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Cattle grazing reduces fuel and leads to more manageable fire behavior

Grazing cattle can help reduce fuel loads on rangelands and mitigate the ever-growing risk of catastrophic wildfires.

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Abstract

Cattle play an important role in wildfire management by grazing fuel on California rangelands. The benefits of cattle grazing have not been thoroughly explored, though. Using statewide cattle inventory, brand inspection and land use data, we have estimated that cattle removed 11.6 billion pounds (5.3 billion kilograms [kg]) of non-woody plant material from California's rangelands in 2017. Regionally, these reductions varied between 174 and 1,020 pounds per grazed acre (195 to 1,143 kg per hectare). Fire behavior is characterized in this paper by flame length. Fire behavior models suggest that these regional fuel reductions lower flame lengths, and lead to more manageable wildfires. In addition, fire-based models show that cattle grazing reduces fuel loads enough to lessen fire hazards in many grazed areas. Moving forward, there may be significant opportunities to expand strategic grazing on rangelands to add extra layers of protection against wildfires.

Recent wildfire seasons in California have been some of the worst on record. This "new reality" highlights the importance of understanding how land management practices such as cattle grazing affect wildfire behavior. Fire behavior is characterized in this paper by flame length. While climate change can lead to more severe fire behavior for California wildfires, our findings suggest that land managers can help balance out these dangers in grasslands by using livestock grazing to reduce fuel loads. CAL FIRE's California Vegetation Treatment Program (CalVTP) utilizes prescribed herbivory, which is the targeted grazing of cattle, sheep and goats to reduce wildland plant populations. While not included in CalVTP, conventional grazing also plays an important role in fuel load reductions.

Livestock grazing is a prevalent land use on California's rangelands and is considered a cost-effective method of reducing fuel loads (Taylor 2006). As such, fuel reduction through livestock grazing is a

These stocker cattle graze seasonally, during spring, reducing fine fuels across a large landscape. *Photo:* Devii Rao.

common management goal in regional, state, county and agency management plans (EBMUD 2000; EBRPD 2013; George and McDougald 2010; Rancho Mission Viejo 2006; Santa Clara County Parks 2018). However, management plans generally do not list target fuel conditions to achieve through livestock grazing.

Since livestock grazing is already in widespread use for wildfire fuel management in California, it is important to understand in greater detail to what extent livestock reduce fuel loads across the state, including how this varies spatially. More research on grazing for fuel reduction has been done on sheep and goats than on cattle (Nader et al. 2007). Especially in California, much of this research has focused on forests and shrublands rather than grasslands, and on woody rather than herbaceous fuels (Green and Newell 1982; Minnich 1982; Narvaez 2007; Tsiouvaras et al. 1989). While cattle graze all rangeland types in California, they primarily graze grasslands, preferring herbaceous forage like grasses and flowering plants (Launchbaugh et al. 2006; Van Soest 1994). When these fuels dry out, they are known as “fine fuel” — fuels with a high surface-area-to-volume ratio that can be quickly combusted in wildfires (USFS 2022). Because they are by far the most widespread and abundant domestic grazers in the state (Saitone 2018), understanding the effects of cattle grazing on rangeland fuel loads is particularly important.

Beef cattle account for the vast majority of rangeland cattle. However, the number of beef cows in California today is only about 57% of their peak numbers in the 1980s (Saitone 2018). This reduction is mirrored by declines in authorized grazing on public lands in the state over that time period (Oles et al. 2017; Saitone 2018). The number of grazed rangeland acres has been in decline as well, both on private (Cameron et al. 2014) and public lands (Forero 2002; Oles et al. 2017). This reduction influences rangeland fuel levels, as less fine fuel is removed through grazing.

Cattle grazing can reduce rangeland fuels in several ways. The most frequently studied and perhaps most important way is by removing fine fuels. This can affect fire behavior by reducing rates of spread, flame lengths and fire intensities. Despite widespread interest in this topic, there is only one published study of the impact of cattle grazing on fine fuels and fire behavior in California (Stechman 1983). This study looked at fire behavior in an annual grassland grazed by cattle; however, the level of residual dry matter (RDM) was much higher than is typical for grazed annual grassland in California. RDM is the amount of herbaceous plant matter from the previous season immediately prior to the first fall rains (Bartolome et al. 2006). Other studies from western U.S. rangelands in sagebrush steppe, mesquite savanna and cheatgrass-dominated grasslands have shown that cattle grazing can reduce fine fuel loads and, in turn, slow fire spread and flame length (Bruegger et al. 2016; Davies et al. 2010; Davies et al. 2015; Diamond 2009; Schmelzer et al. 2014). Several of these studies rely on fire behavior models to analyze the effects of fine fuel reduction on fire behavior (Bruegger et al. 2016; Diamond 2009).

Comparison of ungrazed grassland (inside exclosure) versus grazed grassland (outside exclosure). *Photo:* Royce Larsen.

Cattle grazing can also reduce rangeland fuels by causing long-term changes in species composition and vegetation structure. Perhaps the most important example of this in California is that cattle grazing can prevent or slow the encroachment of shrubs and trees into grassland. Much of coastal California has shown a trend of shrub encroachment on grassland (particularly by coyote brush, *Baccharis pilularis*) in the absence of grazing and fire disturbances (Ford and Hayes 2007). For instance, in the San Francisco Bay Area, limited grazing in the mid- to late 20th century has been linked to widespread shrub encroachment and loss of grassland (Keeley 2005; McBride and Heady 1968; Russell and McBride 2003). Coyote brush encroachment is also occurring on the southern California coast (Brennan et al. 2018). Shrub encroachment, even if by native species, presents a challenge for fire management because dense stands of shrubs increase fire hazard and fire intensity (Ford and Hayes 2007; Parker et al. 2016). Grazing is a key management technique to minimize these more severe wildfires in areas where retention of grasslands is an important goal.

The amount of herbaceous fuel on the ground during fire season in grazed California rangelands is largely a function of herbaceous growth in any given year, the number of livestock grazing per acre (grazing pressure), and vegetation biomass loss due to weathering (Frost et al. 2008; Larsen et al. 2021). Forage production is notoriously variable and unpredictable in California, both between years and across the landscape at a fine scale (Becchetti et al. 2016; Devine et al. 2019). The number of livestock grazing in the state is relatively stable by comparison.

The goals of this study are to inform planning, policy, and risk assessment at the state and regional scales and to clarify the benefit of strategic grazing to mitigate wildfire risk. To accomplish this, we describe the degree to which cattle remove fine fuels from rangelands in different areas of the state and use models to try to understand how this fine fuel removal affects fire behavior. We aim to help answer the following questions:

1. How much herbaceous fuel is removed by cattle from grazed rangelands in California, and how does this amount vary by region in the state?
2. What can fire behavior models tell us about how effective current levels of cattle grazing are at altering wildfire behavior?
3. How do spatial patterns of grazing and fuel reduction within regions inform our understanding of the impact of cattle grazing on fire behavior?

To answer the study questions, we first estimated rangeland fine fuel reduction by cattle in California. Next, we characterized year-to-year and spatial variability associated with fuel reduction. Finally, we applied fire models to predict how estimated regional fuel reduction would affect grassland fire behavior.

Calculating fuel reductions

We assumed that fine fuel reduction by cattle equals the amount of rangeland forage consumed by cattle in California. This is a conservative estimate of the total fuel reduction since it does not explicitly consider fine fuels removed through trampling (Nader et al. 2007), but see AUM in supplemental table 2 in the online supplemental appendix. Consumed rangeland forage is a function of the number of cattle grazing on rangelands (head), the class of cattle, and the time spent grazing on the rangeland (in months; equation 1). We used five datasets to determine the values in equation 1, including the 2017 USDA Agricultural Census, California Brand Inspection Data, County Crop Reports, GAP LANDFIRE vegetation classification and MODIS imagery (supplemental table 1). We also consulted with livestock and range advisors from the University of California Cooperative Extension (UCCE) to estimate irrigated pasture use and further refine the data (See "Animal Unit Months and Forage Removal" in the online supplemental appendix).

The census data provides an inventory of beef cows and "other cattle" in each county. "Other cattle" are all non-cow classes (including both beef and dairy cattle). We used the brand inspection data to estimate the proportion of "other cattle" that were beef cattle, and to estimate the proportion of these that belong to each non-cow class (supplemental tables 1 and 2).

In order to account for inter-county movement of cattle, we created beef production regions in California (fig. 1). These regions were selected to account for the majority of inter-county movements of cattle, and for similarities in forage production and livestock production practices for counties without pronounced patterns of inter-county cattle movement.

Regional rangeland acres were calculated by: (1) summing harvested rangeland acreage statistics from the county crop reports to estimate "Grazed Rangeland" acres, and (2) summing the rangeland acreage types per region using the GAP/LANDFIRE National Terrestrial Ecosystems (GAP) (USGS 2016) classification to estimate "Total Rangeland" acres.

We used the following equation to calculate the total pounds of forage removed on rangelands in each region by cattle (variables are described in supplemental table 2):

$$\textit{forage consumed} = \Sigma_{region\ k} (\Sigma_{county\ j} (\Sigma_{cattle\ class\ i} (head_{ijk} \times months_{ijk} \times AUE_i - IP.adjust_{ijk}) \times 1{,}000\ pounds/AUM))$$

To estimate forage removed per rangeland acre, we divided the estimated forage consumed by rangeland acreage in each region. To account for differences in approaches to estimating rangeland acreage, we calculated this using two datasets: county crop reports and the GAP classification.

Forage production and RDM

RDM is the unused forage at the end of the grazing season (fall) (Bartolome et al. 2006), measured in pounds per acre or kilograms per hectare. The total amount of forage produced per acre on rangelands is generally measured in late spring at peak standing crop. It is an approximate measure of the amount of fine fuel produced per acre annually (excluding

FIG. 1. Beef cattle grazing regions of California.

non-forage species), which is an important determinant of fuel load. RDM is not a perfect measure of fuel load because it excludes non-forage species and is only measured at the end of the fire season. Nevertheless, it gives an approximate value for residual fuel load. When compared to production measurements, RDM can be used to determine fine fuel removal rates by livestock in grazed rangelands.

We evaluated production data from 52 sites in the Central Coast, North Coast and Sacramento-Sierra-Cascade regions that was collected between 2000 and 2019, and RDM data from 105 sites collected between 1987 and 2019. We summarized these data to characterize variability in production between regions and at sub-regional scales, and to qualitatively assess heterogeneity of RDM and fuel reduction rates on grazed rangelands (supplemental table 4). We then compared these reduction rates to regional fuel reduction rates from the census-based fuel reduction estimates.

Modeling fire behavior

Custom fuel models were built using the BehavePlus 6 fire behavior model application to determine how variation in grassland fine fuel loads could affect flame length. Initial parameters were based on the low fuel load, dry-grass model GR2 (Scott and Burgan 2005), and the two grass models from the "original 13 fuel models" as described by Anderson (1982). However, several variables were altered to represent a range of fuel loads in different topographic positions and weather conditions (supplemental table 6). The pattern and scale of results from using the three different fuel models as the base for custom fuel models were similar (supplemental figs. 1–4). Therefore, our discussion is limited to the results of using the GR2 fuel model.

A summer model was built to represent fuel conditions after annual grasses had senesced and dried, and when fire conditions should be most extreme in a given year. For the summer models, we evaluated flame lengths when wind speeds were between 0 and 40 miles per hour (0–64.4 kilometers [km] per hour), and when fuel loads were between 100 and 2,000 pounds per acre (112–2,242 kilograms [kg] per hectare [ha]). Additionally, three separate dead fuel moisture scenarios (high at 13%, moderate at 6% and low at 2%) and two separate slope scenarios (high at 100% and low at 0%) were run. The high dead fuel moisture scenario was set to 13%, since our moisture of extinction (fuel moisture at which fuels are no longer ignitable) was set at 15% and is within the range of values that can be expected in California grasslands (Livingston and Varner 2016). While there is a dearth of literature on dead fuel moistures in California grasslands, the moderate dead fuel moisture scenario was set to 6%, because that was the lowest value measured by Livingston and Varner (2016) in late September. We set this as our moderate value, instead of our low value, because their measurements took place in Northern California, where we might expect higher dead fuel moistures due to a more mesic (moist) climate. Lastly, the low dead fuel moisture value was selected to represent very extreme fire conditions. The higher slope value of 100% slope was selected to represent a high slope scenario, but one that was still reasonable for firefighters to access.

A spring model that included more live fuel and a higher fuel moisture content was also evaluated (supplemental figs. 1 and 2). While the GR2 model is dynamic and automatically reapportions some of the live herbaceous fuel to a one-hour fuel load, we turned off the dynamic feature of our fuel models because we were manually setting the ratio of live to dead fuel as part of the spring and summer scenarios.

BehavePlus 6 defaults to setting a maximum effective windspeed, but studies have shown that this can underestimate flame lengths and rates of spread (Andrews et al. 2013). Therefore, we turned off this feature and did not impose a maximum effective windspeed in our model calculations. Additionally, BehavePlus 6 has the option for the windspeed to be calculated at the midflame height, 20 feet above the vegetation, or 10 meters above the vegetation. We set the input for wind speeds to be at midflame height. This is the average windspeed from the top of the fuel bed to the height of the flame in relation to the fuel.

Regional variations

Approximately 1.8 million beef cattle grazed rangelands in California in 2017. Although there was a slight dip in the number of beef cows in the state during the 2012–2015 drought, their number had rebounded to the decadal average by 2017 (CDFA 2010–2018), indicating that 2017 Census numbers are representative of the predrought cattle numbers.

Beef cows were by far the most abundant beef cattle class, with 677,000 on range in the state in 2017. This was followed by steers, heifers, "mixed" (an amalgamation of different classes that couldn't be separated using the brand inspection data), and bulls.

The number of months cattle spent on rangeland varied by county and by cattle class. Cows were estimated to spend an average of 10.7 months on rangeland (this accounts for cows that were removed from rangeland due to replacement). Steers and heifers were estimated to be on range an average of 7.6 and 7.7 months, respectively, and bulls and "mixed" cattle averaged 6.6 months on range. Time spent on range by each class of cattle varied substantially between counties and regions.

The cumulative fine fuel removal by these cattle varied by region from 85.0 million pounds (34.6 million kg) in the South Coast region to 5,444 million pounds (2,469 million kg) in the San Joaquin-Sierra region (fig. 2). In regions with higher levels of irrigated pasture use (San Joaquin-Sierra and Sacramento-Sierra-Cascade), estimates of fuel removal may be somewhat higher than actual removal rates if irrigated pasture use was higher

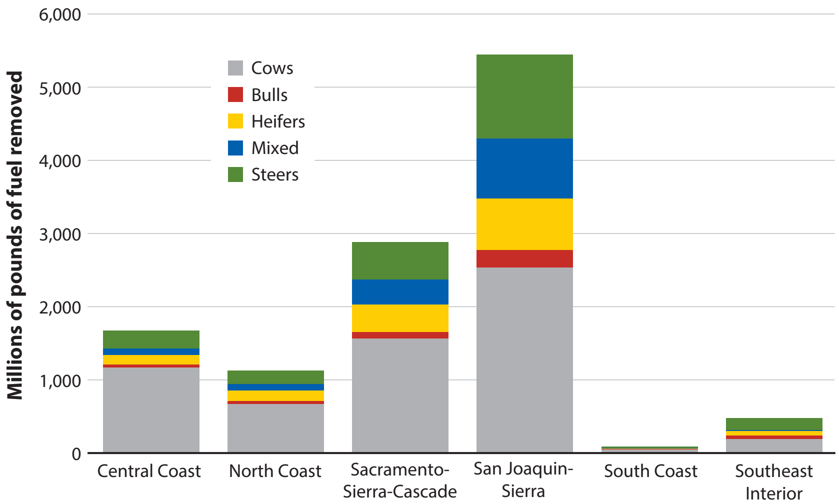

FIG. 2. Millions of pounds of rangeland fuel removed by cattle in each region.

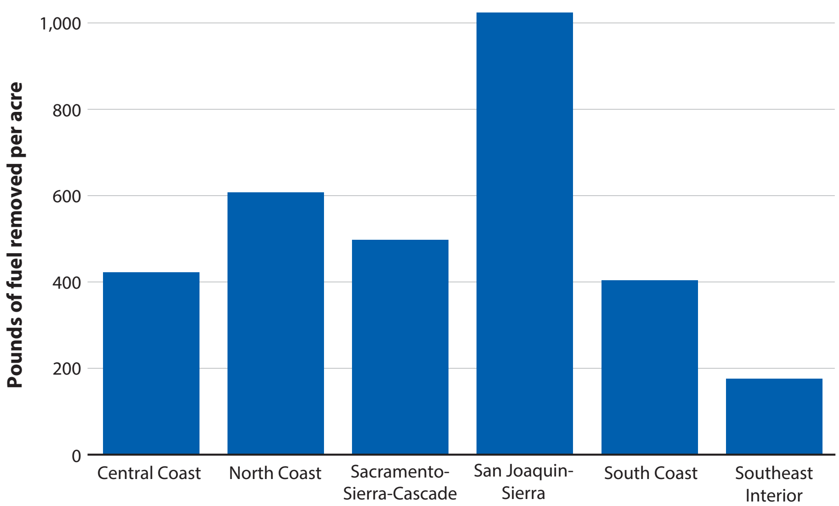

FIG. 3. Pounds per acre of fuel reduction on grazed rangelands in California regions.

in 2017 than the regional estimates used in our analysis. Across the state, the total fuel reduction by cattle in 2017 was 11.6 billion pounds (5.3 billion kg). Overall, this is probably a conservative estimate of fuels reduced on rangelands since it does not take into consideration fine fuels trampled by cattle and incorporated into mineral soil.

There were 19.4 million acres (7.9 million ha) of rangeland grazed by livestock in California according to county crop reports and county Agricultural Commissioners' offices. This is close to the 17 million acres (6.9 million ha) of private grazed rangeland previously reported in the state (CAL FIRE 2017), which is not surprising since many county crop reports do not include federal grazing allotments in their rangeland acreage estimates. On the other hand, our estimate of the total rangeland acreage based on the California GAP was 59.4 million acres (24 million ha). This estimate includes all public and privately owned rangeland, whether or not it is grazed.

The average amount of fuel removed across grazed rangelands in the state was 596 pounds per acre (668 kg/ha). This number varied from 174 pounds per acre (195 kg/ha) in the Southeast Interior region to 1,020 pounds per acre (1,143 kg/ha) in the San Joaquin-Sierra Region (table 1; fig. 3).

When calculated across all rangeland acres identified in the GAP analysis (not just grazed acres), average fuel reduction was only 195 pounds per acre (219 kg/ha). This lower number is largely due to the fact that there is rangeland that is not grazed in every region. The per-acre fuel reduction using the GAP acreage has similar regional trends to fuel reduction based on acreage from the county crop reports (table 1; fig. 4).

The regional values of grazing intensity are far below the amount of forage produced by region in most years. Valley grasslands in the interior of the state generally produce 2,000 pounds of forage per acre (2,242 kg/ha) or more in an average forage year (Bartolome 1987; Becchetti et al. 2016). Central and northern coast

TABLE 1. Acreage and average fuel reduction rates on grazed and total rangelands by region

Region	Grazed rangeland acreage (from crop reports)	All rangeland acreage (from GAP)	Fuels removed – grazed rangelands (pounds/acre)	Fuels removed – all rangelands (pounds/acre)
Central Coast	3,983,153 (1,611,925 ha)	7,242,014 (2,930,739 ha)	419 (470 kg/ha)	230 (258 kg/ha)
North Coast	1,857,912 (751,870 ha)	2,504,836 (1,013,671 ha)	419 (470 kg/ha)	450 (504 kg/ha)
Sacramento-Sierra-Cascade	5,827,095 (2,358,142 ha)	11,703,394 (4,736,196 ha)	495 (555 kg/ha)	246 (276 kg/ha)
San Joaquin-Sierra	5,336,824 (2,159,736 ha)	9,265,683 (3,749,689 ha)	1,020 (1143 kg/ha)	588 (659 kg/ha)
South Coast	211,560 (85,615 ha)	3,659,608 (1,480,991 ha)	401 (449 kg/ha)	23 (26 kg/ha)
Southeast Interior	2,232,720 (903,550 ha)	25,031,549 (10,129,908 ha)	174 (195 kg/ha)	16 (18 kg/ha)
Total	19,449,264 (7,870,838 ha)	59,407,085 (24,041,194 ha)	596 (average) (668 kg/ha)	195 (average) (219 kg/ha)

range grassland sites produce more than 3,000 pounds of forage per acre (3,363 kg/ha) (Becchetti et al. 2016; Larsen et al. 2020). Coastal prairie sites can be highly productive, producing more than 4,500 pounds per acre (5,044 kg/ha) on average in the Central Coast (Larsen et al. 2020). In the highest production years, forage production can be double the average in any given region, and in the lowest production years it can be less than 25% of average production (Larsen et al. 2020). The relatively low grazing intensity reflects the generally conservative stocking strategies used by many ranchers across the state to hedge against the unpredictable and highly variable annual forage production (Macon et al. 2016).

It's important to keep in mind that grazed acres and forage removal rates in this paper are not "hard numbers," but rather are estimates to inform large-scale patterns of fuel removal by cattle. These estimates are based on the best available data, but these data do not describe the intricate (and dynamic) details of cattle grazing across the state. These numbers should be interpreted in the context of understanding regional fuel reduction, not as predictive of grazing practices at subregional scales. There is a need for more consistent and accurate reporting of cattle numbers and grazed acres across the state.

Based on several datasets, forage production and RDM were highly variable within and between regions of the state. Average RDM in each region was significantly less than production, but the amount of fuel reduced was highly variable (table 2).

Collectively, these data show that reductions of fuels measured on ranches can differ significantly from region-wide averages seen in the Census analysis. The Census gives an indication of the county in which grazing occurs, but it does not tell us where those animals graze within the county. The RDM data also show that spatial differences in forage production and grazing practices can lead to differences in the amount of fine fuels and the level of fuel reduction by cattle. This is consistent with other research showing that annual forage production is highly variable across the state, varying at small and large scales in relation to soil characteristics, microclimate, position on the landscape, and tree canopy cover (Becchetti et al. 2016; Devine et al. 2019; Frost et al. 1991).

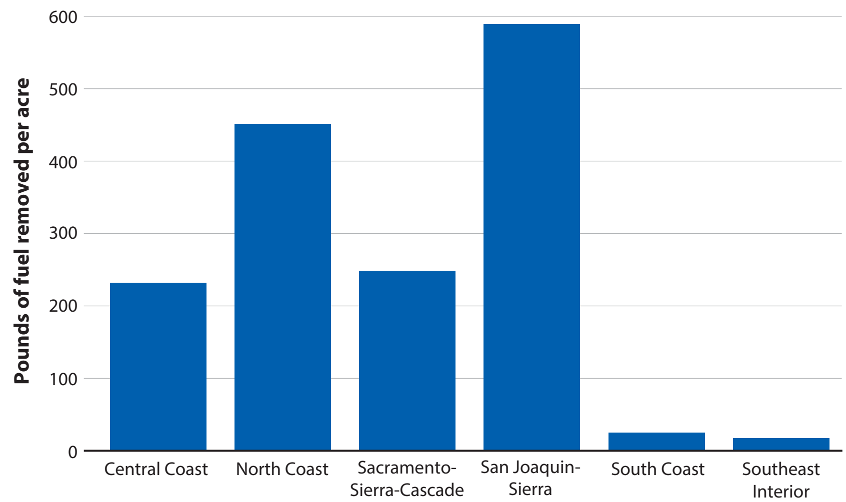

FIG. 4. Pounds per acre of fuel reduction on all rangelands in California regions.

Lower flame lengths

Keeping flame lengths below eight feet (2.4 meters [m]) is seen as a critical threshold that allows fire fighters to use direct measures (such as heavy equipment) on the ground to fight fires. Below four feet (1.2 m), fires can be fought using hand tools (Andrews and Rothermel 1982). However, these thresholds are somewhat fuzzy and dependent on other aspects of the fire, i.e.,

TABLE 2. Forage production and residual dry matter (RDM) from coastal prairie, coast range grassland, and valley grassland sites in Central and Northern California

Region	Data source	Average production (pounds/acre)	Production minus summer decomposition (75% of total)*	Average RDM (pounds/acre)	Average fuel reduction (pounds/acre)
Central Coast (Coastal)	Larsen et al. 2020	4,978 (5,580 kg/ha)	3,734 (4,185 kg/ha)	1,815 (2,034 kg/ha)	1,919 (2,151 kg/ha)
Northern California (Coastal)	Bartolome et al. 2015 and Point Reyes unpublished data 2020	7,053† (7,905 kg/ha)	5,290 (5,929 kg/ha)	2,147 (2,406 kg/ha)	3,143 (3,523 kg/ha)
Central Coast (Coast Range)	Larsen et al. 2020	3,371 (3,778 kg/ha)	2,528 (2,834 kg/ha)	2,055 (2,303 kg/ha)	473 (530 kg/ha)
Central Coast (Coast Range)	NRCS unpublished data 2010	3,055 (3,424 kg/ha)	2,138 (2,396 kg/ha)	1,775 (1,990 kg/ha)	363 (407 kg/ha)
Central Coast (Interior)	Larsen et al. 2020	1,961 (2,198 kg/ha)	1,471 (1,649 kg/ha)	1,053 (1,180 kg/ha)	418 (469 kg/ha)
Sacramento-Sierra-Cascade (Interior)	UC ANR unpublished data	3,096 (3,470 kg/ha)	2,322 (2,603 kg/ha)	800‡ (897 kg/ha)	1,522 (1,706 kg/ha)

* Based on Frost et al. 2005.
† Production values from only two years of data.
‡ RDM values estimated not measured.

spread and fire intensity (Andrews et al. 2011). Based on our fire behavior models, on flat ground in dry summer conditions (when dead fuel moisture is 6%), fine fuel loads below 1,225 pounds per acre (1,373 kg/ha; fig. 5) are predicted to keep flame lengths below eight feet at wind speeds up to 15 miles per hour (24 km per hour). At higher dead fuel moisture levels and lower wind speeds, flame lengths may be kept below eight feet at higher fuel loads. However, in extreme fire weather with very low dead fuel moisture (2%) and wind speeds up to 40 miles per hour (64.4 km per hour), fine fuel loads may need to be reduced below 214 pounds per acre (240 kg/ha) (fig. 5) to keep flame lengths under eight feet. In high slope areas during dry conditions (6% dead fuel moisture) with windspeeds of 15 miles per hour, fine fuel loads would need to be kept below 1,000 pounds per acre (1,121 kg/ha) to keep flame lengths below eight feet. In very dry conditions (2% dead fuel moisture), at wind speeds of 40 miles per hour, fuel loads would need to be reduced below 205 pounds per acre (230 kg/ha) to keep flame lengths below eight feet. While these models are useful for interpreting potential impacts of estimated fuel reduction levels, the results still need to be experimentally validated in California before they are used for policy and planning purposes. Also, these models do not evaluate ignition potential, level of shrub encroachment, and areas with elevated ignition risk, which may have different fuel load thresholds. There is always a level of uncertainty associated with fire behavior modeling. Depending on the aptness of the fuel models, BehavePlus 6 results can be off by a factor of two or more (Sparks et al. 2007).

Understanding the effect of cattle grazing on fire behavior is complicated by the pronounced spatial and temporal variability in forage production, fuel reduction, shrub encroachment and RDM at scales smaller than the region or county. In their measurements at 43 different ranches spanning a rainfall gradient in Central California, Larsen et al. (2020) found RDM values ranging from 75 to 6,258 pounds per acre (84 to 7,014 kg/ha) from 2000 to 2019. Forty percent of grazing fields had RDM values at or below 1,225 pounds per acre (1,373 kg/ha), while only 4% were below 214 pounds per acre (240 kg/ha). This shows that many areas of these grazed rangelands had good fuel conditions for non-extreme fire weather, but few locations had fuel levels low enough to keep flame lengths below eight feet in extreme fire weather. No grazing fields had RDM below these thresholds consistently across all monitoring years.

Strategic grazing

The inherent heterogeneity of grazing intensity and fuel reduction may in fact be its greatest asset in reducing wildfire hazard and risk. Selective grazing by livestock can create patchiness of fuels, reducing continuity of fuels and reducing rate of fire spread and total burned area (Bunting et al. 1987; Kerby et al. 2007;

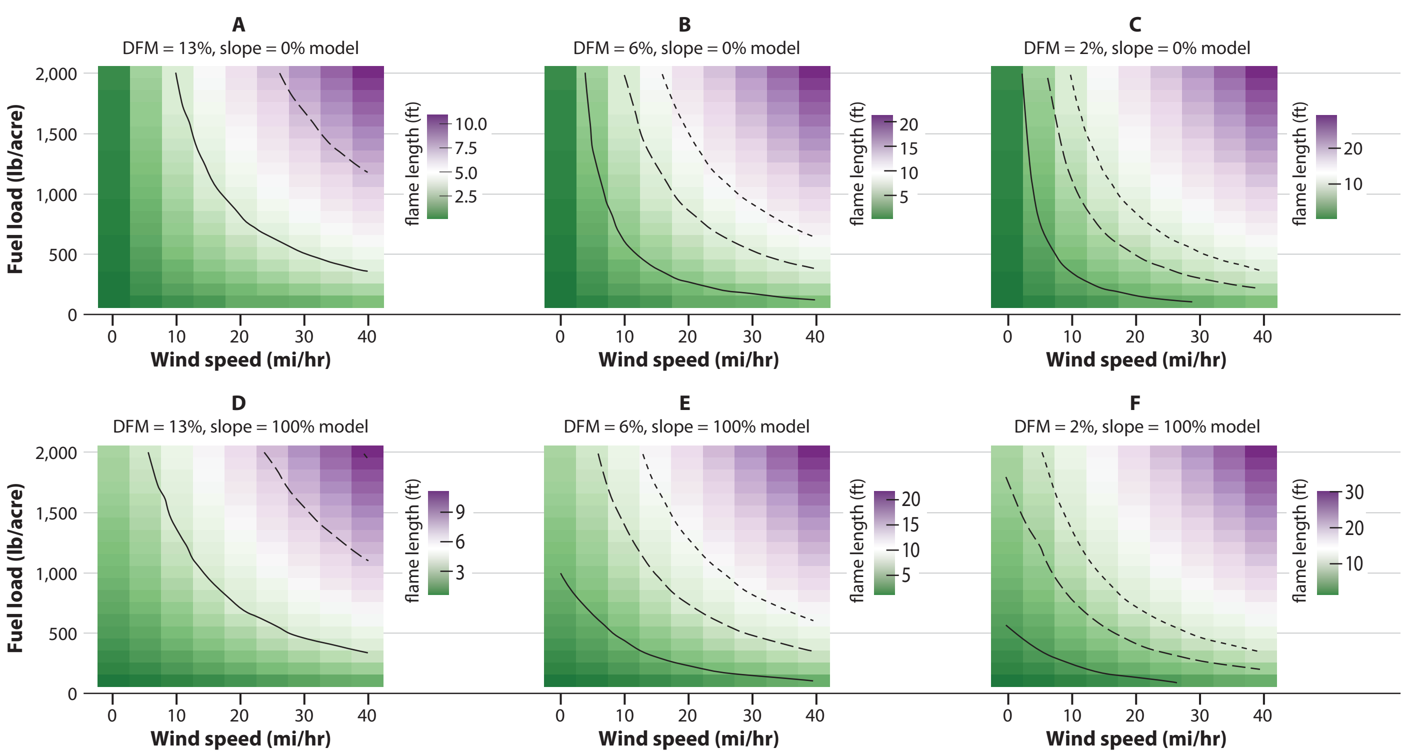

FIG. 5. Results from fire behavior modeling under summer conditions. Conditions were run under three dead fuel moisture scenarios of 13% (A, D), 6% (B, E) and 2% (C, F), and two slope scenarios of 0% (A, B and C) and 100% (D, E and F). Contour lines show when threshold flame lengths of 4 feet (solid line), 8 feet (long-dashed line) and 11 feet (short-dashed line) are surpassed.

This cow-calf operation on the Central Coast has cattle grazing on the ranch year-round, helping to reduce the potential for catastrophic wildfire. *Photo:* Devii Rao.

Launchbaugh 2016; Taylor 2006). At the ranch scale, RDM data from the Central Coast shows that, even in a region with relatively low grazing intensity, fuel reduction of several thousand pounds per acre can be achieved in select locations (Larsen et al. 2020).

Given that grazing intensity on California rangelands is generally conservative relative to the amount of forage produced in most years (as evidenced by the generally low fuel reduction for most regions in the Census analysis), strategic implementation of grazing should be employed to maximize the benefit of livestock grazing for fuels reduction. A strategic grazing program would target grazing on certain areas of the landscape. It should consider maintaining fuel breaks, controlling shrub encroachment, employing grazing near the wildland-urban interface, proximity to urban centers, annual weather patterns (i.e., grazing in advance of Santa Ana or Diablo winds), potential sources of ignition, and the realities of grazing operations (including animal distribution, nutrition, site accessibility, and the need to bank forage for the fall). To be successful, grazing strategies must be logistically feasible and financially sustainable for the grazing operator.

A strategic approach to fuels reduction is especially important given that California rangelands are managed for multiple resource objectives. Reducing fuels on all grazed rangelands to 1,225 pounds per acre (1,373 kg/ha) or less will not be compatible with some of these objectives in some areas. RDM recommendations are based on the type of grassland (dry annual grassland, annual grasslands/hardwood rangeland, or coastal prairie), terrain slope, and percent cover of woody vegetation (Bartolome et al. 2006). RDM standards vary from 300 pounds per acre (336 kg/ha) on some dry, flat inland sites to 2,100 pounds per acre (2,354 kg/ha) on steep, coastal prairie sites (Bartolome et al. 2006). Maintaining adequate RDM is expected to minimize soil erosion, improve forage production, and influence plant species composition at some sites — but many areas have RDM standards above the preliminary fuel load thresholds reported here. In particular, steeper areas have higher minimum RDM recommendations — but these areas would need even lower fuel loads to keep flame lengths below eight feet. Testing these fuel load thresholds on the ground and having discussions between fire modelers and rangeland specialists will be critical to making appropriate recommendations about grazing levels to achieve both fire safety and natural resource objectives. Furthermore, RDM is measured immediately prior to the first germinating rains (September or October) and fuel reductions will need to be achieved earlier in the year if they are meant to apply to the bulk of the fire season. Fuel reduction also must ensure that adequate forage is left to support continued livestock grazing during the fall and winter months.

There are several potential synergies between reducing residual biomass for fire safety and conservation objectives. Excessive residual biomass and height have been found to negatively affect many sensitive or threatened wildlife species (Ford et al. 2013; Gennet et al. 2017; Germano et al. 2011; Riensche 2008), cause problems for weed management (Becchetti et al. 2016), and negatively affect some native plant species (Bartolome et al. 2014; Beck et al. 2015). Where possible, maximum biomass standards for fuel reduction should be strategically implemented to simultaneously promote these and other conservation goals.

Cattle grazing is not the only management tool that can be used to reduce residual biomass. Unlike wildfires, prescribed fires are well planned, and are implemented to achieve one or more specific objectives. Prescribed fires burn thatch, increasing seed access to the soil surface, and creating more suitable light conditions and ground temperatures for grassland forbs (Sugihara et al. 2006). This allows higher levels of seed production and flowering in forbs after late spring fires. Prescribed fire can be used alone, or in conjunction with grazing, to improve habitat for some native plants and sensitive or threatened wildlife species. In the early 1950s, ranchers were permitted to burn a substantial amount of land in California, up to more than 200,000 acres in one year (Biswell 1999). Since that time, prescribed burn acreage has been in steep decline. However, due to recent catastrophic wildfires, there is renewed interest in prescribed burning. Though grazing is substantially more widespread than prescribed burning today, thanks to new legislation (SB 901 and SB 1260) and development of prescribed burn associations across the state, prescribed burning is becoming a viable option again.

Grazing can reduce fuel

Cattle grazing plays an important role in reducing fuels on California rangelands. Without grazing, we would have hundreds or possibly thousands of additional pounds per acre of fuel on rangelands, potentially leading to larger and more devastating fires. Cattle grazing, of course, can't eliminate wildfires completely. But it can make a big impact. Cattle don't consume forage uniformly on rangelands. Instead, they eat in more of a patchwork pattern. Thus, while cattle grazing does not reduce fuels enough to avoid hazardous 4- or 8-foot wildfire flame lengths on all grazed rangelands, many areas will be grazed sufficiently to significantly alter fire behavior (especially in non-extreme fire weather).

To effectively reduce wildfire hazards, rangeland managers and planners must strategically coordinate fuel management practices, such as cattle grazing along with other natural resource objectives and management practices, including prescribed fire. This will require the development of maximum residual biomass standards that can be used to assess fuel loads at critical times and locations during the fire season. To help develop these standards, we need to experimentally validate fire behavioral models in herbaceous rangelands in California.

Widespread wildfires are predicted to increase over time in California due to ongoing climate change. This new reality requires that we take advantage of all the tools available to protect public safety while also meeting broader rangeland management objectives. All of this is occurring against the backdrop of the decline of the number of beef cows grazing in California, including on public lands, over the past several decades (Oles et al. 2017; Saitone 2018). It is not feasible to graze all rangelands to ideal fuel levels, nor is it compatible with management goals across the state. However, there are opportunities to improve fire safety in California by grazing rangelands that are not currently being grazed — or even by increasing grazing intensity on some very lightly grazed areas. Strategic implementation of cattle grazing, including potentially fee-for-service agreements on key private and public lands, can meet multiple natural resource objectives while also lowering fire hazards by reducing fine fuels, reducing fuel continuity and slowing or even stopping shrub encroachment onto grasslands. CA

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References

Anderson HE. 1982. Aids to Determining Fuel Models for Estimating Fire Behavior. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station.

Andrews PL, Cruz MG, Rothermel RC. 2013. Examination of the wind speed limit function in the Rothermel surface fire spread model. Int J Wildland Fire 22:959. https://doi.org/10.1071/WF12122

Andrews PL, Rothermel RC. 1982. Charts for interpreting wildland fire behavior characteristics. General Technical Report INT-131. U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station.

Andrews, PL, Heinsch FA, Schelvan L. 2011. How to Generate and Interpret Fire Characteristics Charts for Surface and Crown Fire Behavior. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. General Technical Report RMRS-GTR-253.

Bartolome JW. 1987. California annual grassland and oak savannah. Rangelands 9:122–5.

Bartolome JW, Frost WE, McDougald NK, Connor M. 2006. California Guidelines for Residual Dry Matter (RDM) Management on Coastal and Foothill Annual Grasslands. Publication 8092. University of California, Division of Agriculture and Natural Resources, Rangeland Monitoring Series.

Bartolome JW, Allen-Diaz BH, Barry S, et al. 2014. Grazing for biodiversity in Californian Mediterranean grasslands. Rangelands 36:36–43. https://doi.org/10.2111/Rangelands-D-14-00024.1

Bartolome, J, Hammond M, Hopkinson P, Ratcliff F. 2015. 1987–2014 Residual Dry Matter Analysis Report and Updated Rangeland Monitoring Guidelines for Livestock Grazed Grasslands within Point Reyes National Seashore and Golden Gate National Recreation Area. Produced by the UC Berkeley Rangeland Ecology Lab for Point Reyes National Seashore.

Becchetti T, George M, McDougald N, et al. 2016. Rangeland Management Series: Annual Range Forage Production. Publication 8018. University of California, Agriculture and Natural Resources. 12 p. https://doi.org/10.3733/ucanr.8018

Beck JJ, Hernández DL, Pasari JR, et al. 2015. Grazing maintains native plant diversity and promotes community stability in an annual grassland. Ecol Appl 25:1259–70. https://doi.org/10.1890/14-1093.1

Biswell H. 1999. *Prescribed Burning in California Wildlands Vegetation Management.* Berkeley and Los Angeles: University of California Press.

Brennan S, Laris PS, Rodrigue CM. 2018. Coyote brush as facilitator of native California plant recovery in the Santa Monica Mountains. Madroño 65:47–59. https://doi.org/10.3120/0024-9637-65.1.47

Bruegger RA, Varelas LA, Howery LD, et al. 2016. Targeted grazing in Southern Arizona: Using cattle to reduce fine fuel loads. Rangeland Ecol Manag 69:43–51. https://doi.org/10.1016/j.rama.2015.10.011

Bunting SC, Kilgore, BM, Bushey CL. 1987. Guidelines for Prescribed Burning Sagebrush-grass Rangelands in the Northern Great Basin. U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station.

[CAL FIRE] California Department of Forestry and Fire Protection. 2017. Fire and Resource Assessment Program (FRAP).

[CDFA] California Department of Food and Agriculture. 2010–2018. *California Agricultural Statistics Review*. Sacramento, CA: California Department of Food and Agriculture.

Cameron DR, Marty J, Holland RF. 2014. Whither the rangeland? Protection and conversion in California's rangeland ecosystems. PLOS ONE 9:e103468. https://doi.org/10.1371/journal.pone.0103468

Davies KW, Bates JD, Svejcar TJ, et al. 2010. Effects of long-term livestock grazing on fuel characteristics in rangelands: An example from the Sagebrush steppe. Rangeland Ecol Manag 63:662–9. https://doi.org/10.2111/REM-D-10-00006.1

Davies KW, Boyd CS, Bates JD, et al. 2015. Dormant season grazing may decrease wildfire probability by increasing fuel moisture and reducing fuel amount and continuity. Int J Wildland Fire 24:849. https://doi.org/10.1071/WF14209

Devine SM, O'Geen AT, Larsen RE, et al. 2019. Microclimate–forage growth linkages across two strongly contrasting precipitation years in a Mediterranean catchment. Ecohydrology 12. https://doi.org/10.1002/eco.2156

Diamond JM, Call CA, Devoe N. 2009. Effects of targeted cattle grazing on fire behavior of cheatgrass-dominated rangeland in the northern Great Basin, USA. Int J Wildland Fire 18:944. https://doi.org/10.1071/WF08075

[EBMUD] East Bay Municipal Utilities District. 2000. East Bay Watershed Fire Management Plan. Oakland, CA: East Bay Municipal Utilities District.

[EBRPD] East Bay Regional Parks District. 2013. East Bay Regional Parks District Master Plan 2013. Oakland, CA: East Bay Regional Parks District.

Ford LD, Hayes GF. 2007. Northern coastal scrub and coastal prairie. In *Terrestrial Vegetation of California, 3rd Edition*. Barbour M (ed.). University of California Press. p 180–207.

Ford LD, Van Hoorn P, Rao DR, et al. 2013. Managing Rangelands to Benefit California Red-Legged Frogs and California Tiger Salamanders. Livermore, CA: Alameda County Resource Conservation District.

Forero LC. 2002. Grass, Graziers, and Tenure: A Case Study on the Shasta-Trinity National Forest. Dissertation. Berkeley, CA: University of California, Berkeley, Department of Environmental Science Policy and Management (ESPM).

Frost WE, Bartolome JW, Churches KR. 2005. Disappearance of residual dry matter (RDM) on annual rangelands in the absence of grazing. XX International Grassland Conference. Dublin, Ireland.

Frost WE, McDougald NK, Demment MW. 1991. *Blue Oak Canopy Effect on Seasonal Forage Production and Quality*. Davis, CA: USDA Forest Service.

Frost WE, McDougald NK, Larsen R, et al. 2008. Disappearance of residual dry matter on coastal and Sierran annual rangeland of California. In Society for Range Management: Building Bridges Grasslands to Rangelands. Louisville, KY. Abstract 2435.

Gennet S, Spotswood E, Hammond M, Bartolome JW. 2017. Livestock grazing supports native plants and songbirds in a California annual grassland. PLOS ONE 12:e0176367. https://doi.org/10.1371/journal.pone.0176367

George M, McDougald N. 2010. Bitter Creek National Wildlife Refuge Independent Rangeland Review. Bitter Creek National Wildlife Refuge.

Germano, DJ, Rathburn GB, Saslaw LR. 2011. Effects of grazing and invasive grasses on desert vertebrates in California. J Wildlife Manage 76(4):670–82. https://doi.org/10.1002/jwmg.316

Green LR, Newell LA. 1982. Using goats to control brush regrowth on fuelbreaks. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station.

Keeley JE. 2005. Fire history of the San Francisco East Bay region and implications for landscape patterns. Int J Wildland Fire 14:285. https://doi.org/10.1071/WF05003

Kerby JD, Fuhlendorf SD, Engle DM. 2007. Landscape heterogeneity and fire behavior: Scale-dependent feedback between fire and grazing processes. Landscape Ecol 22:507–16. https://doi.org/10.1007/s10980-006-9039-5

Launchbaugh KL. 2016. Targeted grazing to manage wildland fuels and alter fire behaviour. In Proceedings: 10th International Rangeland Conference. Iwaasa A, Lardner HA, Schellenberg M, et al. (eds.). Saskatoon, SK. p 674–5.

Launchbaugh KL, Walker J. 2006. Targeted grazing — A new paradigm for livestock management. In *Targeted Grazing: A Natural Approach to Vegetation Management and Landscape Enhancement*. Launchbaugh KL, Walker J., Daines RL (eds.). Centennial, CO: American Sheep Industry Association.

Larsen R, Shapero M, Horney M, et al. 2020. Forage Production Report, California Central Coast, 2001–2019. University of California Agriculture and Natural Resources. http://cesanluisobispo.ucanr.edu/Custom_Program355/Forage_Production_Report/ (accessed August 2020).

Larsen RE, Shapero MWK, Striby K, et al. 2021. Forage quantity and quality dynamics due to weathering over the dry season on California annual rangelands. Rangeland Ecol Manag 76:150–6. https://doi.org/10.1016/j.rama.2021.02.010

Livingston AC, Varner JM. 2016. Fuel moisture differences in a mixed native and non-native grassland: Implications for fire regimes. Fire Ecol 12:73–87. https://doi.org/10.4996/fireecology.1201073

Macon DK, Barry S, Becchetti T, et al. 2016. Coping with drought on California rangelands. Rangelands 38(4):222–8. https://doi.org/10.1016/j.rala.2016.06.005

McBride J, Heady HF. 1968. Invasion of grassland by *Baccharis pilularis* DC. J Range Manage 21:106. https://doi.org/10.2307/3896366

Minnich RA. 1982. *Grazing, Fire, and the Management of Vegetation on Santa Catalina Island, California*. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture.

Nader G, Henkin Z, Smith E, et al. 2007. Planned herbivory in the management of wildfire fuels. Rangelands 29(5):18–24. https://ucanr.edu/sites/UCCE_LR/files/203022.pdf

Narvaez N. 2007. Prescribed herbivory to reduce fuel load in California chaparral. Doctoral dissertation, Department of Ecology, UC Davis.

[NRCS] National Resources Conservation Service. 2010. Unpublished data from the project Central Coast Rangeland Coalition Indicators of Sustainable Rangeland Stewardship.

Oles KM, Weixelman DA, Lile DF, et al. 2017. Riparian meadow response to modern conservation grazing management. Environ Manage 60:383–95. https://doi.org/10.1007/s00267-017-0897-1

Parker VT, Pratt RB, Keeley JE. 2016. Chaparral. In *Ecosystems of California—A Source Book*. Mooney H, Zavaleta E (eds.). Berkeley, CA: University of California Press. p 479–508.

[Rancho Mission Viejo] County of Orange, California Department of Fish and Game and U.S. Fish and Wildlife Service. 2006. *Rancho Mission Viejo Grazing Management Plan*. Appendix G in Southern Orange County HCP/MSAA/NCCP. p G1–G42.

Riensche DL. 2008. Effect of cattle grazing on lizard diversity in California grasslands. T W Sec Wil 44:4–10.

Russell WH, McBride JR. 2003. Landscape scale vegetation-type conversion and fire hazard in the San Francisco Bay Area open spaces. Landscape Urban Plan 64:201–8. https://doi.org/10.1016/S0169-2046(02)00233-5

Saitone TL. 2018. Livestock and rangeland in California. In *California Agriculture: Dimensions and Issues*. Martin PL, Goodhue RE, Wright BD (eds.). UC Berkeley: Giannini Foundation of Agricultural Economics. p 18.

Santa Clara County Parks. 2018. Santa Clara County Parks 2018 Strategic Plan.

Schmelzer L, Perryman B, Bruce B, et al. 2014. Case study: Reducing cheatgrass (*Bromus tectorum* L.) fuel loads using fall cattle grazing. Prof Anim Sci 30:270–8. https://doi.org/10.15232/S1080-7446(15)30112-1

Scott JH, Burgan RE. 2005. *Standard Fire Behavior Fuel Models: A Comprehensive Set for Use with Rothermel's Surface Fire Spread Model*. U.S. Department of Agriculture, Forest Service Rocky Mountain Research Station. General Technical Report RMRS-GTR-153.

Sparks JC, Masters RE, Engle DM, et al. 2007. Comparison of BEHAVE: Fire behavior prediction and fuel modeling system predictions with observed fire behavior varying by season and frequency. In Proceedings of the 23rd Tall Timbers Fire Ecology Conference: Fire in Grassland and Shrubland Ecosystems. Tallahassee, FL: Tall Timbers Research Station. p 170–80.

Stechman JV. 1983. Fire hazard reduction practices for annual-type grassland. Rangelands 5:56–8.

Sugihara N, Wagtendonk J, Fites-Kaufman K. 2006. Fire as an ecological process. In *Fire in California's Ecosystems*. Sugihara N, Wagtendonk J, Fites-Kaufman K, et al. (eds.). University of California Press. p 58–75.

Taylor CA. 2006. Targeted grazing to manage fire risk. In *Targeted Grazing: A Natural Approach to Vegetation Management and Landscape Enhancement*. Launchbaugh KL (ed.). Denver, CO: American Sheep Industry Association. p 107–14.

Tsiouvaras CN, Havlik NA. Bartolome JW. 1989. Effects of goats on understory vegetation and fire hazard. Forest Sci 35:1125–31.

[USDA] United States Department of Agriculture National Agriculture Statistics Service. 2017. 2017 Census of Agriculture. Washington, DC: USDA National Agriculture Statistics Service.

[USFS] United States Department of Agriculture Forest Service. 2022. Fire terminology. www.fs.fed.us/nwacfire/home/terminology.html (accessed June 14, 2022).

[USGS] United States Geological Survey Gap Analysis Project. 2016. GAP/LANDFIRE National Terrestrial Ecosystems 2011. https://doi.org/10.5066/F7Z-S2TM0

Van Soest PJ. 1994. *Nutritional Ecology of the Ruminant*. New York, NY: Comstock Publishing Associates, Cornell University Press.