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# Institutional changes drive land use transitions on rangelands: The case of grazing on public lands in the American West



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## ABSTRACT

Livestock grazing on natural rangeland vegetation is one of the most extensive land uses on the earth, with important implications for livelihoods, food security and the environment. Factors such as population growth and urban development, a shift from resource-based to service-based economies, and intensification in the livestock industry change the extent and practice of grazing worldwide. We investigated how and why livestock grazing on public lands changed since 1940 in the High Divide region of the Northern Rocky Mountains through a detailed analysis of United States Forest Service (USFS) rangeland management records. Based on a 90-year land use history, we process-traced the proximate causes of changes in grazing, identified the decisionmakers, and statistically tested which underlying factors were associated with changes in grazing. The forage annually consumed by livestock in our study area declined by 62% since 1940, the equivalent of about 33,000 fewer cows grazing on public lands for a three-month summer period. Livestock grazing was closed on 21% of the total allotment area. The reductions in grazing were mainly caused by land management and policy factors: evaluations of range condition (27%), carrying capacity estimates (21%) and legal and administrative requirements (14%) derived from the Endangered Species Act (ESA) and National Environmental Protection Act (NEPA). The socio-economic causes of ranch economics (14%) and amenity migration (8%) were comparatively small. Overlap with wilderness and proximity to amenity towns were significant spatial predictors of reductions in grazing. The fate of publicly-owned but privately-used rangelands largely depends on institutions that are able to reconcile the competing values and demands that influence how they are managed.

## 1. Introduction

Rangelands are of key importance in global land use dynamics, even though they generally receive less attention than forest, agricultural and urban land uses. Many rangeland landscapes are evolutionarily intertwined with herbivory (Milchunas and Lauenroth, 1993). The domestication of grazing animals enabled humans to harvest the widely dispersed nutrients of these lands, and thus livestock grazing became one of the most extensive land uses on the earth, covering a quarter of the land surface (Asner et al., 2004). However, factors such as population growth and concomitant development, a shift from resource-based to service-based economies, crop agriculture expansion, intensification in the livestock industry and climate change all change the extent and practice of grazing (Derner et al., 2017; Reid et al., 2014; Sayre et al., 2013). Rangelands are often perceived as marginal lands that are underutilized and underperforming, and are targeted for conversion to crop cultivation, urban development, afforestation or rewilding. As a result, extensive grazing of rangelands is declining globally (Hererra et al., 2014; Sayre et al., 2013).

The reduction in grazing can result in a land use transition, defined as a structural change in land use system from one state to another (Lambin and Meyfroidt, 2010). Such a transition can involve a conversion of rangelands to another use or a modification of their use, through intensification or dis-intensification of grazing. In cases where the removal of livestock is replaced by increased amenity and recreation use or abandonment, it is tempting to view such a transition as a form of nature conservation. However, the termination of grazing does not necessarily result in a passive restoration to a prior state or expected changes in land cover (Cervera et al., 2019). Poorly managed grazing can cause ecological damage, but the removal of livestock grazing can

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also lead to decreases in biodiversity, increases in fuel loads for wildland fire, and encroachment of trees and shrubs into mountain meadows (Huntsinger and Oviedo, 2014; Strand et al., 2014; Miller and Halpern, 1998). The role of working landscapes in supporting rural prosperity, protecting against habitat fragmentation, and providing natural climate solutions could be undermined by a loss of ranching (Bruson and Huntsinger, 2008; Charnley and Sheridan, 2014; Gosnell et al., 2019). Researchers speculate about the possibility of a tipping point, such that once a critical mass of ranches is lost, ranching is no longer viable because of the loss of key infrastructure and community benefits provided by a network of ranches (Huntsinger and Hopkinson, 1996; Liffmann et al., 2000; Huntsinger et al., 2014). Identifying the drivers of land use transitions on rangelands can help illuminate the changing ecological and social roles of ranching.

In the American West, research has documented high rates of rangeland conversion to intensive agriculture and urban development (Travis, 2007). A trend of ranch ownership by amenity owners, including the super-wealthy, replacing traditional livestock businesses is also changing the practice of grazing (Gentner and Tanaka, 2002; Gosnell et al., 2006; Epstein et al., 2019; Farrell, 2020). Grazing on public lands has been declining for decades, but less attention has been paid to that trend, despite widespread dependence by private ranches on public grazing permits and tight connections between private and public land uses (Gentner and Tanaka, 2002; Huntsinger and Sulak, 2007; Yahdjian et al., 2015). Public lands account for more than half of the total lands in the American West, and a majority are grazed. Given their extent, public land management is critical for both maintaining functioning ecosystems and supporting rural economies. Researchers have attributed the decline in public rangeland grazing to a rural transition or restructuring from an Old West based on extractive activities to a New West defined by a service-based economy and urbanization. However, given multiple sources of pressure on ranching and diverse institutional arrangements that govern grazing, it remains a challenge to understand how multiple factors interact to drive land use transitions on rangelands (Sheridan, 2007). A myopic focus on new versus old economies, people, and ecologies produces more blind spots than it uncovers (Robbins et al., 2009). Continued interrogation of social-environmental change in the American West requires disentangling a complex, multi-layered history that recognizes heterogeneity across geographies (Martin et al., 2019; Jones et al., 2019).

The objective of this research is to understand how and why livestock grazing on public lands changed since 1940 in the High Divide region of the Northern Rocky Mountains. We analyzed United States Forest Service (USFS) rangeland management records and created a unique grazing time series that reveals the patterns of use by privately-owned livestock on USFS rangelands since 1940. We used the USFS records to process-trace the proximate causes of changes in grazing through the study period and to identify the decision-makers. Finally, we statistically tested some underlying factors that are hypothesized to be associated with changes in grazing. The USFS records are a rich but under-utilized data source that can uncover land use transitions through long periods of time. The research contributes to an understanding of the long-term social and ecological drivers of land use transitions and the trajectory of working lands in the rural American West. Our findings are relevant for rangelands elsewhere in the world that are confronted with similar challenges of competing uses, changing institutions, and shifting values related to livestock and natural ecosystem management.

#### 2. Background

## 2.1. Grazing governance and land use transitions

A complex of social-ecological and institutional factors drives land use transitions (Lambin and Meyfroidt, 2010). Extensive livestock grazing requires access to large amounts of land, often with tenuous or complex property institutions (Huntsinger et al., 2010; Hererra et al., 2014). Institutions are the formal and informal rules and norms that shape how individuals interact with each other and their environment (North, 1990; Ostrom, 2005). The property arrangements common to grazing create complex governance regimes made up of multi-layered institutions that are distinct from other land cover types. These institutions necessarily evolve and adapt to changing circumstances over time (Ostrom, 1990). Current understanding of land use transitions might not be well adapted to rangelands and the grazing land use. A recent review of rangeland social science in North America found just ten articles from the field of geography since 1970 (Bruno et al., 2020). Understanding the drivers of change in grazing use can help inform strategies for sustainable use and management of rangelands.

#### 2.2. Rangelands in the new American West

This study is concerned with public rangelands in the American West that are grazed by permit to private livestock producers. Ranching in the region relies heavily on access to public land through a permit system, particularly in the interior mountain areas (CAST, 1996). Permits are issued to ranchers for specific public land parcels, called grazing allotments. While permits are officially issued for ten-year periods, they are almost always renewed and typically stay connected to a private land parcel or base ranch, even when the private property changes owners.

While precise numbers are difficult to track, grazing on National Forests generally increased rapidly from the early 1880s through World War I, declined sharply from 1920 to 1950, and continues to decline slowly to the present (Huntsinger et al., 2010). The Bureau of Land Management (BLM) estimates that forage consumed on its lands through the American west has declined by 48% from the 1940s to 2011 (Yahdjian et al., 2015). One of the only in-depth investigations into changes in public lands grazing found that grazing area is half of what was available in the early 20th century in the west central Sierra foothill in California (Sulak and Huntsinger, 2002). In the Shasta-Trinity National Forest, livestock grazing covers only 10% of its peak extent in 1920, and forage harvested declined by 50% on permits that are still ongoing (Huntsinger et al., 2010). In most regions, aggregate statistics obscure the extent and pattern of change, making the details of what drives these changes over time illegible.

Previous literature has identified pressures on ranching in the *New West*, which we summarize below as it is relevant to land use transitions on rangelands in the American West (Sayre, 2002, 2017; Pearce, 2004; Bruson and Huntsinger, 2008; Huntsinger et al., 2010). Drivers of change are different on federally managed land compared to private lands. However, one cannot assume that all decision-making ability lies with managing agency, or that federally-managed land use is fully buffered from market forces. The use of public lands for grazing is tightly intertwined with use of private lands, and non-governmental actors have power in influencing and directing public land use, including through the courts. Such layered governance and mix of tenure arrangements are very common to extensive grazing globally (Hererra et al., 2014).

### 2.2.1. Federal administrative control

The establishment of the Forest Reserves, later called National Forests, in the late 19th and early 20th centuries took land out of the public domain and placed it under permanent control by the federal government. This process was intended to conserve resources for ongoing settlement and economic development of the West (Dana and Fairfax, 1980; McCleery, 2008). Government control of land under a mantra of conservation was tied to the rationale of optimal production, a common justification for government control of land in many parts of the world. The project of bringing a previously open range under administration required new management tools. The carrying capacity concept emerged as a method of identifying a stocking rate for a given allotment that could maximize productivity and be the basis for a stable, ten-year permit. The goal was to maintain rangeland vegetation as close to climax species composition as possible, which was the standard measure of range condition (Sayre, 2017). The creation of the permit system thus instigated costly range condition studies and monitoring that were often the basis for reducing levels of stocking.

## 2.2.2. Rise in political and legal power of environmentalists.

The environmental movement that began in the 1960s and 1970s mobilized constituents that prioritized public land for wildlife and recreation over the productive uses of logging and grazing (Savre, 2002). Passage of the National Environmental Protection Act (NEPA, 1970), the Endangered Species Act (ESA, 1973), and the Federal Land Planning and Management Act (FLPMA, 1976) all elevated environmental value in public land decision-making and created legal recourse for environmental groups seeking to enforce them through new controls on livestock grazers (Sayre, 2002). As a result, the priorities of public land management began to shift from a focus on productivity toward ecosystem management (McCleery, 2008). The threat of lawsuit and need to constantly engage the public also altered agency behavior to manage public grazing more prescriptively (Martin, 2019). These new policies often contradicted existing public land policy, creating a structured normative pluralism of competing values that continues to lead to uncertainty and conflict around how lands should be managed (Purdy, 2019).

## 2.2.3. Competing use by amenity migrants and recreationists

Urban-to-rural migration has intensified in many parts of the American West, with impacts on ranching by increasing land values and creating a clash of cultures (Nelson and Hines, 2018; Burow et al., 2019). Amenity migration is understood as the "pattern of movement of relatively affluent urban or suburban people to rural places in search of particular lifestyle attributes, such as natural scenery, proximity to outdoor recreation, cultural richness of a sense of rurality" (Abrams et al., 2012). In the ten counties that comprise the Greater Yellowstone Ecosystem, more than a third of ranches that sold between 1990 and 2001 were purchased by amenity buyers (Gosnell et al., 2006). Changing demographics can make running a livestock operation more difficult, as newcomers bring traffic, weeds, crime, and congestion and disrupt established cross-boundary cooperation important to grazing management (Huntsinger and Hopkinson, 1996; Forero et al., 1992; Walker and Fortmann, 2003; Pearce, 2004; Yung and Belsky, 2007). Increased recreation can also change the priorities of public land managers as they seek to meet new customers' needs.

## 2.2.4. Economic vulnerability of livestock production

Ranchers often cite economic vulnerability as a primary challenge in ranch sustainability, and most ranch families depend on off-farm income to maintain their livelihood (Haggerty et al., 2018; Sheridan, 2007). In 2002, a survey of public land ranchers found that most did not believe that earning an adequate return was possible given market conditions (Gentner and Tanaka, 2002). Changes in the global meat production industry have made extensive grazing, especially in remote locations far from feed-lots, less profitable (Derner et al., 2017; Pearce, 2004). In recent years, price volatility related to the cattle cycle of growth and liquidation has increased to unprecedented levels, creating additional management challenges for producers given slim margins and high fixed costs (Schulz, 2013). It has long been acknowledged that profit is not the most important goal for public land ranchers, and that ranchers are often economic satisficers (Smith and Martin, 1972). However, ranching businesses cannot survive indefinitely if profits are less than zero without sufficient sources of outside income. Under large economic pressures, ranchers may need to reduce the size of their operations or sell their land and operations.

#### 2.2.5. Aging cohort of ranchers

As with American farmers at large, the current cohort of ranchers in the American West is getting older (Glick et al., 2014). While there is uncertainty about these changes across the West and some indications that average age of ranchers has been stable in recent decades, aging ranchers might lead to increased rates of ranch turnover (Glick et al., 2014; Gosnell et al., 2006). Estate taxes and lack of succession planning force heirs to sell the ranch even if they might prefer to keep ranching (Haggerty et al., 2018).

#### 2.2.6. Loss of rangeland productivity

Past declines in rangeland productivity could theoretically lead to a retreat from previously used areas. A review of land use transitions found that institutional changes and technological innovations are more likely to drive transitions than declines in productivity (Lambin and Meyfroidt, 2010). However, in the context of public land grazing, past declines attributed to livestock use could motivate a reduction in stocking rate or complete closure to livestock. Many areas of the American West are believed to have been heavily grazed during the early 20th century, but the pattern and long-term impact of such grazing is far from understood (Sayre, 2017).

## 2.2.7. Rancher place attachment and "consumptive" values

All of the above factors suggest an increasing likelihood that agency staff will reduce the amount of grazing allowed on an allotment or that a rancher will decide to give up or reduce the size of a public land grazing permit. However, ranchers generally express a strong desire to stay on the land and report that they would continue ranching even if they only break even (Gentner and Tanaka, 2002; Pearce, 2004). Smith and Martin (1972) showed that ranchers of all types are heavily motivated by the consumptive values of ranching, believing that ranching provides a higher state of total well-being than alternatives due to intertwined values of family, rural, and land values. Ranchers tend to be strongly attached to a local area and community, and are reluctant to relocate. The place attachment of ranchers to the landscapes where they work and live makes ranchers reluctant to give up grazing activities (Hinojosa et al., 2016). How the pressures outlined above affect public land grazing is thus not easily predictable, as all these factors work in combination and are modulated by the unique connections of ranchers to the ranching lifestyle and place.

## 3. Methods

## 3.1. Study area

The High Divide is an understudied region of the American West that is highly valued for its large stretches of intact open space. A large proportion of public land with a long history of livestock grazing and amenity-driven migration and population growth are suggestive of dynamics affecting grazing land use. The presence of factors that impact ranching make the study region a *critical case* of grazing land use change on public lands, such that one expects to observe hypothesized dynamics that are relevant for other cases (Flyvberg, 2006). While the study area may not be representative of the American West in the statistical sense, results are expected to be relevant for other areas where ranching relies on access to public lands and to contribute to theory on rangeland use transitions.

The area is characterized by rugged mountain peaks and broad valleys, with elevations spanning 900 to 3860 m. A varied topography sustains diverse vegetation communities, including sagebrush steppe, subalpine forests and meadows, and alpine zones. The federal government owns and manages most of the land (80–95% depending on the county), while interspersed private lands cover valley floors and riparian areas. The federal government began administering public grazing permits to private ranchers ("permittees") with the establishment of the National Forests in 1908. Ranchers keep animals on private base ranches during winter and then trail animals onto sagebrush steppe and high mountain meadows on public land in the summer, a pattern of use defined as transhumance. Permittees rely heavily on these permits for the sustainability of their operation. Despite an overall rural character, the Sun Valley ski resort has long attracted wealthy, urban visitors and second-home owners to the region (Martin et al., 2019). Since the 1960s, designation of five Wilderness Areas and the Sawtooth National Recreation Area have made the area a world-class outdoor recreation destination. The region was also one of two sites of wolf re-introduction in 1995, along with Yellowstone National Park. Its unique river habitat supports endangered anadromous fish, including one of the few remaining wild populations of Chinook salmon (USDA-FS, 2017). One of the most active anti-grazing environmental NGOs, the Western Watersheds Project, is headquartered in this region.

Our research focuses on public land grazing allotments on three districts on the Sawtooth and Salmon-Challis National Forests in Idaho, covering approximately 7600 km<sup>2</sup> (over 1.8 million acres) (Fig. 1). These three ranger districts capture variability in factors that are hypothesized to impact grazing. The Sawtooth National Recreation Area (SNRA) has been a center of both recreation and amenity migration since the 1960s and includes areas of critical habitat for endangered fish. The Lost River ranger district is further from Sun Valley and has no critical habitat for endangered fish, but anecdotally has experienced higher levels of ranch ownership change to amenity buyers. The Challis-Yankee Fork ranger district includes critical habitat to three species of endangered anadromous fish, and the traditional ranching community is considered strong.

## 3.2. Methods

All data analysis and interpretation were informed by semistructured interviews and participant observation with public land ranchers and USFS staff in the region conducted by the lead author for a total of twelve months between June 2017 to December 2019. Observation notes and interview transcripts were not analyzed as part of this study, but time spent in the field is relevant to the authors' interpretation of USFS records and events.

#### 3.2.1. Document review

We analyzed 90 years of USFS rangeland management records for 90 allotments on three ranger districts (RD). Each allotment has a physical record stored in the USFS field offices that includes allotment management plans, annual authorized use instructions, records of actual use, National Environmental Protection Act and Endangered Species Act documentation, and correspondence between ranchers, agency staff and the public dating back to the establishment of the allotment. We reviewed the full record for all allotments and scanned 12,300 pages for later analysis. For each allotment, the lead author extracted data on grazing animal (i.e., cattle or sheep), number of head, season of use, and an estimate of forage consumed in Animal Unit Months to create a timeseries of use from 1940 to 2019. One Animal Unit Month (AUM) is the amount of dry forage required by one mature cow and her calf up for a 30-day period (USDA-FS, 2017). AUMs are calculated from the number and type of grazing animal and the duration of grazing period. Actual AUM use data, submitted by the rancher at the end of the season, was recorded when available. Otherwise we recorded authorized annual AUM use from the contract signed annually between the permittee and USFS.

## 3.2.2. Process-tracing proximate causes of change

To systematically identify the causes of changes in annual AUMs, we tracked *change events* observed in the time series (Table 1). We define a *change event* as a sustained plus or minus change in annual AUMs permitted on the allotment that is part of a trend maintained for at least three consecutive years. The intent is to capture durable changes in the



Fig. 1. Map of Study Area Allotments and Regional Land Ownership.

#### Table 1

Example Process-Tracing and Coding of Change Events.

ID Number	Allotment Name	Year	Change Event Description	AUM Change	AUM Change calculation	Proximate Cause	Decision- Maker
40405	Copper Basin	1988	Personal convenience non-use by permittees; "Permittees are in serious financial straits. I do not know if the allotment will ever be stocked at permitted obligation"	-1226	[1988–1990 mean] – [1979–1987 mean]	Economics: Reduce size of operation	Permittee
40427	Hurst Canyon	2006	New conservation-minded permittee chooses to run below the permit	-533	[2005–2019 mean] – [1978–2005 mean]	Amenity Values and Migration	Permittee
45700	Lower East Fork	1956	FS reduces permit to match carrying capacity determined by utilization studies	-249	[1956–1973 mean] – [1952–1955 mean]	Carrying Capacity	US Forest Service

level of grazing, rather than annual variations. The change events could be implemented on the ground as changes in the area open to grazing, type of livestock allocated to the permit, season of use, or the numbers of stock.

We then reviewed the allotment records to qualitatively process trace the primary *proximate cause* of each (Table 1) – defined as the decision-making criteria, rationale, or value that motivated a change in grazing. Process-tracing is "the systematic examination of diagnostic evidence selected and analyzed in light of research questions and hypotheses posed by the investigator" (Collier, 2011). The method allows for attribution of causal mechanisms in within-case analysis by using deep knowledge developed from multiple data sources to evaluate potential hypotheses for how variables relate to outcomes (Meyfroidt et al., 2016). For each event, we first used all available USFS records to describe the event and how the decision came about on the allotment. The event descriptions were coded into a condensed list of emergent proximate causes. If the change occurred over a few years but with one primary cause, the cumulative change during that period was recorded and coded as one change event.

Some events have overlapping causes, and we strived to code for the principal or precipitating cause. For instance, a conservation-minded grazer might reduce permit to promote wildlife habitat on their ranch. We coded this event as amenity values and migration, rather than wildlife, because the presence of the amenity migrant precipitated the change.

## 3.2.3. Statistical analysis of underlying causes

We used the variability of changes in grazing at the allotment level to statistically identify *underlying factors* of changes – defined as indirect sources of pressure on grazing. We tested for associations between five hypothesized correlates and the outcome of interest with a multiple linear regression using ordinary least squares. The dependent variable was the percent change in average AUMs consumed in 2019 since a 1940–1949 average baseline. When data were not available for this baseline period, the first decade of grazing data available was used as a baseline. Independent variables were chosen based on the document review, literature, and data availability.

We expected that an allotment within a *Wilderness Area or Recommended Wilderness* (H1) to have a higher likelihood of grazing reductions, either due to stricter management by the USFS or greater pressure from recreationists and wilderness advocates. Due to strict standards for livestock management in the presence of fish species listed under the Endangered Species Act, we also tested the role of presence of *critical habitat for endangered anadromous fish* (H2). We included only endangered fish species because of their significance in the region and the fact that livestock can significantly alter riparian vegetation and habitat.

Because *past overgrazing* (H3) likely leads to stricter management by the USFS to reduce grazing, we included the percentage of the allotment in poor condition as determined by range analyses conducted from the 1950s through the 1980s. *Number of permittee transitions on the allotment in the study period since 1950* (H4) was included because ranchers with a longer history on their land are expected to have a stronger commitment to ranching and are more likely to work through challenges to keep their operation going. Transitions within the same family were not counted. Because the documents did not have permittee data for all allotments since 1950, we imputed the missing data using the average rate of transitions for the available period. No data were available to test whether an aging cohort of ranchers at the allotment level is influencing grazing land use.

Finally, given that amenity migrants tend to value recreation use over livestock grazing and their presence can impact agency management, we hypothesized that *remoteness from recreation destinations* (H5) buffer from these pressures. Remoteness can also be considered a proxy of land value, as property values tend to be higher closer to amenity locations. This was coded as a continuous variable for minimum drive time from Sun Valley, Stanley, or Salmon, the three primary destinations for amenity migrants and visiting recreationists. Drive time was calculated with a street network dataset in ArcGIS to the allotment centroid, with a maximum of 263 min (StreetMap USA, 2017). For allotments not accessible by the street network, we assumed a maximum distance of 300 min.

#### 4. Results

#### 4.1. Changes in rangeland use

In the 1940s, an average of 158,995 AUMs were consumed annually across the three districts. By the most recent decade (2010–2019), the number had dropped to 59,853 AUMs, or a 62% decline (Fig. 2). This is the equivalent of about 33,000 fewer cows grazing on public lands for a three-month summer period. The reduction is precipitous across all districts, but highest in the Sawtooth National Forest RD (80% decline), followed by Challis RD (64% decline) and the Lost River RD (49% decline). Since 1940, livestock grazing was closed or removed completely on 1500 km<sup>2</sup> (or 380,000 acres) of land, or 21% of the total allotment area in the study region. Across all districts, AUMs declined most dramatically during the 1940s and 1950s, leveled in the 1960s and 1970s, and then continued to decline more gradually in the 1980s and 1990s. AUMs increased slightly by 48 AUMS from the 2000s to the 2010s. While this is less than a one percent increase, it suggests that the pace of reductions is slowing.

At least one value is reported per decade for 96.2% of all allotmentdecades. Five allotments had no data for the 1940s. We kept these allotments in the analysis because each had sufficient data for the remaining years. To calculate the overall reduction, we assumed missing 1940 values were the same as the most recently reported value, following next observation carried backward (NOCB) in time-series analysis. Given the trend in declining AUMs, this interpolation might slightly underestimate total reductions. For all other decades, missing values are calculated using simple linear interpolation. Eleven of the 101 allotments in the study area were omitted from the study because they did not have a record in the USFS field office, most often because they are co-managed by the BLM. Nine allotments were created out of purchased private ranches and added to the SNRA district after the recreation area was created in 1972. We recorded 0 AUMs for all years prior to establishment of the USFS allotment.



Fig. 2. Average Annual Animal Unit Months on three districts on Salmon Challis and Sawtooth National Forests by allotment. (1940–2019).

## 4.2. Proximate causes of changes in grazing on public lands

Coding of 262 individual change events in the grazing time series identified seven proximate causes of changes in grazing on public lands in the study area (Table 2). This list emerged through the inductive coding process, as informed by time spent in the field and the literature. Only one cause—sustained yield—drove net increases in grazing, whereas the other six causes all led to net reductions in annual AUM.

Changes due to range condition include the many types of decisions made by range managers and permittees to maintain or improve range vegetation for both ecosystem health and productivity. This cause includes decisions such as delaying entrance of cattle until a desired level of growth of the vegetation (i.e., range readiness), closing areas to grazing due to soil erosion, reducing grazing pressure on riparian vegetation, or reducing grazing during a period of drought. Often these reductions were recorded as *non-use for resource protection*. These decisions are not reliant on one theory of the role of cattle in rangeland ecology or a priori estimates of the ideal level of grazing but are instead responsive to conditions on the ground.

The second proximate cause of change is carrying capacity set through studies performed by USFS range management staff to determine the ideal stocking rate for a given allotment. Range staff matched grazing permits to the levels determined by these range studies, and carrying capacity is cited as rationale for changes on permit documents. Agency staff would often take reductions to match carrying capacity estimates upon permit transfers, in order to limit the economic disruption to the current permittee. While permit transfers often came about because a rancher needed to sell their ranch or operation for economic reasons, we recorded the cause of these reductions as carrying capacity because the change was motivated by the carrying capacity studies, regardless of the economic preference of the new permit holder.

Legal or administrative requirements include decisions made to both implement and enforce the statutes and regulations governing the USFS. Range managers suspend permits for non-compliance with the *Allotment Management Plan (AMP) (5a)*, as required by the National Environmental Protection Act (NEPA). Range managers are also required to implement the *Endangered Species Act (ESA) (5b)* by enforcing specific standards set by the Fish and Wildlife Service. In the study region, range managers reduce grazing pressure to achieve utilization standards on riparian vegetation to protect habitat for endangered anadromous fish.

The fourth cause is connected to the economics of the ranch and livestock industry, and impacted AUMs in three distinct ways. While financial records of ranches are not included in the records, permittees need to apply for non-use for personal convenience (6a) when they decide to graze below the level of their permit. These applications, as well as correspondence between agency staff and ranchers, indicated the reason for this non-use as typically economic. If non-use continues for three consecutive years, agency staff are required to remove the AUMs from the permit and offer them to another permittee. If ranch economics are generally not favorable in the region, other permittees would decline to fill the permit and the permit would remain vacant or be formally closed. Documents also show when a permittee applied to *change their permit* from sheep to cattle (6b). The sheep industry has been in rapid decline since the 1940s, and 17 allotments made that change during the study period. Because cattle cannot graze the steep terrain utilized by sheep, the transition reduced the available AUMs on a permit. When a rancher retires or passes away (6c), estate taxes and lack of succession planning often forced heirs to sell the ranch. In these cases, new owners were not interested in filling the permit and other qualifying ranchers declined to take on the additional permit, as the expansion was not economically feasible.

The fifth cause is multiple use and sustained yield, the only cause that leads to a net increase in grazing. The concept originated in the Multiple Use and Sustained Yield Act of 1960, which promoted the "management of all the various renewable surface resources of the national forests so that they are utilized in the combination that will best meet the needs of the American people" and "achievement and maintenance in perpetuity of a high-level annual or regular periodic output of the various renewable resources of the national forests without impairment of the productivity of the land" (Multiple Use and Sustained Yield Act, 1960, Sec. 5, p. 4). The statute provided a basis for considering grazing as one of several values of National Forests to be maintained. Beginning in the 1960s, a focus on sustained yield in particular became the principal goal of range management highlighted in almost all Allotment Management Plans in the study area. The concept provided the rationale for investments in rangelands, such as water developments and sagebrush removal, to increase productivity for grazing.

Amenity values and migration represent changes made in rangeland management due to the ways new migrants relate to the national forests. New migrants often value recreation and wilderness aesthetics, which creates pressure on range managers to manage for these values. New ranch owners can also choose to reduce grazing to increase amenity values on their permitted lands. Where special provisions in the Wilderness legislation allows, traditional ranchers can voluntarily agree to permit buyouts by environmental organizations that lead to permit retirement (Pub. L. No. 114-46. 129 Stat. 476). While this decision

Table 2           Proximate causes of changes in grazing.	
Proximate Cause	Description
<ol> <li>Range condition</li> <li>Carrying capacity</li> <li>Carrying capacity</li> <li>Legal or Administrative requirements - AMP</li> <li>Legal or Administrative requirements - ESA</li> <li>Legal or Administrative requirements - ESA</li> <li>Economics - Reduce size of operation</li> <li>Sustained Yield</li> <li>Amenity Values and Migration</li> <li>Wildlife Values</li> </ol>	General condition of range vegetation for ecosystem health and productivity, including range readiness, soil erosion, riparian vegetation, or response to drought Determine how many cows or sheep can graze how much land for how long based on Clementsian ecological theory that range is restored by succession without disturbance Implement or enforce Alloument Management Plans (AMP) as required by the National Environmental Protection Act (NEPA) Implement or enforce the Endangered Species Act (ESA) for listed anadronous fish Reduce allowed AUMs for economic consideration (e.g., beef prices) Change permit from sheep to cattle due to economics of sheep industry Permittee retires; there is no replacement and allounter remains vacant USFs manages for "maintenance in perpetution to prioritize recreation or other amenity values Reserve forage for wildlife and improve range capacity for habitat

**Table 3** Changes in animal unit months as a result of seven proximate causes on three districts on the Salmon-Challis and Sawtooth National Forests.

Proximate Cause			Challis RD		Lost River RD		Sawtooth Natio Area	nal Recreation	Sub-Total	Total	
			AUM Change	% of Changes	AUM Change	% of Changes	AUM Change	% of Changes	AUM Change	AUM Change	% of Changes
1 Range condition			-6,982	19.3%	-11,690	34.3%	-4,976	30.1%		-23,648	27.6%
2 Carrying capacity			-8,976	24.8%	-6,291	18.5%	-3,690	22.3%		-18,957	22.1%
3 Legal or Administrative requirements	в	AMP	-845	2.3%	-3,208	9.4%	0	0.0%	-4,053	-12,685	14.8%
	q	ESA	-7,610	21.1%	-98	0.3%	-924	5.6%	-8,632		
4 Economics	в	Reduce size of operation	-2,710	7.5%	538	1.6%	-1,876	11.4%	-4,048	-12,249	14.3%
	q	Change from sheep to cattle	-1,393	3.9%	-2,030	6.0%	-1,925	11.7%	-5,348		
	J	Retires, no replacement	-21	0.1%	-2,806	8.2%	-26	0.2%	-2,853		
5 Sustained Yield			5,861	16.2%	4,432	13.0%	785	4.8%		11,078	12.9%
6 Amenity Values and Migration			-1,739	4.8%	-2,970	8.7%	-2,310	14.0%		-7,019	8.2%
7 Wildlife values			-329	0.9%	-2,079	6.1%	-761	4.6%		-3,169	3.7%
Total Absolute Change			36,137	100.0%	34,064	100.0%	16,512	100.0%		85,636	100.0%
Total Net Change			-24,415		-24,122		-14,942			-63,479	



Fig. 3. Decadal Change in AUM by Proximate Cause (1940-2010).

includes economic considerations by a traditional permittee, it is enabled by willing buyers of permits for conservation and amenity values.

Lastly, wildlife values include decisions to reserve forage or improve range capacity for wildlife habitat. Commonly, domestic livestock grazing was reduced or removed from key winter habitats for elk or deer or from areas with risk of transmission of diseases between bighorn sheep and domesticated sheep.

The change in AUMs as a result of each proximate cause is reported in Table 3 and by decade in Fig. 3. The leading cause of change was *range condition*, driving 26.6% of all changes, throughout the study period. *Carrying capacity* reduced grazing by about 21.3%, primarily driving decisions by managers from 1940 to 1970. In contrast, *compliance with legal or administrative requirements* reduced grazing by 14.3%, intensifying in the 1980s and becoming the leading contributor of change in the 2000s.

Decisions based on economics (13.8%) played a role throughout the study period. In the early period, reductions were mostly a result of transitions from sheep to cattle. After 1980, permittees choosing to decrease the size of their operations or retire with no replacement led to reductions. Actions to support sustained yield *increased* AUMs by a total of 11,078 AUMs (12.5% of the total change) and were realized almost entirely in the 1970s and 1980s. Amenity migration did not become significant until the 1990s, and drove a total of 7.9% of change. Wildlife values (3.6%) were the smallest contributors to change over the study period, influencing decisions starting in the 1970s and peaking in the 1990s.

The main drivers of change were mostly consistent across ranger

Table 4

Change	in	AUMs	by	Decision-Makers.
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Decision-Maker	Net Change in AUMs	% of total
USFS	-35,199	53.4%
Permittee	-17,389	26.4%
USFS & Permittee, collaborative	-13,276	20.1%
Court	-30	0.05%
Total	-65,894	100.0%

districts, with a few exceptions. Compliance with the Endangered Species Act for endangered anadromous fish led to 20.9% of reductions on the Challis RD, and only 0.3% and 5.3% on the Lost River and SNRA RDs, respectively. Investments in sustained yield increased grazing by 16.1% and 12.3% on the Challis and Lost River RD, in comparison to 4.5% on the SNRA RD. Amenity migration contributed to 13.4% of reductions on the SNRA, over double the rate on the Challis Ranger District. Thirteen change events totaling 2237 AUMs (1.4% of total) were not coded due to insufficient evidence in the available documents.

We also coded the decision-makers behind changes in AUMs (Table 4). The USFS made the majority of decisions unilaterally. Permittees made almost a quarter of decisions, including all changes driven by economics. Decisions made collaboratively between the USFS and the permittees accounted for about 20% of all AUM changes. These collaborative decisions include all *sustained yield* changes, which were typically led by the USFS but always had the support and cooperation of the permittee. In some cases, the USFS might have led the effort but worked to gain the agreement of the permittee, which was coded as a collaborative action. Courts were responsible for only one decision that led to a permanent change in AUMs. A total of 1170 AUMs of change (less than 2% of total) did not have enough information in the record to assess the decision-maker.

## 4.3. Underlying factors associated with grazing reduction

The regression models identify underlying factors associated with reductions in grazing (Table 5). In the model with all variables, allotments that overlap spatially with a Wilderness Area or Recommended Wilderness Area are significantly associated with a 35% reduction in annual AUMs at a 99% confidence level. The presence of critical habitat for endangered anadromous fish is significantly associated with a 25% reduction in annual AUMs at a 90% confidence level. Historic range condition, remoteness from amenity locations, and number of permittee transfers are not significantly associated with reduction in grazing use. Given that many observations were dropped due to missing data for the permit transfers and range condition – two variables that were not significant in the first regression, – we computed additional regressions omitting those two variables (Table 5). In these new regressions, based

#### Table 5

Factors that contribute to reductions in grazing on public lands. Regression (1) includes all explanatory variables but with fewer observations. Regression (2) omits the two explanatory variables with missing data, thus allowing to increase the number of observations. Regression (3) adds dummy variables for the districts.

	Dependent	Dependent Variable: % Reduction in AUM				
	(1)	(2)	(3)			
% in Poor Condition, historic	0.10					
	(0.24)					
Wilderness Overlap	-0.38***	-0.44***	$-0.43^{***}$			
-	(0.13)	(0.13)	(0.13)			
Endangered Species	-0.27*	-0.21	-0.16			
	(0.14)	(0.14)	(0.17)			
Drive time to Amenity	-0.03	-0.08*	-0.10*			
Town	(0.05)	(0.04)	(0.06)			
Permittee Transfers	-0.02	(0.01)	(0.00)			
remittee muisiers	(0.02)					
Challis District	(0.02)		-0.05			
			(0.20)			
Lost River District			0.10			
			(0.25)			
Constant	0.08	0.08	0.04			
	(0.20)	(0.17)	(0.21)			
Observations	67	86	86			
R <sup>2</sup>	0.18	0.16	0.16			
Adjusted R <sup>2</sup>	0.11	0.13	0.11			
Residual Std. Error	0.52 (df = 61)	0.59 (df = 82)	0.59 (df = 80)			
F Statistic	$2.69^{**}$ (df = 5;	$5.14^{***}$ (df = 3;	$3.16^{**}$ (df = 5;			
	61)	82)	80)			

Note: \*p < 0.1; \*\*\*p < 0.05; \*\*\*\*p < 0.01

on more observations, the "Endangered Species" variable is not significant and the "Drive time to amenity town" is significant, with a coefficient such that for each hour away from the town, the percentage reduction in AUM is reduced by 10%. Adding dummy variables for the districts does not improve the model as these variables were not significant.

#### 5. Discussion

The 90-year land use history reveals a land use transition in which livestock grazing decreased dramatically across the study area. Because the study focused on National Forest lands, grazing was not replaced by a new intensive land use, but management shifted to wilderness, conservation, and recreation. The land use transition is therefore from agricultural provision toward service provision. The degree of change is similar to trends observed in the Sierra Nevada of California, a region with faster rates of population growth and within the influence of much larger urban areas (Sulak and Huntsinger, 2002; Huntsinger et al., 2010). The three ranger districts are subject to different levels of amenity migration and development, but all experienced a major decline in grazing use. The proximate causes of change highlight how shifting institutions within the USFS, shaped by a broader social and economic context, influenced decisions about how to use public lands through time.

#### 5.1. Shifting institutions of rangeland management

A land use transition unfolded on rangelands in this region of the Northern Rockies in five phases (Fig. 4). The first phase was dominated by the USFS focus on bringing the range under administration based on the carrying capacity concept. This phase is associated with the most dramatic reduction in total AUMs across the study area. The limits of the carrying capacity concept to achieve results on the ground gave way to a second phase of range management focused on sustained yield in the 1960s and 1970s. This phase is characterized by high political will for major investments in infrastructure (e.g., water development and fences) and vegetation treatments (e.g., sagebrush removal) with the goal of increasing forage on the public range. Gains in AUMs were mostly realized in the 1970s and 1980s, as projects came to completion. Notably, during this same period, groundbreaking environmental legislation was passed at the national level. These new laws did not immediately lead to changes in grazing in the study region. However, the USFS became a de facto arbiter between those that prioritized the recreation, aesthetic and wildlife values of public land, and those that depended on grazing for their livelihood.

In that context, a third phase of *experimental stewardship* emerged as a first foray into explicit collaborative management between ranchers and the USFS. The 1980s farm crisis made ranch economics the main driver of AUM reductions during this period, as food commodity prices fell dramatically. The Challis region was one of three official experimental stewardship programs established by the Public Rangeland Improvement Act (PRIA, 1978). The goal was to develop cooperation among users in pursuit of innovative rangeland management in order to avoid



Fig. 4. Shifting Institutions of Rangeland Management.

removing cows and help stabilize the rural economy (Sharp, 1982). The program succeeded at bringing diverse stakeholders together to find creative solutions. However, as new wilderness areas were proposed and the divisions in values around public land management that began in the 1970s continued to simmer, the experimental stewardship program became insignificant.

The fourth phase began with the listing of Chinook salmon as an endangered species in 1991. The legal and administrative requirements originating from NEPA and the ESA became the significant proximate driver of reductions in grazing, as the presence of listed anadromous fish put new pressure on USFS staff to manage grazing to stricter standards. A local environmental group, the Western Watersheds Project, used these laws to appeal, and sue when possible, all grazing decisions made by the USFS. Wildlife values also drove decisions to reduce grazing. Staff at the agency readily admit that the threat of lawsuits influences their decision-making (Martin, 2019). One staff member shared that "litigation drives how we do things for grazing permits," specifying that "agencies try to manage lawsuits by becoming more prescriptive, and very specific about everything, even if the condition of the resource is not necessarily improving" (Personal Communication, 2017). The threat of a lawsuit certainly altered agency behavior, but the impact was mostly by influencing agency decision-making rather than changing who makes decisions. Despite increased litigation, the courts were rarely the decision-makers in this region and only one change event was decided by a court.

In the most recent phase, the role of amenity migration and ranch economics in reducing grazing has intensified, raising the question of whether the maintenance of working lands is possible as demographics continue to shift in rural areas. The influence of amenity migration on public land grazing may be localized or depend on distance from amenity centers. While both traditional ranchers and amenity migrants value the aesthetic, recreation, and environmental values of the landscape, the two groups are divided about the value of utilizing rangeland forage for livestock. The dynamics within Wilderness Areas readily demonstrate this tension. The Wilderness Act (1964) explicitly protects historic grazing and the USFS never directly used the rationale of wilderness to reduce grazing. An earlier investigation showed that wilderness designation increased permit turnover but did not affect changes in permitted AUMs or amount of non-use during the 20 years following the passage of the Act (McClaran, 1991). However, in our regression models, overlap with wilderness is a consistently significant predictor of reductions in grazing. This pattern suggests that wilderness indirectly impacted USFS management. Wilderness designation attracts more visitors, increasing opportunities for conflict between recreationists and ranchers (Loomis, 1999). Perhaps agency staff also responds more readily to complaints from recreationists about impacts from cattle within wilderness or are holding ranchers with allotments on wilderness to stricter standards. Wilderness designation also influences ranchers' feeling of belonging on the landscape. The Sawtooth National Recreation Area and Jerry Peak Wilderness Additions Act (2015) included a provision that allows for voluntary buyout of grazing leases by environmental NGOs within and immediately surrounding the new wilderness areas. Permittees on seven allotments have since agreed to buyouts that led to the permanent retirement of their grazing permits, for a total reduction of 2988 AUMs. Ranchers report the inevitability of being pushed out by amenity interests, and that a buyout is "as much money as you'll ever get out of it...though it's still not right" (Personal Communication, 2017).

Despite this trend, AUMs actually increased slightly from 2010–2019. While amenity migration and legal and administrative requirements continue to reduce grazing, evaluations of range condition and recovery from economic losses contributed positively to annual AUMs. Managers allow increases in AUMs after prior reductions due to improved conditions on the ground. Permittees decide to re-fill their permit rather than take personal non-use as economic conditions change. This recent trend could be an indicator that renewed efforts at collaboration between USFS, ranchers, environmentalists, and recreationists are guiding the rural transition to maintain working landscapes (Charnley and Sheridan, 2014; Sayre, 2006).

## 5.2. Land use transition on rangelands

The scientific and cultural institutions within the USFS guided all phases of the land use transition on rangelands. From carrying capacity to endangered species, staff responded to conditions on the ground while they also adapted to changing federal public land governance, interpreted the latest rangeland science, and navigated relationships with a widening array of public land constituents to manage use of federal rangelands. Range condition was the largest and most consistent motivator for range management decisions across all phases of the land use transition. These changes were often a result of managers and permittees trialing together the right level of grazing over time in a process of knowledge co-production. These decisions tended to be made collaboratively between the permittees and the USFS, and were also sometimes reversible, responding to a variable range resource. The key role of agency staff in making local range condition determinations highlights the overall importance of maintaining qualified on-the-ground range managers with adequate resources to manage rangelands.

In contrast, socio-economic factors *directly* caused less than a quarter of all changes. While ranch economics are a significant challenge for ranchers, only a small portion of AUMs disappeared from public land reportedly for economic reasons alone. Similarly, amenity migration changed who used public lands and indirectly impacted agency and rancher decision-making, but demographic changes directly accounted for only a small portion of total changes. Aging ranchers retired, and new owners with a focus on amenities and conservation took over public land grazing permits. This process is accelerating and could become more important to directing future land use transitions. Historic poor condition or past degradation did not increase the likelihood of reductions in grazing, indicating that productivity declines are not driving the land use transition.

It would be a simplification to interpret the important role of agency institutions and staff decision-making as a state-led land use transition to promote conservation and recreation on public lands. There was never an organized and singular policy at the federal or local level to reduce grazing. Instead, shifting institutions and paradigms of range management within the USFS, such as designating wilderness and listing new endangered species, changed how agency staff made decisions. The role of policy and institutions in guiding land use on public land might not come as a surprise given these are government-controlled lands. However, use of these public lands is connected to private lands and markets, and various actors influence how land-use decisions are made. The increased power of environmentalists and recreationists did not directly drive change, but values associated with these actors became more prominent in agency decision-making. These shifting institutions are likely not unique to the USFS. Future work could trace how these institutions evolved in different agencies and locations globally to impact land use.

## 5.3. Limitations and future research

The rangeland management records have a few limitations. Annual AUM records may not fully represent the reality on the ground if some agency staff or permittees purposefully obscure true stocking rates, especially for short term changes in management. However, the long study period allows for analysis of long-term trends. Utilization of the full allotment records also enables triangulation to identify the cause of change events. Another limitation is that agency records are mostly focused on matters relevant to agency management. While financial and economic considerations are often mentioned, the absence of ranch-level financial records made it difficult to fully disentangle the impact of ranch economics and amenity migration. For instance, we could not

include ranch profitability and the profile of ranch owners as explanatory variables in the regression analysis. The number of permittee transitions did not prove to be statistically significant, such that the impact of attachment to the ranching lifestyle on the grazing land use is not captured by the regressions. Residence time is only one indicator of place attachment, albeit one supported by the literature. These limitations suggest that complementary social science methodologies, such as ethnography and qualitative studies, are also required to better understand land use transitions on rangelands (Sayre, 2004; Bruno et al., 2020).

The USFS records also did not allow evaluating how long-term environmental changes – e.g., occurrences of drought – impacted AUMs. The coefficient of variation of precipitation is high in this landscape, and changes in stocking due to reduced precipitation are a regular occurrence. These changes were coded as range condition because permittees typically worked collaboratively with USFS staff to manage reduced forage availability during drought to protect the rangeland.

Given that the study area is fully within National Forests, areas that are closed to grazing or where grazing is reduced remain as conserved open space available for outdoor recreation. Range managers report that they cease vegetation monitoring on these lands once grazing stops. The long-term impacts of changes in grazing on land cover is uncertain, and could lead to important changes in vegetation such as encroachment of conifer species into mountain meadows and sagebrush steppe habitat. The extent of grazing removal calls for better understanding its longterm ecological impacts. The spatially explicit land use data presented here could be used to disentangle the role of grazing from that of other factors in the changing patterns of vegetation.

#### 6. Conclusion

A long-term perspective on the patterns and drivers of rangeland use can inform effective strategies to promote sustainable rangeland landscapes. The public rangelands of the High Divide have undergone a slow but steady land use transition away from livestock grazing and driven primarily by shifting paradigms of range management by the USFS. The increased power of environmentalists and amenity migrants did not directly drive reductions in grazing, for instance through court-ordered removals. It rather indirectly influenced the USFS decision-making at local and national scales. Economics of ranching are certainly a challenge for ranch owners and managers but did not drive the land use transition. This result highlights the key role of policy and institutions in guiding rural land use transitions on rangelands. This finding is relevant for many of the world's rangelands, that are similarly publicly owned but privately used and under multiple competing demands from society.

Demographic, cultural and climate changes will continue to bring new challenges that range managers and permittees alike have resolved in the past mostly by reducing grazing. Given that extensive grazing generally depends on access to large areas of land that are under various governance regimes, the possibility of maintaining working landscapes depends on investing in land management agencies and enabling their productive engagement with a broad set of public land stakeholders. The fate of rangelands worldwide and of the ecosystem services they provide largely depends on institutions for land use governance that reconcile the competing values and demands that influence how they are managed.

## CRediT authorship contribution statement

**Briana Swette:** Conceptualization, Methodology, Data curation, Formal analysis, Writing - original draft. **Eric F. Lambin:** Conceptualization, Methodology, Writing - Review and Editing.

## **Declaration of Competing Interest**

The authors declare that they have no competing financial interests

or personal relationships that could have influenced the work or results reported in this article.

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