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Livestock Mobility Through Integrated Beef Production-Scapes Supports Rangeland Livestock Production and Conservation

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Much of the world's rangelands contribute to food production through extensive grazing systems. In these systems, livestock producers, pastoralists, and ranchers move grazing animals to access variable feed and water resources to create value while supporting numerous other ecosystem services. Loss of mobility due to political, social, ecological, and economic factors is documented throughout the world and poses a substantial risk to rangeland livestock production and conservation of rangeland resources. The integration of production-scapes can facilitate livestock mobility through transportation and trade. This paper describes the beef cattle production system in California, where transporting and marketing animals integrate an extensive grazing system with intensive production systems, including feeding operations. Analysis of livestock inspection data quantifies the magnitude of livestock movements in the state and the scope of production-system integration. Over 500,000 head—47 percent of the state's calf crop—leave California rangelands and are moved to new pastures or feedyards seasonally over a 12 week period each year. Most ranchers in California, from small-scale producers (1 to 50 head) to larger producers (more than 5,000), participate in the integrated beef production system. Less than 1% of steers and heifers go from rangeland to meat processing. Like pastoralists, ranchers strategically move cattle around (and off) rangeland to optimize production within a variable climate. Ranchers indicate that their movements result from changes in forage quality and quantity and support their desire to manage for conservation objectives, including reducing fire fuels, controlling weeds, and managing for wildlife habitat. Inspection data, as well as direct observation, interviews, and surveys within the San Francisco Bay area, reveal the extent to which the region's ranchers rely on saleyards to facilitate the movement of cattle and integration of production systems. Saleyards and cattle buyers drive beef production efficiency by sorting, pricing, and moving cattle and matching them to feed resources in more intensive production systems. However, transactions lack traceability to inform policy and consumer choice. New data technologies like blockchain can provide traceability through integrated production-scapes and facilitate market development to support grazing landscapes and consumer choice.

Keywords: pastoralism, grazing, blockchain, ecosystem services, conservation, ranching, beef production, feedyards

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INTRODUCTION

Grazed lands occupy about 60 percent of the world's agricultural land and substantially contribute to communities' social, economic, and environmental well-being ([FAO] Commission of the European Communities Food Agriculture Organization of the United Nations, 1997; [FAO] Food Agriculture Organization, 2018). For millennia, the sustainable management of grazed lands has depended on pastoralists moving their animals to access enough high-quality feed to create value. Mobility allows grazing animals to opportunistically utilize highly variable plant and water resources over both time and space in response to stochastic events (Niamir-Fuller, 1999). Livestock mobility is critical for livestock production and resource conservation on grazed lands.

Most of the world's grazed lands, 91 percent, can be described as rangelands (Reid et al., 2008). These are lands on which the potential natural or native vegetation is predominately grasses, grass-like plants, forbs, or shrubs. They are often characterized as marginal and managed with little to no agronomic inputs and are generally unsuitable for crop production (Follett and Reed, 2010; [FAOSTAT] Food Agriculture, 2016; Mottet et al., 2017). Grazing by herbivores under the stewardship of pastoralists and ranchers is the primary production system on the world's rangelands, allowing these lands to contribute to the production of food and fiber (Behnke, 1994; Brunson and Huntsinger, 2008; Reid et al., 2008; Davies et al., 2010, 2013; [FAO] Food Agriculture Organization, 2018).

In addition to providing food and fiber, rangelands provide a myriad of other ecosystem services, including supporting biodiversity, capturing and storing water, sequestering carbon, and providing for recreation (Sala and Paruelo, 1997; Davies and Hatfield, 2007); and there are growing expectations that these services will be protected and conserved (Blench, 2001; Barry et al., 2007; Brunson and Huntsinger, 2008). This paper considers how expanding the beef cattle production-scape supports livestock mobility as well as rangeland livestock production and conservation. Through a case study, I demonstrate that ranchers use transportation, trade, and markets to expand their production system boundaries and facilitate the mobility of their livestock so as to manage and benefit from the variability of California's rangelands despite the loss of more traditional or more independent forms of mobility.

The degree of mobility and, consequently, land tenure has been used to define pastoralism types, e.g., nomad, semi-nomad, transhumant, and differentiate them from livestock ranching (Ingold, 1980; Ruthenberg et al., 1980). Whereas, pastoralists and their livestock are mobile and rely on communal lands, ranchers are considered to be stationary and to hold exclusive rights to property. In reality, a clear distinction between pastoralists and ranchers is difficult to draw. While ranchers, at least in the western United States, generally do not either stay or move with their livestock, they will herd animals to move them away from an area or to a new pasture, often on horseback or with dogs (Derose et al., 2020), and transhumant is also a practice (Huntsinger et al., 2010). Similarly, ranchers may not graze communal land, but they also do not always have exclusive land rights. For example, in California, ranchers may own their land, but many access a mix of private and public rangelands through grazing leases (Liffmann et al., 2000; Lubell et al., 2013), which they rely on to sustain their ranching operations (Sulak and Huntsinger, 2007). Grazing rights may be exclusive on leased land, but the ranchers' tenure of this land is often insecure and shared with other uses, including recreation, hunting, and wildlife conservation (Huntsinger et al., 2010; Wolf et al., 2017).

The difference between pastoralism and ranching are best understood along a continuum. However, it is the attributes that pastoralism and ranching share that are critical to understanding extensive livestock production and differentiate it from other agricultural production systems. Ranching and pastoralism are conducted in a non-equilibrium ecosystem–arid and semi-arid rangeland—characterized by the natural growth of herbaceous vegetation, which tends to be highly responsive to weather and relatively unresponsive to grazing (Behnke et al., 1993; Jackson and Bartolome, 2002). Ranchers and pastoralists use livestock mobility and their knowledge of the highly variable ecosystem and the livestock's nutritional needs to support livestock production, rangeland health, and lifestyle (Huntsinger et al., 2010).

Globally, livestock mobility, and pastoralists and ranchers' ability to manage rangelands and sustain their livelihoods are at risk. Pastoralists and ranchers require grazing lands that are extensive and diverse for rangeland livestock production, but access to grazing land is in many places eliminated or restricted. From Africa's drylands to China's grasslands, and to the United States' western rangelands, grazing lands are being taken over by other land uses or set aside for conservation (Yeh, 2005; IIED and SOS Sahel, 2009; Cameron et al., 2014). Growing populations and economics drive subdivision and land-use change, but the widespread misunderstanding of use and management of rangeland resources also lead to loss of use (ACC [African Conservation Centre- US] Maasi-Malpai, 2006; Huntsinger et al., 2010).

Pastoralists have historically been construed as culprits in desertification narratives that blamed them for overgrazing (Swift, 1996; Behnke and Mortimore, 2016; Davis, 2016). Similarly, rangeland degradation in the western United States has been attributed to ranchers and their management of livestock grazing (Huntsinger et al., 2012). While newer paradigms have developed from understanding arid and semi-arid lands as non-equilibrium and valuing local ecological knowledge, these paradigms have yet to fully inform policy or prevent barriers to pastoral and rancher management of rangeland (Krätli, 2016; Wolf et al., 2017). The new pastoral paradigm acknowledges that pastoralists use livestock mobility to strategically manage and benefit from variable rangeland resources and, thus, manage grazing impacts and avoid degradation within a variable climate (Roe et al., 1998; Niamir-Fuller, 1999; Krätli and Schareika, 2010). In non-equilibrium ecosystems, abiotic factors, primarily precipitation, are more significant in determining vegetation structure, function, and dynamics than grazing or other ecological processes (Westoby et al., 1989; Behnke and Abel, 1996). This explanation does not negate the fact that grazing impacts vegetation, but it recognizes that grazing's impact is a function of climate variability.

While the current movement around ranching, "working landscapes," does not call out the role of livestock mobility, it more broadly recognizes that ranchers can manage livestock production to be compatible with the conservation of rangeland resources (Plieninger et al., 2012). However, there remains a need to fully understand the production systems that support livestock mobility and working landscapes, especially as the systems have become more complex, and system boundaries are expanded. In recognition of ecosystem services associated with rangeland livestock production that are not currently valued in trade or marketing, and maybe even obscured in the expanded production-scape, I also consider opportunities afforded by new technology (e.g., blockchain) to communicate values to buyers and consumers.

MATERIALS AND METHODS

Study Area

Cattle grazing is the most extensive land use in California. Nearly 26 million ha of California (62 percent) are classified as rangeland ([CDFF] California Department of Forestry Fire Protection, 2003), with about 12.8 million ha grazed by domestic livestock—mostly beef cattle ([CDFF] California Department of Forestry Fire Protection, 2017). The California Department of Forestry and Fire Protection (2017) defines rangelands as lands on which existing natural vegetation is suitable for grazing domestic livestock for at least part of the year. Like most of the world's rangelands, these are marginal lands that would require substantial interventions to support other agricultural uses. Rainfall is highly variable, with a coefficient of variation >30 percent for most California, suggesting non-equilibrium conditions (Ellis and Swift, 1988; Dettinger et al., 2011). The predominant types of rangeland in California include Mediterranean rangelands, cold desert steppe, and warm desert (Huntsinger and Bartolome, 2014; George et al., 2015) (**Figure 1**).

Although California's Mediterranean annual rangelands are just over one-third of the state's rangelands (**Figure 1**), they support most of the state's beef cattle grazing, providing at least 70–80 percent of the forage in the state (Huntsinger and Bartolome, 2014; Salls et al., 2018). More than 80 percent of these rangelands are privately-owned ([CDFF] California Department of Forestry Fire Protection, 2017). Ranging from sea level to an elevation of about 2,000 m, a long, hot, dry season of 6–9 months is complemented by a wet, cool winter growing season. Many annual rangelands are grazed year-round—with only breeding animals, primarily cows, being left on rangeland through the dry season when feed quality is inadequate for a growing animal.

The Mediterranean annual rangelands are characterized by the dominance of non-native annual grasses in open grasslands and understories. They include about 10 million ha of grassland, 2 million ha of oak woodland and savannah, and nearly 3 million ha of chaparral and coastal scrub ([CDFF] California Department of Forestry Fire Protection, 1988, 2003). Common grassland and understory plant species include Eurasian annual grasses (e.g.,

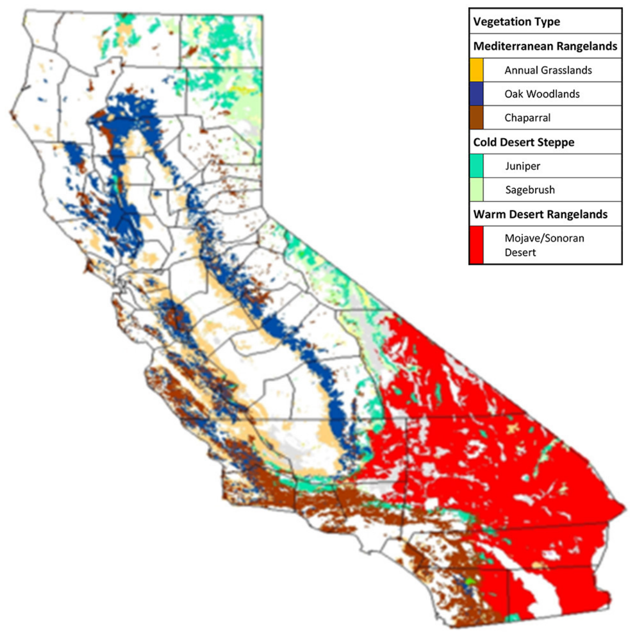

FIGURE 1 | Location of major California rangeland vegetation types (adopted from George et al., 2015). Lands colored white are non-range landcover types (e.g., forest, urban, more intensive agriculture).

Bromus, Avena, and *Festuca* spp.), with a few native perennial grasses (e.g., *Stipa*, *Poa,* and *Elymus* spp.) and a great variety of forbs. Intermixed are more than 66,000 ha of valley-foothill riparian and other moister habitats that may have a higher component of perennial species ([CDFF] California Department of Forestry Fire Protection, 1988, 2003). These rangelands, part of the California floristic province, are recognized as a global hotspot of plant biodiversity (Heady, 1995; Myers et al., 2000; Huntsinger and Bartolome, 2014).

The cold desert steppe is mostly above 1,158 m elevation and includes 2 million ha of sagebrush grasslands and pinyon-juniper woodlands that are more than three fourths federally owned. Grazing on privately-owned lands is supported by transhumance. Livestock graze montane meadows in the summer, which are managed by the US Department of Agriculture, United States Forest Service (USFS), and then graze lower elevation land in the winter, which is managed by the US Department of the Interior, Bureau of Land Management (BLM) (Huntsinger and Bartolome, 2014).

Over 9 million ha of arid lands, California's warm desert is primarily owned by the federal government and managed by the BLM. Low elevations, low rainfall, and warmer temperatures year-round are characteristic. With low resistance and resilience to anthropogenic disturbances (Milchunas, 2006; Belnap et al., 2016), these lands are considered marginal for livestock production. Nevertheless, livestock may graze for 7 months from spring to fall, utilizing pulses of forage that follow sporadic rainfall, especially in higher elevations, where perennial grasses are more abundant (Huntsinger and Bartolome, 2014).

As described for the different types of rangeland in California and similar to other pastoral livestock production systems globally, livestock movements on California's rangelands occur at different scales depending on the spatial and temporal variability of the resources and other aspects of the production system (Adriansen, 1999). California ranchers generally keep stock densities low (e.g., > one animal unit per four to 16 hectares) and use large pastures (e.g., 50 to 1,000+ ha), allowing livestock to graze selectively. Especially in larger fields, cattle may be periodically herded, and cows or experienced animals may be kept to guide young or naïve animals (Vallentine, 2001, p. 206; Launchbaugh and Howery, 2005; Derose et al., 2020).

Grazing of domestic livestock has been a widespread use of land throughout most of California for around 200 years (Burcham, 1981). Beef cow numbers representing the cowherd and the primary type of livestock grazing on California's grazing lands peaked in 1982 at nearly 1.2 million head (Saitone, 2018) and today average about 730,000 beef cows and replacement heifers ([USDA] United States Department of Agriculture, 2017). There are also small numbers of 307,000 ewes and 100,000 non-dairy goats (Huntsinger and Bartolome, 2014).

Within California, the San Francisco Bay Area was selected as the study area to evaluate the driving factors and infrastructure facilitating cattle movement. Despite its notoriety as a hub for high-tech industries, the region's most common land use is cattle grazing (Huntsinger et al., 2016). Ranchers use older traditions, including moving and gathering cattle on horseback, and ecological knowledge to manage cattle grazing over 700,000 ha, 39 percent of the region's private and public lands, including regional parks, habitat conservation lands, and watersheds (Huntsinger et al., 2016). Cattle grazing on the region's annual rangeland promotes species diversity, including the conservation of several threatened and endangered species (Bartolome et al., 2014; Barry et al., 2015).

Livestock carrying capacity on California rangelands varies both seasonally and annually but expressed on a yearly basis ranges from 4 to 12 ha/animal unit/year. In addition to seasonal differences, carrying capacity and stocking rates vary by climate (annual precipitation and temperature) and site conditions such as soil and vegetation health, plant residues, topography, tree cover, water availability, and the presence of noxious weeds (Barry et al., 2016). These factors interact to influence plant growth and the length of the growing season. Livestock management, including movements and resulting rangeland health, is also a significant influence on carrying capacity (Krueger et al., 2002).

Study Methods

I used a mixed-methods approach to understand how cattle movements and production are influenced by market integration. Through data analysis, interviews, and surveys, I studied movement patterns and factors driving individual ranchers to move cattle from grazing land. I identified the infrastructure needed to support livestock movements and the information provided with livestock transactions through data analysis and direct observation of livestock sales.

Cattle Movement Data Analysis

To assess cattle movements, I used data collected by California's brand inspectors. Brand inspectors check brands on livestock when they are transported as required by state law. They also check any documents, such as shipping manifests and bills of sale, that show ownership when livestock is sold and record the description and number of animals shipped. I analyzed movement data collected in 2017 and 2018 at the following times ([CDFA] California Department of Food Agriculture, 2020):

1. At the time of sale or transfer of ownership
2. Prior to moving out of state
3. Prior to slaughter
4. Upon entry to registered feedyard
5. Prior to release from a saleyard

Since the California Hide and Brand Law was approved in 1917, cattle have been inspected to protect owners from loss of animals by theft, stray, or misappropriation ([CDFA] California Department of Food Agriculture, 2020). According to the California Bureau of Livestock Identification, 50 brand inspectors inspect 3.2 million head of cattle a year. Inspections occur in every county in the state except San Francisco, at ∼20,000 ranch locations, 30 livestock saleyards, 31 feedyards, and four major meat processing plants. Cattle owners entirely finance the brand inspection system through brand registration and fees for the inspection service.

There is no current mandate to individually identify an animal in the US, so state brand inspectors identify cattle as individuals or in lots. They use descriptions based on the owners' hot iron brand, if available, breed or color, and class of animal (e.g., cow, bull, heifer, steer, calf). Brand inspectors also record the date of inspection and change in status, location of inspection, the reason for inspection, cattle county of origin, and owner identification. If applicable, inspectors will include information on the cattle buyer and destination and the agent who facilitated the sale.

In California, brand inspection data includes movements of cattle used for dairy, beef, breeding stock, show, and rodeo.

TABLE 1 | Beef cattle production in California and the San Francisco Bay region, grazing land resources, and producer numbers.

	California	Bay Area[a]
Rangeland (ha)[b,d]	12,800,000	183,000
Irrigated pasture (ha)[c,d]	196,000	2,400
% Total grazing land irrigated (ha)	1.5%	1.4%
Number of beef producers[e]	10,254	458
Number of beef cows[e]	682,372	33,073
% producers with 50 head or less	78%	62%
% of total cattle for area[e]	14%	9%
Average herd size (head)	66	72

[a] *Includes Alameda, Contra Costa, Santa Clara, and San Mateo Counties.*
[b] *State data from CDFF 2017.*
[c] *State data from USDA NASS 2017.*
[d] *Regional data from County Crop Reports (Alameda, Contra Costa, Santa Clara, and San Mateo 2017).*
[e] *USDA NASS 2017.*

I categorized cattle as beef or dairy using breed and color information. Cattle of beef breeds were classified as dairy if they originated from a dairy. Dairy cattle in California are primarily raised in confined feeding operations or, if pasture-based, they are raised on improved pastures. Few cattle for dairy production utilize dryland pasture or rangeland. Dairy cattle contribute a significant number of steers and heifers, and cows to beef production. These numbers are presented in the results for comparison (**Table 2**).

Movements of beef cattle from grazing lands to new pasture, animal feeding operations or feedyards, saleyards, or meat processing plants were identified based on inspection type, buyer, and destination information. Cattle movements associated with shows, breeding, or rodeo were excluded based on sale type, event or destination, or buyer. Buyer and destination information was not generally available for cattle sold at saleyards. If beef producers retained ownership through processing, cattle were considered as direct marketed. Data were categorized by the producer's size based on the number of head inspected by premise (owner) identification.

Saleyard Direct Observation and Interviews

I directly observed cattle buyers and sales at seven "feeder" (animals ready to be put on feed after reaching an appropriate size on forages) sales conducted at three different saleyards in California from May to July 2019. Feeder sales are held as special sale events to attract buyers and local cattle sellers during the time described by one of the saleyards as their "busy off-the-grass season." I reviewed the written, oral, and visual information presented to buyers for each sale transaction. Written information was provided in a sales catalog by one saleyard for three observed sales, but each saleyard provided information onscreen. Sales lasted 8 h or more, and around 5,000 head of cattle sold in 300–400 separate lots moved through the sale ring.

I recorded information in an electronic survey during each sale, for 679 lots of 1 to 45 head of cattle from the San Francisco Bay Area. I noted in the survey information announced and actions taken to influence price and marketability by either sale yard staff or buyers. Actions included sorting animals based on size or type. In some cases, buyers requested additional information, such as the geographical origin of the cattle. For example, in one case, a potential buyer wanted to know the distance of the cattle's origin from the coast. The auctioneer called the cattle rancher during the auction to verify. To fully describe the type of information available to livestock buyers and attributes associated with beef cattle production from the producer's perspective, I tracked four lots of cattle sold at a feeder sale from the ranch through the saleyard process. Observation and producer interviews provided a description of attributes associated with grazing management, and livestock feeding and care.

Observation is frequently used in social science to understand the actions of individuals (Clark et al., 2009). Previous research has investigated how spatial, quality, and temporal factors have impacted cattle's price in the western United States by analyzing satellite video auction data (Saitone et al., 2016). Observation provides some additional context to price differences that may not have been revealed in data analysis research.

In addition to observation at the saleyards, I conducted semi-structured interviews with auctioneers ($n = 2$), cattle buyers ($n = 3$), and bay area ranchers ($n = 16$). Interviews were conducted within 1 week. Bay Area ranchers who sold cattle at the sale were randomly selected and interviewed via telephone. These ranchers sold between 15 and 161 head, with a combined total of 1,445 head of steers and heifers. Each interview was structured around two questions: (1) the reasons for selling/buying at the recent market and (2) how they felt selling impacted conservation objectives. I asked auctioneers about the buyer's interests and preparation of sellers. All responses were recorded in writing during the interview and imported into MAXQDA 2020, which was used to code and categorize responses (VERBI Software, Berlin, Germany).

Rancher Surveys

The majority of California ranchers are small, cow-calf producers−78 percent have <50 head ([USDA] United States Department of Agriculture, 2017). I mailed a questionnaire to ranchers located in four counties in the San Francisco Bay Area who sold <50 head during the year (2018). The four counties

TABLE 2 | Beef and dairy cattle contributing to beef production in California by age class for 2017 and 2018 based on movement from grazing lands and dairies.

	Cows				Steers and Heifers			
	Beef		Dairy		Beef		Dairy	
Type of Movement	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**
Grass out of state[a]	52,345	55,003			110,856	118,544		
Grass in State (sale)					50,350	36,914		
On feed	6,536	5,937	25,633	11,982	590,215	651,110	795,075	817,994
Saleyard	118,407	136,127	492,805	509,961	352,384	402,152	228,658	233,345
Wholesale/retail meat	20,154	28,276	299,620	318,767	7,327	14,025	37,381	51,100
Direct Marketed	3,241	5,745	171	100	20,550	19,328	1,927	1,681
Grand Total	**148,338**	**176,085**	**818,229**	**840,810**	**1,128,327**	**1,238,767**	**1,063,041**	**1,104,120**

[a] *Not included in grand total.*

sampled included Alameda, Contra Costa, San Mateo, and Santa Clara counties. Producers in these counties use a mix of private and public rangelands. Access to irrigated or improved pastures is minimal, similar to the statewide availability of irrigated pasture (**Table 1**). The questionnaire was mailed to 465 ranchers in December and March 2019, following the Dillman Total Design Method (Dillman, 2007).

To improve the response rate, I sent out a total of 4 mailings over 2 months: the full survey was sent twice, and two reminder postcards were sent. One hundred and thirteen people returned the questionnaires, representing a 27 percent response rate after accounting for undeliverable questionnaires. The questionnaire was an 8-page booklet with 12 questions. Ten questions were closed-ended, with categorical or Likert scale response choices. I used categorical questions to collect information about rancher experience, ranch size, and marketing choices. Ranchers rated their agreement with a series of statements about why they graze cattle, why they sold cattle using a particular method, and how they manage grazing. Their answers ranged from "completely disagree" (1) to "completely agree" (6). I presented the resulting Likert data as median scores. Figures were developed using Tableau Desktop Professional Edition 2018.1.

RESULTS

Cattle Movement Patterns

Beef cattle have an extensive footprint on the California landscape, where grazing lands contribute just over 1.1 million steers and heifers, and 150,000 beef cows to beef production in 2017 (**Table 2**). Beef cows were counted as contributing to beef production if they were moved to a saleyard, feedyard, or a meat processing plant; however, cows sold at saleyards during special female sales were excluded. Beef cattle from medium and small producers are found on grazing lands in every county in the state but San Francisco (**Figure 2**).

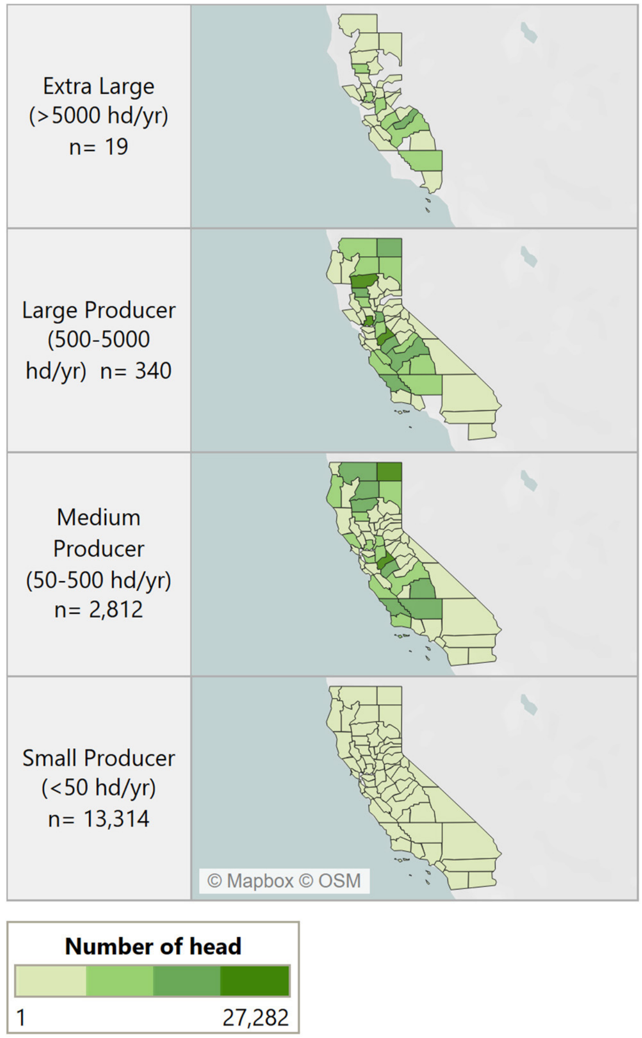

FIGURE 2 | Origin of all beef cattle from California (by county) moved from grazing lands by producer size (2017).

The movement of beef cattle from grazing land in California in 2017 and 2018 has a distinct seasonal pattern (**Figures 3**, **4**). Forty-seven percent of beef steers and heifers (calves and yearlings)—533,583 head that moved off California's grazing lands in 2017—were moved in late spring to summer—May through July (**Figure 3**). A smaller flush of movement occurred in the fall, October through November 2017, when 16 percent or 181,352 head of beef cattle calves were moved from grazing lands, typically but not exclusively from herds in the cold desert steppe where winters are snowy.

The seasonal pattern is similar for beef cows in that 51 percent of beef cows moved in 2017 left California grazing lands from May through July 2017 during the dry season on California's rangelands (**Figure 4**). Beef cow movement includes cows headed to grazing land out of state and those headed to saleyards, feedyards, or meat processing. Data is not readily available to accurately track the movement of cattle back on to California grazing lands. However, presumably, the beef cows leaving for grazing land out of state with no change in ownership return to California in the fall in anticipation of the Mediterranean annual rangeland's growing season. In 2017, cows leaving for grazing land out of state with no change in ownership described 96 percent of the 52,345 beef cows that left for grass out state. This movement of cows back and forth between grazing lands in California and Oregon has been previously documented by the United States Department of Agriculture, Economic Research Service (Shields and Matthews, 2001).

The seasonal movements of around 1.1 million head of beef cattle are in contrast to the nearly 2 million head of dairy cattle, which are also moved through production systems and contribute to beef production, but with little indication of any cyclical or seasonal pattern (**Figures 3**, **4**).

Types of Cattle Movements

In California, growing cattle (steers and heifers) are generally moved from an extensive grazing system to a more intensive production system for continued growth and finishing. On the other hand, culled beef cows are sent from grazing lands directly

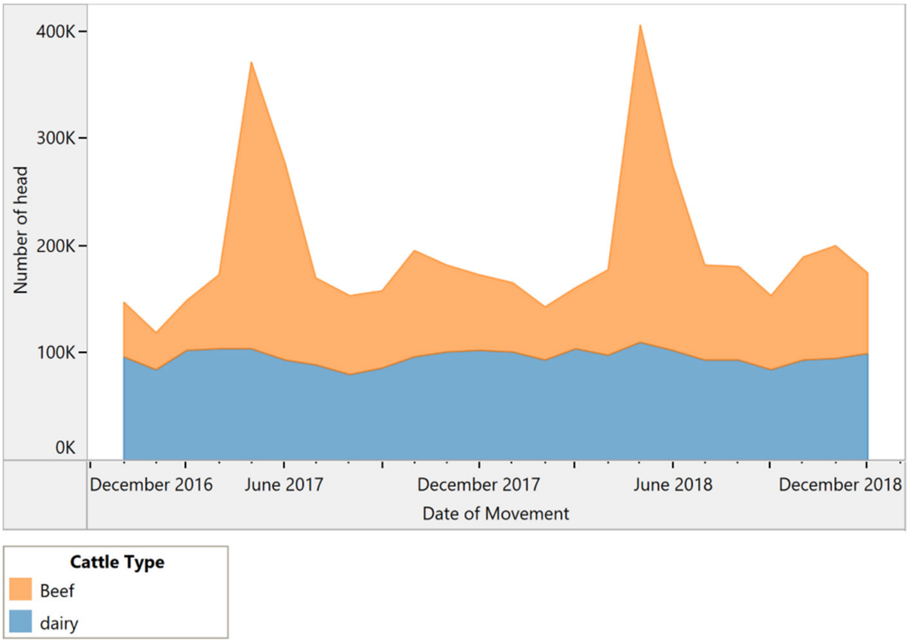

FIGURE 3 | Steers and heifers (number of head) moving from California grazing lands (beef) and dairies or feedyards (dairy) from January 2017 to December 2018.

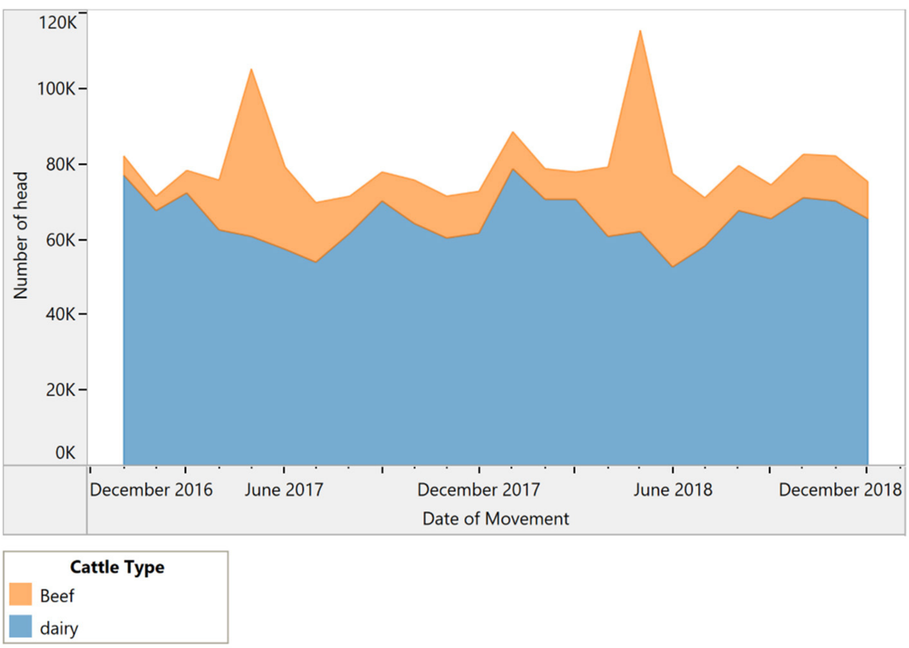

FIGURE 4 | Cows (number of head) moving from California grazing lands (beef) and dairies or feedyards (dairy) from January 2017 to December 2018, includes beef cows moved to grass out of state.

to processing, most frequently through a saleyard (**Table 2**). Saleyards also facilitate the movement of many steers and heifers to more intensive production systems (**Table 2**), but they also may be moved off rangeland through direct sale to a buyer or another producer. Some producers will move cattle and retain ownership. Among small- and medium-scale producers, producers retain ownership of 79 percent of cattle moved to grass out of state, whereas the largest producers retain ownership of 95 percent.

In contrast, retained ownership in the feedyard is most common only among the largest producers. Small- and medium-scale producers, retain ownership in the feedyard of ∼25 percent

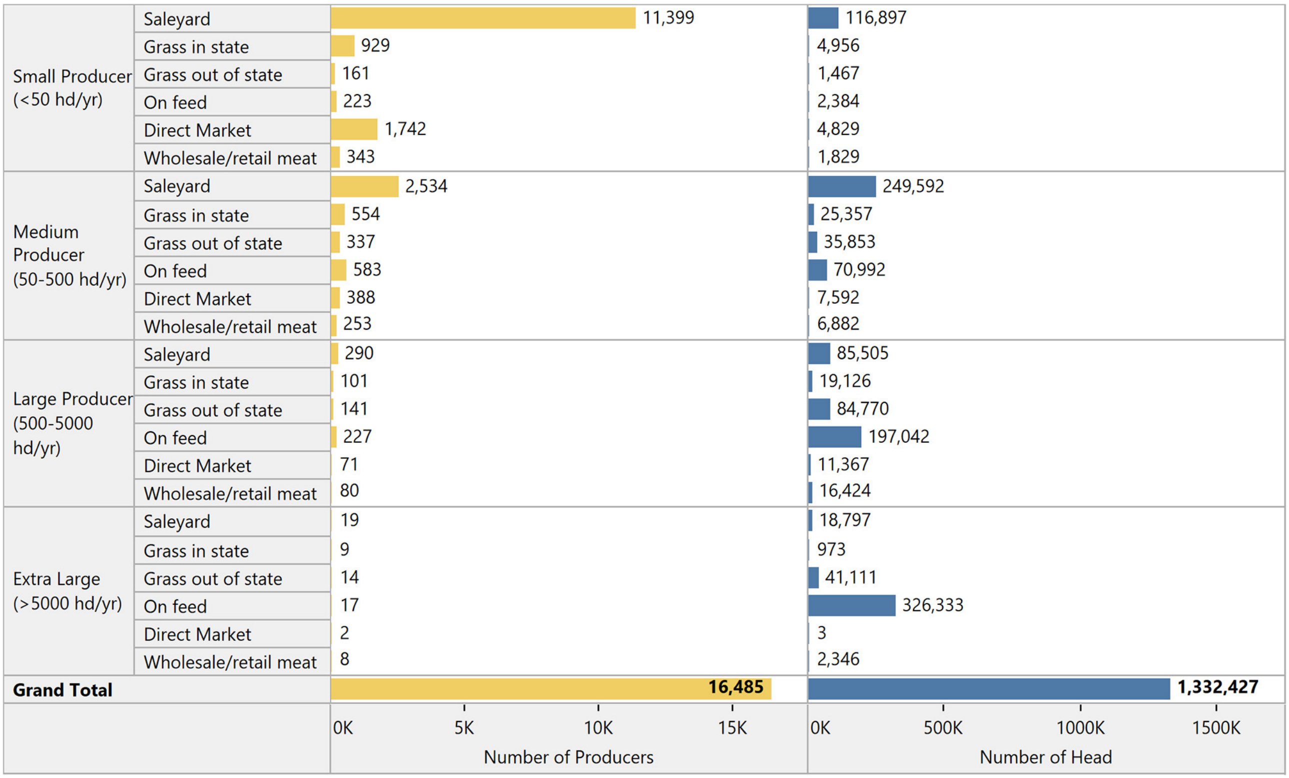

FIGURE 5 | Movements of beef cattle in California by size of ranch producer and destination from grazing land (2017). Size is based on total number of head but producers may use more than one type of movement.

of their cattle, and large producers retain ownership of 49 percent. The seven extra-large producers (more than 5,000 head of cattle) retain ownership of 90 percent of their cattle moved to feedyards.

Thirteen percent of all producers with beef cattle retain ownership of at least one animal all the way through processing. They may sell meat directly to consumers, known as "direct marketing," or keep it for household consumption (**Figure 5**, **Table 2**). However, the number they process for direct marketing or household consumption is small, 23,791 head of cattle, or <2 percent of all beef cattle produced in 2017 (**Table 2**).

Whether through retained ownership or sale, most beef cattle leaving California's grazing lands move into more intensive production systems or move directly to slaughter in the case of beef cows. Many cattle go to feedyards in Colorado, Nebraska, Kansas, Oregon, or grazing land, mostly in Oregon, Wyoming, and Nevada (**Figure 6**). Some of the beef steers and heifers from California's Mediterranean grazing lands may continue to graze extensive grazing lands or rangeland in locations with a summer growing season like Wyoming or Colorado (**Figure 6**). However, there is no data readily available to determine if cattle are moved to rangeland or improved pasture. This movement data also does not include intrastate movements when cattle are moved between fields without a change in ownership; nonetheless, 1.13 million head of beef steers and heifers were tracked in these data for 2017. Based on USDA cattle inventory data, the movement data includes 79 percent of California beef steers and heifers ([USDA] United States Department of Agriculture, 2017) since most are sold or moved out of state.

For all but the very largest producers (**Figure 5**), saleyards support most cattle movement from grazing lands. Small and medium-sized producers marketed nearly 70 percent of their cattle through a saleyard (**Figure 5**). Survey data from small-scale bay area ranchers revealed broad agreement that the saleyards (auctions) provided a fair price for their cattle (**Figure 7**), even though, for some, the saleyards are not nearby. Saleyards are dispersed throughout the state, with the larger saleyards located in the Central Valley near dairy cattle production, processing, and transportation corridors (**Figure 8**). The movement of cattle from the saleyards is not included in cattle movement data from California brand inspectors. However, based on the buyers' interest at feeder sales in 2019, most steers and heifers sold at the saleyard were purchased by a few large volume buyers and are moved into more intensive production systems.

Mature culled cows account for most cattle that are moved directly from California's grazing land to a meat processing facility. Culled beef cows mostly reached the meat processing facility after being sold in a saleyard (**Table 2**), where meat processors or their agents purchase them. Approximately 140,000 beef cows from California's grazing lands were processed for beef in 2017, representing a replacement rate of 18 percent for beef cows based on California's beef cow inventory ([USDA] United States Department of Agriculture, 2017).

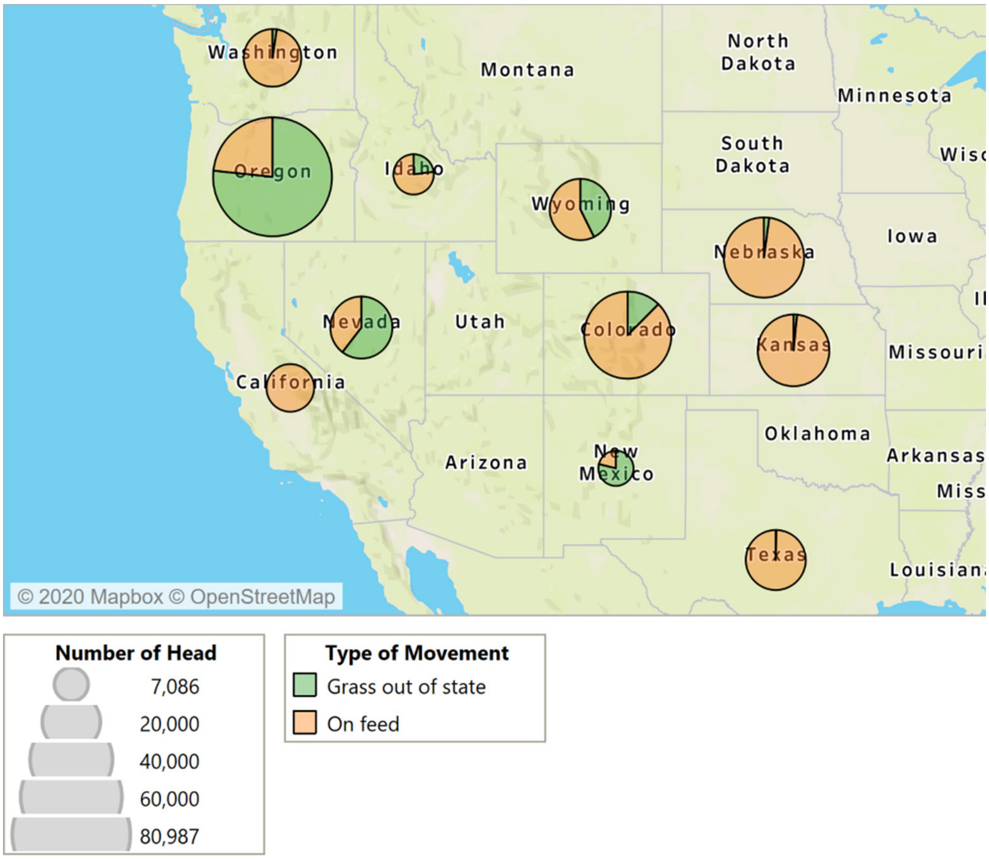

FIGURE 6 | Destinations of beef cattle traveling from California grazing lands to grass (out-of-state) or to feedyards (2017), excludes cattle sold at saleyards.

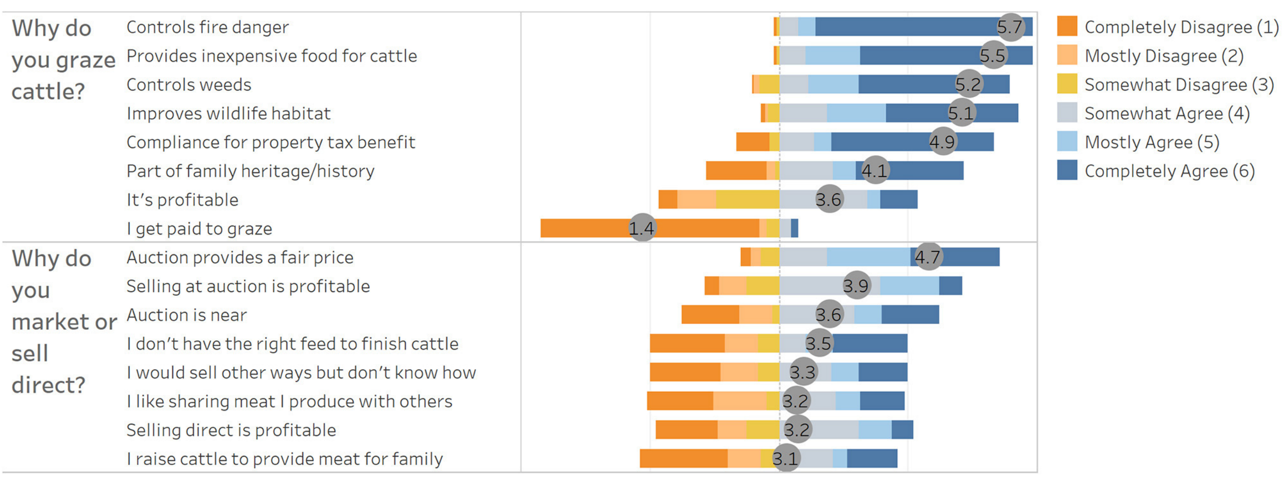

FIGURE 7 | Reasons small-scale beef producers in the San Francisco Bay Area, California graze cattle and sell at auctions or market directly, survey responses.

In addition to the cows moved from grazing land to processing facilities, the cattle movement data documents transhumance, at least when it occurs across state lines. Approximately 50,000 cows, some with calves, left annual rangelands in California in the late spring for grazing lands in Oregon, where there is green summer rangeland or irrigated pasture.

Factors Driving Cattle Movements

San Francisco Bay area ranchers selling calves and yearlings at feeder sales in May, June, and July in 2019 reported forage quality and quantity as influencing the time they chose to sell their calves or yearlings (**Figure 9**). Statements from Ranchers 4 and 15

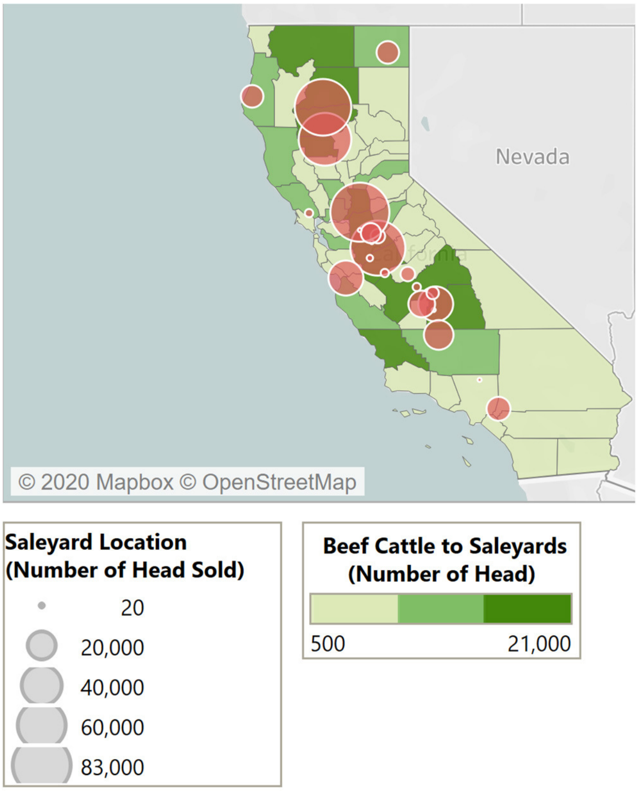

FIGURE 8 | Origin of all beef cattle from California (by county) sold at saleyards with location of sale yards and number of head sold in 2017.

acknowledged the change in feed quality and its impact on animal performance:

> *"This is the typical time of year to sell fall-born calves. You could keep them longer when feed is abundant, but calves do not grow well."*
>
> *"The feed turns this time of year and does not give calves what they need to grow. I retain feed [forage] for the cows."*

In terms of forage quantity, ranchers like Rancher 5 noted the importance of leaving feed (forage on the ground) through the dry season:

> *"We pull the calves and move the cows, so there is feed to come back to."*

When asked how selling at this time impacted conservation objectives, most ranchers spoke about conservation in terms of a desire to prevent overgrazing (**Figure 9**). Ranchers also acknowledged how their grazing management, including livestock sales, worked to support specific conservation interests. For example, Ranchers 7 and 15 recognized the value of grazing management to provide habitat for federally-listed threatened and endangered species:

> *"I take cattle off to rest the pasture during the summer. My grazing is compatible with the California red-legged frog, fairy shrimp, and the giant garter snake. I do not overgraze."*
>
> *"I have no conservations restrictions, but I keep it the best I can. According to the [United States Department of Agriculture, Natural Resources Conservation Service] NRCS biologist, it remains a good habitat for red-legged frog, California tiger salamander, and San Joaquin kit fox. I sold later than usual because I had excess feed, but there was no impact [to conservation]. I don't like to graze to the ground."*

Rancher 11 described how moving cattle, including the timing of sales, reduced fire risk, and protected soils.

> *"It was good to keep calves a little longer. I graze, so it does not burn. I graze closer [to the ground] next to property boundaries since my neighbors don't graze and have grass six feet tall. I keep cows and calves out of the hills during the rainy season to avoid erosion. After the rainy season, I jump [the cow and calves are moved] back and forth between hill and flats."*

Rancher 14 also stated how grazing management (selling) could protect soils.

> *"I sold because we were short of feed [forage]. I leave feed for the following year to come back to. Leaving feed to come back to also helps us with erosion on hillsides."*

A common theme among the ranchers was a commitment to good grazing management regardless of land ownership or conservation requirements. This view was clearly articulated by Ranchers 2 and 16:

> *"I have no directive for conservation, but as all cattlemen, I convert grass to beef, so we need to manage grass... I manage it (public and private), all the same, to keep grass."*
>
> *"I graze all lands (public and private) similarly. If you take care of the land, it takes care of you."*

Indeed, there are straight economic considerations that influence when ranchers move (or sell) cattle from California grazing lands. However, in rancher interviews, even economic reasons for selling, like changing market conditions or the need for cash, typically were explained within the context of forage quality or availability, like Ranchers 1, 6, 13:

> *"The market was going south. I could save a little feed by selling now."*
>
> *"I was watching the market and needed cash. I only marketed the heavy end because I have grass [irrigated pasture] for the lighter cattle to go on."*
>
> *"I had feed and prices were low, but I needed cash to pay bills."*

The balance of economic and ecological goals driving ranchers' decisions around moving (selling) is further exemplified by ranchers who spoke about retained ownership as a factor in selling decisions. Having access to quality forage to support yearling growth is key to a decision to retain ownership as exemplified by Ranchers 7 and 12:

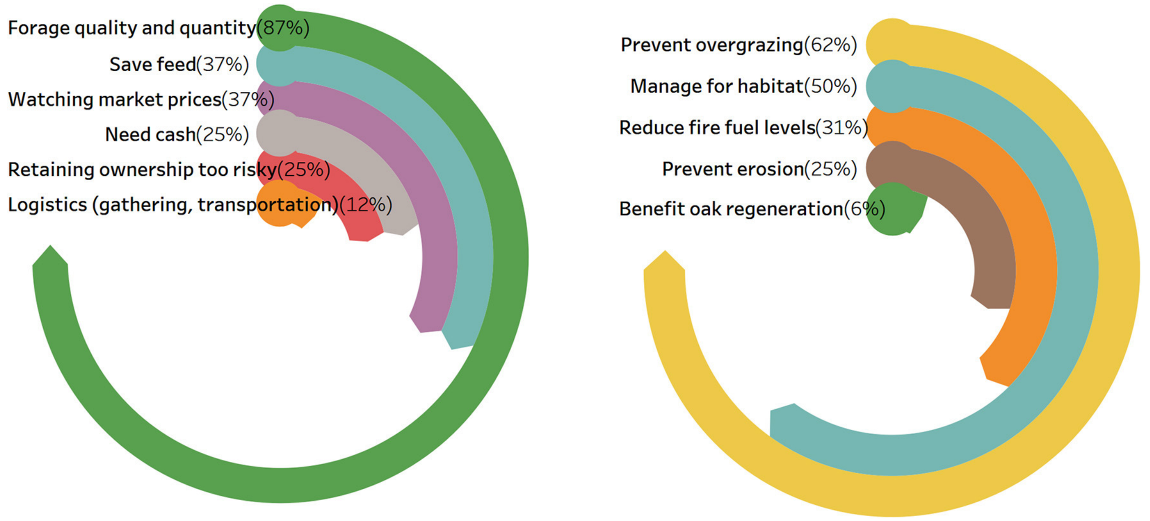

FIGURE 9 | Reasons for time of sale of calves and yearlings from grazing lands in the San Francisco Bay Area, California and expected conservation outcomes, based on interview responses.

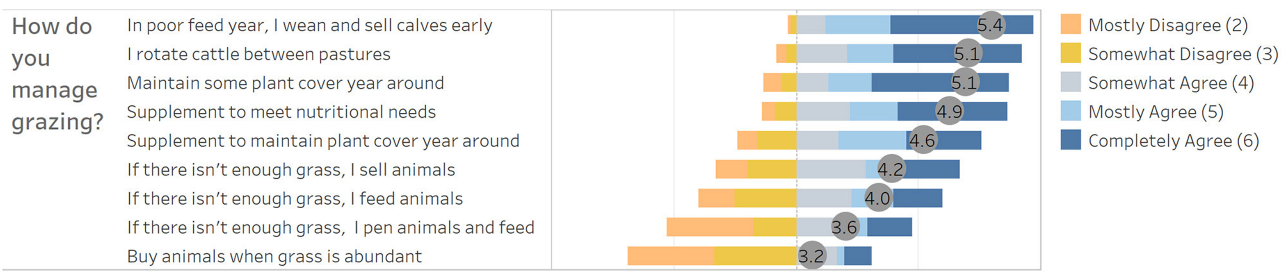

FIGURE 10 | Cattle grazing management by small-scale beef producers in the San Francisco Bay Area, California, survey responses.

> *"We used to sell calves, and now we retain ownership because we have [irrigated] pasture."*
>
> *"When we had permanent [irrigated] pasture, we would sell our calves as yearlings in November, but we lost that pasture, so now we sell our calves."*

A mix of economic and ecological interests was also illustrated in survey data from small-scale producers in the San Francisco Bay area (**Figure 7**). There was strong agreement with economic reasons for grazing, including it is *inexpensive feed* and it *provides tax benefits*, but also for ecological reasons such as *grazing controls fire dangers*, *improves wildlife habitat*, and *controls weeds*. However, very few of these producers regard *grazing as profitable*.

How small-scale producers in the San Francisco Bay area manage grazing also reveals information about factors driving cattle movements (**Figure 10**). Responses from ranchers suggest that their livestock mobility strategies, including rotating or moving cattle between pastures, are aimed at maintaining plant cover and meeting the livestock's nutritional needs, more than reacting to lack of available forage. Early weaning and selling calves is a favored strategy in poor feed years. In response to lack of forage, destocking or selling animals is only somewhat practiced by most producers, and few producers consider feeding.

Infrastructure Supporting Cattle Movements

Interviewed ranchers explained that transportation, saleyards, access to additional quality feed sources, and processing capacity all support cattle movements in California. Ranchers may use a pickup and gooseneck trailer combination to haul livestock to a market or move cattle between pastures. However, most also rely on professional livestock haulers that operate semi-truck and trailer combinations specifically designed to haul livestock. Haulers may transport animals from grazing lands to saleyards, and then to grazing lands or feedyards after they are sold. At the feeder sales, semi-truck and trailers were lined up to transport purchased cattle, and after a winning bid, buyers assign lots of cattle to different groups for transport. Livestock haulers are also required for the final transport to a processing facility. The value of transportation to managing grazing lands was acknowledged in the survey of bay area ranchers. When asked about future challenges to managing their grazing lands, some ranchers noted that recently proposed federal regulations regarding hours of service by truck drivers as well as state regulations requiring newer vehicles that met emissions standards may limit the availability of livestock haulers and increase transportation costs and could impact ranching sustainability.

While transportation is required to move animals for production system integration, sale yards facilitate matching livestock with a production system. Saleyards are the primary marketing method for most small and medium-size producers (**Figure 5**). They allow producers to market all classes and types of cattle. At a saleyard, buyers come together to bid on cattle providing current market price through competitive bidding. The saleyard may sort cattle from a seller into lots of similar size and kind. Buyers put together loads of similar cattle from different sellers. The sorting and grouping of cattle conducted at a sale yard can add value. For example, small groups of cattle may receive a more competitive market price when combined to make a load of cattle.

Cattle buyers utilized specialized knowledge gained through experience to choose cattle at the feeder sales to go back on grass or into a feedyard based on age, weight, breed, sex, and geographical origin. Buyers are looking for certain types of cattle to fit specific forage or feed conditions available to them, and some clear patterns can be observed. Recently weaned, lighter cattle are more likely to go back to feeding on grass, including irrigated pasture, while yearlings or heavier cattle may go directly to a feedyard. Breed type may also influence cattle destination. One buyer noted that he would no longer put black-hided cattle on feed in Colorado because of his experience with a higher incidence of a brisket disease, a genetically-transferred heart disease that impacts cattle at higher altitudes.

Buyers learn about cattle through written, visual, and oral information during the sale (**Table 3**). Some information such as weight, sex, breed, and vaccinations support premium prices or result in discounted prices relative to other cattle. Based on the ranch name and location, reputation may also influence the price or even a buyer's interest in bidding. A buyer may be willing to pay more if he knows that cattle from a particular producer perform well.

Buyer's decisions are not only influenced by the supply of cattle at the market but also by the available forage or feed, or processing capacity. For example, one buyer remarked that he was placing fewer cattle on grass because there were far fewer acres of irrigated pasture available in the Klamath Basin, Oregon than 5 or 6 years ago. Instead, he was buying cattle to place in a feedyard in Washington, where by-products from processing potatoes and distillers grain keep feed costs down.

Little information is provided to buyers about managing the cattle or feed resources, including grazing management. Grazing land management that provided ecosystem services, including conservation of wildlife habitat or watershed protection, is not attributed to the cattle. Ranchers surveyed in the San Francisco Bay area overwhelmingly disagreed with the statement that "they are paid to graze" (**Figure 7**). Nevertheless, bay area beef producers can identify ecosystem services that they attribute to their grazing management (**Table 4**). Cattle buyers moving cattle into more intensive production systems also recognize resource management practices such as feeding by-products and animal welfare practices such as low-stress livestock handling that they provide without attribution (**Table 4**). Unless cattle are associated with a specific-value added program (e.g., natural, organic, source-verified), information transferred through the production systems is limited to physical details that can be visually assessed or measured, such as weight, color, sex, frame size, and hot-iron brand if available (ranch origin).

DISCUSSION

Beef cattle graze throughout California (**Figure 2**), and most of the landscape they graze is rangeland. Like rangelands throughout the world, this land is often not suitable for cultivation, yet it supports livestock production. Arguably, extensive livestock grazing is not the most efficient production system in absolute terms of the number of head produced or livestock gains per hectare (Huntsinger et al., 2012; Tichenor et al., 2017). For instance, the California dairy industry provides more cattle—a larger number of culled cows—to beef production than beef cattle producers (**Table 2**), and they operate on a smaller land footprint in California (without considering land used out of state to grow their feed). However, extensive livestock grazing contributes to food production on land with limited to no ability to contribute otherwise (Reid et al., 2008). Perhaps, more importantly, rangelands are high in biodiversity and ecosystem service production, which can often be enhanced or protected with ranching (Huntsinger and Oviedo, 2014).

Beef Cattle Production on Extensive Lands Supports Conservation

Integrating extensive grazing systems with other production systems supports livestock production while maintaining extensive grazing lands in California. Integration provides alternative feeds resources to support production and allows ranchers flexibility to manage for multiple ecosystem services. Most ranchers seasonally move cattle, with many ranchers selling their growing calves or yearlings where they are finished in a more intensive production system. Ranchers surveyed overwhelmingly indicated that grazing provides inexpensive feed and serves to reduce fire fuel, control weeds, and improve wildlife habitat (**Figure 7**). Roche et al. (2015) showed a similar finding in a survey of California ranchers. Nearly all (97%; $n = 490$) agreed with the statement, "whenever possible, I try to conserve natural resources."

Conversion to other land uses, including cultivated agriculture, where feasible, has resulted in ongoing losses of rangeland in California (Sulak et al., 2008; Cameron et al., 2014), but intensification on grazing land is not a common practice. Rangeland improvement practices, including seeding, fertilization, and control of brush and trees, were tested and promoted by agricultural extension and government assistance programs beginning in the late 1800s to increase forage quality and quantity for livestock production (George and Clawson, 2014). However, since the 1980s, rangeland management in California has increasingly emphasized multiple goals, including

TABLE 3 | Information available to cattle buyers for feeder cattle from San Francisco Bay Area ranches and impact on sale price.

Attribute	Information Available to Buyers of Feeder Cattle			Sale Price Impact	
	Written	**Visual**	**Oral**	**Premium Price**	**Discount Price**
Number of head	Onscreen	Observed	No	Truck lots	Small number
Weight, frame	Onscreen, average weight	Observed	Announced, heavy end, light end	Light weight (230–270 kg)	Heavy weights (>385 kg) or small frame
Class (sex and age)	Sale catalog, if available	Observed	Announced sometimes	Steers	Heifers, bull calves
Color (hide), horns	Sale catalog, if available	Observed	No	Black hide	Horns
Breed	Sale catalog, if available	Observed, breed types	Announced sometimes		Dairy, Bos indicus features
Shots (vaccines)	If provided, Sale catalog, if available	No	If provided, announced	Two rounds of vaccines	No vaccine information
Ranch Name	Sale catalog, if available	Observed, brand	Announced sometimes	Reputation, performance history	
Ranch Location (town)	Sale catalog, if available	No	Announced sometimes		Coastal locations
Origin (ranch-raised or bought)	Sale catalog, if available	Maybe, brands	Announced sometimes	Reputation	
Sire information	If known, Sale catalog, if available	No	If known, announced	Reputation, performance records	
Weaning status	If occurred, Sale catalog, if available	No	If occurred, announced	30 day minimum	
Program (Natural, No Implants, Source verified)	Sale catalog, if available	Observed, ear tag	If applicable, announced	Eligible for export markets	
Feed (pasture type)	Sale catalog, if available	No	No		
Grazing Management	No		No		

TABLE 4 | Example of production attributes, identified by producers of beef cattle originating in the San Francisco Bay area, that are not tracked or shared through the integrated production system.

Class	Head	Producer 1 (Cow-calf)		Producer 2 (Stocker)	Producer 3 (Feed yard)
		Attributes presented at sale (auction)	**Attributes not shared**	**Attributes not shared**	**Attributes not shared**
Steer	61	Natural (no implants), At Branding: vaccinations and dewormer; Booster: vaccinations (Product names provided). Sorted off cow (not weaned)	Conservation grazing management program on public land. Grazing supports habitat for native flora and fauna, and reduces fire fuel loads	Irrigated pasture provides hunting grounds for wintering raptors and feed for migrating birds along the Pacific Flyway	Health program. Low-stress livestock handling. Daily ration includes food processing waste and agriculture by-products. Feedyard produces manure and bedding which fertilizes nearby field and vegetable crops

native species conservation and providing other ecosystem services (Spiegal et al., 2016). Supported by integration with other production systems, California's rangelands in public and private ownership remain as extensive grazed landscapes, covered with native or naturalized plants. Ranchers move cattle and manage grazing to support native biodiversity by reducing non-native plant species and accumulated residual dry matter, and increasing landscape-level diversity (Bartolome et al., 2014).

The value of maintaining extensive grazing lands to contribute to food production while providing multiple other ecosystem services is not unique to California (Curtin and Western, 2008; Reid et al., 2008). Grazing systems on different continents function in ecologically similar ways; conserving native and wildlife grazers, and many species associated with grazing lands, requires protecting extensive natural landscapes (McNaughton, 1985; Harris et al., 2009; Niamir-Fuller et al., 2012). While conversion of grazing lands to other land uses jeopardizes vast landscapes, interventions, or strategies purported to save rangeland or pastoral livestock production may also have negative consequences for conservation and ecosystem services. These strategies include ending extensive livestock grazing (e.g., Chinese grazing ban, Han et al., 2008), often along with encouraging pastoralists to settle and adopt intensive forms of agricultural production (Scoones, 1995; Flintan et al., 2011). Agriculture intensification increases yield per unit area, but settlement and agricultural intensification may do little to improve the well-being of the pastoralist or the condition of degraded rangeland. Intensification can lead to both more and less intense grazing—both factors that may adversely impact ecosystem services (Niamir-Fuller, 1999; Angassa and Oba, 2008). The loss of native biodiversity from the intensification of agriculture on grazing lands is documented, as is the threat to biodiversity and other ecosystem services from both over- and under-grazing (Milchunas et al., 1998; Mcintyre et al., 2003; Metera et al., 2010; Cameron et al., 2014) resulting from lost flexibility for grazing management and the failure to understand non-equilibrium systems (Ho, 2001).

With regards to agriculture intensification, pastoral management of non-equilibrium rangelands should not be confused with the management of improved pastures or pastures created by the conversion of native forested habitats to grazing land, like in the Amazon or New Zealand. On pasturelands that are developed by removing native forest, intensive management that includes rotational grazing, seeding of legumes and improved cultivars, and integration of livestock with cropping systems may be a viable strategy to spare native habitats while increasing agricultural output (Phalan et al., 2011; Latawiec et al., 2014). Intensification of rangelands, however, results in degradation and puts at risk resource values, including native biodiversity, which instead is often complimented or enhanced by the kind of managed grazing of pastoral systems that work with the natural environment (Niamir-Fuller et al., 2012; Alkemade et al., 2013; Cameron et al., 2014; Kaufmann et al., 2018).

Mobility Matches Cattle Production to Forage Resources

Ranchers expect and work with variability in forage quality and quantity by moving livestock across biomes and pastures and into other production systems, where forage or feed resources are available to meet livestock production needs. Moving cattle to different production systems is typical in the United States and in some other parts of the world where beef production occurs in three phases (cow-calf, stocker, finisher) (Nin et al., 2007). The three-phase system developed due to cattle's relatively long biological production cycle and the different resource and management needs for each phase of production; these same factors have been a disincentive to vertical integration (Ward, 1997). The three-phase system typically includes integration of grazing systems, which support cow-calf and stocker production, with intensive systems that finish cattle in a feedyard. For California ranchers, who manage non-equilibrium systems, these movements are timed to manage variability and fit forage resources. While ranchers are able to sell their calves into the next phase of production, the timing of the sale allows cattle to "fit" the resource, which is evident from the substantial seasonal movement of cattle from California's grazing lands (**Figures 3**, **4**). Based on rancher statements and similar to traditional pastoralists who move livestock to track forage resources, cattle movements are informed by livestock needs and changes in forage quality and quantity. On California's non-equilibrium rangeland, annual forage productivity varies unpredictably by a factor of three or more based on weather (George et al., 2001b). Where forage quality may be predictable based on season, the weather also creates uncertainty about the timing of the seasons (George et al., 2001a,b).

The seasonal movements of cattle from grazing lands align with seasonal changes in forage quality and quantity, particularly on California's annual rangelands. Bentley and Talbot (1951) defined three seasons, inadequate green forage, adequate green forage, and inadequate dry forage nearly 70 years ago. These descriptions are still used by rangeland managers to explain the seasonal patterns of California's annual rangeland as it pertains to supporting livestock production (George et al., 2001b; Becchetti et al., 2016). The onset of the inadequate dry season, which describes the summer's dry annual forage, corresponds with the movement of steers and heifers and some cows off California's annual rangelands. Although the annual dry forage provides some energy for grazing animals, it is low in protein, phosphorus, carotene, and other vital nutrients, and inadequate to support young growing animals without feed inputs or prolonging production time (George et al., 2001a,b). Mature beef cattle can be maintained during the inadequate dry season, though ranchers expect and manage cows, knowing they will typically lose weight and body condition (Renquist et al., 2006).

The new growing season begins with the inadequate green forage season in the fall.

Seeds stored in the soil from the previous year's growth germinate with fall precipitation. This season's onset and length depend on weather conditions, which creates uncertainty in determining carrying capacity. However, as the survey responses and interviews indicate, Bay Area ranchers stock to maintain dry forage through the summer, so they have feed to come back to. Residual forage helps ranchers manage the new forage season's unpredictable start and provides dry matter to support livestock during the "inadequate" green period. While dry residual forage is often low in protein and other vital nutrients, new green forage with its high-water content can inhibit livestock from consuming enough to meet their nutritional requirements–hence the name "inadequate green forage season" (Becchetti et al., 2016).

The final forage season, rapid spring growth, or adequate green forage begins with warmer weather in late winter or early spring, depending on precipitation. During this season, livestock performance improves, and the forage is nutritionally adequate for growth, maintenance, reproduction, and gestation. Livestock weight gains are highest during this period. Rapid spring growth continues for a short time until either plant growth is limited by a lack of soil moisture or plants mature. Peak standing crop marks the end of the rapid spring growth season (Becchetti et al., 2016). In a study at a research center in the Sierra foothills of California, Raguse et al. (1988) found that average daily gains of yearling cattle increased from December to early May and then rapidly decreased. Rancher's decisions to move growing animals off the rangeland in late spring, early summer reflects this seasonal decline in forage quality. Controlling the rapid spring growth with grazing also benefits native species conservation (Bartolome et al., 2014).

The seasonal movement of steers and heifers, and cows from grazing lands in the fall (**Figures 3**, **4**) also corresponds to weather and forage changes. These movements are typically associated with forage changes in California's high elevation cold desert steppe and warm desert range. Both cold desert steppe and warm deserts, which are primarily federal land, managed in partnership with the United States Forest Service (USFS) or the Bureau of Land Management (BLM), have relatively low numbers of grazing livestock. However, movement allows ranchers to graze ephemeral forage as well as shrubs and native perennial grasses (Huntsinger and Bartolome, 2014). Cattle may be herded by ranchers within the leased land, or lead cows with knowledge of the range will move cattle to good foraging locations.

Transhumance, the seasonal movement of cows, has been documented within California and between California and Oregon, Nevada, and Idaho (Huntsinger et al., 2010). Although the seasonal movement of cows between the cold desert steppe or warm desert range and ranches on California's annual rangelands was not captured in the inspection data, the data shows over 50,000 cows (7% of the state's cow herd) moving from summer pasture to neighboring states from California's rangeland.

Managing grazing lands by fitting livestock needs to the environment was also documented among California ranchers in Roche et al. (2015) study. They found that the highest-rated ranch management practice was "matching calving to the environment." Matching calving to the environment sets up ranchers to market or move weaned calves off grazing lands when the rangeland becomes insufficient in quality to meet a growing animal's needs. For example, calving near the beginning of the growing season, the period of inadequate green forage, means that a beef cow will reach peak lactation as her growing calf becomes ready to take advantage of the abundant, high-quality forage during the rapid spring growth season. Roche et al. considered this practice an aspect of economic sustainability. Moving growing cattle off rangeland by selling them is a management strategy. California's ranchers use for managing the interannual forage production cycle inherent in non-equilibrium rangeland. It should not be confused with destocking, which is selling to reduce stock numbers in response to an unexpected loss in forage production from an event such as drought (Morton and Barton, 2002). Droughts and wildfire have forced some California ranchers to destock or feed (Macon et al., 2016).

Decisions regarding the movement of livestock on grazing lands by California ranchers in transhumance and through trade are not unlike decisions that pastoralists have made for centuries where livestock needs are matched with forage to take advantage of the variable climates impact on vegetation (Fernandez-Gimenez and Le Febre, 2006; Krätli and Schareika, 2010). Like pastoralists, ranchers use their knowledge of their environments to manage resource use (Niamir, 1995; Fernandez-Gimenez, 2000). Whether within ranges or between biomes, seasonal weather patterns, forage growth, and livestock nutrition and production requirements typically guide livestock movement—although increasingly pastoralists and ranchers may be required to move animals in response to societal influences, such as landowner requirements, political boundaries, land-use changes or designation. Ranchers' ability to either move or sell livestock into another production system might, in some part, compensate for required movements or loss of access to some grazing lands.

As with many tools used for pastoral development (Krätli, 2016), equilibrium thinking misinforms some rangeland management policies and practices on California non-equilibrium rangelands. For example, some public agencies and NGOs have removed livestock grazing from lands they manage (Fried and Huntsinger, 1998), and now with conservation values, including native species habitat loss, they struggle to put grazing back (McGarrahan, 1997; Barry et al., 2015). Moreover, most public grazing contracts often set fixed stocking terms and charge ranchers a set price per animal unit month (AUM), each of which fails to account for inter- and intra-annual variability in forage quantity and quality. This pricing creates a problem when a public landowner wants a rancher to extend grazing time or increase stocking rates on low-quality forage and continue to pay the set AUM rate for forage that does not meet livestock production needs (Becchetti, T. email message to author October 5, 2019).

Equilibrium assumptions also influence ideas about improving ranching's economic viability. Like in most pastoral societies, ranching is an economically marginal activity (Wetzel et al., 2012). Marketing a ranch-raised product at a higher price has been promoted as a strategy to increase returns from grazing lands (Huntsinger et al., 2010; Forero et al., 2014). Based on retail sales of labeled grass-fed beef, which grew in the US from $17 million in 2012 to $272 million in 2016, there is a growing market for direct sales from ranch-to-fork (Cheung and McMahon, 2017). While California ranchers could market ground beef from ranch cows, a type of animal the grass-fed industry describes as "default grass-fed," accessing enough quality forage year-round to grass finish steers and heifers on California's rangeland is a challenge because of the seasonality of both forage abundance and forage quality on California rangelands. Ranchers like pastoralists specialize in taking advantage of the environmental variability- this management allows them to improve productivity (Krätli, 2016). It is also difficult for producers to compete with cheaper imported grass-fed beef or beef from grass-feeding operations. In other words, working within California's non-equilibrium rangeland system to find forage on other grazing lands, or feed in another production system to finish growing animals, best provides for livestock production and rangeland management.

Integrated Production Systems Facilitate Mobility

Livestock grazing systems have been classified in ways that describe both the management of livestock and the social structures of the people that own and manage them, including pastoralism, transhumance, and ranching. In each of these cases, the system is based on some form of matching seasonal and annual forage availability to livestock production needs within the context of the forage resources available to producers and the producers' social needs. The integration of extensive grazing systems through transportation, and through trade with intensive production systems, effectively expands the capacity of the beef production system without sacrificing livestock grazing systems and their associated benefits.

In the literature, grazing and confined animal feeding are often considered independent types of production systems, as in Tilman et al. (2002, p. 675), "Pastoral livestock production makes extensive use of ecosystem services and eliminates many of the problems of confinement production." Also, the introduction of feedyards and processing plants and other capital infrastructure is considered to "commercialize livestock production" (Fratkin and Mearns, 2003) as well as require all producers, including small-scale to standardize production (Lundström, 2019). However, as illustrated by the beef cattle production system in California and practiced in many other parts of the world (Krätli et al., 2013), grazing and confined animal feeding are not mutually exclusive. By selling an animal at a saleyard, even a rancher in California raising one head on grazing lands can participate in the integrated production systems, with little to no standardization of production. Market integration allows even small-scale ranchers with extensive livestock production systems to produce a marketable product.

Most ranchers in California, from the small producers (<50 head) to the extra-large producers (more than 5,000), participate in the integrated beef production system. Less than 1% of steers and heifers go from rangeland to meat processing, and <2% are direct marketed. While the largest ranchers are more likely to retain ownership through finishing, small- and medium-scale producers can also retain ownership. Retained ownership has been promoted to cow-calf producers by agricultural economists because of its potential to increase returns; however, producer's aversion to risk has been shown to limit retained ownership among cow-calf producers (Pope et al., 2011). Backgrounding or preparing calves for feedyards by weaning and introducing cattle to feed is a practice that leads to increased retained ownership (White et al., 2007), but most California ranchers manage extensive rangeland with no such facilities. As noted in the premiums paid for California calves (**Table 3**), buyers are willing to pay a premium for calves weaned for 30 days as many show up to the saleyard having just been removed from the cow.

While the beef production system is not generally vertically integrated and the supply chain phases operate independently, the integrated system transfers beef production decisions and opportunities from extensive grazing systems to more buyers and producers operating more intensive production systems. These producers also determine the final product produced for meat processing. However, besides supporting grazing management, selling calves can transfer the market risk of owning stockers or feeders, allowing ranchers to focus production on calf production, where market prices are relatively more stable (Brownsey et al., 2013). Larger producers may be better able to weather the risk of owning stockers and feeders but do not necessarily increase their profits from retaining ownership through these phases of production (Langemeier, 2019).

Small- and medium-scale producers in California almost exclusively rely on trade (selling at the saleyards) to support livestock moving off rangelands. However, even among all the largest producers (more than 5,000 head, $n = 19$), saleyards are used to sell at least some cattle. When large producers do not retain ownership, they often market their cattle in large lots directly to a buyer. The importance of saleyards and the buyers, who match cattle with other grazing or feed resources, cannot be overstated. The ability of saleyards to market all classes, quality, and types of cattle provides an opportunity for ranchers to effectively utilize forage for livestock production and meet other resource management objectives. Ranchers indicated that selling cattle from grazing lands helped prevent overgrazing, manage for habitat, and in some cases, reduce fire fuel loads, prevent erosion, and support oak regeneration (**Figure 9**). Mobility provided by the saleyards and integration of production systems optimizes the use of forage on rangelands beyond the boundaries of discrete operations. Ranchers use the saleyards and buyers to create value from rangeland by contributing to the production of a marketable product.

While saleyards are used by ranchers to facilitate livestock mobility, the saleyards and cattle buyers also drive production efficiency by sorting cattle and matching them to feed resources. Most of the attributes of interest to cattle buyers at feeder sales relate to potential efficiency in terms of rate and cost of weight gain (**Table 3**). Discounting heifers, small frames, and exotic crosses (*Bos indicus* features) is a penalty for less efficient animals. These cattle generally grow slower and yield less than a medium, crossbred steer ([NRC] National Research Council, 1996). They are also less likely to produce a high-quality carcass. Premiums or higher prices for vaccinated cattle from reputable producers reflect the expectation of higher performance. Buyers want cattle that can get off to a better start with fewer health problems. Improved efficiency can reduce the cost for producers growing and finishing cattle and minimize resource use and greenhouse gas emissions (Capper, 2011; Herrero et al., 2013; Becoña et al., 2014). No premiums are provided for conservation values provided by grazing management and rancher stewardship but, by default, discounts on market prices related to efficiency serve as an environmental impact fee to the producer.

A drive to maximize production efficiency in the beef production system can go too far and negatively impact livestock production communities and environments. As previously noted, extensive grazing systems that support natural plant communities are not inherently the most productive. Forcing these systems to maximize production or failing to recognize non-production values of managed livestock grazing will put high-value natural ecosystem services at risk. For example, China has been promoting a "sustainable livestock industry" by intensifying all phases of livestock production. In 2002, the Chinese government required the removal of 30 million head of livestock from 92 million hectares of grazing land. The "grazing ban" was implemented to restore degraded rangeland and support sustainable intensification. To compensate pastoralists who lost grazing lands, the Chinese government provided them grain and feedyards to raise their livestock. Meanwhile, researchers in China are working to identify and develop livestock genetics that will yield more meat under an intensive production system. The grazing ban has changed ethnic pastoralists' lifestyles, who have been stewarding the grasslands for generations. Ecological impacts from the grazing ban to the grassland ecosystem, which has evolved over thousands of years with pastoralist and livestock grazing, are uncertain (Han et al., 2008; Cheng et al., 2011; Li and Huntsinger, 2011). Balancing production efficiency with ecological interest requires a comprehensive understanding of production systems, including their integration with other production systems and policies that recognize non-production values, including many ecosystems services.

Even though ranchers surveyed in this study mostly agreed that saleyards provided a fair price, it is evident that ranchers continue to be price takers. Furthermore, conservation values and ecosystem services ranchers provide with managed grazing are not generally recognized and not easily reflected in prices. Landowners, including public agencies that lease rangelands to ranchers, may directly benefit from these ecosystem services and, therefore, may be willing to accept lower fees from ranchers. However, in practice, the market for rangelands for grazing in California is tight enough that lease rates are often still high ([CASFMRA] California Chapter American Society of Farm Managers Rural Appraisers, 2020). Some consumers may be willing to pay more for products associated with grazing for conservation benefits; in practice, the certification process and marketing can be expensive. The production system is also not well set up to otherwise label final products with the origin or production practices (Woodard, 2014). Since ranchers primarily produce calves and yearling and, as a by-product, mature cows and bulls, it is difficult for them to connect their production and management efforts with beef consumers. High rent, low margins, and competition in beef calf production from both other rangeland-based producers and the dairy industry tend to lead ranchers to subsidize their ranch with off-ranch income (Smith and Martin, 1972; Torrell and Bailey, 2000).

While income from rangeland livestock production may not be the primary driver for many beef cattle producers, their economic sustainability is considered critical to conservation. There is growing interest in valuing ecosystem services from rangelands and from pastoralism and pastoral livestock (Plieninger et al., 2012; Silvestri et al., 2012; Hoffmann et al., 2014), and incentivizing or paying pastoralists and ranchers to provide them (Davies and Hatfield, 2007; Sayre et al., 2012). The integrated production system that currently creates value for livestock products for California ranchers fails to capture the value of these services and obscures them as their ranch-raised cattle are feedyard finished and mixed with beef from other production systems, including dairy beef. Current value-added programs for meat products like natural, organic, or grass-fed are limited in beef production attributes that are accounted for and promoted. Marketing beef with specific credence attributes requires transferring verifiable information (Caswell and Mojduszka, 1996; Umberger and Feuz, 2004).

Blockchain to Support Integrated Markets

New data technologies promise to support the transfer of information through an integrated production system, which could allow ranchers to document different attributes of their cattle's care and health and their stewardship of resources (**Table 4**). Tracking beef through the entire production system (e.g., from ranch to fork) is possible when individual animal ID is coupled with new data technologies. Blockchain, developed as a ledger for bitcoin, connects transactions with timestamps and transaction data to keep data linked. Its creation of a time-data chain allows for information like where and when an animal was born, how it was fed or grazed, what vaccines it received, and where and when it was transported to be tracked with the animal.

At least four beef production projects have been conducted demonstrating this technology's ability to provide transparency and transfer information through beef's integrated production systems. McDonalds conducted the first test of blockchain to track and verify cattle management through the supply chain in 2016 (McDonalds, 2017). They demonstrated proof of concept by tracking 8,967 head of Canadian cattle produced with sustainable practices—this pilot project represented 1 day's supply to McDonalds restaurants in Canada. Sustainability practices verified included maintaining well-managed grazing systems, implementing management plans to protect water and waterways, adhering to animal welfare practices, and supporting local rural economies.

Another pilot project was conducted by JD.com, a major Chinese e-commerce site. This project was focused on restoring consumer confidence in food safety and providing transparency about the origin of meat products. In May 2017, JD.com used blockchain to track meat from beef producers in Inner Mongolia to consumers in Beijing, Shanghai, and Guangzhou. Consumers were provided with information, such as the cow's breed, slaughter date, and what bacteria testing it went through. Then in March 2018, JD.com began tracking the production of Angus-beef sourced from farms in Australia. Blockchain data assures customers that only Angus beef from Australia is sold under a specific label (Zhao, 2018).

Other aspects of livestock production are also being tracked and shared with consumers with blockchain. In Fall 2019, Wong, a supermarket chain in Peru, partnered with SUKU, a Silicon Valley, California-based company, to use blockchain to cover all meat products sold in 20 stores. The products are stamped with SUKU, meaning that the product has been tracked from pasture to shelf; the blockchain platform allows customers to view the animal and meat's history, including animal health treatments (Ashgar, 2019).

In 2019, BeefChain, the first blockchain company to receive certification from the United States Department of Agriculture (USDA) as a Process Verified Program (PVP), began selling products. The USDA certification allows BeefChain to audit ranches and feedyards for compliance with value-added programs. Their PVP programs include standard USDA programs like age and source verified and natural (not treated with any hormones or antibiotics). BeefChain also has a program that identifies and tracks calves born on Wyoming grazing lands through an integrated production system. A Wyoming-born calf born can be finished in a feedyard in Washington or Nebraska and remain in the program. BeefChain's goal is to increase the value of cattle for ranchers by providing a digital identity (RFID tag or label) and traceability (blockchain) from the grazing lands to consumers (Pirus, 2019). While blockchain can connect consumers to beef raised on ranches and produced through an integrated production system, it is unclear if consumers will be willing to pay more.

CONCLUSION

Ranchers' decisions to move cattle around and off California's grazing lands are similar to decisions that pastoralists have made for millennia where livestock's needs are matched with variable forage resources. Livestock mobility, which is critical to livestock production and the management of resources on non-equilibrium rangeland systems, is supported by the integration of beef production systems. Ranchers move animals across biomes and pastures, and they move cattle to other production systems, typically to more intensive systems. Intensive production systems, including other grazing land and feedyards, provide feed resources for improving the efficiency of growing and finishing cattle. Integrating the beef production-scape through transportation and trade (saleyards and markets) expands system boundaries beyond local resources, even when non-market-based forms of livestock mobility or expanding the production-scape have been hindered. This integration supports finishing cattle for markets, the maintenance of extensive rangeland, and grazing management.

Extensive rangelands maintained with native and naturalized plants, and managed grazing can support natural diversity, including providing habitat for wildlife. Developing the whole value chain has supported California's ranchers in managing grazing and providing multiple ecosystem services from rangelands, including beef production. Communication and data technologies, like blockchain, may help transfer production information through integrated production systems to improve livestock performance and inform markets and consumers.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Committee for Protection of Human Subjects, University of California Berkeley. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

Concept, research, analysis, and writing were all conducted by SB.

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