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# Improving rangeland climate services for ranchers and pastoralists with social science

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Rangeland climate services — knowledge resources that integrate information on climate to facilitate decision-making for ranchers and pastoralists — have the potential to facilitate sustainable decisions under variable climate conditions. Yet the design of climate services often fails to fully address the behavioral, cultural, social, and institutional factors that motivate or disincentivize end-users. Thus, we review how research on risk and uncertainty preferences, different ways of knowing, social relations, and institutional arrangements affect the use of these services. We focus on web-based climate services and provide two case examples of services used in the United States and globally. We conclude with considerations for improving rangeland climate services, for instance, by including end-users in the development process.

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## Introduction

Rangelands — including native grasslands, shrublands, and savannas — cover more terrestrial surface than any other land cover [1] and provide many ecosystem services, including forage production for livestock, water quality and quantity, biodiversity conservation, and carbon sequestration [2]. Rangelands are crucial to rancher and pastoralist (producer) livelihoods, with ranching primarily practiced in settings where land is held privately or leased by individual operators and pastoralism primarily practiced where land is held and used in common by groups of herders. Climate variability and extremes are a major source of uncertainty and risk on rangelands [3–5]. Multiple scholars have argued for improved understanding of, and support for, rangeland management decisions under climate change [6••,7].

Ranchers' and pastoralists' adaptation strategies to respond to climatic variability and extremes include moving herds, adjusting herd size or composition and increasing supplemental feeding [6••,8•,9,10]; enrolling in forage loss insurance and accessing additional land through acquisition or lease [11••]; or — in the case of pastoralists — reciprocal relationships with other pastoral groups [12]. Mobility, often over large areas, is a primary strategy to adapt to inter-annual variation in the spatial and temporal distribution of forage resources, and to avoid impacts of extreme climate conditions like severe drought or winter storms [13]. Livestock producers in the U.S. often maintain a conservative stocking rate to minimize risks associated with climatic and market fluctuations [8•]. Some producers instead use flexible stocking strategies to take advantage of forage variability, including moving herds to different pastures or increasing herd size during wet periods and destocking during dry periods to avoid overgrazing, though there is mixed evidence that a flexible annual stocking strategy is more profitable in the long-term [14,15].

Climate services, defined as knowledge resources (e.g., informational websites) that integrate information on climate to facilitate decisions for specific users or objectives [16,17•], have the potential to increase the efficiency and sustainability of rangeland use under climate change [18,19••]. Climate services specific to rangelands include decision support frameworks for stocking rate, species conservation, herd movement, and soil erosion prevention (Table 1). These services offer historical, near-real time, or predictive information that can help producers make adaptation decisions. Many rangeland climate services take advantage of remotely sensed data to display past or potential future vegetation changes — presented as biomass, vegetation cover, or vegetation indices — and integrate weather and climate data either mechanistically with vegetation growth models or visually with climate data displayed alongside vegetation data. Climate services are based on models using variables (e.g. rainfall across a region) that estimate vegetation condition, so outputs may include a range of uncertainty [20] (e.g. Ref. [21]). Table 1 provides examples of rangeland climate services (see a more exhaustive list in Supplemental Material) that meet the following criteria: the services a) support rancher or pastoralist decision-making through information on vegetation for livestock grazing (targeting producers and/or government or NGO staff who advise them), b) are web-based and/or mobile-accessible, c) can be dynamically updated with new climate and/or vegetation data, and d) provide spatially explicit information at scales commensurate with livestock management decisions. We use these criteria to define the rangeland climate services of interest and distinguish them from static services derived from 'rules of thumb' — such as the 'take half, leave half' forage utilization rule — that provide decision assistance but may be based on outdated assumptions of environmental stationarity [22].

Despite the availability of rangeland climate services, uptake is uneven among ranchers and pastoralists [11••,23••,35••,36]. Underuse of rangeland climate services in part reflects broader trends in technology use among this population [37]. Indeed, logistical factors like user interface have been found to impede use of climate services [38•]. However, we suggest that other processes may be at play. A perennial problem in climate services design is that researchers and practitioners fail to fully acknowledge the behavioral, cultural, social, and institutional factors that motivate or disincentivize their use by target end-users [39–41]. In order to improve the development and use of rangeland climate services, this review explores how rangeland and related social science research offers insight on the use of climate services by ranchers and pastoralists.

## Social science lenses to understand rangeland climate services use

Climate services have the potential to help ranchers and pastoralists plan and respond to changing conditions [4,18,19••,42]. Developers might assume that their service will be used if it estimates with reasonable certainty how an end-user might maximize net social and environmental benefits from rangelands. However, real-world producers process climate service information through multiple lenses before making production decisions (Figure 1). We — a group of rangeland social and biophysical scientists — chose to focus on the four social science lenses below based on a) our own expertise from developing, implementing, and evaluating rangeland climate services, and b) past research on rancher and pastoralist climate adaptation decision-making [43–46]. The social science lenses presented here reflect multiple levels of influence on climate adaptation decisions [47]. In the Section 'Considerations for improved rangeland climate service development', we give recommendations for how to enlist these lenses to produce useful and usable rangeland climate services.

To ground this review, we describe two case examples of rangeland climate service projects in which authors of this paper have been involved. First, RangeSAT is a web-based service created to provide near-real time estimates of biomass using Landsat satellite surface reflectance products for adaptive grazing management in Oregon and Idaho, United States (USA) (Figure 2) [31,32]. Ranchers in these regions graze livestock on their privately owned land and on rangeland and pastures owned or managed by The Nature Conservancy (TNC) and federal and state governments. RangeSAT allows each end-user to view pasture-specific and ranch-specific maps and graphs of above-ground biomass at a single point in time or across time, from 1984 to the present. Climate variables can be viewed alongside graphs of satellite-based estimates of biomass, as well as the normalized difference vegetation index (NDVI). Second, Livestock Early Warning Systems (LEWS) were designed for use in Mongolia and East and Southern Africa (Figure 3). LEWS combine ground-based rangeland monitoring data, remotely sensed data, and weather data to model current and predicted near-term forage availability, usually 60 days in advance [30]. LEWS provide pasture condition forecasts over large spatial extents to assist governments, producer organizations, and individual producers with management decisions, such as moving and selling livestock. Initially developed for Kenya, the technology has been adapted to other contexts. In Mongolia, an SMS platform allows users to receive LEWS information on pasture conditions along with weather forecasts and winter condition warnings at the district level [48].

### Individual risk and uncertainty preferences

The intent of climate services is to organize information and data to aid decision-making. In rangelands, future forage quantity and quality are common dependent variables in decision models and are influenced by exogenous and uncertain events like fire, species invasions, or extreme weather, for example, Ref. [46]. Furthermore, management decisions have long-term feedback effects on rangeland condition (e.g. continued overgrazing reduces productivity and may increase invasive species spread) [22]. Informational uncertainty and associated risk can obscure which actions will lead to positive outcomes for any decision-maker [49] and rangeland decision-makers often lack training in risk management [11••]

**Table 1**

**Examples of rangeland climate services with recent associated publications, chosen to represent variation across geographic regions, outputs (e.g. indicators), and temporal range of data. Note the services listed here may change and their underlying data are dynamic. See Supplemental material for a more exhaustive list of services**

| Service name (URL) | Relevant citations | Geographic location[a] (and Reporting units[b]) | Vegetation or climate information | Temporal period[c] |
|---|---|---|---|---|
| AfriScout (https://www.pciglobal.org/afriscout/) | [23••] | Ethiopia, Kenya, Tanzania (Fixed — country and regional scale) | Surface water and vegetation indices | Near-real time, historical |
| FEWS NET (Famine Early Warning System Network) (https://fews.net/) | [24,25•] | Africa, Central Asia, Central America, and Caribbean (Fixed — continental or country scale) | Vegetation indices, climate indices, mechanistic vegetation growth models | Near-real time, historical |
| FORAGE (https://www.longpaddock.qld.gov.au/) | [26] | Australia (User defined) | Rainfall, ground cover, pasture growth, land type, foliage projective cover (tree density), drought assessment | Long-term projections, short-term projections, near-real time, historical |
| GrassCast (https://grasscast.unl.edu/) | [21,27] | Central Plains/ Southwest USA (Fixed — subcounty) | Biomass | Short-term projections |
| LEWS (Livestock Early Warning Systems) (http://cnrit.tamu.edu/glews) | [28–30] | East Africa, Mongolia, Kenya (User defined) | Forage | Long-term projections, short-term projections, near-real time, historical |
| RangeSAT (https://www.rangesat.org/) | [31,32] | Oregon/Idaho USA (User defined) | Biomass or NDVI | Near-real time, historical |
| RAP (Rangeland Analysis Platform) (https://rangelands.app/) | [33•,34] | Western USA (User defined) | Vegetation cover by plant functional group or bare ground, biomass, plus other conservation layers | Historical |

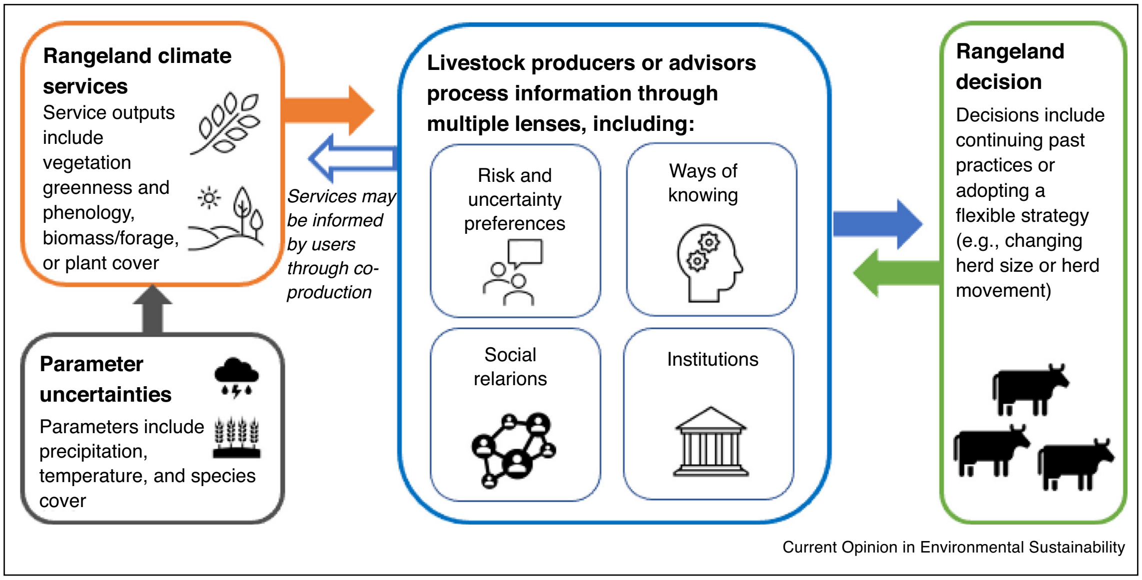
[a] Land area covered by the service.
[b] Categories of reporting units are 1) user defined: provides information for a specific user defined pasture or grazing area (i.e. users can either have access to pre-defined boundaries or can upload a boundary file (i.e. shapefile) of their own; and 2) fixed: static or dynamic maps displaying gridded climate and remotely sensed data across the globe, country or region.
[c] We divide temporal range of services into 4 categories: 1) historical (previous years of data), 2) near-real time data (current conditions to a few months lag (delay), 3) short-term projections (one month to one year forecasts), and 4) long-term future projections (decades).

and information on trade-offs [50] that would help them make decisions in this context.

Economic models that guide and assess decision-making in livestock production systems assume rationality — that individuals consistently weigh the expected costs and benefits of unknown inputs and outputs in evaluating choices [51]. However, observed human behavior often deviates from model predictions, particularly when individuals face uncertainty [52]. Behavioral economics has developed several explanations for this deviation [53]. Prospect theory proposes that individuals are loss averse, placing more weight on expected losses than potential gains [54]. This weighting creates an anchoring effect around management norms and conservative decisions that do not result in significant gains but avoid potential losses. Recent work has investigated how loss aversion affects decision-making in livestock and other agricultural production [46,55–58]. Ambiguity aversion — favoring the known over the unknown — may further exacerbate deviation from rationality among livestock and other agricultural producers [59,60]. Roe *et al.* [61] suggest that most pastoralists seek reliability in outputs through 'ongoing efforts to reduce the probability of those hazards he or she cannot avoid by managing temporal and spatial diversity in grazing opportunities, and diversity in livestock capabilities and response' (p.388).

LEWS forecasts provide an example of how individual risk and uncertainty preferences may affect service use. LEWS provide 30, 60 and 90-day forecasts of forage conditions with uncertainty in the forecasting increasing with the number of days into the future. Many pastoralists who have participated in workshops reserve judgement on the reliability of the forecasts until they can evaluate forecast performance for their location and assess how forecast information interacts with other uncertain information, like where other pastoralists are moving herds. While the pastoralists' response may seem like common sense, it is not always considered by service developers and could hinder their success (e.g. Ref. [23••]).

**Figure 1**




Rangeland climate services provide outputs — for example, estimates of vegetation greenness and phenology (e.g. based on normalized difference vegetation index (NDVI)), biomass/forage, or cover — all of which contain uncertainties over time and space due to a variety of sources error (e.g. model, input data, parameterization). For example, many forecasting tools include uncertainties in input parameters such as climate data (precipitation and temperature), vegetation type, and land management practices. The types of outputs provided by services are sometimes informed by input from end-users through a process of co-production. Ranchers, pastoralists, and their advisors interpret the service outputs through multiple lenses, from individual to institutional, before making a decision that could include continuing past practices or adopting a flexible strategy (e.g. changing herd size or herd movement). The results of this decision may in turn affect how users interpret service outputs in the future.

## Ways of knowing environmental change

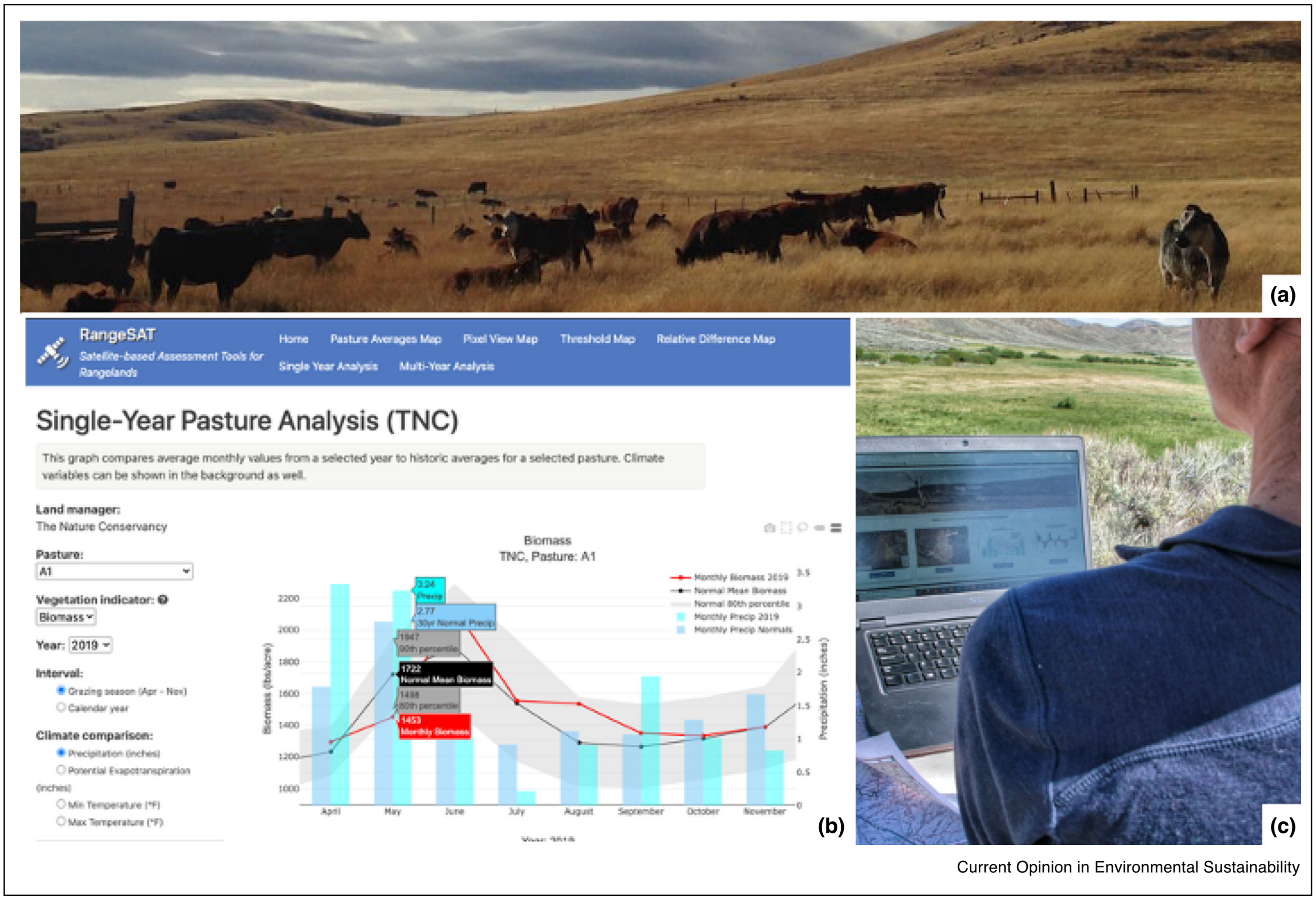
Differences between Western scientific and local ways of knowing climate have been documented for ranching, pastoralism, farming, and other natural resource decision contexts [62–65]. The climate knowledges literature has demonstrated that local knowledge of climate change is shaped by everyday cultural, labor, and livelihood practices [66,67]. These practices engage people with landscape elements such as vegetation and water, which in turn are affected by climate and weather. Researchers drawing on Ingold's dwelling perspective [68], which recognizes landscapes as part natural and part social, have shown land managers like ranchers and pastoralists gain climate knowledge through the types of practices they engage in, which vary depending on the livestock or crops they tend, technologies they use, identities they hold, and ecosystems they work in [62,64,69]. Western scientific knowledge of climate is derived from individual variables and statistical aggregates at large spatial scales [64,69]. Local climate knowledge tends to be more holistic and inductive; farmers, ranchers, or pastoralists frequently understand and describe how the climate is changing through the use of indicators that are connected to social, material, cultural, or technological landscape constituents [70,71,72•]. Rangeland climate service developers have begun to acknowledge and sometimes incorporate local ways of knowing environmental change into applications (e.g. Refs. [23••,73,74•]). For instance, when Machado *et al.* [23••] found that their vegetation maps did not lead to significantly different decisions by pastoralists compared to their baseline, they called for future research to assess 'how pastoralists perceived the maps in the context of their traditional knowledge and their strategies to find pasture' (p. 14).

In the case of RangeSAT, the development team (including university scientists, TNC staff, and ranchers) found that the monitoring indicators and methods ranchers routinely use sometimes differed from those used by the scientists. Primarily, ranchers wanted to know 'how much was there' — using indicators like plot-based estimates of residual vegetation — while scientists wanted to know 'how much was taken' to understand grazing management — using indicators including NDVI and biomass.

## Institutions and social relations

Rangeland decision-makers operate within institutional contexts created by historic conditions and reinforced by ongoing social and political interactions (e.g. Refs. [23••,75]). Institutions are conceptualized broadly as policies, laws, rules, and norms that organize human interactions, with a distinction between formal institutions (e.g. state laws) and informal institutions (e.g. pastoralists'

**Figure 2**




Depictions of RangeSAT. **(a)** Cattle grazing on the Zumwalt Prairie in northeastern Oregon, USA, where the service was conceived. (Photo credit: Julia Amato, TNC). **(b)** Screenshot of RangeSAT (https://www.rangesat.org) displaying the single-year pasture analysis service for a single pasture. This graph shows average monthly biomass for the current year (red line) compared to the 30-year average (black line), and the 80$^{th}$ percentile range (grey). Current climate data (precipitation here) are displayed in bars (light blue) compared to 30-year averages (darker blue). **(c)** RangeSAT in action on the Zumwalt prairie. (Photo credit: Heidi Schmaltz, TNC).

resource use norms). There are a variety of institutional arrangements that can affect rangeland climate service use, from top-down models in which regional or national governments prescribe service use [12], to more devolved models such as integrating climate services into community-based rangeland management [76]. Community-based, compared with top-down institutional arrangements, are often participatory, more responsive to local-level challenges, and garner more trust and perceptions of legitimacy from local service users [77], though high-level policies may be necessary for coordination, accountability, and sustainability [78]. Barrett *et al.* [19••] describe a recent example of a climate services program for pastoralists and crop farmers in Kenya that sought to integrate information dissemination into the multi-level institutional context by tailoring information to the national, county, or ward level and engaging governmental and non-governmental advisory board members at each level. The authors' assessment found that the decentralized information provision was associated with higher household incomes for producers and overall income gains were greater than the cost of service provision.

Social relations, including community cohesion and disseminating information through social networks, are central to communication about rangeland management because they shape beliefs about information and its use [44]. The desire to sustain ranching communities is often a motivating factor in rancher decisions in the U.S., and sometimes given more weight in decision than economic returns [79]. Social relations play a large role in pastoralists' decision-making as well. For instance, Ng'anga'a *et al.* [80] found social capital variables, including membership in a cooperative and receiving assistance from a friend, were predictive of the uptake of climate change adaptation strategies by Kenyan pastoralists.

**Figure 3**


Depictions of LEWS. **(a)** Pastoralist moving livestock to new pasture in Övörkhanghai Aimag (province) in Mongolia where LEWS were first implemented to provide pastoralists with near real time estimates of livestock forage, along with 30 and 60-day forecasts of forage conditions. **(b)** Workshops were held with stakeholders to discuss and gather feedback on LEWS map products of forage, forage anomalies, rainfall, and satellite-derived vegetation condition indices. **(c)** Meeting with forage officers in Alag-Erdene soum (district) to discuss early warning status and provide training on new LEWS products. (Photo credits: Jay Angerer).

Access to land is also crucial to pastoralists' ability to make adaptation decisions; this access often depends on social relations of reciprocity with neighboring groups that facilitate herd movement and pasture sharing [12,23••]. Finally, trust is a key variable shaping why agricultural users in general [81] and livestock producers in particular [82] privilege information from local social networks and organizations over experts outside of their networks. Rangeland climate service creators can draw on multiple strategies to address the social dynamics that may inhibit scientists or centralized governments from influencing climate decisions. Service co-production through repeated interactions between scientists and service users is increasingly common in recent projects (e.g. Refs. [19••,73,74•,83]).

The LEWS case illustrates the influence of both institutional arrangements and social relations on service use. Several key factors facilitated successful LEWS use. Partnering with local livestock cooperatives, as in Namibia, where a national agricultural cooperative disseminates information on pasture conditions and trends, or with locally embedded project offices, which occurred in some Mongolia districts, accelerated dissemination by drawing on existing networks and relationships of trust. Applying a co-production approach from the outset with both ministry-level government staff and local-level end-users cultivated buy-in and helped avoid conflicts over competing methods and technologies, while ensuring dissemination methods were compatible with local technology.

## Considerations for improved rangeland climate service development

This review provides rangeland climate services creators, funders, and other stakeholders with the individual, sociocultural, and institutional perspectives needed for assessing potential disconnects between service creators and end-users, enabling them to take steps to improve services. While presented separately in this review, different decision influences interact with one another; for instance, as described above, actors embedded in both local and national or international networks in Mongolia were trusted sources of information about LEWS and translated between different ways of knowing. Given the myriad factors affecting climate service use, we suggest the following considerations for service developers to improve service usability and usefulness:

1 Climate service creators should recognize that aversion to loss and uncertainty may affect end-users' willingness to make a management change based on new information. This effect could be amplified by the level of uncertainty associated with climate service outputs, though more research is needed to better understand this problem. Climate service creators and funders could encourage trials of their services by providing technical or financial support, a recommendation backed by research on how innovations are adopted in agricultural settings [84]. Service developers could also include opportunities for users to simulate different outcomes based on multiple scenarios.
2 As illustrated in the RangeSAT case, management indicators relevant to livestock producers do not always align with those favored by service developers. Thus, it is important for developers to first understand end-user ways of knowing environmental change to provide usable information [23••,72•,74•]. Co-production can provide opportunities for service end-users and developers to discuss the costs and benefits of different system indicators, leverage the opportunities of both Western scientific and local knowledge, and experiment with practical applications [41,65,85••,86•]. Importantly, developers must build in sufficient time for the process of co-production, which includes building trust and creating a process that is viewed as legitimate by all parties [87,88].
3 Because information from local and known sources is generally more accepted by ranchers and pastoralists, climate service developers can leverage local networks to increase the relevance and use of their services [89]. Trusted local actors who also have experience with Western scientific networks are particularly important for translating processes and information across institutional scales in rangelands and other natural resource contexts [90], which was the role local project offices played for LEWS in Mongolia.

We believe the issues we raise on climate service usability and usefulness, while specific to rangeland decisions, illustrate larger questions that service developers and funders should be asking to improve decision-making across issues and geographies. Future research could extend the research reviewed here by exploring how the climate risk and uncertainty preferences of different rangeland users affect service use, assessing opportunities for integrating climate services into social networks, or determining the extent to which co-production affects climate service use.

## Conflict of interest statement

Nothing declared.

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## Declaration of Competing Interest

The authors report no declarations of interest.

## Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.cosust.2021.07.001.

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- •• of outstanding interest

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Rangeland livestock producers must manage risks related to climate variability; this article reviews global literature on rangeland livestock production and climate variability to identify risk management strategies that are in widespread use across dryland rangeland systems and geographies. The authors find that across the globe, strategies livestock producers use to reduce risk related to climate related variability are: (1) dynamically managing forage supplies, (2) dynamically managing animal demand, and (3) using and diversifying social networks. This study highlights areas in which research can support decision-making to reduce risk related to climate variability.

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This qualitative study presents a framework of care for understanding rancher decision-making, arguing for 'the need to understand ranchers'efforts not just to make sound economic decisions, but to live lives that are in their terms good and moral.' The authors bring ethical dimensions into a literature that is often dominated by economic analyses.

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The author sought to understand why Utah cattle ranchers do not adopt drought-management strategies. Rancher concerns about drought largely vary with current weather (i.e. when there is ample precipitation, drought is forgotten). Accordingly, in this survey of Utah cattle ranchers, 44% of non-adoption decisions reflected a 'lack of need' for drought strategies (i.e. ranchers did not think they were necessary). The author recommends that understanding the ways that ranchers process information must be considered in boosting awareness of undersubscribed drought-adaptation options. He suggests using 'innovation systems' for more grass-roots engagement among ranchers, researchers, and Extension to co-produce knowledge and identify more relevant interventions.

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This study examined the Kenya Meteorological Department (KMD) adaptation of national level probabilistic information to offer localized weather and seasonal information products (i.e. local seasonal rainfall and onset/cessation forecasts) and livelihood advisories. The investigators compared income (i.e. reduced losses) in agro-pastoralist households with access to KMD's localized products and with those households using national level weather and seasonal information products. Households receiving KMD's local advisories and seasonal forecasts had marginally higher income levels, indicating that weather and climatic information yields improved economic outcomes when produced at local scales.

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