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CASE STUDIES

# Loss of seasonal ranges reshapes transhumant adaptive capacity: Thirty-five years at the US Sheep Experiment Station

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## Abstract

Transhumance is a form of extensive livestock production that involves seasonal movements among ecological zones or landscape types. Rangeland-based transhumance constitutes an important social and economic relationship to nature in many regions of the world, including across the Western US. However, social and ecological drivers of change are reshaping transhumant practices, and managers must adapt to increased demands for public rangeland use. Specifically, concerns for wildlife conservation have led to reduced access to seasonal public lands grazing for western US livestock producers. To understand how managers adapt to loss of grazing areas (called "seasonal ranges") we create agroecological calendars from manager records spanning 35 years (1986–2021) at the US Sheep Experiment Station in Idaho and Montana, US. The calendars illustrate how a loss of winter and summer ranges after 2013 coincided with shifts in the operation's adaptive strategies, leading to more grazing of fall crop residue and purchased winter feed, and reducing flexibility to move livestock to cope with variable forage conditions. These changes shifted the job duties and experiences of farm workers and managers, and raised several new questions related to sheep production and vegetation management outcomes that merit future research. Transhumant system transformation has implications for human relationships with nature, rural communities, sheep genetics, production, and vegetation communities. For livestock operations that rely on government-managed lands to sustain transhumant traditions, innovative forms of collaboration and social adaptation that help secure access to seasonal ranges will be as important as technological innovations to address biodiversity conservation, climate change adaptation, and food system sustainability issues that are reshaping access to grazing lands.

**Keywords** Rangeland livestock systems · Climate change · Biodiversity conservation · Public lands management

## Abbreviations

| | |
|---|---|
| ARS | Agricultural Research Service |
| BLM | Bureau of Land Management |
| DOI | Department of Interior |
| HQ | Headquarters |
| PC | Paternal Composite Line |
| US | United States |
| USDA | United States Department of Agriculture |

*Original data are archived at the US Sheep Experiment Station in Dubois, Idaho.

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USFS United States Forest Service
USSES US Sheep Experiment Station

## Introduction

### Transhumant livestock production

Transhumance is a form of rangeland-based livestock production involving semi-annual stock movement among land types or ecosystems, typically over an elevation gradient (Bindi 2022; Huntsinger, Forero, and Sulak 2010; Starrs 2018; Li et al. 2016). Transhumance constitutes an important social and economic relationship to nature in many regions of the world. Transhumance is characterized in terms of: 1) mobility, 2) connectivity, 3) temporal synchrony, 4) local interdependence, 5) local ecological knowledge, 6) adaptive capacity legacy[1] and 7) mixture of land tenure (Easdale et al. 2023). Traditional transhumance systems are commonly associated with the Mediterranean and the Alps, where the practice is recognized as an UNESCO Intangible Cultural Heritage of Humanity (Easdale et al. 2023). However, transhumance persists around the world, including across Europe, East, West and Southeast Asia, and Africa (Starr 2018, Scoones 2023; Zhang et al. 2013; Fernández-Giménez and Ritten 2020), and in the Western US (Huntsinger, Forero, and Sulak 2010). Here, public lands ranchers, called grazing permittees, run operations that move cattle and sheep seasonally across an elevation gradient through seasonal ranges (though this work may be conducted by a number of individuals, including rancher owners, family member, staff managers, guest worker herders, or contract "day" labor). Seasonal ranges are defined as different land types used for seasonally-appropriate grazing, and may include a mix of public and private lands. Livestock move from semi-arid shrublands and improved pastures or croplands during cold months onto montane and sub-alpine rangelands for warm season grazing (Huntsinger, Forero, and Sulak 2010). As transhumant systems face the threat of transformational change globally, it is important to document their characteristics and explore leverage points for adaptation using tools like agroecological calendars that display and translate system dynamics across disciplines (Kassam et al. 2018). This paper develops an agroecological calendar approach to studying the impacts of loss of seasonal ranges to a transhumant system and identifies areas where social-ecological analysis and additional research could help improve our understanding of these changes in the United States.

[1] Easedale et al. (2023) described legacy as "an inter-generational legacy evidenced in the ecosystem status, type of herds, knowledge and skills to perform their livelihoods.".

Rangelands are the dominant terrestrial ecosystem type on Earth and cover more than 200 Mha in the US (Havstad et al. 2007; Reeves and Mitchell 2011; Boone et al. 2018). Rangelands include extensive uncultivated lands where the dominant vegetation is grass, grass-like plants, forbs and shrubs (Havstad et al. 2007). Rangelands are characterized by 1) high levels of variability, 2) relatively low levels of water availability, 3) mixed public and private ownership patterns, and as 4) complex social-ecological systems (Havstad et al. 2007). As managed working lands, rangelands contribute vital ecosystem services to society, including biodiversity habitat, nutrient and carbon cycling, clean air and water, and cultural services at large spatial scales (Huntsinger and Oviedo 2014; Díaz et al. 2018; Ricketts and Sandercock 2016). Ranchers operate in these environments by maintaining flexible, low-input systems that help them anticipate, reduce, or adapt to risks from highly variable ecological contexts (Derner and Augustine 2016; Briske et al. 2015; Espeland et al. 2020). They also maintain informal community economies and local knowledge needed to manage relationships between land, water, livestock, family, wildlife, and other rangeland users and consumers (Knapp and Fernández-Giménez 2009; Barry 2021; Barry and Huntsinger 2021).

Globally, mobile pastoral systems and transhumance systems exploit variability across rangelands (Nori and Scoones 2019; Lind et al. 2020; Li and Huntsinger, 2011, Reid et al. 2014). Scholarship on these diverse systems include a number of themes: 1) the importance of pastoral mobility for adaptive capacity (Scoones 2023; Turner and Schlecht 2019); 2) the potential ecological benefits of transhumance (Manzano and Malo 2006; Hevia et al. 2016; Huntsinger et al. 2012); 3) impacts to transhumance, adaptive capacity and social-ecological systems of loss of access to seasonal grazing areas (Bencherifa 1991, Zhang et al. 2013; Lind et al. 2020); 4) conflicts between large predator conservation goals and transhumant livelihoods and land use patterns (Cummins 2009; Carlson et al. 2020; Unks 2023); 5) intersections with system transformation and broader sociological change, including rural depopulation and urbanization (Starrs 2018); 6) the continued stereotype that pastoral systems are 'backward' or harmful to rangeland systems (Scoones 2023; Turner 2004); and 7) the importance of social networks and relationships with urban centers to sustain flexibility (Unks 2023; Scoones 2023).

The ability of US transhumant producers to stay in business is increasingly threatened by shifting agricultural economies, changing societal values for land use, and increased risks from the ecological impacts of climate change (Bindi 2022; Huntsinger and Oviedo 2014; Barry 2021; Scoones 2021). Across the western region, range livestock systems largely rely on federally administered grazing on public lands, which are also used for recreation, timber and energy

development, and conservation goals including for predator conservation (Maher et al. 2021; Mosley et al. 2020; Marín-Yaseli and Martínez 2003; Wulfhorst et al. 2006). In this context, social dynamics can eclipse the threat of climate variability on livestock production, and ranchers report less capacity to adapt to changing social contexts than they do to adapt to ecological and climate variability (Greene et al. 2022). These social dynamics include rising land prices, reduced labor supply, and changing public views of agriculture, as the industry is implicated for impacts to biodiversity and climate change (Fox 1985; Martin et al. 2019; Sayre 2018; Wrabley Jr 2008; Kauffman et al. 2022). As agricultural sustainability and biodiversity conservation issues become more urgent, researchers and decision-makers have a growing interest in understanding how managers navigate social change to maintain production systems and associated livelihoods (Starrs 2018; Bindi 2022; Briske et al. 2015; Uboni et al. 2020). However, few studies have documented transhumant systems or broader production landscapes in the Western US outside of California (see: Hunstinger and Oviedo 2014; Barry and Huntsinger 2021).

## Transhumance and shifting values for rangeland use

Transhumance and domestic sheep grazing are millennia old practices (Ventresca et al. 2020), and various forms of range sheep grazing were practiced on the North American continent in the early Spanish colonial period, with flocks moving across the Southwest tended by Pueblo and Dine peoples (Gulliford 2018). The expansion of range sheep production across the US West coincided with European conquest, providing food and fibre for settlers, miners, and armies, and later becoming an important livelihood for immigrant herders employed by large sheep 'outfits' or ranches, or operating independently (Gulliford 2018). Through the early decades of the twentieth century, grazing and meat and wool production was a priority for US public lands use, including on Department of Agriculture National Forest lands (Sayre 2017, see: Withorn and Withorn 1970, Museum of the Rockies Archive 1987). At that time, conflicts over the "multiple-use" policy, codified in the Multiple-Use Sustained-Yield Act of 1960, on rangelands centered on the tensions between cattle and sheep producers and rangeland science emerged as a Progressive Era response to management concerns (Sayre 2017). By mid-century, national food and fiber production priorities increasingly shared the landscape with wildlife conservation and wilderness protection goals, as the Wilderness Act (1964), National Environmental Policy Act (1970), and Endangered Species Act (1973) came into law and public concern for environmental protection grew, though with localized differences (Hamilton et al. 2014; Inglehart 1995). Over time, high elevation grazing lands became increasingly valuable for recreation, including for ski resort development (Gulliford 2018), and federal land management agencies gradually permitted fewer total acres and less forage for public grazing (Swette and Lambin 2021). For example, Swette and Lambin (2021) calculated a 64% reduction in forage consumed by livestock and a 21% overall reduction in the number of grazing allotments on US-Forest Service administered land in Idaho. The US Forest Service administered 5,492 permits across the entire National Forest System for grazing in 2020, down from 18,808 in 1966 (USDA Forest Service, 2020, 1966).

Reductions in federal grazing were partially the result of successful efforts by conservation advocates to change land management policy or to secure voluntary removal of livestock from areas where livestock and wildlife goals were in direct conflict with one another (Kerr 1998). Sheep and cattle often graze in biologically diverse, intact ecosystems home to wild sheep and other large ungulates, carnivores, shrub and grassland obligate birds, and other species of concern. This has long driven conflicts between ranchers and predators and issues related to disease transmission and habitat impacts of grazing (Bleyhl et al. 2019; Bates and Davies 2014; Mosley et al. 2020). In some cases, grazing has been removed entirely from these allotments, in other cases livestock species or grazing management has changed to reduce the risk of depredation resulting in the destruction of individual carnivores, disease transmission (particularly the between domestic and wild sheep), or other grazing-related impacts to wildlife (Kerr 1998; Wittman and Bennett 2024).[2]

Additionally, recent advancements in gray wolf (*Canus lupus)* and grizzly bear (*Ursus arctos*) population recovery efforts and associated changing political ecological contexts across the Northern Rockies have spurred continued political and scholarly activity (Martin 2021; Martin et al. 2019). Recent research sought to understand emergent patterns in ranch ownership and management resulting from ongoing social change in the region (Sage et al. 2022; Wells et al. 2019; Haggerty et al. 2018), and to trace livestock-wildlife coexistence practices such as the use of livestock guardian dogs (Young et al. 2018; 2015; Mosley et al. 2020). While reduced access to public grazing lands is commonly cited as a major threat to US range livestock sustainability (Brunson and Lynn Huntsinger 2008; Uboni et al. 2020), little is understood about how US ranch operators adapt to a loss of traditional seasonal grazing lands.

[2] As a case in point, a plan developed in the Hells Canyon area of Idaho aimed to remove the threat of *Mycoplasma ovipneumoniae* transmission among domestic and wild sheep on USFS land with a complex plan to keep the two species apart (Huntsinger et al. 2012),

## Ranching and rangeland adaptation

Rangeland production system are social-ecological systems, meaning that their interactive social and ecological dynamics cannot be disentangled (Huntsinger and Oviedo 2014; Brymer et al. 2016). A body of research has considered how land access and land use change are reshaping transhumant systems globally, resulting in increased sedentary or pasture-based production, integration with global markets, and even changes in rangeland vegetation (Uboni et al. 2020; Aryal et al. 2018a, b; Namgay et al. 2014; Palombo et al. 2013; Vassilev et al. 2011; Fernández-Giménez 2015).

In the US, ranch operational change typically occurs over decadal or multigenerational time scales (York et al. 2019; Wilmer and Sturrock 2020). Ranchers adapt to changing consumer preferences, economic conditions, or biological and ecological dynamics in multiple domains. Incremental changes include shifts in the timing, methods, or sequence of animal health, nutrition, and husbandry, grazing and pasture management, genetic selection, and marketing, using a combination of scientific, professional expertise and local knowledge (Espeland et al. 2020; Knapp and Fernández-Giménez 2009). Some of the adaptations are transformational, for example with shifts from sheep to cattle production or the integration of more crop residue grazing. While innovations in genetics, grazing, and management science have bolstered the US ranching sector's capacity for production efficiency and biodiversity conservation outcomes, rangeland-based production still occurs on extensive, variable landscapes where grazing and livestock management rely on local ecological knowledge to persist under uncertainty (Wilmer and Fernández-Giménez 2015). As such, the range production systems in operation today would likely be recognizable to producers of the past century, though they employ modern transportation, communication, and veterinary technologies. However few scientific studies have documented this change from a production perspective. As these systems change, there is a growing need for methods to document local land management knowledge and translate agricultural systems for teaching, learning, and collaboration opportunities (Sharifian et al. 2022; Oteros-Rozas et al. 2013). Documentation of ranching adaptation is important to help foster continued ranching community viability through the transmission of knowledge and culture, to inform partnerships between ranchers and government agencies and scientists, and to translate agricultural issues to the broader public.

In this case study, our objective is to document how managers on a Western US range sheep research ranch adapted to the relatively abrupt loss of both summer and winter rangeland grazing. This loss of seasonal ranges occurred when range sheep production came into conflict with wildlife conservation goals on federal lands, reflecting a mismatch of societal values for land use priorities common across the region. To document these changes, we use agroecological calendars, a tool for understanding patterns in social, environmental, and agricultural or subsistence systems (Kassam et al. 2018; 2021). We construct calendars to organize 35 years of management records from the US Sheep Experiment Station (USSES), a government operated research ranch in east Idaho and southwest Montana (Seefeldt and Laycock 2006). This time period (1986–2021) spans the years before and after the operation lost the ability to graze seasonal winter and summer ranges (in 2013) following concerns that sheep grazing would negatively impact wild sheep and grizzly bear conservation efforts (USDA-ARS 2017). Below, we outline our conceptual framework and provide additional context on Western US range sheep production before describing our methods and findings.

## Agroecological calendars

Agroecological calendars are graphical or conceptual representations of social-ecological relationships organized seasonally in time. The calendars can help managers and scientists take a closer look at patterns and shifts in managers' key production decisions that reflect adaptations to climate and social events (Kassam et al. 2018). In a ranching or transhumant system, those decisions can include herd management and livestock genetics choices, grazing management, or agribusiness strategies (University of Nebraska-Lincoln Beef 2023), as well as attention to ecological and phenological, social, and climatic indicators during the year. By displaying connections among ecological, livestock, and social dimensions of rangeland systems, calendars can link phenological, climate, and geographical processes together with social and cultural patterns of production (Kassam et al. 2021). The calendars are holistic, constructed from the point of view of communities or land managers, and can be compared over time to reveal both seasonal and long-term transformational patterns in production cycles (Fig. 1).

Agroecological calendars have the potential to promote a shared understanding of agroecosystem relationships and decision making. For example, fire calendars co-produced by Indigenous fire managers and scientists in New South Whales, Australia, helped support cultural fire management practices (McKemey et al. 2021). In the farming sector, calendars have been used to communicate and educate managers and farmers about practices that are well adapted to economic and ecological conditions (National Drought Mitigation Center, NOAA/NIDIS 2020). Production calendars can also translate agricultural decision contexts to collaborators or technical support professionals (University of Nebraska-Lincoln Beef 2023; Wilmer and Sturrock 2020). To our knowledge, range sheep calendars for the Western US

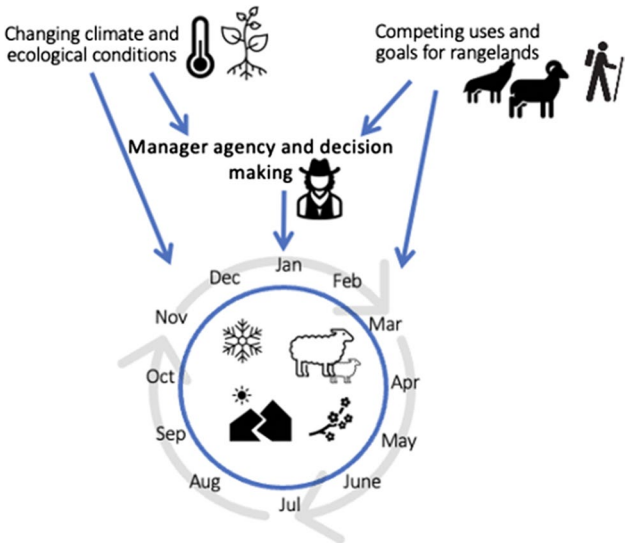


**Fig. 1** Our conceptual framework suggests that agroecological calendars translate how managers make meaning of climatic, ecological, and social processes on rangelands by displaying key patterns in decisions and social-ecological relationships across the seasons

have not yet been published since an early comprehensive report by Hochmuth, Franklin, and Clawson (1942).

## Case study site

### Western US intermountain range sheep systems

This study focuses on specifically a range sheep system representative of those the Western US intermountain region (spanning Idaho, Montana, Utah, Wyoming). This industry supplies lamb/mutton and wool to domestic and international markets, and is comprised of a small number of large operations (> 1,000 sheep),which typically hold public lands grazing permits (Hahn 2020; Jones 2004). The 2017 US Agriculture Census recorded 257 operations with sheep inventories (including lambs) over 1,000 head in these states (USDA 2017).[3]

Sheep are intermediate feeders, meaning that they select mixed rangeland diets of forbs (wildflowers) and grasses with some shrubs (Buchanan et al. 1972; Baum et al. 2022; Bork, West, and Walker 1998; Strasia et al. 1970; Laycock 1967). Range sheep on large-scale commercial operations are owned by ranchers but managed daily by herders in large (800–1000 ewe), dense "bands" that move across grazing areas daily and bed together. Lambs born in the spring are reared on rangelands until weaning in the late summer or fall, when they are marketed for direct slaughter or feedlot finishing. Some operations will retain some lambs as breeding replacements, or other flocks for targeted grazing operations employed to remove weeds or fine fuels in key areas. Following marketing, ewes are bred and returned to lowland shrublands for fall and winter grazing or until the snowpack limits forage accessibility. Low shrublands are often used as winter range in the region because of the accessibility and nutritional quality of browse during cold months (Julian et al. 2020).

However, in recent decades the profitability of range sheep production has been impacted by labor, US farm and trade policies, and changing consumer choices (Jones 2004). Today large operations rely on family labor and on international and domestic herders and shearing crews. Federal payments from the 1954 National Wool Act, which averaged 230 percent of the market value of wool and mohair in 1990 and 1993, were phased out by 1996 after wool was no longer considered a strategic material by the US military (National Research Council 2008; Jones 2004). Demand for lamb and mutton declined over the twentieth century, though it is now relatively stable and growing among some demographics (Hahn 2020). Most sheep meat sold in the US is consumed as lamb, coming from animals under 14 months of age, and about half of US lamb is supplied year-round via the import market (Hahn 2020).

### US Sheep Experiment Station

Our case study is focused on management records collected by the US Sheep Experiment Station (USSES) (Fig. 2), a commercial-scale range sheep research facility based in Dubois, Idaho. The USSES is operated by the United States Department of Agriculture (USDA)- Agricultural Research Service (ARS) Range Sheep Production Efficiency Research Unit in cooperation with the University of Idaho Agricultural Experiment Station. The USSES grazes two types of properties: ARS-administered lands and federal lands administered by other agencies. ARS administered lands were withdrawn from the public domain in 1915, 1916, 1919, and 1922 under Executive Orders 2268, 2491, 3141, 3165, and 3767, respectively. Between 1940 and 1942, additional small tracts of land were purchased from the private sector. A commercial scale flock of both dual-purpose meat/wool sheep and meat sheep breeds support research in food animal production, rangeland ecology, and integrated agroecological research. The USSES explicitly seeks to operate as a "living laboratory" for regional commercial range sheep production, with the added benefit that records and decisions

[3] US sheep producers also include a large number of small, private-lands flocks with diverse genetic and marketing approaches not examined here. The upper Intermountain states (Wyoming, Utah, Idaho, Montana) included 3420 operations with 1–24 head of sheep (including lambs) in 2017 (USDA National Agricultural Statistics Service 2017).

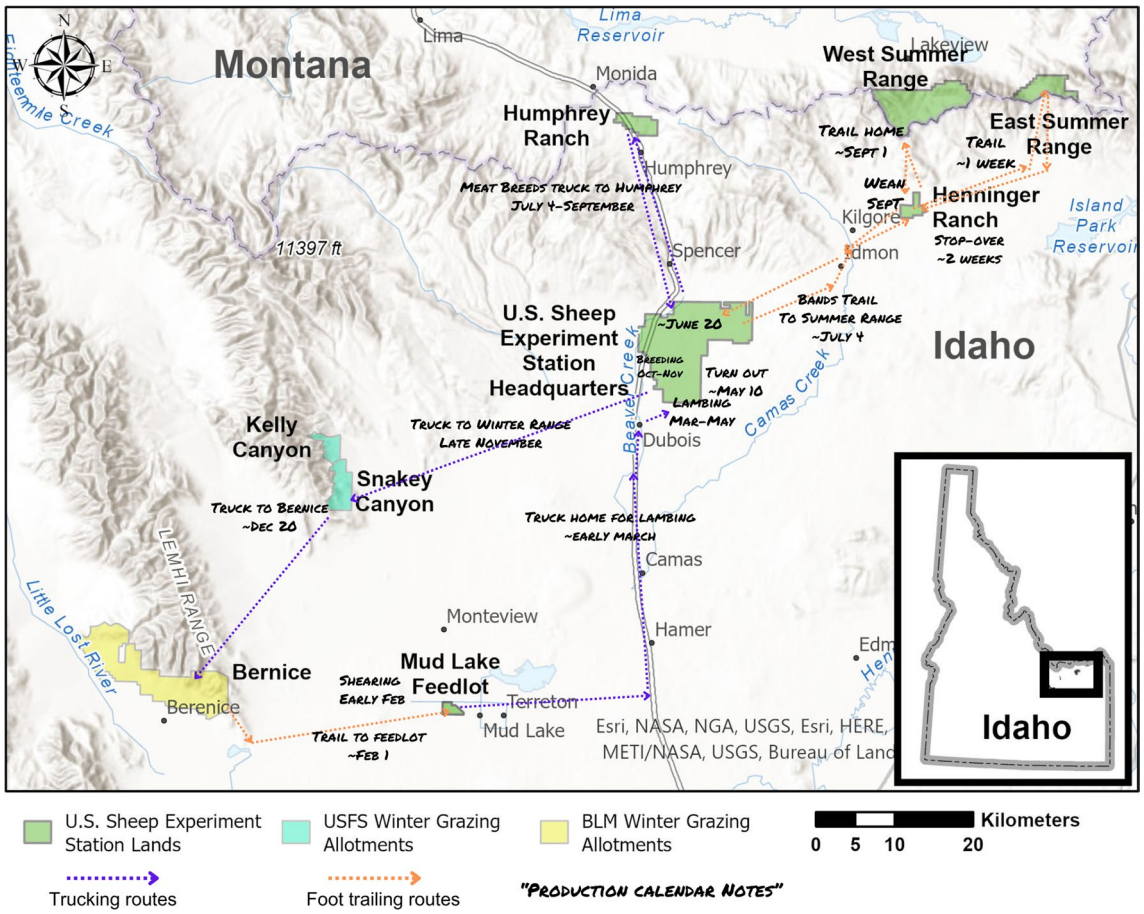


**Fig. 2** The US Sheep Experiment Station (USSES) is a commercial scale range sheep research facility operated by the United States Department of Agriculture (USDA)-Agricultural Research Service (ARS) Range Sheep Production Efficiency Research Unit in cooperation with the University of Idaho Agricultural Experiment Station. Certain US Forest Service (USFS) lands (Kelly Canyon, Snakey Canyon), Bureau of Land Management (BLM) lands (Bernice), and ARS Summer Range areas are seasonal ranges no longer grazed by USSES sheep. Arrows indicate trailing (orange) and trucking (purple) sheep movements under Calendar A, with production notes from USSES employee Boyd Leonard. Design by N.K. Strong

are readily available for the synthesis and analysis of this study. The USSES's research mission and funding, relatively low stocking rates, and scientific capacity distinguish it from private commercial operations.

The USSES's rangeland resources contracted considerably during the 2010's. Gradually, through different pathways, access to both winter and summer ranges became unavailable for USSES grazing. Between 2013 and 2015, USSES leadership established a temporary grazing-rest study on ARS-administered Summer Ranges in Montana. This temporary voluntary removal of sheep grazing for a non-use study was in response to public concerns over incompatibility of carnivore-conservation goals and domestic sheep grazing in the Centennial Mountains. Then, in 2013 and 2017 respectively, Bureau of Land Management (BLM) and US Forest Service (USFS) each suspended sheep grazing in various central-Idaho grazing allotments due to concerns over potential contact between bighorn sheep and domestic sheep (Fig. 2). This resulted in lost access to traditional sheep winter grazing areas for private sheep producers and the USSES. This study aims to identify and discuss the patterns in social and ecological implications of these changes at the USSES through the conceptual lens of the agroecological calendars.

## Methods

### Data collection and analysis

We created agroecological calendars from data pulled from USSES records covering 1986–2021, and triangulated this data with notes from with meetings with USSES managers, modifying the approach described by Kassam et al. (2018). We first gathered and organized manager logs, grazing records, scientists' records, meeting notes,

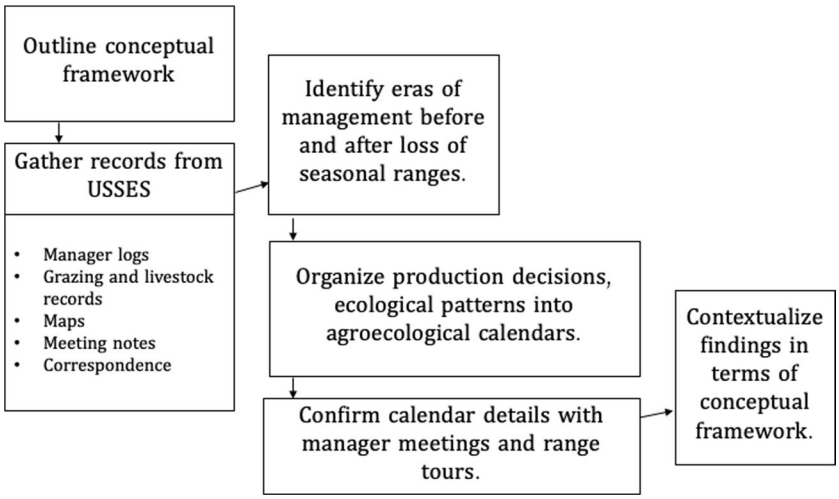


**Fig. 3** Flowchart of methods used to create and discuss agro-ecological calendars

photos, and the USSES Environmental Impact Assessment (2017, see Fig. 3). We read and annotated these records, and sorted a list of key events and management decisions into patterns. We targeted decisions related to grazing management, stocking rates, forage and land use, staff daily operations, and strategic decision-making considerations into tables. We did not explicitly evaluate profitability or financial records. We cross referenced these patterns in decisions with grazing maps and manager meeting notes. To capture changes coinciding with loss of seasonal ranges, we divided the 35-year period into two eras of management. Calendar A spans 1986–2013 and Calendar B 2014–2021. These time periods roughly correspond to the leadership of two operations managers and mark a transition period between a more extensive transhumant production system and second system operating with less access to seasonal ranges, which took several years to implement (USDA-ARS 2017). For each calendar, we report patterns in annual events and decisions in the realms of social (worker activities), ecological (hydrological phenological, biological, and ecological events or patterns), and agricultural (livestock production events such as lambing, grazing movements, breeding, shearing, and other production activities) dimensions in a table (Supplement A). We peer-checked our findings during reflective meetings and range tours with the managers. Though we had full and ongoing consent to attribute the data to the operations managers, they declined co-authorship, as was the tradition of USSES technical and support staff.

We present a generalized view of two agroecological calendars (Figs. 3 and 4, with full details in Supplement A) representing two eras of management at the USSES. These calendars are approximate summaries of change that occurred gradually over the two time periods.

## Results

### Calendar A: 1986–2013

Calendar A (1986–2013 Fig. 4, see also Supplement A) indicates that the traditional transhumant range sheep production cycle was designed to link sheep production needs with rangeland forage production opportunities across nearly 120 km (75 mi). After breeding near Dubois, Idaho, sheep moved on foot across winter ranges in the desert foothills of the Lemhi Mountains in Idaho, and then onto dry lot feeding before shearing occurred. As spring (March–May) lambing season approached, USSES staff transported sheep by truck to the lambing area near the spring grazing areas of the sagebrush steppes near Dubois, Idaho. As summer progressed, staff walked sheep uphill in the summer to the montane and alpine meadows of the southern Centennial mountains in Montana. Trailing to the summer range traditionally occurred on or near July 4. Summer grazing was attended by lone herders, aided by livestock guardian and herding dogs, horses, and regular visits from expert career USSES staff "camp tenders." Camp tending involved regular camp movement and resupply. In the Summer Ranges, camp tending was done in a backcountry setting via horse pack string, while on other seasonal ranges the job was done with pickup trucks. Sheep moved back to Idaho in September for sage-steppe fall grazing at Headquarters (Fig. 2). In years of drought, seasonal forage limitations on lower elevation late spring ranges prompted the flock to move uphill sooner to summer range resources. Conservative stocking rates and forage resources that were extensively located, secure, and diverse in terms of topographic and forage quality, allowed managers to adjust to dynamic phenology or wildlife behavior relatively easily (see Turner and Schlect 2019). (Fig. 5).

Within this broad annual pattern, smaller patterns shaped human-animal-rangeland relations distinctly during

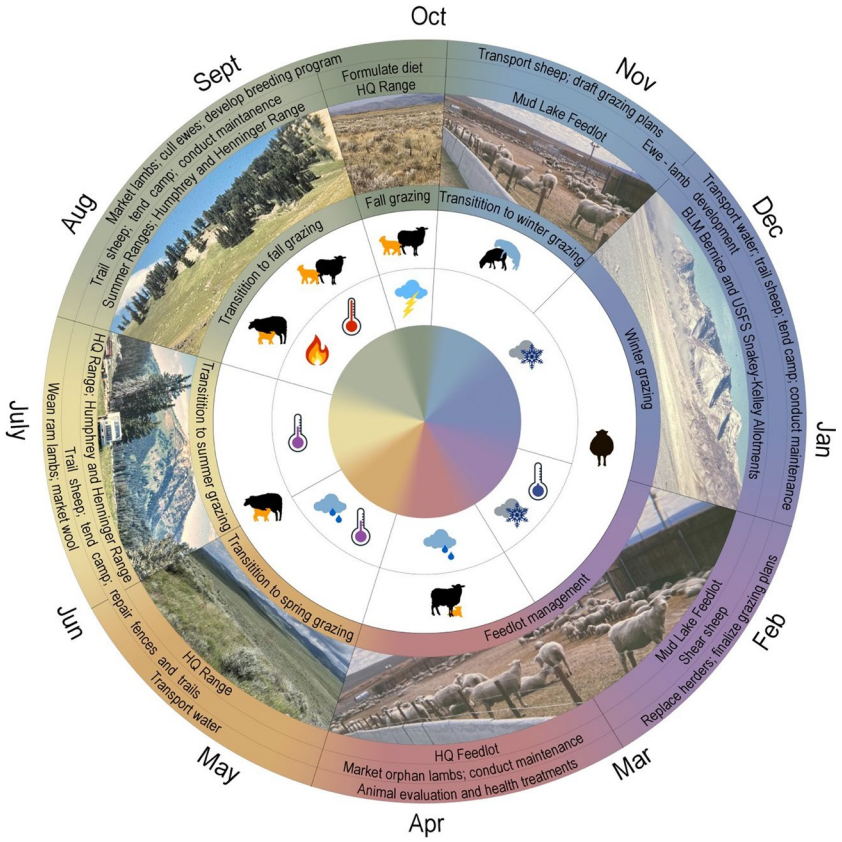


**Fig. 4** Calendar A, a graphical representation of the agro-ecological calendar for the US Sheep Experiment Station from 1986–2013 when winter and summer ranges were still available. The calendar indicates patterns in system management and relationships among ecological, livestock, and social dynamics. Additional details are outlined in Supplement A, Table 1

**General Comments 1989**

The sagebrush rangelands were very slow to respond this year,probably a result of two consecutive drought years combined with the devastating blizzard of 1989. On tuesday night,January 31, an arctic front moved in accompanied by the worst blizzard in the history of Clark County. Recorded temperatures of 27 degrees below zero, combined with continuous winds averaging 35 miles per hour, dropped the wind chill factor to 90 degrees below zero. Winds did not subside until February 5.

The only vehicle able to enter the station during that time was a Search and Rescue snowcat which brought insulin to one employee and supplies to the families. Location leader Hudson Glimp called it "the most incredible thing I've ever seen. There were fifteen to twenty foot drifts up to a hundred yards long running from rooftop to rooftop." Station personnel worked in life threatening situations and kept livestock losses to only 30 sheep.

Most ranchers had their stock farther from cover and many suffered tremendous losses. One neighbor lost 869 cattle and 750 sheep. Many cattle drifted with the winds and several loads of Dubois cattle were hauled back from Roberts.

Vegetation was also affected by the storm. As one drove across the sagebrush range after green up, numerous strips were noticeable which appeared to be dead. These areas did eventually respond and weren't apparent beyond about the first week of June. The plant showing the greatest overall impact was sagebrush. Looking at them toward the north, everything looked fine. But as you looked toward the south,blowing snow had literally stripped the bark from the upper branches. Growth response was slow, but there did not appear to be any permanent damage.

**Fig. 5** Management records compiled by former USSES operations manager Quinn Jacobson documented the impacts of drought and multi-day blizzards on ranch operation and vegetation conditions in 1989

shearing,[4] lambing season, daily grazing management, weekly camp moves and other activities (Fig. 3). In turn, the sheep grazing helped shape the rangeland ecosystem (Leytem and Seefeldt 2008; Laycock 1967). The operation and staff became part of the community and regional industry culture (Stoddard 1992). A popular August annual ram sale, summer industry group tours and picnics, and winter producer meetings also brought USSES staff, scientists, and local ranchers together over the years. In addition to

[4] In the 1970s, shearing took place after lambing in the spring. Managers shifted shearing to February, before lambing in March–May, in the 1990s to avoid weather and animal-husbandry related challenges.

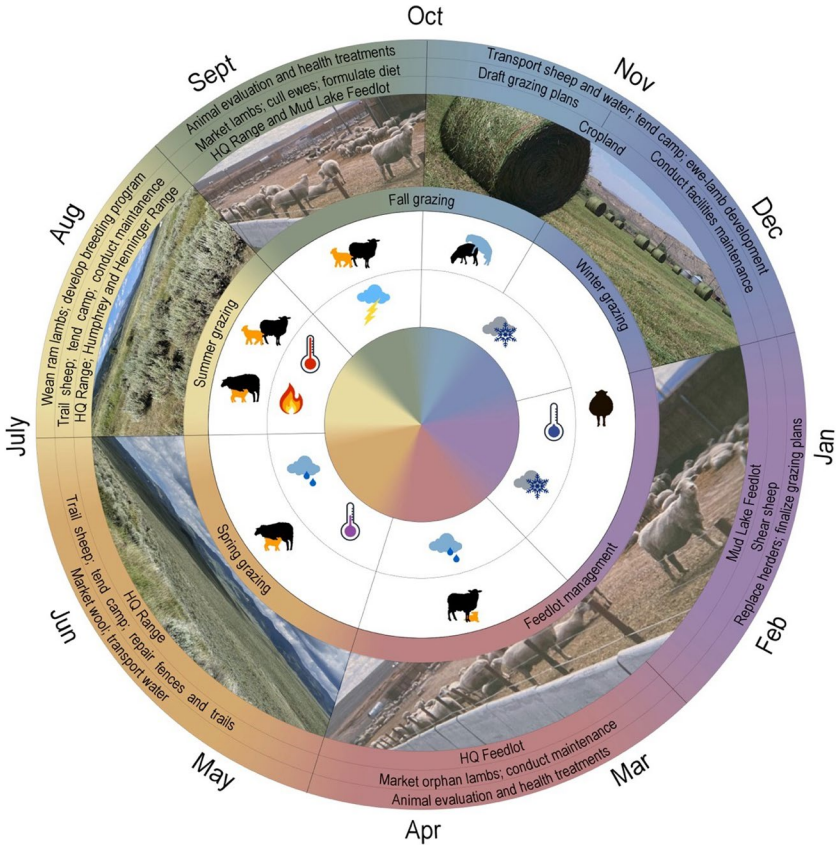


**Fig. 6** Calendar B, a graphical representation of the agro-ecological calendar for the US Sheep Experiment Station from 2013–2021 when traditional winter and summer ranges were no longer available and replaced by grazing on crop fields and lower elevation montane ranges, respectively. The calendar indicates patterns in system management and relationships among ecological, livestock, and social dynamics. Additional details are outlined in Supplement A, Table 2

daily operational tasks, the USSES staff engaged in proactive planning and found time during the summer months to improve ranch infrastructure, including water tank development, and road, trail and building maintenance. Manager logs also recorded how the structure of USSES operations and individual staff efforts dealt with extreme events and interconnected social-ecological disturbances that sometimes stacked together during difficult years. (Fig. 6).

## Calendar B: 2013–2021

The second agroecological calendar reflects a less extensive, more spatially constrained management context. Calendar B covers 2014–2021 (Fig. 6, see also Supplement A) and displays how USSES managers brought their own decision-making acumen and talents to ranch operations to sustain the production system. This calendar also reflects the ways in which the USSES adjusted to loss of access to both summer and winter range resources, which occurred gradually between 2013–2017, while also adapting to industry, economic, and ecological changes. Specifically, to comply with environmental regulations, USSES leadership developed a series of alternative scenarios for sheep grazing without the summer and winter ranges. These were subject to public notice and comment, and were then published in the ARS location's Environmental Impact Statement (USDA-ARS 2017).

One of the key challenges for USSES after 2013 was to adjust to the loss of seasonal ranges while maintaining a flock of breeding ewes that would sustain the "living laboratory" for range and animal science research, defined as a commercial scale research operation that serves to inform real-world applications to ranchers. The loss of the summer ranges prompted more intensive grazing on lower elevation rangelands, while managers made up for the loss of winter ranges by shifting sheep onto rented alfalfa stubble fields and by extending the flock's time in the feedlot. Calendar B indicates how sheep no longer trailed to Montana for the summer. Instead, they were trucked to graze the foothills Henninger property (once only used as a stop-over during trailing to summer range), and a federal grazing permit on US Forest Service (USFS)-administered lands in Idaho during the summer months. Depending on need, managers decided to place two herders with each band on USFS lands when predator risk and(or) public interactions were expected to be high.[5] Most seasonal movements among grazing areas were done via truck, rather than on foot, as access to sheep

[5] Meat sheep breeds, which do not exhibit flocking behavior and are thus not grazed in a "band", now constituted a higher proportion of the total sheep flock and were trucked with a fourth herder to the other foothills property, Humphry, see Fig. 3.

drives became limited and concerns about dealing with traffic increased.

When cool season plants senesced in mid-August, staff marketed lambs, identified the sheep numbers set for the following year, and grazing sheep returned from foothills properties or forest lands to the sagebrush steppe on the Headquarters in September. USSES staff hauled water to sheep daily and worked to secure winter feed rations from other farms. Breeding was conducted several weeks earlier under this period than during Calendar A to wean larger lambs. After breeding, without winter range, mature ewes were trucked to graze alfalfa crop stubble fields leased from local farmers. Staff sorted ewes and rams into confined feeding pens in late December, where sheep stayed until they were trucked to Headquarters in late February before lambing.

During this period, staff invested additional time in grazing planning and coordination, sometimes developing novel seasonal grazing approaches and contingency plans to adapt to dry years when live water and forage resources can become scarce in late summer. Specifically, foothills properties (named Humphry and Henninger, Fig. 2) became a de facto drought forage bank for dry summers such as 2021, but when forage and water became scarce on these properties, the ultimate drought back-up plan was to bringing sheep down to the sagebrush shrublands on the Headquarters property to re-graze pastures where they could at least maintain body condition. Without continued access to winter and summer ranges, the grazing pressure on lower elevation lands increased from intermittent use in late spring and fall to season-long use. Management goals to enhance forage production and availability for livestock became more prominent as labor and feed costs trended upward. During this time, the USSES sustained a relatively consistent flock size (Table 1).

## Loss of adaptive capacity

Over the 35-year study period, managers at the USSES continued a long-established form of transhumant livestock production while adapting to the loss of grazing access in traditional winter and summer ranges. The extent, type, and timing of range grazing changed to include more time on lower elevation pastures, on crop stubble, and in the feedlot. Here, we synthesize four themes that support the conclusion that the USSES experienced a loss of transhumant adaptive capacity over this 35-year period. These themes are: 1) risk reduction strategies and flexibility of the operation, 2) profitability, 3) livestock and rangelands conditions, 4) the working knowledge, experiences, and place connections of workers. For each theme we also summarize relevant ties to existing research and emergent research needs revealed through our study.

**Table 1** Annual average USSES ewe inventory for each study period by breed

| | 1986–2013 | 2013–2021 |
|---|---|---|
| Annual total ewes (range) | 2,861 (2,342–4,010) | 1,737 (1,409–1,858) |
| Ewe count by breed (range) | | |
| Rambouillet | 782 (354–1,120) | 460 (354–530) |
| Columbia[1] | 437 (114–733) | 47 (3–82) |
| Targhee[1] | 574 (425–919) | 348 (201–414) |
| Polypay[1] | 554 (384–1,271) | 326 (232–442) |
| PC[1] | - | 149 (52–331) |
| Suffolk | 94 (47–144) | 137 (71–198) |
| Katahdin[2] | - | 59 (20–97) |
| Crossbred[3] | 404 (54–1,064) | 259 (151–371) |

[1]The Columbia, Targhee, Polypay, and PC (Paternal Composite Line) breeds were developed at the US Sheep Experiment Station and released to the public in 1919, 1926, 1980, and 2020, respectively

[2]The Katahdin breed is a small haired sheep breed developed in Maine, US. Scientists at the US Sheep Experiment Station began evaluating the Katahdin breed in 2019 for its suitability for production in extensive, range-base systems

[3]Crossbred ewes are generally a component of breed evaluation and new breed development programs (e.g., Polypay and PC composite breeds)

## Shifts in risk and uncertainty reduction strategies

The loss of seasonal ranges corresponds with shifting approaches to adaptation and risk reduction strategy in the operation. The production system described by Calendar A was designed to exploit heterogeneity across sagebrush steppe, montane meadows, and high elevation sagebrush/forb pastures across grazing seasons to match livestock forage demand with supply, a common strategy in transhumant, ranching, and pastoral systems (Fernández-Giménez et al. 2015; Derner and Augustine 2016; Joyce et al. 2013). The loss of seasonal ranges left managers not only with less forage overall, but with a reduced capacity for mobility and less ability to match livestock nutritional needs with plant phenology and seasonality at critical times of year (summer and winter) for flock health and production. Managers adapted by incorporating crop residue grazing, a well understood mutually-beneficial practice in transhumant systems globally (see Aryal et al 2018a, b and Sayre 2023), and by extending the period of dry lot feeding by about three weeks each year. Therefore, Calendar B reflects a slight, but ecologically and agriculturally important, shift in risk reduction strategies towards the use of market-based approaches (buying feed or leasing pasture) and the creation of new relationships with other farm sectors, neighbors, and networks (Sayre 2023). The capacity of this less extensive system to adapt to future types of variability will be critical to the continuation of the

production system, but the outcomes are unclear. For example, if future adaptations involve a shift to additional use of water-intensive forage crops for confined feeding, additional environmental and social effects are likely to emerge. Climate science suggests that the complex impacts of climate change, such as changes in forage diversity, production, and quality, more frequent or intense drought and other extreme events, variable water resources, and changing fire regimes will continue to create novel complexity and economic stress for managers (Briske et al. 2015; Derner et al. 2018).

## Profitability

Though the USSES does not operate as a for-profit business, the operational changes we document have implications for ranch profitability and regional production systems. There are ranch, community and sector-wide economic consequences of the loss of public grazing lands (Lewin et al. 2019). Because smaller sheep operations in western US states rely on infrastructure (e.g. meat and wool processing pipelines and markets), industry group activities, genetic resources, and other management information derived from large producers, the ripple effects for these changing land uses may be broader than conventionally thought. Recent economic analyses in other system suggest that transhumance conducted on foot is more profitable than semi-extensive management or transhumance where sheep are moved in trucks (Fernández-Giménez and Ritten 2020; Fernández-Giménez et al. 2021). The most pressing issue for range sheep producers in the region is labor costs, which rise with additional operational complexity, for example with the need to add additional staff to mitigate livestock-wildlife or livestock-recreationist interactions, to mange more complex grazing calendars, and to haul additional water during drought. Access to private-land grazing or purchasing harvested feeds to replace lost ranges is another potential expense. For example, recent economic analysis by Dollerschell and colleagues (2024) indicate a 3.09 USD difference per animal unit month between public and private leased grazing though overall costs were not significantly different on the two types of grazing lands (2023). Furthermore, if alternative grazing lands are not available, moving sheep to feedlots becomes necessary. In such cases, daily harvested feed costs alone at the USSES (excluding fuel and equipment costs) may be 3.8 to 6.6 times greater than private grazing leases. This expense is further inflated when considering equipment, infrastructure, and maintenance costs for feedlot systems. Although the labor force usually remains the same (i.e., a herder and camp tender can satisfy the labor needs of the feedlot), operational knowledge and skill requirements may be greater. Operators must be able to formulate and mix diets, operate relatively complex feed processing and delivery equipment, and recognize and treat diseases common to feedlot environments. Such skillsets often warrant greater pay.

## Animal and rangeland outcomes

Our case study also allows us to hypothesize various nutritional and production implications of the loss of seasonal ranges for ecosystems and livestock which merit further experimental evaluation. For example, one of the legacies of the USSES is the development of environmentally adapted range sheep genetics, including the development or co-development of new breeds the Targhee (circa 1926; Terrill 1947), Columbia (circa 1919; Hazel and Terrill 1946), and Polypay (circa 1980; Hulet et al. 1984). This involved integrating ecological and animal science knowledge with rancher and production experiential knowledge, led by scientists and staff with experience in agricultural production systems who could operate a "living laboratory" at the experiment station (Seefeldt and Laycock 2006). Evidence that USSES sheep have been well adapted to their environment is consistent productivity including a lambing rate above 150% (Taylor et al. 2009) while the national industry average was below 110% (National Agriculture Statistics Service, 2017). Research from USSES sheep has shown genetic selection for dietary preference is possible, providing land managers with a tool to use sheep not only as grazers, but to improve lands as harvesters of noxious weeds and other undesirable plants (Snowder et al. 2001). More recent and on-going research at USSES is directed at understanding and selecting for sheep with a tolerance for bitter flavors, with the goal to increase shrub browsing and meet rangeland management goals (Henslee et al. 2019a, b; Henslee et al., 2020; Davenport et al. 2021). These genetic adaptations face new challenges in production calendar B. After the loss of winter range, managers recorded that range sheep bred to survive long, dry winters grew too heavy on crop stubble or in the feedlot. Without continued influence of the winter range environment, manager and the flock are anticipated to adapt to a novel environmental context.

After the loss of grazing access to winter and summer ranges at the USSES, a new grazing sequence put increased grazing pressure on lower elevation pastures. Shifts in summer grazing resources also increased potential interactions with public land recreationists on easier-to-access foothills areas. Quantification of the effects of removing sheep grazing from these seasonal ranges and intensified use of lower elevation sites in the summer merits further study. The removal of grazing from rangelands may not necessarily result in linear reversal of grazing effects on plant communities (Westoby et al. 1989). Research elsewhere has documented how reductions in livestock grazing are associated woody encroachment, and shifts in plant community composition in mountain rangeland areas (Palombo et al. 2013;

**Fig. 7** **A**. USSES summer range grazing by sheep bands involved daily attention from herders and frequent visits from camp tenders in the backcountry-like setting of the Centennial Mountains of Montana beginning in the early 1920s. **B**. During a range tour with early career staff in the fall of 2021, former USSES Operations Manager Quinn Jacobson is pictured looking across the West Summer Range toward the summit of Sheep Mountain, which previously supplied summer seasonal pasture for USSES bands. Domestic sheep grazing was completely but temporarily deferred from USSES summer ranges in the Centennial Mountains due to concerns for carnivore conservation by 2015. Photos: USSES staff

Vassilev et al. 2011). Future replicated experiments could quantify the effects of these management changes on plant communities while accounting for the influence of shifts in seasonality and hydrological patterns driven by climate change. Other areas where experiments are needed include studies to the consequences in production system transformation for methane emissions, lamb weaning weights, flock health, or ewe longevity as diets shifted (Czortek et al. 2018; Vassilev et al. 2011; Buchanan et al. 1972; Laycock et al. 1972).

### Shifts for workers and loss of local knowledge

The loss of seasonal ranges impacted the job duties and lives of USSES staff, and therefore had implications for the practice and development of local operational knowledge and agricultural workers' identities (Bruno et al. 2022; Fernández-Giménez 2015). These changes are likely indicative of cultural and social changes experienced by livestock producers around the region. For example, USSES staff made a large time investment to re-plan the operational system following the loss of seasonal ranges. Additionally, by 2016, staff no longer trailed sheep from range to range, had reduced time tending camps, and spent less time in remote backcountry settings as they had for nearly a century (Fig. 6, A). As a result, backcountry navigation, observation of high-country ecologies, and training on high elevation sheep grazing management were practiced less frequently. Trails and stock driveways (areas designated for livestock movement) on the ARS Summer Range grew in with woody vegetation and deadfall after active clearing by managers was reduced, and water developments were left unattended in the high country. As remaining ARS properties used for grazing are accessible by pickup or off-road vehicle, the need for horses was reduced, and pack saddles and herder tents were stored away. In later years, staff spent additional time trucking, clearing snow, and driving vehicles among dispersed properties, and botanical and grazing research focused on lower elevation sites. As one sheep herdsman remarked, "*The Summer Range is where I really enjoyed life. Now I'm just stuck down here*." Furthermore, the subsequent period with reduced attention to high elevation grazing research at the USSES created a missed opportunity to contribute new knowledge to sustainable rangeland management contexts in the region where research can help inform grazing management (Mosley et al. 2020; Zobell et al. 2023; Leytem and Seefeldt 2008). Despite these changes, seasoned USSES staff and retirees continued to make a concerted effort to teach new staff about the landscape, plant species, weather and hydrological patterns, sheep grazing history, and specific livestock management techniques needed to graze the Summer Range, in case the opportunity arise in the future (Fig. 7B).

## Discussion

### Implications for transhumance

Our study links US Intermountain range sheep system dynamics to the broader literature on mobile pastoral systems, including transhumance systems in Europe and elsewhere (Starrs 2018). This is a potentially empowering connection to empirical data, theories, and social solidarity among pastoralists and scholars globally. Specifically, our study links producers and researchers in a relatively rural, isolated sector of the US economy to broader conversations about the importance of pastoral mobility for adaptive capacity (Scoones 2023; Turner and Schlecht 2019), and the potential ecological benefits of transhumance (Manzano and Malo 2006; Hevia et al. 2016). In our study area, these benefits are hypothesized to stem from continued access to

the use of sheep as a vegetation management tool to shape wildlife habitat and reduce wildfire risks, and as economic strategy to limit land use conversion out of rangeland and maintain extensive, connected tracts of wildlife habitat (Brunson and Huntsinger, 2008). However, the contribution of the system to local economic and community well-being both from economic and ecological outcomes merits further study. Additionally, our study follows the global literature tracking the impacts to transhumance, adaptive capacity and social-ecological systems from loss of access to seasonal grazing areas as societal values for land use change, a persistent challenge for pastoralists globally (Bencherifa 1991, Zhang et al. 2013).

The USSES and western range sheep production face similar challenges to other systems in terms of conflicts between wildlife conservation (Cummins 2009). The USSES production system is representative of range sheep systems in the region that use herding practices and livestock guardian dogs to mitigate depredation from coyotes, birds of prey, black and grizzly bears, and the grey wolf, which was extirpated from the region in the early twentieth century but reestablished in the local area after it was reintroduced into nearby Yellowstone National Park by federal wildlife officials in the early 1990s. Where on-the-ground livestock and wildlife coexistence strategies continue to emerge from creative thinking and unlikely partnerships between wildlife, rangeland, and livestock managers, agroecological production calendars could serve as a boundary-spanning tool to design co-beneficial grazing and wildlife management strategies that reduce conflict.

## Agroecological calendars to document and inform adaptation

The USSES agroecological calendars contribute to our theoretical and practical knowledge of land management, agroecosystems, and system transformation by revealing how managers adapted to various climatic and social changes. This view into ranch-scale adaptation reveals the capacity of managers to plan for and respond to shifting social baselines, even when they have little control over large scale drivers of change. Our analysis brings to light three ways USSES managers and their livestock adapted to new management contexts. These were through care work, gradual adjustments to timing and sequence of management decisions, and through substitution.

First, USSES managers worked to prioritize care for ranch operations and livestock (Fig. 5). They cared for and maintained staff wellbeing, flock health, ranch infrastructure, or rangeland natural resources. For example, manager records included reports celebrating their staff's work to enhance infrastructure, pasture or livestock conditions, as well as their dedication during extreme events, including the life-threatening blizzard of 1989 (Fig. 5). Care work, or work that involves the nurturing of wellbeing in others, provides a key source of self-efficacy and manager success in an otherwise uncertain and largely uncontrollable system (Wilmer et al. 2020; Fernández-Giménez et al. 2022).

A second form of adaptation involved gradual manager adjustments in sequence or timing of livestock production events, such as lambing or shearing, to better fit ecological or climate conditions (Derner et al. 2018; Derner and Augustine 2016). Managers indicated that seasonal movements from spring to foothills ranges occurred two to three weeks earlier by the 2020s than it had in the mid 1980s. The agroecological calendar view of adaptation can contribute to planning and strategic approaches to climate-change related shifts in the seasonality, hydrology, and phenology, dynamics which are already reshaping production calendars. For example, botanists have observed that the timing of sagebrush flowering has already advanced an average of 21 days since the 1970s in the Greater Yellowstone Ecosystem (Bloom et al. 2022). Managers' ability to adapt to social and ecological changes and their interactions will require continued scientific and local knowledge development (Briske et al. 2015).

Substitution was a third tool that helped managers respond to new conditions (Uboni et al. 2020). When USSES managers lost access to a traditional tool, tactic, or aspect of their production system, they found an approximate substitute. For example, when high elevation summer ranges became unavailable, sheep were still moved uphill with shifts in seasonal phenology, but to slightly lower quality rangelands where they had to adjust herding practices to deal with new challenges (increased public and wildlife interactions). As a second example, when moving sheep on foot became more challenging and the distance they traveled shrank, managers turned to trucking (Fig. 6, Supplement A). Substitution enabled the continuation of a livelihood and operational system but did not address a potential loss of local knowledge, connectivity, and mobility as sheep were removed from winter and summer ranges. Lower elevation ranges are not a complete replacement for prime sub-alpine grazing areas, which offer a respite from hot summer weather, provide pastures with high forage nutritive value to support an important stage of the sheep production cycle, and give producers a wider phenological window for growing season grazing than do sagebrush steppe or foothills pasters. Trailing sheep on foot requires managers communicate with neighboring sheep operations and landowners to organize logistics and secure permission for driveway access, and it requires high levels of staff and animal coordination during trailing events. Trucking is still logistically challenging but can be conducted without maintaining local social networks and without knowledge of trailing routes, sheep behavior on the drive, or the

pattern of decisions needed to successfully move sheep for many kilometers (Starrs 2018). A more drastic form of substitution, via conversion out of range sheep production to cattle, may be common on private ranches but is under-studied.

## Conclusion

Our study uses agroecological calendars to document how, at a large sheep research ranch, a loss of seasonal ranges drove shifts in strategies for managing risk and uncertainty, rangeland and livestock production patterns, and ranch worker experiences and knowledge, resulting in a transformation of the operation's adaptive capacity. Notably, the loss of seasonal ranges reduced mobility and flexibility, increased the use of crop aftermath resources and feedlots, and created lost opportunities for scientific and local knowledge development. Nonetheless, USSES staff sought to remain flexible through creative uses of existing rangeland resources, adaptive planning, and care work. Agricultural system change is commonly theorized in terms of the effects of innovation adoption to reconfigure production systems and communities (Spiegal et al. 2022; Rosenzweig et al. 2020), but scholars are increasingly recognizing the role of changing social values and historical contexts in these processes (Aryal et al. 2018a, b; Dentoni et al. 2017). Production system change at the USSES was largely a response to public land use and wildlife conservation values, not because managers proactively sought to achieve intensified agricultural production goals. The agroecological calendar approach allows for a holistic picture of ranch change to complement existing work focused on innovation adoption theories designed to address production or technological changes (Didier and Brunson 2004; Spiegal et al. 2022). Over 35 years, the USSES successfully adapted to the loss of seasonal ranges, adjusted to dynamic weather conditions, and maintained a viable ewe flock size. However, shifts in grazing management and other production strategies have limited capacity to address transformational social and dramatic climatic change when the core components of transhumant adaptive capacity–mobility, genetic and ecological adaptations, social and ecological connectivity, and local knowledge—are at stake.

Accordingly, for range sheep producers and public-lands dependent communities, social and policy-based forms of adaptation are also increasingly important (Brugger et al. 2018; Fernández-Giménez et al. 2019). Operations and communities actively engage in political advocacy, educational efforts, collaborative management, or conservation innovations (Wilmer and Fernández-Giménez 2015; Fernández-Giménez, 2016). Increasingly, conservation organizations and ranching communities are seeking out opportunities to find common ground, either through science-based or collaborative management approaches (Sayre and Knight 2010; Huntsinger, Sayre, and Macaulay 2014; Fernández-Giménez et al. 2019). This reflects a recognition that the capacity of rangelands-based livestock operations to maintain and advance sustainable food and fiber production is interdependent with biodiversity outcomes. The persistence of these systems may depend not only on grazing and livestock management acumen but also on collaborative capacity to enhance coexistence among agriculture and non-agricultural goals on shared landscapes.

Solutions to multifunctional land use social conflict remain elusive across the US West, though they may be imperative to effective climate adaptation, food production, biodiversity conservation solutions, and rural social well-being (White 2008; Bestelmeyer et al. 2021; Steger et al. 2021). The USSES manager logs include notes on failed efforts of local interagency or interdisciplinary groups to bring various land use interests into dialogue before the USSES seasonal ranges were lost. While the capacity of local communities to collaboratively manage their common-pool resources is well established in the literature (Ostrom 1990; Robbins 2019), the question of how to build local capacity to mobilize solutions for coexistence of agricultural and conservation goals on heterogenous landscapes under various or multiple scales of governance remains an open but urgent question (Brunson and Lynn Huntsinger 2008; Knapp et al. 2020). The USSES agroecological calendars show us the downstream impacts to transhumant livestock systems from changes in land use driven by wildlife conservation concerns. Forward looking, collaborative decision-making processes about land use can serve to bring this knowledge to bear on real-world land use planning. Methods to reduce conflict over diverse goals for rangelands, to enhance livelihoods as well as conservation outcomes, and to create a future of coexistence are imperative to reducing further production system intensification and the increased loss of local operational expertise. Our study demonstrates that agroecological calendars are a promising and accessible tool to help foster understanding among producers, decision-makers, and researchers about understand operation-scale patterns in agricultural systems and their implications for people, livestock, and ecosystems.

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