Rangeland Ecology & Management 89 (2023) 87–93

Contents lists available at ScienceDirect

Rangeland Ecology & Management

journal homepage: www.elsevier.com/locate/rama

Using Virtual Fencing to Create Fuel Breaks in the Sagebrush Steppe☆

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A R T I C L E I N F O

Article history:
Received 4 January 2022
Revised 16 July 2022
Accepted 22 July 2022

Key Words:
Animal distribution
Cattle grazing
GPS collar
Precision agriculture
Wildfire

A B S T R A C T

Wildfires are increasingly impacting ecosystem processes and ecological services provided by sagebrush rangelands in the western United States. Mitigating this problem involves actions taken before, during, and after fire. In recent years, there has been increased emphasis on prefire fuel management, including fuel breaks. Cattle grazing can be used as a tool to manage fine fuel loading within fuel breaks; however, spatially focusing grazing impacts inside a linear fuel break is challenging. We evaluated using virtual fencing (VF) technology for concentrating grazing impacts inside a 200-m wide, 3-km long fuel break within a 410-ha pasture in sagebrush steppe. The fuel break was bounded by four 35-m wide virtual fences, each consisting of boundaries for auditory (10-m wide) and electrical cues (25-m wide), and a traditional 5-strand barbed wire perimeter fence delineated the pasture perimeter. In June 2021 we introduced 16 dry cows and 23 cow/calf pairs into the fuel break following a 5-d VF training period; cattle were removed after 30 d. Cows were fitted with VF collars (calves not collared) that use Global Positioning System positioning to contain cattle inside fuel break boundaries and record animal locations at 5-min intervals. End-of-trial forage utilization was 48.5% ± 3.7% and 5.5% ± 0.7% for areas inside and outside of the fuel break, respectively. Daily percentage of cattle locations inside the fuel break was initially $>$ 94% but declined to approximately 75% by the end of the trial. Percentage daily locations of dry cows and cow/calf pairs inside the fuel break was 98.5% ± 0.5% and 80.6% ± 1.1%, respectively ($P < 0.001$). Our data suggest virtual fencing can be a highly effective method of concentrating grazing to reduce herbaceous fuel biomass within linear fuel breaks. Efficacy of this method could be substantially impacted by use of dry versus cow/calf pairs.

Introduction

Wildfire is a primary disturbance of sagebrush ecosystems in the western United States and impacts a wide variety of ecological processes and ecosystem services (Davies et al. 2011). While these ecosystems have evolved with fire, the amount of fire on some sagebrush landscapes has increased dramatically in recent years (Coates et al. 2016; Crist et al., *this issue*). These alterations in fire regime are often associated with continued expansion of non-native annual grasses (Brooks 2004; Eiswerth et al. 2009). Invasive annual grasses act to increase the amount and continuity of fine fuels and desiccate earlier in the growing season compared with native perennial bunchgrasses (Brooks 2008). The net effect of these changes has been to increase probability of wildfire ignition and spread and allow for fire ignition earlier in the growing season (i.e., effectively extending the fire season; Davies and Nafus 2013; Crist et al., *this issue*).

Mitigating the effects of wildfire on sagebrush rangeland involves fuel management actions taken before, suppression efforts

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https://doi.org/10.1016/j.rama.2022.07.006
1550-7424/Published by Elsevier Inc. on behalf of The Society for Range Management.

during, and vegetation and soil rehabilitation after the fire. Success of rehabilitation efforts has been inconsistent in accordance with site and year abiotic conditions (Epanchin-Niell et al. 2009; James et al. 2011), despite large annual capital and logistical expenditures (Knutson et al. 2014). Conversely, the efficacy of wildfire suppression has increased in association with developing technologies and increased funding (Murphy et al. 2013; Maestas et al. 2016). Prefire fuels management activities on sagebrush rangelands have historically been funded at disproportionately lower levels compared with rehabilitation and suppression; however, recent and growing interest in preemptive fuel management has increased funding associated with these activities (NRCS 2016).

Prefire fuel management broadly involves alteration of fuel structure, composition, and/or amount in either spatially targeted locations or more generally across more expansive landscapes. Livestock grazing has been used effectively to reduce probability of fire ignition and spread at the pasture scale via reduced fine fuel biomass (Davies et al. 2010 and 2017; Orr et al. *this issue*), while more targeted fuel reduction efforts often focus on cutting or burning of shrub and tree fuels (Young et al. 2015). Recently there has been considerable effort to put in place a network of spatially targeted fuel breaks to help fire operations personnel to safely contain the spread of fire in large sagebrush landscapes (BLM 2020). The purpose of these fuel breaks is partly about creating fuel conditions that could potentially slow or halt the spread of a wildfire, but the predominant reason for fuel breaks is to create a "safe" space for fire operations personnel to stage and conduct fire-suppression activities. To maximize efficacy from a fire operations standpoint, such fuel breaks would be barren of any fuels; however, such conditions are rarely desirable on multiple-use rangeland due to overarching values associated with management of exotic species (e.g., annual grasses), wildlife habitat (e.g., greater sage-grouse), and outdoor recreation (e.g., hunting, hiking).

The operational reality is that most fuel breaks in the sagebrush steppe will contain some level of herbaceous and shrub fuels. While shrubs are a calorically dense fuel that contributes significantly to heat energy release during fire, the percentage of shrubs combusted during wildfire is a function of the amount and continuity of herbaceous fuels. Davies et al. (2015 and 2016) found that grazing reduced herbaceous fuels and fine fuel continuity, which was associated with decreased shrub combustion. The reduction in fine fuels and decreased combustion of shrub fuels resulted in reduced flame length and rate of fire spread. Therefore, managing herbaceous fuels using livestock grazing has potential as a tool to create new fuel breaks and as a tool to increase utility of existing fuel breaks by maintaining herbaceous fuels inside management-determined thresholds, which should reduce combustion of shrub fuels and associated heat energy release in a wildfire.

While grazing could help manage herbaceous fuels inside fuel breaks, containing grazing animals and focusing grazing impacts within fuel break boundaries presents a logistical challenge (Clark and Porter, 2022). Traditional fencing could be used for this purpose; however, this is an expensive and, on public rangeland, process-laden option (Boyd et al. 2022). Another emerging option for containing grazing animals within fuel breaks is the use of virtual fencing (VF) (Anderson 2007; Umstatter et al. 2011; Anderson et al. 2014; Campbell et al 2018, 2020; Boyd et al. 2022). VF uses Global Positioning System (GPS) collars that emit auditory and electrical cues when animals approach user-defined virtual boundaries. In the current case study, we evaluated the efficacy of VF to contain animal distribution and forage utilization inside the boundaries of a desired fuel break in sagebrush steppe habitat in southeastern Oregon. We also tested the effectiveness of VF in containing dry cows versus cow/calf pairs inside desired fuel break virtual boundaries and predicted that containment would be less efficacious for cow/calf pairs because of cows following their non-collared calves outside virtual fence boundaries.

Materials and methods

Study area

We conducted this study within a perimeter-fenced 410 ha pasture at the Northern Great Basin Experimental Range, located approximately 55 km west of Burns, Oregon (43.48 N, 119.72 W). Pasture elevations ranged from 1 390 to 1 450 m and average slope from flat to 4%. Plant communities inside the pasture were dominated by Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis* Welsch). Common understory herbaceous species included needlegrass (*Achnatherum* sp. P. Beauv.), bluebunch wheatgrass (*Pseudoroegneria spicata* [Pursh] A. Love), bottlebrush squirreltail (*Elymus elymoides* [Raf.] Swezey), Idaho fescue (*Festuca idahoensis* Elmer), and Sandberg's bluegrass (*Poa secunda* J. Presl). The non-native annual cheatgrass (*Bromus tectorum* L.) was also present in limited amounts within the pasture. Most precipitation occurs as rain or snow during the October–March period, and crop year inputs (September–June) average 25.7 cm (data file, Eastern Oregon Agricultural Research Center, Burns, Oregon).

Fuel break design and data collection

All animal care and management used in this study were evaluated and approved by the Oregon State University Institutional Animal Care and Use Committee (IACUC 2021-0189). We used VF to create boundaries for a 200-m wide, 3-km long fuel break that traversed the entirety of the study pasture from southwest to northeast (Fig. 1). This was a new, not existing, fuel break. The area occupied by the fuel break was 62 ha. The fuel break itself was bisected on its long axis by a nonpaved pasture road. Three equally spaced polyethylene stock tanks were placed inside the fuel break, next to the road, and filled as needed throughout the trial period. Cattle were placed into the experimental pasture on June 21, 2021 and remained there until July 20 (i.e., 30-d trial period). We used 16 mature angus dry cows and 23 angus cow/calf pairs; calves were approximately 4 mo old at trial initiation.

Virtual fence system

We used a VF system designed and manufactured by Vence Corp (San Diego, CA). The user interfaces with the system through a solar or AC-powered base station via cellular link using the HerdManager software platform. The base station then uses a VHF radio signal to communicate desired coordinates of virtual boundaries and other information to a GPS collar worn by the animal. The collar is powered with a lithium battery and monitors animal location at user-determined intervals. Collars have a speaker for auditory cues and two metal electrical contacts spaced 5 cm apart that press against the animals' neck. The collar is adjusted to fit individual animals and uses a weight ballast to keep the electrical nodes in contact with only one side of an animal's neck; thus, in theory, when the animal receives an electrical stimulus, it turns away from that stimulus, causing the animal to alter its path of travel away from the virtual boundary. Collars were programmed to first deliver an auditory cue to an animal as it approached a virtual boundary (i.e., "auditory boundary"), followed by a mild electrical stimulus if the animal continued its direction of travel (i.e., "electrical stimulus boundary"). The spatial locations of both the auditory and electrical stimulus boundaries are user determined. When an animal crosses an auditory boundary, it hears a 0.5-sec electronic tone followed by a 1.5-sec pause. This pattern repeats until the animal exits the auditory area. When an animal crosses

Figure 1. Diagram of 410-ha study pasture used in a 30-d virtual fencing trial in southeast Oregon. Green lines depict pasture boundaries defined by traditional wire fences. Animals were placed in the "fuel break zone" on trial d 1. The fuel break zone was bounded by a series of four virtual fences within the "pressure zone," each fence consisting of a 10-m wide auditory stimulus band (white in graphic) and a 25-m wide electrical stimulus band (red in graphic). If an animal left the fuel break zone, as it crossed successive virtual fences, the previous virtual fence would turn off, allowing the animal to return to the fuel break zone without receiving additional stimulus. If an animal crossed virtual fences while returning to the fuel break zone, those fences would turn back on as they were crossed (i.e., when the animal returned to the fuel break, all fences would again be on).

an electrical stimulus boundary, it receives a 0.5-sec shock (800V) followed by a 1-sec sound stimulus and then a 3.5-sec pause. This level of electrical stimulus is comparable with that delivered by a single-wire electric fence (personal communication, Todd Parker, Vence Corp.). If the animal remains in the electrical stimulus area, this pattern repeats up to 20 times, after which the animal receives no auditory or electrical stimulus for a period of 3 min. If the animal still remains in the electrical stimulus area for $>$ 4 cycles, the collar is disabled and all cues will cease unless the collar is remotely reactivated by a person using the HerdManager software. In the current trial we checked daily for collars that had been deactivated and reactivated them as needed. Animal location data are transmitted from the collar to the base station and from the base station to cloud-based storage within HerdManager.

Management zones

For the fuel break trial, zones for management of cattle distribution included a fuel break zone, pressure zone, and "outside" of the fuel break/pressure zone (i.e., in the larger pasture; see Fig. 1). The pressure zone included a 10-m wide auditory boundary, which began at the edge of the fuel break zone, and an electrical stimulus boundary that extended a further 25 m outward from the fuel break boundary (see Fig. 1). Since our trial included uncollared calves that had not yet been weaned, we expected that calves leaving the virtual-fenced fuel break would create additional challenges for containing mother cows inside the 200-m wide fuel break zone. To mitigate this challenge, we used a series of three virtual secondary fences within the pressure zone to provide additional containment. These secondary fences extended outward from the virtual boundary described earlier and included the same auditory and electrical stimulus widths (see Fig. 1). Secondary fences decreased the likelihood of cows escaping into the outside zone by increasing the number of virtual boundaries. When an animal crosses the initial auditory and electrical stimulus virtual boundaries, it encounters the subsequent boundary (i.e., a secondary fence). At that point collars were programmed to turn off the previous virtual boundary, allowing the animal to return to the fuel break zone without receiving additional stimulus. When an animal recrosses a virtual boundary (e.g., returns to the fuel break zone), that boundary is activated again. These virtual boundaries existed as programming within individual collars, so the activity of one cow with respect to boundaries turning on and off did not affect the virtual boundary status of other cows/collars. Including secondary fences, the total width of the pressure zone extended 140 m outward from the fuel break zone (see Fig. 1).

Virtual fence training

One week before trial initiation, we "trained" 39 mature cows (calves were present in the training pen but not collared) to be used in the study with Vence virtual fence collars. For purposes of training, we placed cattle that had been previously fitted with Vence collars in a rectangular 90×120 m pen with a stock tank at the Northern Great Basin Experimental Range for 6 d. The pen was perimeter fenced with 2-m high wooden fencing. We designed two conterminous sides of the pen as virtual boundaries. For d 1–3 of training, the virtual boundaries were defined by an electrical stimulus boundary that extended 5 m inward from the perimeter fence, and the electrical stimulus boundary was bordered by an auditory stimulus boundary that extended inward for 5 m from the edge of the electrical stimulus boundary. For d 4–6 of training we expanded the width of the auditory boundary inward an additional 10 m. Immediately after training, "trained" cows were herded into the southwest entrance of the fuel break. Collars were set to record and transmit animal locations at 5-min intervals.

Forage utilization

At the conclusion of the trial, we used the Landscape Appearance Method (USDA-USDI 1999; Jansen et al. 2021) to determine utilization patterns in the entire 410-ha pasture. We sampled 179 equally spaced points across the pasture (150-m buffer between points and pasture boundary). A single observer experienced with the technique visually characterized utilization of perennial grasses in a 2-m radius as falling into one of six utilization categories: 1) no use, 2) slight use (1–20%), 3) light use (21–40%, 4) moderate use (41–60%), 5) heavy use (61–80%), or 6) severe use (81–100%). Midpoint utilization values were averaged within zone. Immediately

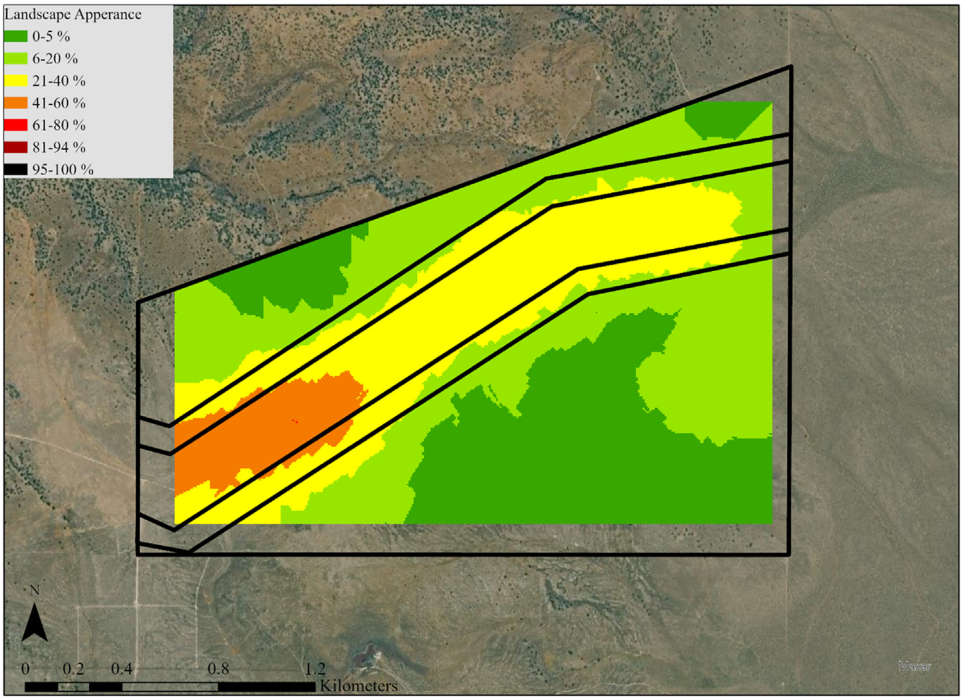

Figure 2. Utilizations patterns based on Kriging analysis using the Landscape Appearance method in the 410-ha study pasture used in a 30-d virtual fencing trial in southeast Oregon.

after collection of utilization data, standing crop data were collected at 170 randomized points by clipping all herbaceous plants in 1-m^2 quadrats. We used 50 points in the fuel break zone, 50 points in the pressure zone, and 70 points in the outside zone, and a 100-m buffer was set between points. Samples were oven-dried at 60°C for 72 h before weighing.

Data analysis

Initial processing of location data was done in ArcGIS (ESRI 2020) and Rstudio v 3.6.3 (RCore Team 2019) with the tidyverse package (Wickham et al. 2019), and statistical analyses were performed in SAS v 9.4 (SAS Institute Inc., Cary, NC). Total number of cattle locations received from all the collars combined was 303 860 spatial data points. Proportions of locations in the fuel break, pressure, and outside zones were calculated for each collared animal by averaging 5-min location readings by day for all animals, dry cows, and cow/calf pairs. The effect of lactation status (i.e., dry cows vs. cow/calf pairs) on daily proportion of locations in the fuel break zone was modeled using repeated measures analysis of variance (Proc Mixed) with trial day as the repeated factor and cow and cow · lactation status as random effects. Values for post-trial utilization were grouped into utilization ranges on a pasture-wide basis using Kriging analysis in ARC GIS (ESRI 2020). Location (i.e., fuel break, pressure, and outside zones) effects on post-trial utilization and standing crop values were determined using analysis of variance followed by mean separations using the LS Means procedure in SAS. All means are reported with their associated standard errors, and effects were considered to be significant at $P \leq 0.05$.

Results

Post-trial utilization and post-trial standing crop of herbaceous forage differed by location ($P < 0.001$), and all locations differed from each other ($0.001 < P < 0.027$). Post-trial utilization averaged 48.5% ± 3.7%, 11.8% ± 3.0%, and 5.5% ± 0.7% for fuel break, pressure, and outside zones, respectively (Fig. 2). Post-trial standing crop for the fuel break, pressure, and outside zones was 405.9 ± 21.0, 533.3 ± 23.9, and 697.4 ± 40.2. kg/ha, respectively. Average number of daily shocks per cow was 2.3 ± 0.6 for dry cows and 10.1 ± 2.4 for pairs. Proportions of daily cattle locations in the fuel break, pressure, and outside zones are presented in Figure 3. Across all cattle, proportion of daily locations in fuel break, pressure, and outside zones averaged 0.87 ± 0.01, 0.05 ± 0.03, and 0.07 ± 0.06, respectively, with locations in the fuel break generally decreasing over time. Dry cows averaged 0.98 ± 0.005, 0.006 ± 0.002, and 0.009 ± 0.004, whereas cows with calves averaged 0.81 ± 0.010, 0.07 ± 0.005, and 0.12 ± 0.009 for proportion of daily locations in the fuel break, pressure, and outside zones, respectively. The proportion of daily locations in the fuel break ($P < 0.001$) and pressure zones ($P = 0.003$) differed between dry cows and cows with calves. Dry cows showed no discernable pattern in daily locations in the fuel break over time, whereas values for cows with calves decreased over the duration of the trial and had nearly equal odds of being located within or not within the fuel break by the last day of the trial.

Discussion

Fuel breaks are an important tool for managing the spread of wildfire in large rangeland landscapes of the western United States, and that importance is growing, given the increasing presence of wildfire in these landscapes (BLM 2020). Cattle grazing represents an efficient use of an existing resource for fuel manipulation and is perhaps the only tool that can realistically be deployed at spatial scales large enough to manage herbaceous fuels within fuel breaks (Clark and Porter, *this issue*). Our work suggests that VF technology can be effective in confining grazing distribution to inside rangeland fuel break boundaries, resulting in significantly reduced herbaceous fuel biomass within the fuel break. We found that virtually fenced cattle grazing resulted in a 42% reduction in standing fine fuel biomass and nearly 50% utilization as compared

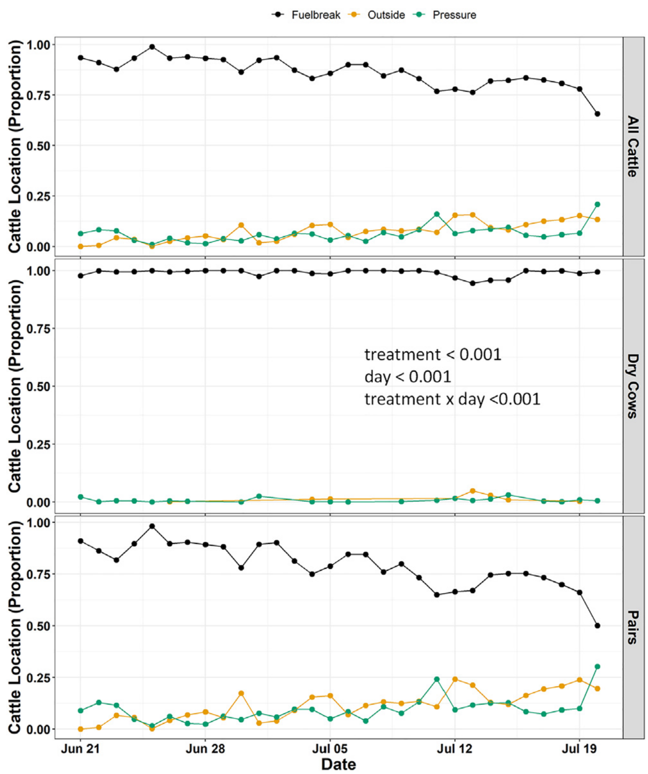

Figure 3. Proportion of daily cattle locations in fuel break, pressure, and outside zones (see Fig. 1) for cattle used in a 30-d virtual fencing trial in southeast Oregon. Top panel depicts results for all cattle, and middle and bottom panels depict results for dry cattle and cows with calves (i.e., "Pairs"), respectively. *P* values in middle panel reflect comparisons of proportion of daily locations in the fuel break zone by treatment (i.e., dry cattle vs. pairs).

with approximately 5% utilization in the larger pasture. Maintaining fuel conditions inside fuel breaks is important because the purpose of a fuel break is to create conditions that decrease extreme fire behavior but also safe areas for deployment of people and equipment needed fight an approaching wildfire (NRCS 2016; BLM 2020). Previous work (Davies et al. 2016) indicated that grazing-induced herbaceous fuel reductions of the magnitude we observed decreased fire behavior (i.e., area burned, rate of spread, flame depth, and flame height) in sagebrush-bunchgrass plant communities with similar fuel structure and amount to that in the current study.

Our findings agree with a small but growing body of evidence indicating efficacy of VF for a variety of livestock management applications. Campbell et al. (2018) reported strong efficacy of virtual fences for excluding cattle from riparian areas, and Boyd et al. (2022) found that virtual fences effectively excluded cattle from burned sagebrush steppe rangeland. Campbell et al. (2020) reported nearly 100% effectiveness in excluding cattle from sites where ongoing restoration was taking place, and Lomax (2019) effectively used virtual fences to control and alter grazing distribution of pastured dairy cattle. We also found that by the end of a 30-d trial period, the effectiveness of the technology for confining cows with calves was only about half that realized for dry cows. This result suggests that 1) reproductive status of animals should be an important management consideration when deploying virtual fence technology as described in the current write-up, and 2) improvements in the operational protocol (e.g., improved secondary fence design or variable volume, frequency, or cadence of audio cues relative to proximity to a VF boundary) could increase utility of virtual fences for cows with calves.

Our use of both dry cows and cow/calf pairs may have provided behavioral incentive for the former to leave the fuel break, due to the increased propensity of the latter to do so, particularly in the final days of the trial. Others (e.g., Keshavarzi et al. 2020) have noted that social interactions can be a powerful determinant of cattle grazing behavior. That said, those behavioral patterns were not realized in the current study (i.e., containment of dry cows inside the fuel break was nearly 100% for the duration of the trial), even as forage supply inside the fuel break declined by nearly 50% and utilization patterns (see Fig. 2) and location data (Fig. 3) suggested that cows with calves were using forage outside of the fuel break with increasing frequency. This suggests that the aversive stimuli of the virtual fence boundary were a more powerful determinant of behavior for dry cows than social cues associated with cows with calves leaving the fuel break. Additionally, our use of a 200-m wide virtual fence inclusion polygon provided a rigorous test of containment capabilities of the virtual fence system relative to a wider fuel break. As fuel break width increases, edge-to-interior ratio decreases, reducing animal interactions with perimeter VF surrounding the fuel break. Nonetheless, our fuel break width was within that recommended for the fuel composition and height present in the study pasture (BLM 2020).

Water location is an important consideration in designing grazed fuel breaks as it serves as a central attractant that plays an important role in determining livestock distribution (Ganskopp 2001). In the current study, animals that crossed the virtual fence boundaries had to return to the fuel break to access water. As described earlier (see Methods and Materials), when animals outside of virtual fence containment "recrossed" virtual fence boundaries on their way to water, those fences were reactivated and would again provide auditory and electrical stimuli to help keep the animal inside fuel break boundaries. Water attractants may be particularly valuable in helping to contain animal distribution when the virtual fence boundary is not defined by clear visual association. In the current work there were no planned or naturally obvious visual associations to define the virtual boundaries of the fuel break. In order for virtual fencing to be effective in controlling animal distribution, grazing animals must be able to perceive virtual fence boundaries as predictable and controllable and visual cues may help foster that learning process (Lee et al. 2018). For example, Boyd et al. (2022) effectively used VF to exclude cattle from a recently burned area and the auditory and electrical stimulus boundaries began at the edge of the burn. In that case the burn itself provided visual cues (e.g., vegetation height and darkened soils) that may have helped the animals to delineate virtual fence boundaries. Similarly, effectiveness of VF in excluding cattle from riparian areas (e.g., see Campbell et al. 2018) may be aided by visual differences between upland and riparian habitats. In contrast, the permanency of visual cue associations with VF cues is unclear and it is possible that visual cues could hinder grazing systems with dynamic virtual fence boundaries (McSweeney et al. 2020). In addition to water, protein supplement stations can also be employed as an attractant to cattle being used to manage herbaceous fuels inside fuel breaks (see Stephenson et al., *this issue*) and could help increase the effectiveness of virtual fencing.

Management implications

Virtual fences are a spatially and temporally opportunistic system of influencing cattle distribution to manage fine fuels inside fuel break boundaries. This is an important advantage over traditional permanent fencing because the need for fuel breaks will change in both space (e.g., spatially dynamic resource values or conditions) and time (e.g., years of low fuel accumulation/low fire probability). VF allows managers to accommodate those changing conditions without investing in permanent infrastructure. Traditional fences can also have negative impacts on wildlife species such as pronghorn (Taylor et al. 2016) and greater sage-grouse (Van Lanen et al. 2017), whereas virtual fences do not. While not tested in the current study, others have found that cattle quickly learn to respect new boundaries and disregard previous virtual fence boundaries as virtual fences are activated and deactivated (Campbell et al. 2017, 2018; Ranches et al. 2021). Also of management interest, using the landscape appearance method, the difference in utilization between fuel break and outside locations was 43 percentage points, whereas standing crop estimates were 42% higher outside of the virtual fence compared with fuel break locations. Thus, comparing our estimates of utilization using the landscape appearance method with standing crop data indicates these methods produced nearly identical results in terms of estimating biomass reduction with grazing.

A limitation of the current work is that our experiment was designed as a case study, which limits our ability to draw generalizable conclusions about the efficacy of cattle grazing in virtually fenced fuel breaks. That said, our work demonstrates that it is possible to use VF to confine cattle within multidimensional inclusion polygons in large rangeland landscapes, whereas most previous work has focused on one-dimensional exclusion of animals from an area where grazing was not desired (e.g., Campbell et al. 2018; Boyd et al 2022). When paired with emerging technologies for predicting fine fuel biomass (e.g., Rangeland Analysis Platform, 2021) and empirically derived models for linking the spatial distribution of fine fuels and fire probabilities (see Smith et al., *this issue*), designed grazing with VF has the potential to create "fuelscapes" that are consistent with decreasing fire probabilities and increasing rangeland plant community resilience to the benefit of a wide variety of management expectations and values.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The authors wish to thank Andrew Olsen for reviews of an earlier draft of this manuscript.

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