that rangeland condition was much worse than 20 yr ago. Herders in both *soum* reported increases in undesirable plant species, declines in species richness, and the disappearance or decreasing abundance of specific desirable plant species. Comparing the two *soum,* more herders in the forest-steppe site (90%) reported that rangeland condition was much worse than reported by herders in the steppe site (65%). In qualitative responses to open-ended questions, herders identified multiple indicators of and causes behind degradation, including very heavy grazing. In a large, sparsely populated country like Mongolia, herders' observations may serve as an early warning of rangeland change, provide insights into causes of change, and identify key uncertainties. Community-based rangeland management organizations (CBRMs) could help to translate herder observations into action by participating in formal monitoring based on herder-identified indicators and implementing changes in management in response to observed change. However, herders cannot address all issues that might be contributing to troubling ecological trends without higher-level policy coordinating rangeland monitoring and herder movements at regional and national scales.

Key Words: adaptive capacity, local knowledge, nomad, participatory monitoring, pastoralist, traditional ecological knowledge

INTRODUCTION

Pastoralists in Mongolia have always lived in extreme environments, but in the past 20 yr herders have faced additional challenges to managing rangeland sustainably posed by economic, social, political, and environmental changes, including climate change. In Mongolia, all rangelands are state property, held in common and managed by local herders with little government oversight and involvement. Although national law authorizes local government to regulate stocking rates and seasonal movements, local authorities have little capacity or resources to carry out this mandate (Fernández-Giménez and Batbuyan 2004; Fernández-Giménez et al. 2008). For this reason, herders' capacity and willingness to adapt their management to a changing environment depends in part on their ability to detect and respond appropriately to feedback from the ecological systems they manage at relevant spatial and temporal scales (Berkes et al. 2000; Reynolds et al. 2007). Adaptation also depends on functioning collective action institutions that provide enforceable guidelines governing rangeland use and ensure that all the users of a given area act upon this information in a coordinated fashion. This study investigates the nature of herder observations, and their explanations of causes of rangeland change, in two sites representative of two of Mongolia's dominant ecological zones, the steppe and forest steppe. In the context of emerging community-based institutions for rangeland management in Mongolia, we expect that herders' local observations, coupled with new community-based institutions, may play a key role in sustainable grazing management in a rapidly changing environment.

Current estimates of degradation in Mongolia, mainly based on remote sensing (Sankey et al. 2009; Hilker et al. 2013; Liu et al. 2013), point to sociopolitical as well as climatic causes; however, there is little scientific consensus on the extent or causes of recent rangeland changes in Mongolia (Addison et al. 2012). Further, the results of some field studies have not been consistent with conclusions from remote-sensing studies (Sternberg et al. 2011; Addison et al. 2012). Major economic,

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social, and political changes since the transition to a market economy and collapse of the collective herding system in the early 1990s affected herders' land-use patterns and livelihoods. The political and economic transitions led to changes in livestock mobility, a lack of formal or customary institutions governing pasture use, increased poverty and wealth disparities among herders (Fernández-Giménez 2002; Fernández-Giménez et al. 2012), growing livestock populations, and shifts in herd composition.

In addition to political and social changes, climate change is contributing to declines in forage production, diminishing water sources, and shifting boundaries of ecological zones in Mongolia (Batima et al. 2005; Angerer et al. 2008; Fassnacht et al. 2011; Venable et al. 2012; Hilker et al. 2013; Liu et al. 2013). The most pronounced changes were detected in mountainous regions, and to a lesser extent in the Gobi (Batima et al. 2005; Hilker et al. 2013; Liu et al. 2013), consistent with the documented northward expansion of the desert steppe (Angerer et al. 2008). A potential consequence of climate change in the last 40 yr is that rangeland productivity in grazing exclosures in the Gobi (Addison et al. 2012), and throughout Mongolia has declined by 20–30% (Angerer et al. 2008). Despite these challenges, pastoralism remains a fundamental part of Mongolian economy and culture, providing up to 40% of Mongolia's employment and 20.6% of the country's gross national product (Usukh and Binswanger-Mkhize 2010), in a country where 70% of the land mass is classified as rangeland.

Effective adaptation of grazing management in response to change depends on the ability to observe ecological change accurately (i.e., monitoring), and to alter management in response to observations (i.e., integration of information into rangeland management institutions and policy) (Berkes et al. 2000; Herrick et al. 2006; Batkhishig and Fernández-Giménez 2012; Fernández-Giménez et al. 2012). To address the gap in local government capacity to implement and enforce rangeland management laws, donors have facilitated and supported the establishment of over 2 000 community-based rangeland management herder organizations across Mongolia since 1999 (Mau and Chantsalkham 2006). In the absence of a standardized national rangeland monitoring system in Mongolia (Addison et al. 2012), traditional ecological knowledge (TEK) could be an important source of ecological observations to inform management responses to change. TEK is "a cumulative body of knowledge, practice and belief, evolving by adaptive processes and handed down through generations by cultural transmission" (Berkes 2008, p. 7). TEK is dynamic knowledge (Agrawal 1995) that accumulates and changes with new experiences and learning, as well as interactions with other forms of knowledge, including science (Huntington 2000; Thomas and Twyman 2004; Fazey et al. 2006; Berkes and Berkes 2009; Knapp and Fernández-Giménez 2009). Within a population, TEK may vary in terms of depth, range, and amount of knowledge possessed by individuals (Davis and Wagner 2003; Thomas and Twyman 2004; Knapp and Fernández-Giménez 2009). In past studies, TEK has filled in gaps at temporal and spatial scales where quantitative data may not exist (Huntington et al. 2004; Knapp et al. 2010). TEK can also engage local populations in decision-making processes about ecological management (Huntington 2000; Roba and Oba 2009; Knapp et al. 2010) and reduce the response time between when an ecological change was observed and management response implemented (Danielsen et al. 2000, 2005). Reynolds et al. (2007) urged that local environmental knowledge be valued and applied to combating desertification and advancing dryland development because it provides a long-term view of change where high interannual variability might mask long-term changes in "slow" variables.

Uncertainty about how to integrate TEK into a scientific framework might be reduced if we understood how indicators used by herders complemented or aligned with those used in formal ecological monitoring (Oba et al. 2007). In Mongolia, past research indicates that herder observations of rangeland systems in Mongolia reflect a strong understanding of ecological processes and change (Fernández-Giménez 1993, 2000; Marin 2010). Herders recognize different species and uses of plants and their relative nutritional value, and accurately estimate production (Fernández-Giménez 1993, 2000; Kakinuma and Takatsuki 2012). Herders have observed changes in climate (i.e., precipitation and temperatures) and rangeland conditions that scientific measurements have corroborated (Fassnacht et al. 2011; Addison et al. 2012; Venable et al. 2012).

Because herder observations may be a useful source of information on ecological change in Mongolia, and the important role that herders play in putting knowledge into practice (Kristjanson et al. 2009), the objectives of our study are 1) to document herder observations of ecological change in rangeland conditions over the past 20 yr, 2) to identify indicators of rangeland change used by herders, and 3) to describe herder explanations of causes driving change in rangeland conditions over the past 20 yr. With this research, we seek to identify and explore the usefulness of indicators that herders use as potential sources of information to monitor and adapt to ecological changes in Mongolia's rangelands.

We expected that herders' explanations of causes driving ecological change (i.e., livestock grazing and/or climate) would vary between the study regions (steppe versus forest steppe). Specifically, we hypothesized that herders in the forest steppe would attribute changes in rangeland condition to livestock grazing more than climate, as past research has shown that the forest steppe exhibits conventional Clementsian successional dynamics of vegetation change, whereas herders in the steppe would attribute changes to climate more than livestock grazing, as predicted by the nonequilibrium dynamics of vegetation change that partially characterize this ecological zone (Fernández-Giménez and Allen-Diaz 1999; Zemmrich et al. 2010; Cheng et al. 2011).

A final objective was to test if herder observations reflect regional differences in impacts due to climate change. We hypothesized that herders in the more mesic and northern study area (forest steppe) would observe greater changes in rangeland condition than herders in the more arid and southerly study area (steppe) because impacts of climate change are expected to be more severe in locations with inherently cooler temperatures and higher precipitation associated with higher latitudes (Yu et al. 2003; Batima et al. 2005; Intergovernmental Panel on Climate Change [IPCC] 2007; Angerer et al. 2008). Further, observed changes due to climate in Mongolia have been greater in mountainous areas compared to the desert steppe (Batima et al. 2005).

STUDY AREAS AND METHODS

Study Areas

Bayangol *soum* of Selenge *aimag* and Undurshireet *soum* of Tuv *aimag* (*soum* are similar to counties in the United States and *aimag* are similar to states) are located in the forest-steppe and steppe ecological zones, respectively. Stocking densities in sheep forage units (SFU), in which one sheep is equal to 1 SFU, a cow 5 SFU, a camel 6 SFU, a horse 7 SFU, and a goat 0.9 SFU, for Bayangol in 2010 consisted of 218 045 SFU per 186 868 ha, or 130 708 head of livestock composed of 6 839 horses, 12 628 cows, 69 155 sheep, and 42 086 goats. In Undurshireet in 2010, there were a total of 229 187 SFU per 262 349 ha, consisting of 144 039 livestock, composed of 43 camels, 10 381 horses, 7 130 cows, 70 335 sheep, and 56 150 goats (*Soum* Statistics 2010). Both *soum* are sites for the recent implementation of donor-sponsored community-based rangeland management projects: the United Nations Development Program's Sustainable Grassland Management Program (UNDP-SGM) in Bayangol (2004–2008) and the Swiss Agency for Development and Cooperation–funded Green Gold Pasture Ecosystem Management Program (SDC-GGPEM) in Undurshireet (ongoing since 2007).

The forest-steppe zone has higher mean annual precipitation (300–400 mm) than the steppe zone (125–250 mm; Jigjidsuren and Johnson 2003). Although local production data were not available for the two study *soum* at the time of writing, past studies in the forest steppe and steppe found that the forest steppe was characterized by higher production (500–800 kg ha^{-1}) compared to the steppe zone (300–400 kg ha^{-1}; Fernández-Giménez and Allen-Diaz 1999). Ecological data collected in the study *soum* during the summer of 2012 indicate that dominant perennial grass species in Bayangol are *Stipa krylovii* Roshev, *Cleistogenes squarrosa* (Trin.) Keng and *Poa attenuata* Trin. Other dominant vegetation consists of the palatable semishrub *Artemisia frigida* Willd., and two sedges, *Carex duriuscula* C. A. Mey. and *Carex korshinskyi* Kom. Higher precipitation and mountainous topography in the forest steppe near Bayangol support forests of *Larix siberica* Nois ex. Steud. Vegetation in Undurshireet is dominated by *Stipa krylovii* Roshev, and *Stipa gobica* Roshev. Other dominant vegetation includes the shrub *Kochia prostrata* (L.) Schrad, and *A. frigida* Willd. Bayangol and Undurshireet *soum* are both located within 200 km of Mongolia's capital, Ulaanbaatar, and both are located next to major rivers—the Kharaa River in Bayangol and the Tuuli River in Undurshireet. Both *soum* received considerable rain during the summers of 2010 and 2011, which signified the end to a multiyear drought. Because both of these sites are relatively mesic, and because of their location near the markets of Mongolia's capital, Ulaanbaatar, these areas face pressure from immigrants and livestock from drier and more remote regions of Mongolia.

Data Collection

Two researchers collected these data in the summer of 2011 in Bayangol *soum* of Selenge *aimag*, and Undurshireet *soum* of Tuv *aimag* of Mongolia as a part of a larger research project assessing the impacts of climate change and community-based management on Mongolia's rangelands. Face-to-face interviews were conducted with 20 participants in each *soum* for a total of 40 interviews. Interviewees were located with the help of a local guide, who we asked to direct us to the most knowledgeable herders in the area. Interviews ranged from 15 to 40 min in duration. Although who one considers "knowledgeable" can be subjective, the majority of interviewees had lived in the study area for at least two decades and were referred to us by their peers in addition to our guide (Davis and Wagner 2003). Knapp and Fernández-Giménez (2009) found that peer referrals were an effective way of identifying the most knowledgeable informants in a ranching community.

We first asked interviewees to complete a short closed-ended oral questionnaire about changes they observed in weather, stream flow, and rangeland conditions. After the closed-ended questionnaire was completed, we asked follow-up qualitative and open-ended questions related to their questionnaire responses. In this article we report only on observations about changes in rangeland conditions. When selecting a time frame with which to compare current trends in our questions, 20 yr ago (about 1991) was selected because it was a challenging and memorable time, marked by the transition from a centrally planned economy in a socialist state to a free-market economy and democratic system of government. This time frame represents economic and institutional changes that have implications for herder's land-use patterns, and has been used as a baseline in other studies (Sankey et al. 2009).

During the administration of the closed-ended questions, follow-up clarification and explanation was provided if an individual did not understand the question, and herders often elaborated on their answers to the questions. Closed-ended questions consisted of presenting herders with a question, and asking them to select the response that most reflected their observations based on a Likert-type scale (see Table 1 for questions and possible responses). Herders were given the opportunity to expand on their responses from the closed-end questionnaire portion of the interview.

Qualitative questions consisted of asking herders to define "degradation" (expressed in Mongolian as *doroitson gazar* (degraded land), *ulaan hairga* (red gravel), *halzgai gazar* (bald or denuded land), *belcheeriin talhlagdaj* (pounded or powdered rangeland), *gazriin talhlagdalt* (land reduced to powder) and to explain what caused it. We also asked herders to identify specific plant species that had increased or decreased.

Comparable numbers of male and female herders were interviewed in Bayangol and Undurshireet (10 female and 9 male interviewees in Bayangol plus one couple, and 6 females and 11 males in Undurshireet plus three couples). Average age of interviewees in both *soum* was 53. Average number of years of herding experience was 33 in Bayangol and 36 in Undurshireet. This research took place under Institutional Review Board Study Protocol 11-0245-00 from the University of Arizona.

Data Analysis

Differences in responses to the closed-ended questionnaire items between the study sites were assessed with the use of Pearson's X^2. Qualitative interview transcripts were transcribed and coded with the use of both emergent and a priori codes (Warren and Karner 2010). A priori codes were grounded in

Table 1. Mongolian herders' ($n = 40$) responses to survey questions of rangeland conditions in the present (2011) compared to 20 and 5 yr ago in two localities. Herders were asked to respond to three closed-ended questions about vegetation changes in the past 20 yr and one relative to 5 yr ago given the below response categories. A significant X^2 value indicates a significant difference between responses from the two *soum*.

Question	Response	Bayangol, Selenge, *aimag* % (*n*)	Undurshireet, Tuv *aimag* % (*n*)	Total % (*n*)	X^2	*P* value
Compared to 20 yr ago (1991), rangeland condition is:	Much worse	90 (18)	65 (13)	77.5 (31)	5.28	0.0215
	Somewhat worse	5 (1)	35 (7)	20 (8)	—	—
	Not sure	5 (1)	0	5 (1)	—	—
Compared to 20 yr ago (1991), have there been any changes in the overall number of different kinds of plants that grow here now?	The overall number of different plants has declined	90 (18)	80 (16)	85 (34)	1.31	0.52
	The overall number of different plants is the same	10 (2)	15 (3)	12.5 (5)	—	—
	Respondent was not here or not old enough to remember	0	5 (1)	2.5 (1)	—	—
	The overall number of different plants has increased	0	0	0	—	—
Have the kinds of plants that grow here now changed when compared to 20 yr ago (1991)?	The kinds of plants are the same as they were 20 yr ago	13.6 (3)	9.09 (2)	11.36 (5)	2.4	0.49
	We are seeing new kinds of plants we did not see 20 yr ago	13.6 (3)	9.09 (2)	11.36 (5)	—	—
	Some plants that used to grow here we no longer see or have become much more rare	72.7 (16)	72.7 (16)	72.72 (32)	—	—
	Respondent was not here or not old enough to remember	0	9.09 (2)	4.5 (2)	—	—
Compared to 5 yr ago (2006), rangeland condition is:	Much worse	10.5 (2)	15 (3)	20 (8)	11.21	0.0243
	Somewhat worse	10.5 (2)	30 (6)	10 (4)	—	—
	About the same	10.5 (2)	20 (4)	20 (8)	—	—
	Somewhat better	52.6 (10)	5 (1)	27.5 (11)	—	—
	Much better	15.8 (3)	30 (6)	17.5 (7)	—	—

Table 2. Indicators of degradation described by Mongolian herders. Data are the number of herders that mentioned each type of indicator in open-ended questions about defining degradation or in elaborations when answering closed-ended survey questions.

	Bayangol ($n=20$)		Undurshireet ($n=20$)		Total ($n=40$)	
Indicator of degradation	%	(n)	%	(n)	%	(n)
Kinds of plants growing are undesirable or not nutritious	80	(16)	60	(12)	70	(28)
Bare patches increasing/sand encroachment	40	(8)	45	(9)	42.5	(17)
Decreased production/plant size	20	(4)	40	(8)	30	(12)
Decreased number of plant species	5	(1)	10	(2)	7.5	(3)
Livestock body size decrease	0	—	10	(2)	5	(2)
Blowing sand or dust	5	(1)	5	(1)	5	(2)

our experience with herders and our research interest in indicators and causes of degradation. We developed emergent codes based on new, unanticipated themes that arose from the interviews. Once codes were developed, we read through the transcripts, assigning codes to passages of interview texts. Coding was conducted in Mongolian and key passages were translated to English for this article. We organized these codes and quotations in an Excel spreadsheet. We then summarized and compared the coded passages within and between study sites and calculated the frequencies of indicators and causes mentioned. Qualitative and quantitative results were evaluated and are presented together here to present a richer understanding of herder ecological observations, knowledge, and beliefs. Translated interview excerpts are included where useful to support our analysis and illustrate how herders express their knowledge. Plants that herders mentioned were identified with assistance from rangeland scientists in Mongolia, and plant identification publications (Jigjidsuren and Johnson 2003).

Limitations of Our Data

Our interviews were intended as rapid assessments of herders' observed changes, and not as in-depth ethnographic research. For this reason, we were unable to return to study areas to verify with respondents that our findings reflected their knowledge and experience. Our sample population, by design, reflected the views of herders who had lived in the study area for at least 2 decades. Opinions of less experienced, younger, and newer inhabitants of the area are not represented. Although herders were asked clarifying questions to their responses to qualitative questions, herders were not presented with, or asked to rank, explanations or indicators of degradation.

RESULTS

Quantitative and qualitative data expressed widespread observations of decline in rangeland conditions in the last 20 yr in the two study sites, but qualitative definitions of and explanations for degradation varied within and between sites.

Herder Observations of Rangeland Changes

Respondents in Bayangol (90%) were more likely to say that rangeland conditions were much worse than 20 yr ago, compared to 65% of respondents from Undurshireet ($X^2=5.28$, $P=0.02$). Remaining respondents either did not know, or felt things had gotten somewhat worse. It is notable that no respondent in either *soum* said that rangeland condition had gotten better, or had stayed the same, compared to 20 yr ago (Table 1). In the closed-ended questions, similar numbers of herders in both *soum* (90% in Bayangol and 80% in Undurshireet) observed a decrease in the number of different kinds of plant species in the past 20 yr (Table 1). A majority of herders in both Bayangol and Undurshireet (73% in each *soum*) observed decreasing prevalence or disappearance of some species they used to see in the rangeland (Table 1). A few herders reported observing unfamiliar species that they hadn't seen before (13.6% in Bayangol and 9.1% in Undurshireet). In contrast to 20 yr ago, herders in both *soum* observed some improvement in rangeland conditions when comparing current conditions with those 5 yr ago. Significantly more herders in Bayangol (53%) than Undurshireet (5%) said that conditions were somewhat better compared to 5 yr ago. More herders in Undurshireet (30%) than Bayangol (15%) said that conditions were much better now compared to 5 yr ago.

Herder-Identified Definitions and Indicators of Degradation

Herders in both Bayangol and Undurshireet used similar and multiple indicators to describe degradation (Table 2), including declining trends in rangeland production, species composition, and plant persistence.

Rangeland Production and Plant Vigor. Twenty percent of herders in Bayangol and 40% of herders in Undurshireet described degradation as a decrease in rangeland production. One herder in Bayangol described that 20 yr ago, the rangeland vegetation used to be "As high as a horse's belly." One example of a change in rangeland production observed by herders was reduced hay production, noting in Undurshireet that, "This place used to provide hay meadows for the national fund," but now production was greatly decreased. Similarly, in Bayangol, one herder observed that, "The hay fields grew nicely but have mostly stopped."

Decreased rangeland production was also marked by the observation of reduced reserves available for difficult periods during the year. One herder in Undurshireet expressed, "There's nothing (for the livestock) to eat in the winter or summer. In all the countryside the nice, yellow dry grasses from last year that the livestock would eat, now this nice thing is gone."

Herders in both *soum* described reduced plant vigor, observing that plants that were smaller and "dwarfed" now compared to 20 yr ago. Herders described plants and plant

roots as becoming "sparse," contributing to decreased rangeland growth.

Increases in Known, Undesirable Plant Species. The most common spontaneously identified indicator of rangeland degradation was the increase in known, undesirable plants. In qualitative responses, 80% of interviewees in Bayangol and 60% in Undurshireet described degradation as an increase in familiar undesirable species (Table 2). Herders in both *soum* noted an increase of *Artemisia adamsii* Bess. and *buduun uvs* or "thick plants," which are considered poor forage (Fernández-Giménez 2000; Kakinuma and Takatsuki 2012). In most cases, observations of ecological changes (e.g., increasing *A. adamsii* abundance) were accompanied by judgments about the forage value of a plant. Herders also reported an increase of unidentified weedy species, *hog urgamal* and *zerleg luuli*, "garbage plant" and "wild/undomesticated plant" respectively. "*Hog urgamal*" does not refer to a specific plant, but instead generally refers to weedy, ruderal species such as *Chenopodium album* L. and *A. adamsii* (J. Chantsallkham, personal communication, October 2013). Herders often described poor rangeland condition as *zerleg* or "growing wildly," suggesting "wild" is not a positive attribute to describe the kinds of plants in the rangeland.

One grass species thought to be increasing by a few respondents in each *soum*, *shivee* or *Stipa grandis* P.A. Smirn, is not considered a valuable forage species after awn emergence (Jigjidsuren and Johnson 2003). Some herders stated that they considered it "bad for livestock," and grouped it with *A. adamsii* when talking about the increase of undesirable plants.

Although many interviewees (Table 1) also identified the decline in the total numbers of different kinds of plants in the closed-ended questions, they were more likely to cite an increase in undesirable species in response to an open-ended question about degradation (Table 2). Only 5% of herders in Bayangol and 10% in Undurshireet cited a decline in the number of species as their primary indicator of degradation in the open-ended questions.

Decrease in Desirable Species. Herders observed a decrease in specific desirable plants, mostly valuable grasses (Table 2). Sixty-two percent of species said to be declining in Bayangol and 48% of those declining in Undurshireet were grass species, described as palatable and valuable plants elsewhere in interviews (i.e., "*nariin uvs*" or "thin grasses" which commonly refers to palatable grass species in the *Festuca*, *Poa, Koelaria*, and *Stipa* genera; see Fernández-Giménez 2000; Kakinuma and Takatsuki 2012).

Herders also recognized declines among many desirable species considered "good" for livestock, beyond grass species. For example, 100% of respondents in Undurshireet thought *Artemisia frigida* Willd., a palatable and nutritious half-shrub, to be decreasing. In Bayangol, five interviewees thought that plants of the *Allium* genus (wild onions), which are used in human food, hay, and dried animal feed (Jigjidsuren and Johnson 2003), were declining compared to 20 yr ago.

Though forage value was important in determining plant value, herders also described plants that had "persistence in the fall and winter" as valuable. One herder described, "The plants that were strong are thinning out."

Although herders in both *soum* reported a general decline in productivity, species composition, and species richness (Table 1), herders talked about some areas being worse than others. Specifically, herders mentioned that "degraded" areas were closer to the Tuuli River:

> The degraded places are many here and there. Hmmmm, well, always by the bank of the river and places close to the river but if you go a bit away from there to a remote place it is OK. The winter camps and such (are in reasonable condition).

Not all observers agreed on whether a particular species was increasing or decreasing. For example, in Bayangol, only 33% cited *A. frigida* as declining, whereas 66% reported no change, in contrast with 100% of Undurshireet herders who reported it as declining. In Bayangol *soum*, all herders who mentioned a species of the *Allium* genus felt that it was decreasing. In contrast, in Undurshireet, 45% believed that species from the *Allium* genus were decreasing, whereas 55% of interviewees believed these species were increasing.

Herders universally considered *A. adamsii* to be bad for livestock, explaining, for example that "By eating principally *sharilj* (*A. adamsii*) and the like livestock will get diarrhea," and not gain weight. Despite this, another herder observed that livestock were somewhat successful at adapting to eating less desirable species: "The grasses are not growing as much and weeds (*zerleg urgamal*) are growing a lot. Livestock now have learned to eat this vegetation. Due to their hunger they've learned to eat it."

Bare Ground, Encroaching Sand, and Livestock Body Size. In addition to an increase in undesirable species, the most common indicators of degradation cited by herders were an increase in bare ground or sand encroachment (45% in Bayangol and 50% in Undurshireet). Herders used a variety of phrases to describe bare ground, including "bald places" and "red gravel," translated literally (*haltzgai gazar, ulaan hairga*). One respondent described, "The rangeland is totally different now. Generally, sandy desertification is happening. Before there was almost no sand and now the movement of sand is becoming a lot." Increase in the amount of bare ground was often described in the context of increasing sand movement. Ten percent of herders in Undurshireet and none in Bayangol used reduced livestock body size as a secondary indicator of worsening rangeland (Table 2).

Causes of Degradation

Herders cited a range of causal factors to explain the negative changes they observed (Tables 3 and 4). Herders in both *soum* identified similar causes of degradation, but with differing frequencies. Interviewees rarely mentioned only one cause, and more typically cited two or three as possible explanations. The most common explanations were overstocking of the range, reduced precipitation, warming temperatures, lack of government support, desertification, and the type of livestock grazed (Tables 3 and 4).

Overstocking. Double the number of herders in Bayangol (60%) cited overstocking as a cause of degradation compared

Table 3. Causes of decline of rangeland described by Mongolian herders. Data are the number of herders who mentioned a specific explanation in open-ended questions, or in elaborations when answering closed-ended survey questions. *Otor* refers to rapid and sometimes long-distance movements of livestock for fattening before winter or to avoid a shortage of forage, as may occur in a drought or *dzud* (Fernández-Giménez et al. 2012).

	Bayangol ($n = 20$)		Undurshireet ($n = 20$)		Total ($n = 40$)	
Explanation of decline	%	(*n*)	%	(*n*)	%	(*n*)
Too many livestock	60	(12)	30	(6)	45	(18)
Reduced precipitation	45	(9)	40	(8)	42.5	(17)
Migration from other areas/undefined boundaries/*otor*	40	(8)	40	(8)	40	(16)
Plants/plant roots shrinking or weakening	35	(7)	40	(8)	37.5	(15)
Lack of government/legal support	20	(4)	25	(5)	22.5	(9)
Drought/*dzud*/desertification	25	(5)	20	(4)	22.5	(9)
Changes in temperature	20	(4)	15	(3)	17.5	(7)
Kinds of livestock	15	(3)	5	(1)	10	(4)
Reduced migration/movement/increasing sedentary lifestyle	10	(2)	10	(2)	10	(4)
Dust/wind	5	(1)	10	(2)	7.5	(3)
Changes in the timing of precipitation	5	(1)	—	—	2.5	(1)
Nature is getting old	5	(1)	—	—	2.5	(1)
Poor distribution of households because of poor access to watering points	—	—	15	(3)	7.5	(3)

to Undurshireet (30%). Herders described the impacts of overstocking in a variety of ways, including excessive trampling of the ground by livestock, and an increase in species of livestock that were perceived to be more destructive by herders, such as horses and goats (Tables 3 and 4). The weakening of plant roots due to livestock grazing or sand accumulation was connected to decreased rangeland growth in both Bayangol (35% of respondents) and Undurshireet (40%).

A few herders characterized the impact of overstocking as "hoofed *dzud*." *Dzud* is a Mongolian term that refers to a natural disaster resulting in the death of large numbers of livestock, especially related to a harsh winter (Begzsuren et al. 2004). *Dzud* can describe a range of conditions that reduce forage availability, such as excessive snowfall, sudden temperature changes accompanied by wind or ice cover in the rangeland that make forage unavailable, or a snowless winter (Begzsuren et al. 2008). A hoofed *dzud* refers to excessive trampling and grazing by livestock that causes soil compaction and eliminates vegetation (Fernández-Giménez et al. 2012).

Unregulated Rangeland Use. Forty percent of interviewees in each *soum* identified multiple issues associated with unregulated rangeland use as causing rangeland degradation, including 1) immigration of people and livestock from other regions of Mongolia that lead to overstocking of the local *soum* range, 2) poorly defined *soum* boundaries leading to use by herders from other districts, and 3) lack of leadership coordinating rangeland use at the *soum*, *aimag*, and national levels. Herders mentioned livestock coming for *otor* as problematic and contributing to overgrazing. *Otor* does not have a direct translation in English, but refers to movements of livestock for fattening before winter or to avoid a shortage of forage, as may occur in a drought or *dzud* (Humphrey and Sneath 1999; Fernández-Giménez et al. 2012). Twenty percent of herders in Bayangol and 25% in Undurshireet expressed dissatisfaction with a lack of government support and collaboration on issues of rangeland access and promoting secure rights to use rangelands.

Lack of Infrastructure. Herders also cited infrastructure-related causes of degradation. In Undurshireet, 15% of herders spoke of damaged or defunct wells that limited access to remote range, and consequently resulted in overgrazing in some areas, whereas others went underutilized. Other herders spoke of the lack of organization and/or infrastructure to promote protection of hay fields.

Reduced Migration. Ten percent of herders in both Bayangol and Undurshireet spoke of reduced nomadic movement as a cause of degradation (Tables 3 and 4). Another herder described degraded areas as "places around settlements," and reported that degradation occurred when families made camps too close to one another, suggesting a perceived relationship between high livestock and human densities and degradation.

Kinds of Livestock. Fifteen percent of herders in Bayangol and five percent in Undurshireet implicated the kind of grazing animal as a cause of degradation. Among herders, horses and goats were considered disproportionately damaging to the rangeland compared to other livestock (Table 4).

Meteorological and Hydrological Changes

Herders observed feedback loops between precipitation and vegetation and used this to explain rangeland declines. Herders expressed the view that decreased precipitation resulted in decreased vegetation, which reduced soil protection from wind and created less favorable growing conditions for plants.

Reduced or Altered Precipitation. In both Bayangol and Undurshireet, similar numbers of respondents (45% in Bayangol and 40% in Undurshireet) explained that the declining rangeland condition was due to reduced precipitation. Herders described decreased precipitation as directly reducing vegetation growth. Five percent of herders in Bayangol and 10% in Undurshireet saw reduced precipitation as increasing the amount of blowing dust and soil, and as causing degradation, "Rain doesn't come, the 'red dust' blows all over is the reason degradation is appearing." Herders

Table 4. Illustrative quotations of Mongolian herders' explanations of the causes for rangeland degradation.

Explanation of decline	Illustrative quotation
Too many livestock	"The rangeland is really being overworked." (Bayangol) "Livestock have exceeded carrying capacity, and for this reason the vegetation is getting worse." (Bayangol)
Reduced precipitation	"In recent years, for the reason that moisture is insufficient plants stopped growing and bare patches are increasing. Very little rain is coming. [The decline in rangeland growth] is connected to this." (Undurshireet)
Migration from other areas/undefined boundaries/*otor*	"After 1990, after the privatization, it's becoming unpleasant. From 94–95 there was drought and *dzud* and herders from Uvurhangai and Dundgobi came in and the livestock has exceeded the carrying capacity, and hoofs *dzud* is taking place." "The numbers of households are increasing. Distance between households is decreasing, so these places are becoming bare because families set up their homes too close to one another." (Undurshireet)
Plants/plant roots shrinking or weakening	"When good palatable plants grow, and livestock eat them, the roots come out by grazing. That's why I think the plants roots became worse and the plants kinds became fewer. So the kinds of plants are decreasing." (Undurshireet)
Lack of government/legal support	"Because there has been no decision from the local administrators that should fix this, there is a lot of arguing between herders from different *soum*." (Undurshireet)
Drought/*dzud*/desertification	"In recent years there has been consecutive drought and because of this the plants dry out and die. The rangeland has declined in the past 20 years and above all sand has come in. Now desertification is happening is what I think. But, if rain comes it can turn things around." (Bayangol)
Changes in temperature	"In recent years, climate change is affecting us, in the winter it is very cold, summer is really hot and the natural world is changing very much." (Undurshireet) "In my opinion, the plants dry out because right before the summer when the plants are forming, it heats up. In this way, I think that the drought affects the plants." (Bayangol)
Kinds of livestock	"The rangeland is being abused. Out of livestock, the worst animal for the range is the horse. It kills and eats the roots and turns over the soil. Cows eat with their tongues and for this reason are OK." (Bayangol)
Reduced migration/movement/increasing sedentary lifestyle	"In recent years, among herders there has been a shift to a more sedentary lifestyle. This means that no matter if households have few livestock or many, [they] usually don't move and do not change ranges and just stay in one place and build their house and settle in one place. Almost all households are like this. From this the rangeland is declining and those settlements sites are getting bare particularly within 500 mile radius of the settlement" (Bayangol)
Dust/wind	"Grass becomes scarce and land is becoming bare because the spring is too windy. Spring storms pull out vegetation by the roots and turn up the soil and that's why it is becoming bare." (Undurshireet)
Changes in timing of precipitation	"The plants sprout in May and don't sprout in July. For that reason now this rain that's here now (in July) is too late." (Bayangol)
Poor distribution of households because of poor access to watering points	"This degraded rangeland has grown a lot for the reason that the watering spots are very few and all the livestock crowd together around these areas, so bare spots emerge with great compaction. It has all recently become like this. In our area there is the problem that several wells in this area are exhausted." (Undurshireet)

connected sand accumulation with reduced plant growth, "In recent years, dust storms have increased a lot. The plant roots have stopped growing because of the accumulation from the sand storms." Herders explained that dust storms caused plant roots to shrink, as well as shrunken plants roots contributing to increased dust storms. One herder attributed the decreased plant root growth to aging plant roots and the aging of the natural world in general. One herder reported that the timing of precipitation also was causing degradation. He felt that rains came late, not when plants were first forming, and this resulted in plants not growing to their full potential. One herder mentioned extreme variation between years as exacerbating rangeland decline. Far more herders stated that weather and precipitation departed from how it used to be than cited climate change specifically (5%).

Temperature Increases, Drought, Wind, and Desertification. A few herders (20% in Bayangol and 15% in Undurshireet) observed that temperature increases, and timing of these increases, affected vegetation. For example, one herder expressed, "In my opinion, the plants dry out because right before the summer when the plants are forming, it heats up. In this way, I think that the drought affects the plants." Ten

percent of herders in each *soum* mentioned drought or (weather-driven) *dzud*.

Wind was identified as a phenomenon affecting rangeland decline by 5% of herders in Bayangol and 10% of herders in Undurshireet. Herders described excessive spring wind as inhibiting plant growth (Table 2).

Equal percentages of interviewees (15%) in each *soum* offered "desertification" as an explanation for rangeland decline. Despite the fact that none of the interviewees explained what they meant by "desertification," it was often cited in conjunction with increased movement of sand and reduced precipitation.

More Than One Cause. Sixty-eight percent and 67% of herders in Bayangol and Undurshireet, respectively, named more than one cause as causing degradation. For example, one herder described:

> Usually, precipitation is low so that's why it's like this. Well now, the *otor* livestock from outside, and the people coming for otor are a lot so the pressure of the livestock is becoming too much. Usually, this wouldn't happen in this area. Now, there's a lot of livestock and there is desertification and livestock come and from that desertification now plants have stopped their growing. That's the first reason. The second is that now precipitation is lower. But now starting last year it's OK, things are getting refreshed.

Other herders expressed uncertainty about which cause is responsible for changes, "The rangeland yield is becoming much worse: it could be changing from year to year depending on precipitation, or from the increase in livestock."

Observed Improvement in the Past Five Years

Herders were more optimistic about trends observed over the last 5 yr (Table 1). Explanations for the recent improvement in rangeland consisted of both a weather-related explanation and a management-related one. Herders cited the end of a multiyear drought with the return of precipitation in summers 2010 and 2011. In Bayangol, several respondents cited the UNDP-SGM community-based rangeland management project, which helped enable pastoral migrations and allowed areas of the rangeland to rest and recover. At least one herder spoke favorably about this project's organized removal of *A. adamsii*, which she believed increased the prevalence of more desirable plants.

DISCUSSION

Herders in both *soum* observed negative changes in the past 20 yr in a variety of indicators, and used a suite of causes to explain degradation. Consistent with our expectations, Bayangol forest-steppe herders were more likely to cite livestock overgrazing over precipitation as a driving factor in vegetation change compared to steppe herders in Undurshireet. Observations in the two *soum* partially support our hypothesis that herders in Bayangol would observe greater changes in rangeland condition because the greater impacts due to climate change are expected in the forest steppe versus the steppe. The following discussion further explores indicators and causes described by herders. We examine what these observations might mean in terms of early warning of change, and the potential for integration with management through community-based rangeland management organizations (CBRMs).

Indicators Herders Used to Assess Degradation

Indicators identified by herders included observations of increasing bare ground, decreasing production, less desirable species composition, and declining species richness, which are similar to variables scientists measure to detect degradation on rangelands (de Soyza et al. 1998; Elzinga et al. 1998; Whitford et al. 1998; Herrick et al. 2005; Pellant et al. 2005). In our interviews, local knowledge and scientific knowledge converged on similar indicators, thus strengthening the credibility of these indicators in terms of their ecological significance and management utility in this context. Herders often made observations of more than one variable, perhaps reflecting a holistic view of a complex system (Reed et al. 2008; Berkes and Berkes 2009). Herders in both *soum* cited similar indicators (i.e., shift to less desirable plant composition, increasing bare patches), which suggests that similar indicators may be adapted for use across different regions (Oba 2012). The convergence of indicators used by herders and in formal ecological monitoring suggests a way to overcome uncertainties about how to integrate local knowledge with formal monitoring (Oba et al. 2007). For example, enlisting and training herders to take rapid and repeatable quantitative or qualitative measurements of the indicators they have already identified as key could help bridge the capacity and resource gap in formal rangeland monitoring in Mongolia and provide a much-needed source of information to inform local management decisions. This kind of training in rangeland monitoring techniques has been successfully carried out in some CBRM project sites, demonstrating the feasibility of herder monitoring in Mongolia (Batkhishig and Fernández-Giménez 2012). Future efforts could support the dissemination of knowledge from the most experienced herders, and facilitate integration of this knowledge into management decisions. Implementing such an effort could not only increase the capability of herders to respond to observed change at the local level, but potentially provide data needed to inform rangeland management institutions at the *aimag* and national levels.

Mongolian pastoralists in this study cited vegetation or soil variables as indicators of rangeland health much more frequently compared to livestock body condition, whereas herders in other pastoral systems (Fernández-Giménez and Fillat Estaque 2012; Oba 2012) used body condition more frequently. This could have been a result of the format of the interview, where closed-ended questions about rangeland condition were administered prior to open-ended questions. It is possible more people would have cited livestock body condition if closed-ended questions had been less focused on vegetation attributes. For example, another researcher found that in Arkhangai and Omnogobi, herders did cite livestock weight and meat quality as indicators of rangeland quality (L. Bonilla, personal communication, October 2012). We recommend additional qualitative interviewing of herders over a larger range of ecosystems in Mongolia to identify a full suite of

indicators relevant within and between Mongolia's diverse rangeland types.

Herder Understanding of the Causes of Rangeland Change

Consistent with what is known about the causes and dynamics of vegetation change in the steppe and forest steppe (Fernández-Giménez and Allen-Diaz 1999; Zemmrich et al. 2010; Cheng et al. 2011), herders in Bayangol were more likely to attribute rangeland degradation to grazing-related factors compared to herders in Undurshireet, who more often saw climate as the driver of change. Past research found that steppe vegetation dynamics can exhibit characteristics of both nonequilibrium and equilibrium systems (i.e., steppe dynamics appear to be driven by both climate and grazing depending on the variable observed) but that the forest steppe exhibits characteristics of equilibrium dynamics (i.e., grazing intensity is the primary driver of vegetation change) (Fernández-Giménez and Allen-Diaz 1999; Zemmrich et al. 2010). Herder explanations of causes in the two *soum* reflected these underlying dynamics.

Potential Local Impacts of Climate Change Observed by Herders

Consistent with our hypothesis that observed effects of climate change would be greater in more mesic regions located at higher latitudes, herders in Bayangol were more likely to say that overall rangeland condition was much worse compared to 20 yr ago than herders in Undurshireet. However, there were no significant differences between *soum* in responses to other questions about changes in the kind of species or the number of different kinds of species over the same time period. Based on herders' qualitative comments, we therefore infer that declines in production are the main factor that accounts for the differences in herders' assessments of rangeland condition in the two study areas. This conclusion aligns with scientific observations of a 20–30% decline in productivity in grazing exclosures over the last 40 yr (Angerer et al. 2008) and remotely sensed decline in aboveground biomass in the past 21 yr in the northern regions of Mongolia (Sankey et al. 2009; Hilker et al. 2013; Liu et al. 2013). Because herders in Bayangol attributed their observed changes to livestock more often than climate, we speculate that observations of more extreme general decline in Bayangol's rangeland conditions reflect greater cumulative and interacting impacts of climate and grazing, compared to Undurshireet.

Although our interpretation of the causes of change described by herders is speculative, herders in both *soum* observed rangeland changes that are consistent with scientific observations (Sankey et al. 2009) and predictions of reduced production and the northward expansion of the desert steppe associated with climate change (Yu et al. 2003; Batima et al. 2005; Angerer et al. 2008; Hilker et al. 2013). For example, some herders in both *soum* described that the influence of warmer temperatures (20% in Bayangol and 15% in Undurshireet) and reduced precipitation (45% in Bayangol and 40% in Undurshireet) resulted in stunted plant growth. Highly variable and reduced precipitation and warmer temperatures may be characteristics of the northward spread of the desert steppe into regions previously characterized by equilibrium dynamics. Determining the interacting roles of grazing, climate, and climate change on specific vegetation variables is complex, and is an area where scientific investigation, or integrated knowledge systems (Reynolds et al. 2007; Karl et al. 2012) including TEK, may be important for designing future research and policy to address causes of rangeland decline. However, regardless of whether or not herders know the specific causes behind rangeland decline, herders in Undurshireet and Bayangol will need to continue to adjust livestock grazing practices in response to shifting rangeland dynamics and reduced and increasingly variable forage production.

Observations as an Early Warning of Change

Perhaps because of the interacting effects of climate change and changes in grazing management, in our interviews, the majority of herders observed general decline, and remembered rangeland condition as better or much better in 1991. Notably, herder perceptions of rangeland condition 20 yr ago were mainly positive in comparison with the present, despite the economic and social hardship that characterized the early 1990s in Mongolia. In contrast, in our interviews herder observations diverged from those in research conducted during the early 1990s, wherein herders in Mongolia regarded rangeland degradation as temporary, reversible, and localized (Fernández-Giménez 1993; Sneath 1998; Fernández-Giménez 2000). More recent research in the forest steppe has also documented herder observations of general decline in rangeland conditions (Kakinuma et al. 2008). In this study, herder knowledge demonstrated widespread consensus that conditions were declining compared to what they remembered 20 yr ago, which aligns with evidence from other lines of inquiry such as remote sensing (Sankey et al. 2009; Hilker et al. 2013; Liu et al. 2013). Although some herders in our study reported improvement in rangeland condition in the last 5 yr, consensus was strong that even with recent improvement reported by some herders, conditions were still perceived as worse than 20 yr ago. If adaptation depends on detection of change in the ecological systems and an appropriate response (Berkes et al. 2000), then TEK in this study suggests that herders are not limited by their ability to detect undesirable change, but instead by their capacity to act on this knowledge through rangeland management practices.

The Role of Community-Based Rangeland Management Organizations

Adaptation to ecological change depends on incorporating observations of change into proactive rangeland management practices. Formal community-based rangeland management organizations (CBRMs) were organized in Mongolia starting in the late 1990s, and recent studies have examined their efficacy at building social capital and contributing to sustainable rangeland management (Upton 2008; Batkhishig and Fernández-Giménez 2012; Fernández-Giménez et al. 2012; Leisher et al. 2012; Addison et al. 2013). Although there are many factors including natural assets, local government, and local weather conditions that influence herder ability to manage rangelands and respond to extreme events (Fernández-Giménez et al. 2012), knowledge exchange and the opportunity to learn from diverse knowledge sources increased the adaptive capacity of

herders who were part of CBRMs (Batkhishig and Fernández-Giménez 2012). In case studies, CBRMs increased adaptive behavior by helping to apply lessons from the past events in preparation for the future, and facilitating collective decision-making (Fernández-Giménez et al. 2012). In our interviews, there was broad recognition of weak institutions as one cause of undesirable rangeland change, suggesting community recognition of a problem, and the potential desire for alternative management. CBRMs may provide one avenue to bridge the gap between knowledge and action by providing a forum where observations can be applied to management at the local scale.

Transhumance: Adapting Practices to Changing Rangeland Dynamics. CBRMs may also benefit sustainable rangeland management by encouraging traditional seasonal migrations or transhumance. A few herders in each *soum* stated that lack of migrations was contributing to rangeland degradation. There is a strong ecological rationale behind the practice of transhumance, which gives vegetation in grazed areas a recovery period between uses and helps match the physiological and nutritional demands of livestock with energy and nutrients available in diverse habitats across seasons and landscapes. A study comparing reported degradation in Mongolia, Inner Mongolia (People's Republic of China), and Buryiata (Russia) in the 1990s found that areas with the least pastoral mobility experienced the highest levels of reported degradation and lowest vegetation cover in a satellite image, despite comparable stocking numbers in more mesic zones (Sneath 1998). Transhumance has been found to be an effective coping strategy for severe events like drought in pastoral systems throughout the world (Ellis and Swift 1988; Oba 2001; Nyong et al. 2007). Management, infrastructure, and policy that support the traditional practice of transhumance could potentially increase herders' ability to adapt, while providing ecological benefits for the rangeland and enhancing the overall sustainability of pastoral social–ecological systems.

Furthermore, transhumance could become even more important as a strategy to prevent further degradation in the face of changing rangeland dynamics in the steppe and forest steppe. Because transhumance responds both to rangeland change caused by climate and change caused by overstocking, it might be an effective strategy to prevent degradation even when precise causes of change are unknown in the short term.

Policy Support for Herders: Limitations of CBRMs and Transhumance. Despite the observations of rangeland condition decline and identification of plausible causes, and the existence of adaptive practices such as transhumance and community-based management organizations to help implement them in some areas, effective management and policy responses may exceed local herders' observational capacity and sphere of influence. Herders in one place may move elsewhere in response to observations of local change in order to conserve their local range, but without regional-scale monitoring information, they cannot see the cumulative impacts of their decisions across the larger landscape. Fernández-Giménez et al. (2012) found that weak cross-boundary rangeland management institutions increased herder vulnerability to extreme climate events such as *dzud*. Although herders within one *soum* may successfully organize to monitor rangeland and regulate their seasonal movements, they have little control over herders from other *soum* who enter their territory to escape drought or *dzud*. Without better cross-boundary coordination of movements, enforceable guidelines governing rangeland use, and economic incentives for herders to manage land sustainably (Fernández-Giménez et al. 2012), CBRMs provide only a partial solution. Herders in our interviews observed rangeland decline; however, this knowledge cannot be effectively used to prevent further negative changes without higher-level institutional support to address cross-boundary and regional- and national-level livestock mobility. Although a history of managing risk in uncertain environments does provide herders and ranchers with tools to address future change outside the range of historic variability (Ash et al. 2012), more proactive adaptation is necessary because existing coping strategies are likely inadequate to meet future challenges (such as increased immigration resulting from spatial variability in extreme events; Reynolds et al. 2007; Ash et al. 2012). Herder TEK may be necessary for adaptation, but may not be sufficient given the rate and scale of change. Integrated knowledge systems (Karl et al. 2012) that use herders' informal observations, participation in formalized monitoring, and science might help design and inform the institutions and policy needed to adapt to current and future environmental changes in Mongolia.

IMPLICATIONS

Ecological monitoring is thought to play a key role in increasing resilience to climate change in pastoral social–ecological systems (Angerer et al. 2008; Fernández-Giménez et al. 2012). Herders in this study described indicators that converge with and complement scientific observations, and can contribute to a more robust understanding of ecological change. Past research has shown that when local people are involved in identifying monitoring indicators and carrying out monitoring, the resulting information is more likely to be applied to management in a timely manner (Danielsen et al. 2005). Herder observations may signal that potentially irreversible changes in some Mongolian rangeland ecosystems are underway. Building on herder observations and indicators, the time is right to engage Mongolian herders in formal rangeland monitoring in a broader and more systematic way. The challenge herders face is applying their knowledge to management at appropriate social, spatial, and temporal scales to avoid further undesirable rangeland change. CBRMs may increase adaptive capacity at a local level by helping integrate herder TEK and observations into monitoring and management, and coordinating rangeland use and transhumance movements (Batkhishig and Fernández-Giménez 2012). However, CBRMs are only a partial solution, and higher-level institutions are needed to facilitate coordinated rangeland monitoring at a national scale and to regulate and coordinate cross-boundary and cross-region livestock movements. Rapid and repeatable rangeland monitoring techniques, informed by TEK, could provide a needed feedback loop between local ecological changes, adaptive grazing management at a local level, and rangeland policy development and implementation at regional and national levels.

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LITERATURE CITED

Addison, J., J. Davies, M. Friedel, and C. Brown. 2013. Do pasture user groups lead to improved rangeland condition in the Mongolian Gobi Desert? *Journal of Arid Environments* 94:37–46.

Addison, J., M. Friedel, C. Brown, J. Davies, and S. Waldron. 2012. A critical review of degradation assumptions applied to Mongolia's Gobi Desert. *Rangeland Journal* 34:125–137.

Agrawal, A. 1995. Dismantling the divide between indigenous and scientific knowledge. *Development and Change* 26:413–439.

Angerer, J., G. Han, I. Fujisaki, and K. Havstad. 2008. Climate change and ecosystems of Asia with an emphasis on Inner Mongolia and Mongolia. *Rangelands* 30(3):46–51.

Ash, A., P. Thornton, C. Stokes, and T. Chuluun. 2012. Is proactive adaptation to climate change necessary in grazed rangelands? *Rangeland Ecology & Management* 65:563–568.

Batima, P., J. Natsagdorj, P. Gombluudev, and B. Erdenetsetseg. 2005. Observed climate change in Mongolia. AIACC Working Paper No. 12. 25 p.

Batkhishig, B., and M. E. Fernández-Giménez. 2012. Meaningful learning for resilience-building among Mongolian pastoralists. *Nomadic Peoples* 16:52–77.

Begzsuren, S., J. E. Ellis, D. S. Ojima, M. B. Coughenour, and T. Chuluun. 2004. Livestock responses to drought and severe winter weather in the Gobi Three Beauty National Park, Mongolia. *Journal of Arid Environments* 59:785–796.

Berkes, F. 2008. Sacred ecology. 2nd ed. Philadelphia, PA, USA: Taylor & Francis. 313 p.

Berkes, F., and M. K. Berkes. 2009. Ecological complexity, fuzzy logic and holism in indigenous knowledge. *Futures* 41:6–12.

Berkes, F., J. Colding, and C. Folke. 2000. Rediscovery of traditional ecological knowledge as adaptive management. *Ecological Applications* 10:1251–1262.

Cheng, Y., M. Tsubo, T. Y. Ito, E. Nishihara, and M. Shinoda. 2011. Impact of rainfall variability and grazing pressure on plant diversity in Mongolian grasslands. *Journal of Arid Environments* 75:471–476.

Danielsen, F., D. Balete, M. K. Poulsen, M. Enghoff, C. M. Nozawa, and A. E. Jensen. 2000. A simple system for monitoring biodiversity in protected areas of a developing country. *Biodiversity and Conservation* 12:1671–1705.

Danielsen, F., A. E. Jensen, P. A. Alviola, D. S. Balete, M. Mendoza, A. Tagtag, C. Custodio, and M. Enghoff. 2005. Does monitoring matter? A quantitative assessment of management decisions from locally-based monitoring of protected areas. *Biodiversity and Conservation* 14:2633–2652.

Davis, A., and J. R. Wagner. 2003. Who knows? On the importance of identifying ''experts'' when researching local ecological knowledge. *Human Ecology* 31:463–489.

de Soyza, A. G., W. G. Whitford, J. E. Herrick, J. W. Van Zee, and K. M. Havstad. 1998. Early warning indicators of desertification: examples of tests in the Chihuahuan Desert. *Journal of Arid Environments* 39:101–112.

Ellis, J. E., and D. M. Swift. 1988. Stability of African pastoral ecosystems: alternate paradigms and implications for development. *Journal of Range Management* 41:450–459.

Elzinga, C. L., D. W. Salzer, and J. W. Willoughby. 1998. Measuring and monitoring plant populations. Denver, CO, USA: Bureau Land Management, Department of Interior, 1730-1. 477 p.

Fassnacht, S. R., T. Sukh, M. E. Fernández-Giménez, B. Batbuyan, N. B. H. Venable, M. Laituri, and G. Adyabadam. 2011. Local understandings of hydro-climatic changes in Mongolia. *In:* Proceedings of the Cold Region Hydrology in a Changing Climate Symposium as part of the International Union of Geodesy and Geophysics Conference; 28 June–7 July 2011; Melbourne, Australia. Wallingford, UK: International Association of Hydrological Sciences Publication 346, pp. 120–129.

Fazey, I., J. A. Fazey, J. G. Salisbury, D. B. Lindenmayer, and S. Dovers. 2006. The nature of experimental knowledge for environmental conservation. *Environmental Conservation* 33:1–10.

Fernández-Giménez, M. E. 1993. The role of ecological perception in indigenous resource management: a case study from the Mongolian forest-steppe. *Nomadic Peoples* 33:31–46.

Fernández-Giménez, M. E. 2000. The role of Mongolian nomadic pastoralists' ecological knowledge in rangeland management. *Ecological Applications* 10:1318–1326.

Fernández-Giménez, M. E. 2002. Spatial and social boundaries and the paradox of pastoral land tenure: a case study from postsocialist Mongolia. *Human Ecology* 30:49–78.

Fernández-Giménez, M. E., and B. Allen-Diaz. 1999. Testing a non-equilibrium model of rangeland vegetation dynamics in Mongolia. *Journal of Applied Ecology* 36:871–885.

Fernández-Giménez, M. E., and B. Batbuyan. 2004. Law and disorder: local implementation of Mongolia's land law. *Development and Change* 35:141–165.

Fernández-Giménez, M. E., B. Batkhishig, and B. Batbuyan. 2012. Cross-boundary and cross level dynamics increase vulnerability to severe winter disasters (dzud) in Mongolia. *Global Environmental Change* 22:836–852.

Fernández-Giménez, M. E., and F. Fillat Estaque. 2012. Pyrenean pastoralists' ecological knowledge: documentation and application to natural resource management and adaptation. *Human Ecology* 40:287–300.

Fernández-Giménez, M. E., A. Kamimura, and B. Batbuyan. 2008. Implementing Mongolia's land law: progress and issues. *In:* Final report to the Central Asian Legal Exchange. Nagoya, Japan: Central Asian Legal Exchange, Nagoya University. 45 p.

Herrick, J. E., B. T. Bestelmeyer, S. Archer, A. J. Tugel, and J. R. Brown. 2006. An integrated framework for science-based arid land management. *Journal of Arid Environments* 65:319–335.

Herrick, J. E., J. W. Van Zee, K. M. Havstad, L. M. Burkett, and W. G. Whitford. 2005. Monitoring manual for grasslands, shrublands and savanna ecosystems. Volume II. Las Cruces, NM, USA: USDA-ARS Jornada Experimental Range. 200 p.

Hilker, T., E. Natsagdorj, R. H. Waring, A. Lyapustin, and Y. Wang. 2013. Satellite observed widespread decline in Mongolian grasslands largely due to overgrazing. *Global Change Biology*. doi:10.1111/gcb.12365

Humphrey, C., and D. Sneath. 1999. The end of nomadism? Society, the state and the environment in Inner Asia. Durham, NC, USA: Duke University Press. 355 p.

Huntington, H. P. 2000. Using traditional ecological knowledge in science: methods and applications. *Ecological Applications* 10:1270–1274.

Huntington, H. P., T. Callaghan, S. Fox, and I. Krupnik. 2004. Matching traditional and scientific observations to detect environmental change: a discussion on Arctic terrestrial ecosystems. *Ambio Special Report* 13:18–23.

[IPCC] Intergovernmental Panel on Climate Change. 2007. Fourth Assessment Report: Climate Change 2007. Available at: http://www.ipcc.ch/publications_and_data/ar4/syr/en/spms1.html. Accessed 18 July 2012.

Jigjidsuren, S., and D. A. Johnson. 2003. Forage plants of Mongolia. Ulaanbaatar, Mongolia: Admon Publishing. 563 p.

Kakinuma, K., T. Ozaki, S. Takatsuki, and J. Chuluun. 2008. How pastoralists in Mongolia perceive vegetation changes caused by grazing. *Nomadic Peoples* 12:67–73.

Kakinuma, K., and S. Takatsuki. 2012. Applying local knowledge to rangeland management in northern Mongolia: do 'narrow plants' reflect the carrying capacity of the land? *Pastoralism: Research, Policy and Practice* 2:23.

Karl, J. W., J. E. Herrick, and D. M. Browning. 2012. A strategy for rangeland management based on best available knowledge and information. *Rangeland Ecology & Management* 65:638–646.

Knapp, C. N., and M. E. Fernández-Giménez. 2009. Understanding change: integrating rancher knowledge into state-and-transition models. *Rangeland Ecology & Management* 62:510–521.

Knapp, C. N., M. E. Fernández-Giménez, and E. Kachergis. 2010. The role of local knowledge in state-and-transition model development. *Rangelands* 32(6):31–36.

Kristjanson, P., R. S. Reid, N. Dickson, W. C. Clark, D. Romney, R. Puskur, S. MacMillian, and D. Grace. 2009. Linking international agricultural research knowledge with action for sustainable development. *Proceedings of the National Academy of Sciences* 106:5047–5052.

Leisher, C., S. Hess, T. M. Boucher, P. van Beukering, and M. Sanjayan. 2012. Measuring the impacts of community-based grasslands management in Mongolia's Gobi. *PLoS ONE* 7:e30991.

Liu, Y. Y., J. P. Evans, M. F. McCabe, R. A. M. de Jeu, A. I. J. M. van Dijk, A. J. Dolman, and I. Saizen. 2013. Changing climate and overgrazing are decimating Mongolian steppes. *PLoS One* 8:e57599.

Marin, A. 2010. Riders under storms: contributions of nomadic herders' observations to analyzing climate change in Mongolia. *Global Environmental Change* 20:162–176.

Mau, G., and G. Chantsalkham. 2006. Herder group evaluation, policy options for the government of Mongolia. Ulaanbaatar, Mongolia: UNDP Sustainable Grasslands Program.

Nyong, A., F. Adesina, and B. Osman Elasha. 2007. The value of indigenous knowledge in climate change mitigation and adaptation strategies the African Sahel. *Mitigation and Adaptation Strategies for Global Change* 12:787–797.

Oba, G. 2001. The importance of pastoralists' indigenous coping strategies for planning drought management in the arid zone of Kenya. *Nomadic Peoples* 5:89–119.

Oba, G. 2012. Harnessing pastoralists' indigenous knowledge for rangeland management: three African case studies. *Pastoralism: Research, Policy and Practice* 2:1.

Oba, G., E. Sjaastad, and H. G. Roba. 2007. Framework for participatory assessment and implementation of global environmental conventions at the community level. *Land Degradation and Development* 19:65–76.

Pellant, M., D. Pyke, P. Shaver, and J. E. Herrick. 2005. Interpreting indicators of rangeland health. Denver, CO, USA: Bureau of Land Management. 122 p.

Reed, M. S., A. J. Dougill, and T. R. Baker. 2008. Participatory indicator development: what can ecologists and local communities learn from each other? *Ecological Applications* 18:1253–1269.

Reynolds, J. F., D. M. Stafford Smith, E. F. Lambin, B. L. Turner II, M. Mortimore, S. P. J. Batterbury, T. E. Downing, H. Dowlatabadi, R. J. Fernández, J. E. Herrick, E. Huber-Sannwald, H. Jiang, R. Leemans, T. Lynam, F. T. Maestre, M. Ayarza, and B. Walker. 2007. Global desertification: building a science for dryland development. *Science* 316:847–851.

Roba, H. G., and G. Oba. 2009. Community participatory landscape classification and biodiversity assessment and monitoring of grazing lands in northern Kenya. *Journal of Environmental Management* 90:673–682.

Sankey, T. T., J. B. Sankey, K. T. Weber, and C. Montagne. 2009. Geospatial assessment of grazing regime shifts and sociopolitical changes in a Mongolian rangeland. *Rangeland Ecology & Management* 62:522–530.

Sneath, D. 1998. State policy and pasture degradation in Inner Asia. *Science* 281:1147–1148.

Soum Statistics. 2011. National Statistical Office of Mongolia. Available at: http://www.nso.mn/v3/index2.php?page=menu&m_id=265&s_id=0. Accessed 12 July 2012.

Sternberg, T., R. Tsolmon, N. Middleton, and D. Thomas. 2011. Tracking desertification on the Mongolian steppe through NVDI and field-survey data. *International Journal of Digital Earth* 4:50–64.

Thomas, D. S. G., and C. Twyman. 2004. Good or bad rangeland? Hybrid knowledge, science, and local understandings of the vegetation dynamics in the Kalahari. *Land Degradation and Development* 15:215–231.

Upton, C. 2008. Social capital, collective action and group formation: developmental trajectories in post-socialist Mongolia. *Human Ecology* 36:175–188.

Usukh, B., and H. P. Binswanger-Mkhize. 2010. Fostering the sustainable livelihoods of herders in Mongolia via collective action. Ulaanbaatar, Mongolia: Selenge Press. 38 p.

Venable, N. B. H., S. R. Fassnacht, G. Adyabadam, S. Tumenjargal, M. E. Fernández-Giménez, and B. Batbuyan. 2012. Does the length of station record influence the warming trend that is perceived by Mongolian herders near the Khangai Mountains? *Pirineos* 167:71–88.

Warren, C. A. B., and T. X. Karner. 2010. Discovering qualitative methods: field research, interviews and analysis. 2nd ed. New York, NY, USA: Oxford University Press. 306 p.

Whitford, W. G., A. G. de Soyza, J. W. Van Zee, J. E. Herrick, and K. M. Havstad. 1998. Vegetation, soil and animal indicators of rangeland health. *Environmental Monitoring and Assessment* 51:179–200.

Yu, F., K. P. Price, J. Ellis, and P. Shi. 2003. Response of seasonal vegetation development to climatic variations in eastern central Asia. *Remote Sensing of the Environment* 87:42–54.

Zemmrich A., M. Manthey, S. Zerbe, and D. Oyunchimeg. 2010. Driving environmental factors and the role of grazing in grassland communities: a comparative study along an altitudinal gradient in Western Mongolia. *Journal of Arid Environments* 74:1271–1280.