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Prescribed fire effects on resource selection by cattle in mesic sagebrush steppe. Part 1: Spring grazing☆

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ABSTRACT

Prescribed fire is commonly applied world-wide as a tool for enhancing habitats and altering resource-selection patterns of grazing animals. A scientific basis for this practice has been established in some ecosystems but its efficacy has not been rigorously evaluated on mesic sagebrush steppe. Beginning in 2003, resource-selection patterns of beef cows were investigated using global positioning system (GPS) collars for 2 years before and for 5 years after a fall prescribed burn was applied to mesic sagebrush steppe in the Owyhee Mountains of southwestern Idaho, USA. Resource-selection functions (RSF) developed from these data indicated cattle selected for lightly to moderately burned areas for all 5 postfire years. Cattle had been neutral towards these areas prior to the fire when their distribution was primarily affected by slope, sagebrush dominance, and distance to upland water. Resource-selection responses to the fire lasted 2–3 years longer than would be expected for fire-induced, forage-quality improvement effects. Although this is a case study and caution should be taken in extrapolating these results, if applied under conditions similar to this study, livestock producers and natural resource managers can likely use fall prescribed fire in the mesic sagebrush steppe to affect cattle resource-use patterns for 5 years postfire.

1. Introduction

Prescribed fire is commonly applied to rangelands throughout the world as a tool for enhancing habitats and managing resource-selection patterns of grazing animals (Butz, 2009; Pyne, 1995; Wikeem and Strang, 1983). A scientific basis for this management practice has been established in montane grasslands, tall grass prairie, mixed prairie, shortgrass prairie, shrub steppe, and savanna (Augustine et al., 2010; Bates et al., 2009; Hobbs and Spowart, 1984; Klop et al., 2007; Peek et al., 1979; Vermeire et al., 2004). The sagebrush-steppe ecosystem occupies about 44.4 million ha in western North America. Higher elevation, mesic communities, dominated by mountain big sagebrush (*Artemisia tridentata* Nutt. ssp. *vaseyanna* Beetle) and/or antelope bitterbrush (*Purshia tridentata* [Pursh] DC), form a substantial proportion of the sagebrush steppe and serve as principal livestock grazing areas. Despite their prominence, use of prescribed fire for managing resource selection by livestock has never been rigorously evaluated on mesic sagebrush steppe rangelands.

Fire has always played an important ecological role, promoting heterogeneity on mesic sagebrush steppe rangelands. Prior to settlement, natural ignitions temporally converted areas of sagebrush-grassland to perennial grassland. Fire-killed sagebrush and bitterbrush eventually regrew, principally from seed, and returned the landscape back to sagebrush-grassland (Lesica et al., 2007). Fire also killed fire-sensitive, tree species like western juniper (*Juniperus occidentalis* Hook.) which tend to encroach into mesic sagebrush steppe (Miller and Rose, 1999).

Modern introductions of highly-flammable, exotic invasive plants like cheatgrass (*Bromus tectorum* L.) and medusa head (*Taeniatherum caput-medusae* [L.] Nevski) have increased fire frequencies in some areas and raised concerns about the modern role

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of fire in the sagebrush steppe (Whisenant, 1989; D'Antonio and Vitousek, 1992; Brooks et al., 2004; Pierson et al., 2011). However, while fire in the lower-elevation, more arid portions of the sagebrush steppe (e.g., Wyoming big sagebrush [*A. tridentata* Nutt. ssp. *wyomingensis* Beetle]-dominated communities) may cause severe degradation by converting sagebrush-grasslands into annual grasslands dominated by cheatgrass, type conversions of this nature are not inevitable (Davies et al., 2008) and are much less likely in the mesic sagebrush steppe where cheatgrass is less competitive with native perennial grasses (Chambers et al., 2007). In fact, within mesic sagebrush steppe, the concern is often about a modern lack of fire rather too much fire. Fire suppression or exclusion can lead to overmature, dense, excessively woody stands of mountain big sagebrush and antelope bitterbrush. Lack of fire can also promote encroachment of western juniper eventually resulting in a type conversion from sagebrush-grasslands to dense woodlands (Miller and Rose, 1999). Trees and shrubs can outcompete herbaceous plants for light, moisture, and soil nutrients (Wrobleski and Kauffman, 2003). Consequently, progression towards dense, overmature shrub stands or juniper woodlands can dramatically reduce the vigor, productivity, and availability of forage plant species important to rangeland livestock and wildlife (e.g., mule deer [*Odocoileus hemionus* Rafinesque]) (Miller et al., 2000). Prescribed fire is increasingly being applied by nature resource managers, to overmature stands of sagebrush or sagebrush stands suffering from tree encroachment, to carefully restart a fire cycle previously stalled by fire suppression. The intended purposes of these prescribed fires are often manifold but commonly fire is applied to improve livestock distribution.

Many factors affect livestock behavior and consequent resource-selection patterns (Bailey et al., 1996; Senft et al., 1987). Vegetation composition, cover, and forage characteristics affect use patterns of grazing animals (Bailey, 1995; Ganskopp and Bohnert, 2009; Ganskopp et al., 1992; Gillen et al., 1984; Howery et al., 1996). Water and mineral sources, topography, weather, and site microclimate also affect choice of foraging and resting areas, distance traveled between these focus areas, and time spent in them (Bailey, 1995; Bailey, 2005; Bailey et al., 2008; Cook, 1966; Howery et al., 1998; Loza et al., 1992; Mueggler, 1965; Senft et al., 1985). To be effective, livestock management treatments, including prescribed fire, must account for or work in concert with the most dominant of these environmental factors.

The intent of this research project was to evaluate spatial and temporal effects of prescribed fire on resource selection, activity budgets, and movement path characteristics of beef cattle in mesic sagebrush steppe rangelands. Two studies were carried out where, the first evaluated these cattle behavioral responses during spring (early May) just prior to peak forage production and, the second was conducted mid-summer (July) as forage plants began to senesce. The present paper presents findings from the first study. Two additional papers in this series present the findings from the mid-summer study and the results from cattle activity budget and movement path evaluations of both studies. Specific objectives of the spring grazing study were to: 1) model the resource-selection responses of cattle to prescribed fire and environmental factors; and 2) evaluate the efficacy of upland prescribed fire application for managing cattle distribution.

2. Methods

2.1. Study area

The study was conducted at the Whiskey Hill study area (324 ha), a fenced rangeland pasture within the Reynolds Creek Experimental Watershed (43° 9′ 49″ N, 116° 47′ 51″ W) located 80 km south of Boise in southwestern Idaho (Fig. 1). Climate is continental with maritime influences. Winters are cold and wet. Long-term (1962–2009) mean annual precipitation at the Whiskey Hill gauges (095 and 095b) was 453 mm (NWRC, 2010) with roughly 34% occurring as snow (Hanson, 2001). Annual precipitation during the study varied from a low of 186 mm in 2003 to a high of 600 mm in 2005 with amounts for all other study years being 8–67 mm less than the long-term mean. Summers are warm and dry. The growing season is about 100 days but frost can occur during any month of the year. Long-term (1967–2010) mean daily maximum, minimum and mean air temperatures at the nearby Lower Sheep Creek weather station (127 × 07) were 12.7, 3.8, and 8.3 °C, respectively (Hanson et al., 2001; NWRC, 2010). Mean daily air temperature varied during the study from a low of 8.6 °C in 2005, 2008, and 2009; 8.8 °C in 2004 and 2006; 9.4 °C in 2003, and to a high of 9.6 °C in 2007. Note that mean daily air temperatures for all study years were above the long-term mean.

Topography of the study area is a ridge with west and east-facing hillslopes and topped by granite outcrops. Elevation ranges from 1523 to 1878 m. Slope ranges from flat to very steep (177% or 60.5° maximum) with aspects in all four cardinal directions well represented. Soils are primarily derived from granitic parent materials and composed of a complex of Takeuchi (coarse, loamy, mixed, frigid Typic Haploxerolls) and Kanlee (fine, loamy, mixed, frigid Typic Argixerolls) soil series.

Three vegetation cover types; including mountain big sagebrush – mountain snowberry (*Symphoricarpos oreophilus* A. Gray), antelope bitterbrush – mountain big sagebrush, and native

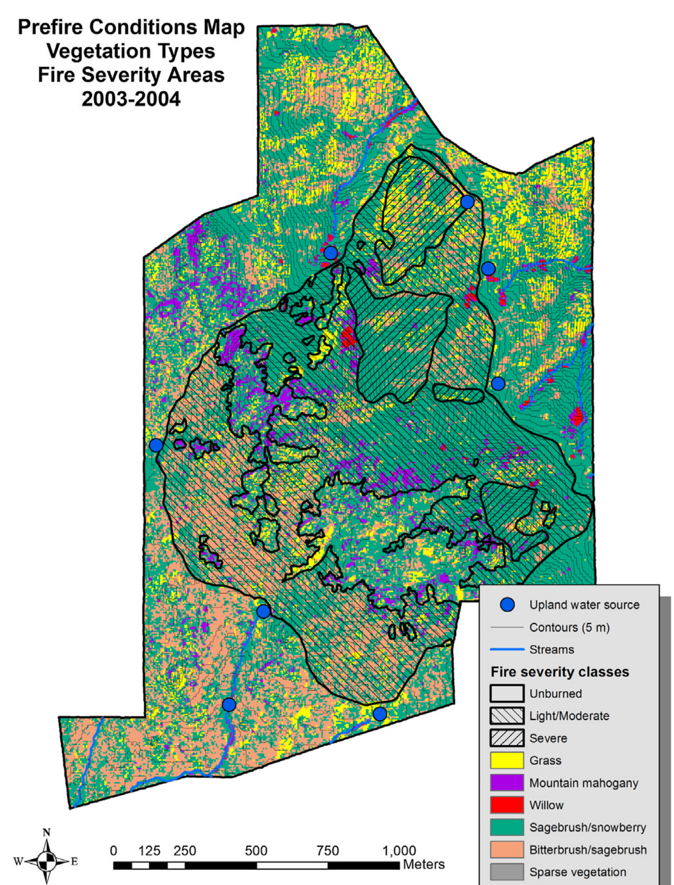

Fig. 1. Map illustrating the dominant prefire vegetation types and areas that later received different fire severity levels at the Whiskey Hill prescribed fire study area (324 ha) in the Owyhee Mountains of southwestern Idaho.

bunchgrass types, dominate the study area as they do in the mid-elevation portions of the sagebrush steppe throughout much of the Intermountain West (Fig. 1). Besides the 2 dominant species, the mountain big sagebrush-mountain snowberry type includes western juniper, yellow rabbitbrush (*Chrysothamnus viscidiflorus* [Hook.] Nutt.), Saskatoon serviceberry (*Amelanchier alnifolia* [Nutt.] Nutt. ex M. Roem. *alnifolia*), bluebunch wheatgrass (*Pseudoroegneria spicata* [Pursh] A. Love), Sandberg bluegrass (*Poa secunda* J. Presl.), squirreltail (*Elymus elymoides* [Raf.] Swezey), Idaho fescue (*Festuca idahoensis* Elmer), basin wildrye (*Leymus cinereus* [Scribn. & Merr.] A. Love), mountain brome (*Bromus marginatus* Nees ex Steud.), tapertip hawksbeard (*Crepis acuminata* Nutt.) and western aster (*Symphyotrichum ascendens* [Lindl.] Nesom). Other components of the antelope bitterbrush-mountain big sagebrush type include western juniper, native bunchgrasses, and biscuitroots (*Lomatium* spp. Raf.). Bluebunch wheatgrass, Sandberg bluegrass, squirreltail, Idaho fescue, and needlegrasses (*Achnatherum* spp. Beauv.) dominate the native bunchgrass cover type. Cheatgrass has a minor to common presence in all three of these dominant vegetation types. A curl-leaf mountain mahogany (*Cercocarpus ledifolius* Nutt.) woodland with very sparse understory occurs as a fourth, less common vegetation type and is primarily confined to the granite outcrops on ridge crowns and adjacent slopes. When contrasted with the other 2 shrub-dominated cover types described above, the mountain big sagebrush-mountain snowberry type generally had the most herbaceous cover, both in the interspaces and under the shrub canopy (Clark unpublished data).

Cattle had access to headwaters of one perennial stream, Succor Creek, and two intermittent streams, Hamilton Gulch and Gardner Gulch, while in the study area. The riparian zones of these streams were dominated by herbs including sedges (*Carex* spp.), rushes (*Juncus* spp.), and Kentucky bluegrass (*Poa pratensis* L.) with occasional stands of peachleaf willow (*Salix amygdaloides* Andersson) and rose (*Rosa woodsii* Lindl.) (Fig. 1). Small, seasonally moist meadows typically less than 0.25 ha in size and dominated by Kentucky bluegrass and rushes (*Juncus* spp.) where located on stream terraces and in upland swales. These meadows were generally located at lower elevations within the study area and at substantial distances from upland water sources.

2.2. Fire treatment

About 131 ha of the central portion of the study area were burned during the Whiskey Hill prescribed fire conducted on 27 September 2004. The purpose of this fire was to reduce brush cover, enhance availability of herbaceous forages, and kill as many encroaching western juniper trees as possible without adversely impacting ecosystem health. The fire produced a mosaic of lightly to moderately burned areas (108 ha), severely burned areas (23 ha), and unburned areas (33 ha) within the burn perimeter (Fig. 1). Unburned areas represented 59.6% of the total pasture area, light/moderate fire severity 33.3%, and high fire severity 7.1%. Highest burn severity occurred where the fire made head runs upslope in dense stands of the mountain big sagebrush-mountain snowberry vegetation type. Unburned areas within the burn perimeter occurred primarily on ridge tops dominated by granite outcrop and mountain mahogany with sparse understory. Fire-severity polygons for lightly-to-moderately burned, severely-burned, and unburned areas were acquired using a dual-channel GPS unit (Trimble Pro XRS, Trimble Navigation, Inc., Sunnyvale, California) immediately after the prescribed fire. These GPS data were post-differential corrected to an expected accuracy of ± 0.85 m (95% CEP). Generally, in all burned areas, existing mountain big sagebrush and bitterbrush were killed or greatly suppressed by the fire. Burned areas recovered fairly quickly with perennial forbs increasing cover in formerly shrub-dominated areas during the first year postfire followed by a large increase in perennial grasses in the same areas during the second year postfire (Clark unpublished data). The resultant postfire landscape was a perennial grassland with inclusions of unburned shrubs and trees.

2.3. Cattle GPS tracking

During each of the 7 study years, 10 lactating, mature beef cows were randomly selected from a larger, total ranch population of about 800 cows. Starting in early May of 2003, the 10 selected cows of the year were fitted with GPS tracking collars (model 2200 LR: Lotek Wireless, Inc., New Market, Ontario, Canada; and Clark ATS + GPS collars [Clark et al., 2006]) programmed to collect and store GPS locations every 10 min. These collared cows were then grazed with their suckling calves and 2 uncollared bulls for 15 days within the fenced, 324-ha study area. A second, 15-day prefire grazing trial was conducted with a new random sample of 10 collared cows, their suckling calves, and 2 uncollared bulls during early May 2004. Postfire grazing trials were conducted in early May of 2005, 2006, 2007, 2008, and 2009. New, randomly-selected cows were used in each of the post-fire years. The start date of each trial was based on the phenology of the dominant grasses and thus varied ± 9 days across the 7 years. Trials generally occurred during the period when bluebunch wheatgrass was in the boot to inflorescence emergence stages. Assuming a mean cow body weight of 544 kg (i.e., 1.15 metabolic AUEs each with calf) and each bull represented 1.5 metabolic AUEs, the stocking rate in the pasture was about 0.045 AUEs ha^{-1} or 44.7 ha AUM^{-1} each trial. Typically, this would be viewed as a very light stocking rate for mesic sagebrush steppe rangelands. Our intent with this research, however, was to provide both private and public land managers with information on cattle resource-selection responses to prescribed fire. While private lands are often grazed during the first 2 years following a prescribed fire, resource managers on federal agency lands in the US typically follow a guideline of excluding livestock grazing entirely from burned pastures for at least 2 years postfire. This postfire grazing-rest guideline is intended to allow burned vegetation to recover vigor before being grazed. These guidelines are just that, guidelines not strict rules or laws, and they still await rigorous scientific evaluation on mesic sagebrush steppe and many other rangeland types. Consequently, our intent here was to use a conservative stocking rate (i.e., a very light rate) that a public lands resource manager would likely use during the first 2 postfire years if he/she chose not to strictly follow the agency postfire-rest guideline. In addition, rather than vary the stocking rate, with higher stocking during prefire than postfire, as would likely be done in a management setting, we chose to hold stocking rate steady throughout the study duration in an attempt to avoid confounding stocking rate effects with those of the prescribed fire treatment.

The number of cows successfully tracked and the number of viable locations per collar varied among years due to equipment failures and malfunctions (Table 1). Collar datasets were cropped to within the fence boundary and systematically screened for location errors using travel velocity (<74 kph) and dilution of precision (DOP < 6) thresholds. This post processing yielded an expected spatial accuracy for all viable GPS locations of ± 3.3 m, based on comparisons to a stationary reference collar installed over a known point.

Collared cows in this study, based on the GPS tracking data, behaved primarily as independent individuals but did occasionally associate into groups. Although complete behavioral independence among collared cows was not necessary for our RSF analyses, which were conducted using pooled data (see below), confirmation of a high level of independence was still important. An association

Table 1
Experimental units (collared cows) and GPS location sample sizes for each year of grazing trials conducted before and after application of a prescribed fire treatment on a mesic sagebrush steppe rangeland in the Owyhee Mountains of southwestern Idaho.

Year	Cows	Locations		
		Total	Maximum[a]	Minimum[b]
2003	10	21,815	2206	2168
2004	10	20,506	2081	1855
2005	10	20,861	2222	1594
2006	6	13,389	2241	2213
2007	3	6531	2294	1952
2008	4	7423	1871	1835
2009	8	16,627	2098	2026

[a] Maximum number of GPS locations cow^{-1} for the corresponding trial year.
[b] Minimum number of GPS locations cow^{-1} for the corresponding trial year.

analysis was conducted for each study year using the ASSOC1 software program (Weber et al., 2001). These analyses confirmed collared cattle spent at least 75% of their time separated from each other by more than 75 m during all study years. Given the relative sizes of the study area and our RSF sampling units or plots (100-m dia; see below), this level of behavior independence was considered adequate for our objectives. This level of dynamic interaction or association among individual collared cows seemed fairly typical based our combined experience on this and other rangeland types. Other researchers (e.g., Harris et al., 2007), however, have observed association among range cattle at levels perhaps high enough to restrict how resource-selection analyses are conducted.

2.4. Resource selection analyses

Prescribed fire and environmental effects on the probability of resource use by cattle were evaluated using the multiple regression approach described by Sawyer et al. (2006, 2007, 2009). A generalized linear model (GLM; McCullagh and Nelder, 1989) was used to estimate the probability of resource use as a function of fire treatment and environmental variables. Model errors were assumed to have a negative binomial distribution. Our approach diverged from Sawyer et al. (2006, 2007, 2009), however, by instead of estimating probability of use for each individual animal and then averaging the RSF coefficients across animals, we pooled data from all collared animals to estimate the population-level model and then bootstrapped individual animals to estimate standard errors (SEs) and 90% confidence intervals (CIs) for the RSF coefficients (Manly, 2009).

Basically, our analysis approach consisted of 5 steps where we: 1) measured predictor variables within 2193 randomly-selected, circular plots of 100-m dia, 2) counted the number of cattle GPS locations within these plots, 3) used the relative number of cattle locations in the plots as the response variable in a multiple regression analysis to model the probability of use as a function of fire treatment and environmental variables, 4) bootstrapped the individual cows to estimate SEs and 90% CIs for model coefficients, and then 5) mapped predictions of the final resource selection model.

First, a set of 2500 circular, 100-m dia plots was randomly selected with replacement from throughout the fenced study area. To avoid issues where plots overlapped the fence boundary, 307 plots with center points located <50 m of the fence were removed from the selection leaving 2193 plots to be used in the analyses. Plots with 100-m dia were used as this size provided the best compromise between detecting cattle movement throughout the study area and ensuring the number of cow locations in the plots approximated a negative binomial error distribution in the GLM models (Sawyer et al., 2009). Each plot was then attributed with topographic, vegetation, fire severity, and cultural predictor variables using a GIS. Mean elevation (m), mean slope (degrees), slope standard deviation (degrees), and aspect cardinal direction (categorical with 4 levels) of the sample units were derived from a custom digital elevation model (5 m) (Pacific Meridian Resource, Inc., Emeryville, California). Prefire cover percentages for grass, mahogany, willow, sagebrush, or bitterbrush cover types in each plot were derived using a supervised classification of airborne hyperspectral imagery (5 m GSD) (Earth Search Sciences, Inc., Lakeside, Montana) acquired August 8, 2001. Mean and standard deviation values for the Normalized Difference Vegetation Index (NDVI) or greenness in each plot were also derived from the hyperspectral imagery. Postfire cover percentages for unburned, lightly to moderately burned, and severely burned treatment classes in each plot were derived from the fire severity-class polygons described above (Fig. 1). Of the 2193 plots, 853 were entirely unburned, 273 received low/moderate fire severity, 54 received high fire severity, and the remaining 1013 plots were a mixture of unburned and/or differing fire severities. Distance (m) to fences, roads, streams, and upland water sources (e.g., ponds and developed or undeveloped springs and seeps) were determined by nearest neighbor analysis of the distances between plot center points and these cultural linear and point features.

Next, each viable collar data set from each study year was subset by randomly selecting 75% of the locations for RSF model development and reserving the remaining 25% for model validation. The relative frequency of cattle use for each of the 2193 plots was estimated, for both the model development and validation subsets, by counting the number of locations from each animal that occurred in the plot.

A Pearson's pair-wise correlation analysis was conducted prior to GLM development to screen for multi-collinearity among predictor variables ($|r| > 0.60$). Several collinearities were detected and these were generally consistent across all study years. Collinearities were dealt with by including only one variable of a collinear pair of variables in any one model. For any model set which contained one of the variables from a collinear pair, an additional model was fitted which replaced this variable with the remaining variable of the pair and both these models were retained for consideration in the final model selection process. Probability of cattle use was modeled as a continuous response variable in the GLM. An offset term (McCullagh and Nelder, 1989) was used in the GLMs to relate relative frequency of use to the suite of predictor variables. Model coefficients were estimated using the following Equations (1) and (2) (Sawyer et al., 2009):

$$\ln(E[l_i]) = \ln(total) + ß_o + ß_1 X_1 + \cdots + ß_p X_p, \tag{1}$$

which is equivalent to

$$\begin{aligned} \ln(E[l_i/total]) &= \ln(E[\text{Relative Frequency}_i]) \\ &= ß_o + ß_1 X_1 + \cdots + ß_p X_p, \end{aligned} \tag{2}$$

where, l_i is number of GPS locations within sampling unit i ($i = 1, 2, \ldots, 2193$), *total* is total number of GPS locations within the entire study area, β_o is an intercept term, $\beta_1, \ldots, \beta_p$ are unknown coefficients for the predictor variables $X_1, \ldots, X_p$, and $E[.]$ represents the expected value. The offset term, ln(*total*) serves to convert the integer counts of the response variable to relative frequency values. These GLMs estimate true probability of use and thus are resource selection probability functions (RSPF; Manley et al., 2002) for the sample of animals.

An *a priori* set of 36, four-variable candidate models was formulated for the two prefire study years (Burnham and Anderson, 2002). Quadratic terms were tested for distance variables (i.e., distance to fences, roads, streams, and upland water sources) and for elevation, and slope. According to convention, models containing quadratics also contained the corresponding linear form of these variables. Following the approach described by Burnham and Anderson (2002), Akaike information criterion (AIC) scores were used to select the best performing prefire model from this candidate set.

Next, a set of five-variable models was developed by adding a fire-related variable, such as distance to nearest severely burned polygon boundary (m) or light/moderate fire severity cover (%), to the best fitting prefire model. The performance of these 5-variable models was evaluated for all 5 postfire years and the best overall model was selected based on AIC score. For each variable in the final, 5-variable model, differences in coefficient estimates among years were evaluated using the bootstrapped 90% confidence intervals for the estimates.

Our goal, by using this two-step model selection approach, was to identify whether there was a fire effect after we had accounted for the effects all other landscape and environmental characteristics. We think this approach provided a clear evaluation of the effect of fire, which could have been confounded with a linear combination of other covariates (e.g., aspect + slope + distance to water), and thus been mistakenly identified as a statistically important covariate if only a one-step model selection approach had been applied.

The predictive ability of the final 5-variable model was evaluated with Spearman Rank correlation analyses using the validation datasets reserved from each animal for each study year. The number of GPS locations was counted in 20 equal-sized classes (or bins) ranked from highest to lowest probability of cattle use (Boyce et al., 2002; Wiens et al., 2008). The Spearman analyses compared the location counts with bin ranking ($r_s > 0.70$).

Finally, for each study year, predicted resource-selection patterns from the final 5-variable model were mapped on a 25-m × 25-m grid covering the entire study area (Figs. 2–4). Estimated probability of use values assigned to the grid cells were classified into 4 classes representing low, moderate, high, and very high probability of use. The classification was based on the quartiles of the distribution of predictions; consequently, each class contained approximately the same number of grid cells.

The GIS analyses were conducted using ARCGIS ArcMap 9.3.1 (ESRI, Redlands, California) and Geospatial Modelling Environment 0.4.0 (Spatial Ecology LLC, Glasgow, Scotland). All statistical analyses were performed in the R Language and Environment for Statistical Computing v2.11.1. Population-level RSPF model coefficients were reported as significant when bootstrapped 90% confidence intervals for coefficient estimates did not include zero.

The spatial scope of inference for this study is confined to the 324 ha study area. Although the experiment is replicated and controlled within this area, it is still just a single, relatively small landscape. Consequently, the reader should consider this research as a case study and exercise caution when extrapolating the findings presented below to other rangeland areas.

3. Results

3.1. Prefire resource selection

Prefire fittings of the final 5-factor resource-selection model are presented in Table 2. Slope, sagebrush dominance, and distance to upland water were important factors affecting cattle resource-

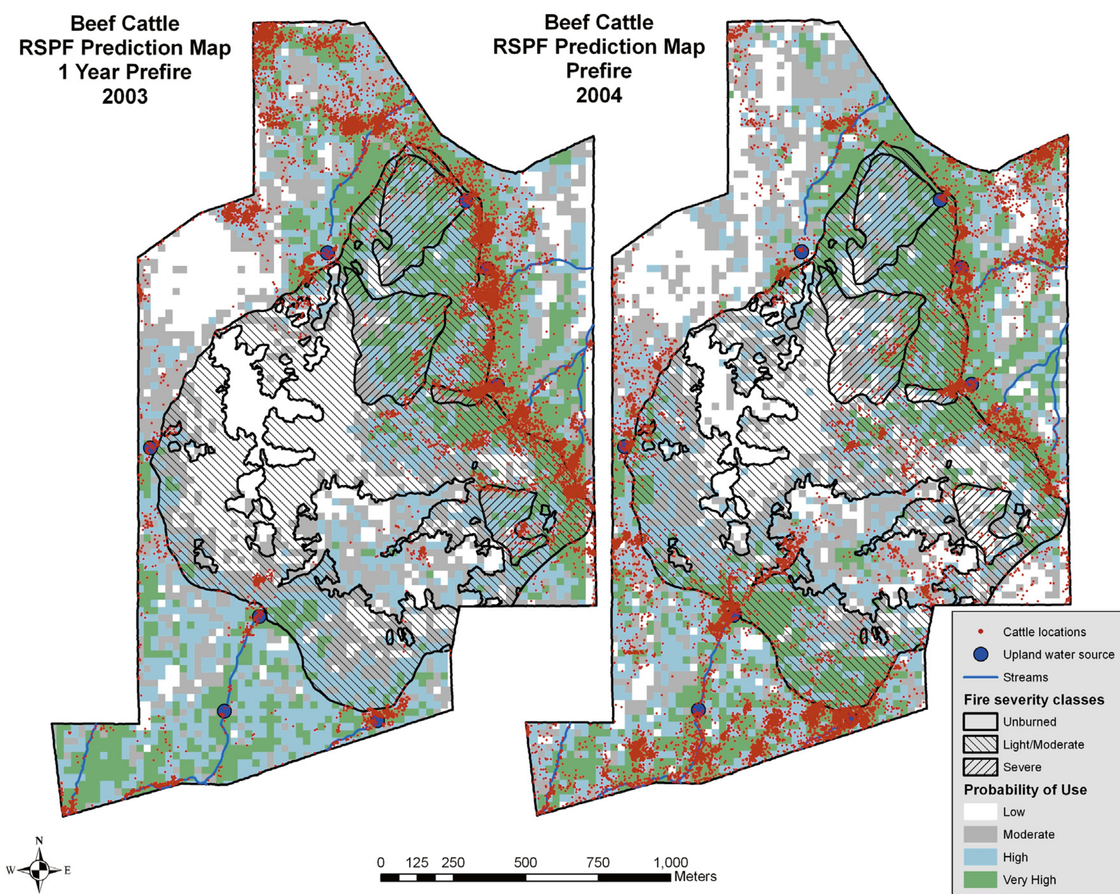

Fig. 2. Maps illustrating predicted cattle use patterns (Prefire), derived with a population-level resource selection function, relative to fire severity and cattle GPS collar locations at the Whiskey Hill prescribed fire study area (324 ha) in the Owyhee Mountains of southwestern Idaho during 2003 (1 year prefire) and 2004 (prefire).

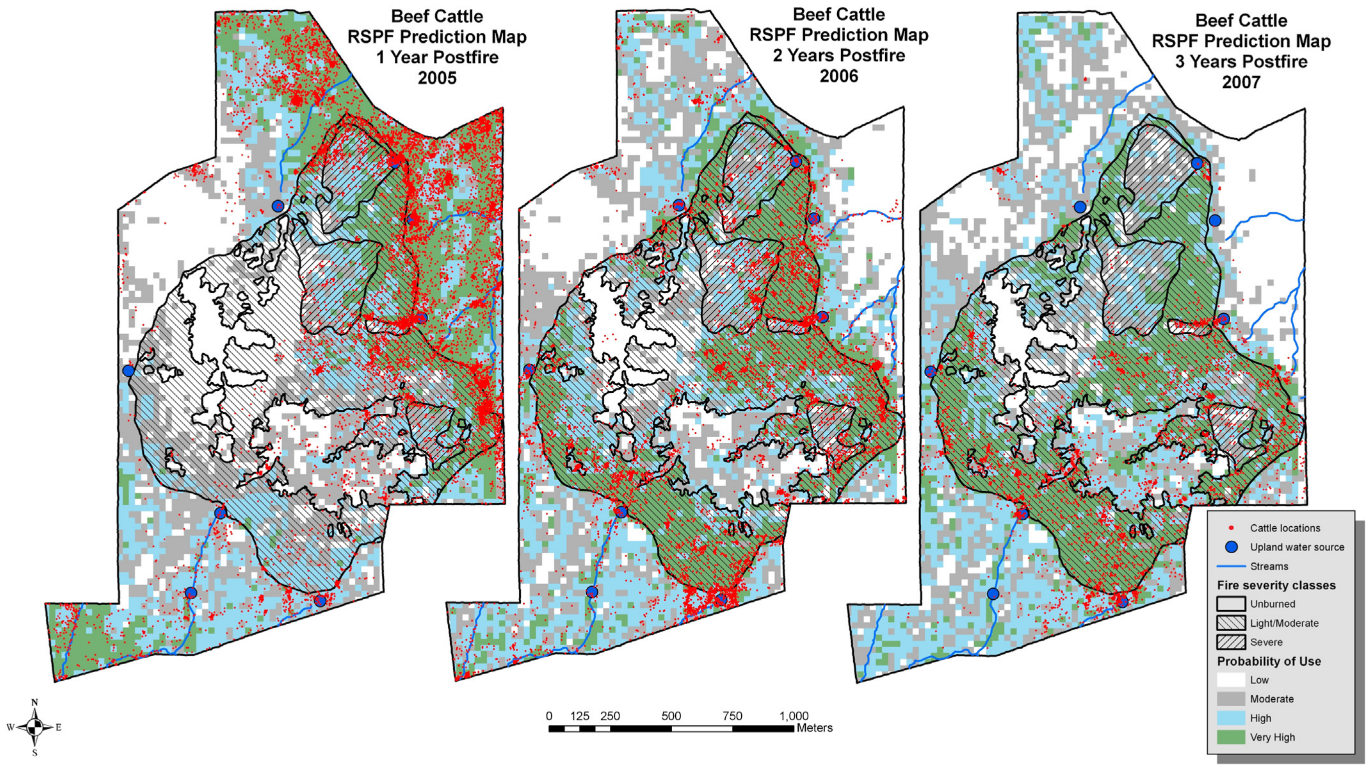

Fig. 3. Maps illustrating predicted cattle use patterns (Postfire), derived with a population-level resource selection function, relative to fire severity and cattle GPS collar locations at the Whiskey Hill prescribed fire study area (324 ha) in the Owyhee Mountains of southwestern Idaho during 2005, 2006, and 2007 (1, 2, and 3 years postfire, respectively).

selection patterns during both prefire years (Fig. 2). With each degree increase in slope the predicted level of cattle use decreased by 15.0 and 18.1 percentage points in 2003 and 2004, respectively. Areas with mean slopes of 13.8° and 12.0° had the highest predicted level of use in 2003 and 2004, respectively (Table 3). Areas dominated by sagebrush were selected for by cattle prior to the fire. With each percentage point increase in plot cover classified as sagebrush, the predicted level of cattle use increased by 4.9 and 2.6 percentage points in 2003 and 2004, respectively. Areas classified as 70.5% and 62.3% sagebrush had the highest predicted use in 2003 and 2004, respectively (Table 3). Cattle selected for areas relatively near upland water prior to the fire, particularly, during 2004. With each 100 m increase in distance from upland water sources, predicted cattle use decreased by 5.4 and 25.2 percentage points in 2003 and 2004, respectively. Areas with a mean distance to upland water of 238 m and 188 m in 2003 and 2004, respectively, had the highest predicted use (Table 3).

Elevation and its quadratic form influenced cattle resource selection in 2003 but were non-significant in 2004 (Table 2). Cattle use during 2003 increased with increasing elevation, peaked at 1697 m, and then decreased with further elevation increase (Table 3). About 80.0% of the study area, however, occurred above 1697 m elevation. Consequently, although the model indicated a significant positive effect of elevation, cattle use in 2003 was still focused in fairly low elevations of the fenced study area.

The fire-related factor in the model, low/moderate fire severity, did not affect prefire cattle resource selection during either prefire year (Table 2). In other words, prefire conditions (e.g., fuel load, type, continuity, or moisture) that typically affect fire severity (Sapsis and Kauffman, 1991) did not appear to influence cattle resource selection prior to the fire.

3.2. Postfire resource selection

Postfire fittings of the final 5-factor resource-selection model are presented in Table 2. In contrast to prefire years, low/moderate fire severity was a dominant factor affecting cattle resource-selection patterns during all postfire years (Figs. 3–5). With each percentage point increase in the plot cover classified as having received low/moderate fire severity, predicted cattle use increased by 0.76, 1.9, 2.3, 1.9, and 1.2 percentage points for trial years 2005, 2006, 2007, 2008, and 2009, respectively. Cattle exhibited a stronger selection for areas of low/moderate fire severity during the second, third, and fourth postfire years (i.e., 2006–2008) than the first and fifth postfire years (Fig. 5). Areas classified as having 27.8, 75.9, 84.0, 65.1, and 69.6% low/moderate fire severity composition had the highest predicted use in 2005, 2006, 2007, 2008, and 2009, respectively (Table 3).

Elevation and its quadratic form were significant predictors of cattle resource selection during all postfire years except 2008 (Table 2). Predicted cattle use increased with increasing elevation, peaked at mid elevation, and decreased with further elevation increase. Cattle use in 2005 peaked at a lower elevation than during 2006, 2007, and 2009 (Figs. 3–4). Areas with a mean elevation of 1675 m had the highest predicted cattle use in 2005 with 86.8% of the study area and 98.4% of the burned area occurring above this elevation (Table 3). Areas with a mean elevation of 1736 m, 1756 m, and 1730 m had the highest predicted use in 2006, 2007, and 2009, respectively (Table 3). About 64.4% of the study area and 76.0% of the burned area occurred above 1730 m elevation. Cattle tended to use a wider range of elevations during 2008 than other study years (Fig. 4).

Slope and sagebrush cover (i.e., coverage by the sagebrush-snowberry vegetation type) also affected cattle resource selection

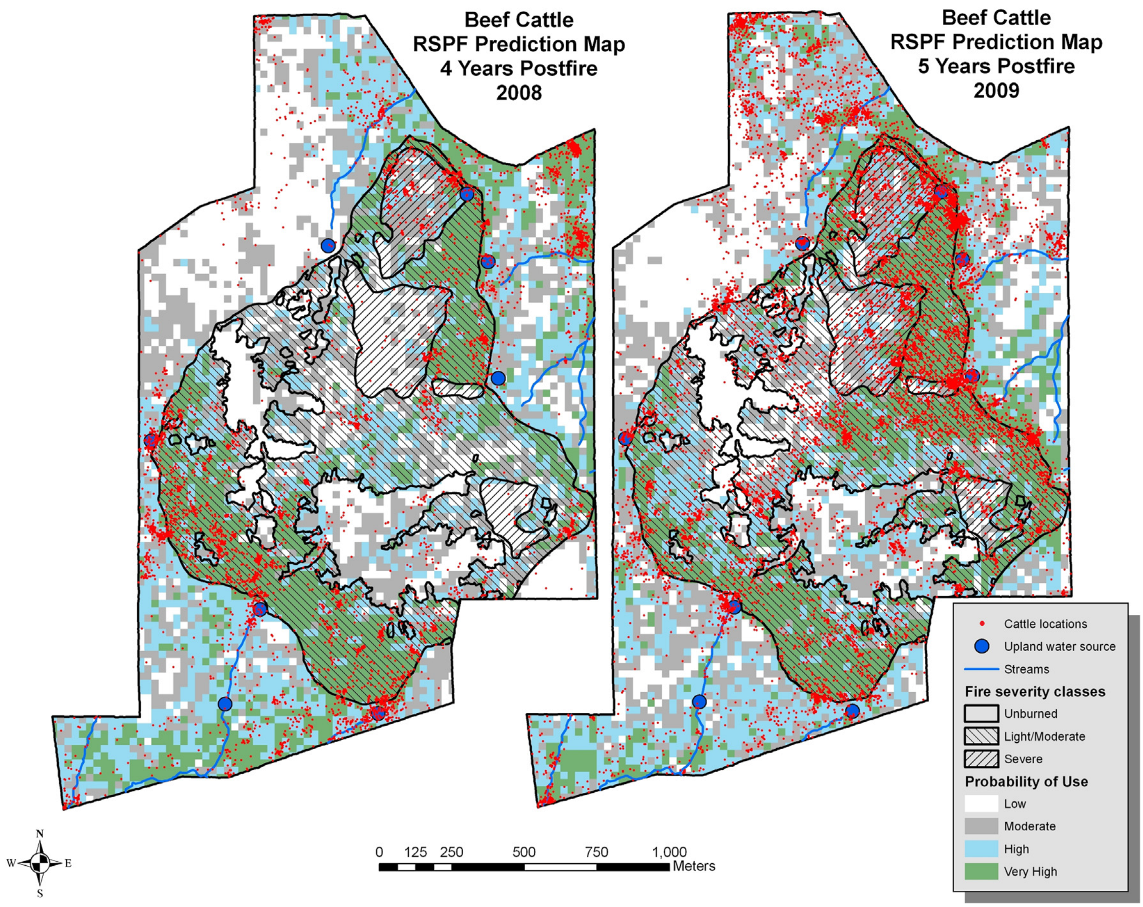

Fig. 4. Map illustrating predicted cattle use patterns (Postfire), derived with a population-level resource selection function, relative to fire severity and cattle GPS collar locations at the Whiskey Hill prescribed fire study area (324 ha) in the Owyhee Mountains of southwestern Idaho during 2008 (4 years postfire) and 2009 (5 years postfire).

Table 2
Coefficients (*β*) and lower (LCL) and upper (UCL) 90% confidence limits of population-level beef cattle resource-selection functions for 2 years before (2003 and 2004; Prefire) and for 5 years after (2005–2009; Postfire) application of a prescribed fire treatment for western juniper control and reduction of mountain big sagebrush and antelope bitterbrush cover on a mesic sagebrush steppe rangeland in the Owyhee Mountains of southwestern Idaho.

Years	Coefficients & confidence limits (90%)	Predictor variables						
		Intercept	Elevation (m)	Elevation^2 (m)	Slope (deg)	Sagebrush[a] (%)	Distance to upland water (m)	L/M fire severity[b] (%)
2003	*β*	**−321**[c]	**0.386**	**−1.18E-4**	**−0.163**	**0.0479**	**−5.39E-4**	−1.51E-3
	LCL	−392	0.356	−1.40E-4	−0.175	0.0428	−1.23E-3	−3.46E-3
	UCL	−293	0.470	−1.10E-4	−0.133	0.0518	−8.50E-5	4.62E-4
2004	*β*	145	−5.12E-3	−3.35E-6	**−0.200**	**0.0256**	−2.53E-3	8.36E-4
	LCL	−53.3	−0.0938	−2.45E-5	−0.222	0.0218	−3.28E-3	−1.88E-3
	UCL	94.0	0.0711	2.17E-5	−0.185	0.0302	−1.96E-3	2.24E-3
2005	*β*	**−108**	**0.146**	**−5.03E-5**	**−0.125**	**0.0295**	**2.00E-3**	**7.55E-3**
	LCL	−179	0.107	−7.56E-5	−0.150	0.0248	1.11E-3	5.13E-3
	UCL	−75.4	0.230	−3.87E-5	−0.0872	0.0364	3.01E-3	9.29E-3
2006	*β*	**−320**	**0.327**	**−1.10E-4**	**−0.118**	**0.0262**	−6.33E-4	**0.0188**
	LCL	−540	0.259	−1.83E-4	−0.156	0.0178	−1.28E-3	0.0159
	UCL	−220	0.625	−7.83E-5	−0.0875	0.0377	3.34E-4	0.0219
2007	*β*	**−531**	**0.604**	**−1.74E-4**	**−0.171**	**0.0286**	−1.01E-4	**0.0232**
	LCL	−693	0.456	−2.30E-4	−0.207	0.0146	−1.98E-3	0.0200
	UCL	−403	0.791	−1.30E-4	−0.147	0.0408	1.66E-3	0.0251
2008	*β*	100	−0.108	2.75E-5	**−0.141**	**−0.0110**	**−8.36E-4**	**0.0191**
	LCL	−353	−0.185	−1.16E-4	−0.225	−0.0151	−1.17E-3	0.0159
	UCL	171	0.402	4.85E-5	−0.0737	−2.54E-3	−4.30E-4	0.0234
2009	*β*	**−75.2**	**0.0889**	**−2.83E-5**	**−0.0860**	**0.0142**	2.66E-4	**0.0123**
	LCL	−238	0.0182	−8.03E-5	−0.110	0.0104	−3.80E-4	9.42E-3
	UCL	−12.6	0.273	−8.17E-6	−0.0616	0.0191	7.73E-4	0.0143

[a] Percentage of sample unit area (100 m dia. circular plot) classified as being occupied by the sagebrush cover type.
[b] Percentage of sample unit area classified as having received light to moderate fire severity during the prescribed burn on 27 September 2004.
[c] Coefficients in bold face were significantly different from zero at the 0.05 alpha level.

Table 3
Predicted cattle use derived by population-level beef cattle resource selection functions for 2 years before (2003 and 2004; Prefire) and for 5 years after (2005–2009; Postfire) application of a prescribed fire treatment for western juniper control and reduction of mountain big sagebrush and antelope bitterbrush cover on a mesic sagebrush steppe rangeland in the Owyhee Mountains of southwestern Idaho.

Years	Predicted use class	Predictor variables				
		Elevation (m)	Slope (deg)	Sagebrush[a] (%)	Distance to upland water (m)	L/M fire severity[b] (%)
2003	Very high	1697	13.8	70.5	238	NS[c]
	High	1732	13.6	58.2	279	NS
	Moderate	1764	13.3	55.4	315	NS
	Low	1817	14.9	54.8	389	NS
2004	Very high	NS	12.0	62.3	188	NS
	High	NS	12.7	55.3	254	NS
	Moderate	NS	14.0	60.5	364	NS
	Low	NS	16.9	60.8	415	NS
2005	Very high	1675	15.6	67.9	282	27.8
	High	1738	13.3	59.1	272	33.5
	Moderate	1778	11.7	54.9	291	42.8
	Low	1819	14.9	57.0	375	42.4
2006	Very high	1736	13.2	68.5	NS	75.9
	High	1747	12.0	57.2	NS	33.5
	Moderate	1756	13.5	57.1	NS	18.1
	Low	1772	16.9	56.1	NS	19.0
2007	Very high	1756	12.3	63.3	NS	84.0
	High	1760	11.6	59.2	NS	35.4
	Moderate	1758	13.7	60.4	NS	16.5
	Low	1737	18.0	56.1	NS	10.5
2008	Very high	NS	10.6	49.4	214	65.1
	High	NS	12.7	57.3	278	32.8
	Moderate	NS	15.4	64.6	333	30.6
	Low	NS	16.9	67.6	396	18.0
2009	Very high	1730	12.5	67.2	NS	69.6
	High	1741	12.7	57.0	NS	37.2
	Moderate	1750	13.8	57.2	NS	20.5
	Low	1789	16.6	57.5	NS	19.2

[a] Percentage of sample unit area (100 m dia. circular plot) classified as being occupied by the sagebrush cover type.
[b] Percentage of sample unit area classified as having received light to moderate fire severity during the prescribed burn on 27 September 2004.
[c] Effect was non-significant at the 0.05 alpha level.

during all postfire years (Table 2). Predicted cattle use decreased by 11.7, 11.1, 15.7, 13.2, and 8.24 percentage points for each degree increase in slope during 2005, 2006, 2007, 2008, and 2009, respectively. With each percentage point increase in plot cover classified as sagebrush, predicted cattle use increased by 3.0, 2.7, 2.9, and 1.4 percentage points for 2005, 2006, 2007, and 2009, respectively. In contrast to other postfire years, predicted cattle use in 2008 decreased by 1.1 percentage points for each percentage point increase in sagebrush cover. In 2008, cattle generally favored areas which had been dominated by the antelope bitterbrush cover type prior to the fire.

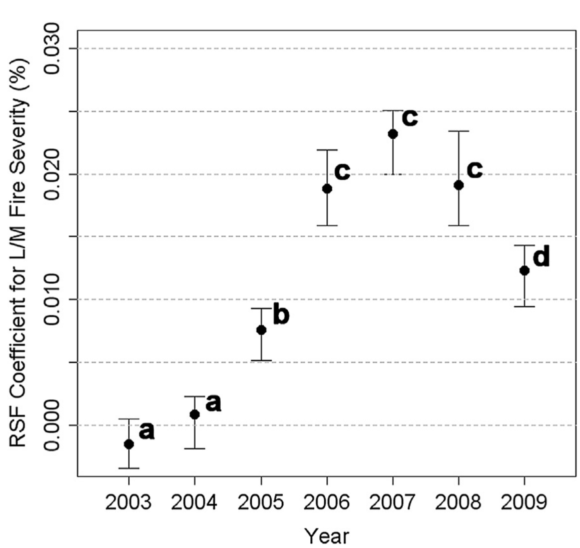

Fig. 5. Coefficient estimates for the light-to-moderate fire severity effect on population-level, cattle resource-selection responses among 7 study years and between prefire–postfire periods where, differing letter labels indicate the 90% confidence intervals (bars) for the estimates did not overlap and the estimates were different.

Distance to upland water was influential only during the 2005 and 2008 postfire years (Table 2). Cattle selected for areas relatively distant from upland water sources in 2005 but selected for areas near upland water in 2008 (Table 3). With each 100 m increase in distance from upland water sources, the probability of cattle use increased by 20.0% in 2005 but decreased by 8.4% in 2008. The difference being in 2005 cattle selectively used lower elevations where streams probably served as water sources while in 2008 cattle used a wide range of elevations, particularly, moderate and high elevations where upland sources were the closest available water (Figs. 3–4).

3.3. Model validation

The final 5-variable model was validated for each study year using the 25% of each collar animal's location data that were randomly selected and reserved for this purpose. Spearman rank correlations (r_s) calculated between the prediction class ranking and animal location counts within each class for prefire years 2003 and 2004 were 0.939 and 0.983, respectively. Spearman correlations for postfire year models 2005, 2006, 2007, 2008, and 2009 were 0.997, 0.986, 0.973, 0.985, and 0.969, respectively. These relatively high scores indicate this resource selection function was a powerfully predictive model (Wiens et al., 2008), incorporating environmental and fire treatment effects, and performing well for all 7 study years.

4. Discussion

Prescribed fire, applied in the fall for juniper and brush control, affected resource selection by cattle for all 5 postfire years of this study. Lactating beef cows grazing this mountainous, sagebrush-steppe rangeland during spring consistently selected for areas that had previously received low/moderate fire severity. Cattle were neutral, neither avoiding nor selecting for these same areas, during the 2 years prior to the fire. Findings from other ecosystems (e.g., Biondini et al., 1999; Coppedge and Shaw, 1998; Hobbs and Spowart, 1984; Peek et al., 1979; Van Dyke and Darragh, 2007) suggest the attractiveness of burned areas to grazing animals gradually attenuates over time with selectivity for these areas returning to prefire levels within 3–5 years postfire. In our study, collared cattle selected positively for lightly to moderately burned areas during the first postfire year, increased the strength of this selectivity during the second postfire year, remained similarly elevated during the third and fourth postfire years, and then declined in the fifth postfire year to a level slightly higher than the first postfire year. Rather than returning to prefire levels, however, cattle selectivity for these burned areas remained positive even after 5 postfire years.

What promoted the longevity of this response? Prescribed fire tends to improve forage quality (Hobbs and Spowart, 1984) and palatability (Peek et al., 1979), enhance herbaceous production (Bates et al., 2009), and reduce impedance caused by dense brush thus improving forage accessibility. Cattle generally respond positively to these changes in resource conditions (Allison et al., 1985; Bailey et al., 1996; Ganskopp and Bohnert, 2009; Ganskopp and Rose, 1992; Ganskopp et al., 1992) and are attracted to fire-treated areas (Vermeire et al., 2004). Although fire-induced forage quality and palatability improvements are typically short-lived (e.g., 1–2 years) (Hobbs and Spowart, 1984), our study suggests prescribed fire can affect cattle resource-use patterns for as long as 5 years postfire. Consequently, we suspect our cattle were responding to more than a short-term improvement in forage quality. Herbaceous forage production on burned sagebrush steppe rangeland tends to peak 2–3 years postfire (Bates et al., 2009). In our study, cattle selectivity for low to moderately burned areas was greatest during the second and third postfire years suggesting cattle were responding to enhanced graminoid production on the burned relative to unburned areas even after any potential forage quality and/or palatability improvements had attenuated.

Cattle often select for riparian zones and other low-elevation areas when confined within fenced pastures and overuse of these areas may lead to resource damage (Bailey et al., 2004, 2008; Kauffman and Krueger, 1984). Elevation influenced cattle resource selection during 5 of 7 years of our study. Notably, cattle selected for higher mean elevations during postfire years 2006, 2007, and 2009 than during the prefire year 2003 and the initial postfire year 2005. These preferred, higher elevations tended occur within the burned area about midway between the highest (1871 m) and lowest (1661 m) elevations of the burn and well upslope from the headwater stream channels and riparian areas present on the study area. Conversely, elevations with the highest predicted prefire and initial postfire cattle use occurred nearer to the headwater stream channels and just above the lowest elevations of the burn. The significant quadratic nature of elevation effects during most study years was likely due, at least in part, to the presence of granite outcrops and associated dense stands of mountain mahogany on the ridge crowns which made cattle accessibility of these highest-elevation areas very difficult. Consequently, predicted postfire cattle use tended to peak at mid elevations but declined with further increases in elevation.

Slope has long been noted as a factor influencing range cattle distribution (Cook, 1966; Ganskopp and Vavra, 1987; Gillen et al., 1984; Mueggler, 1965). Our original hypothesis was prescribed fire might entice cattle to use steeper slopes than they would otherwise use. Cattle in this study area, however, tended to use moderate slopes both prefire and postfire. Consequently, at first glance, one might simply conclude fire did not promote a change in slope use. Digging a little deeper, however, we found there really was not any fire-related incentive for cattle to use steeper slopes because most of those steep slopes were located in unburned rather burned areas. The mean slopes of the unburned ($13.4^\circ \pm 7.9^\circ$ SD) and lightly to moderately burned areas ($14.3^\circ \pm 6.9^\circ$ SD) were moderately steep and quite similar. About 71% of the steepest slopes ($>40^\circ$), however, were located in unburned areas where the maximum slope was 60.5° compared to a maximum slope of 52.4° in burned areas.

Effects of sagebrush dominance or plot coverage on cattle resource selectivity were not clear-cut. During most study years predicted cattle use favored areas where the prefire cover had been dominated by the sagebrush-snowberry cover type. Prefire and for the first 3 years postfire, cattle likely selected for sagebrush areas because the accessibility or availability of perennial grass forages was almost certainly higher there than in bitterbrush-dominated areas. Bitterbrush often occurred on sandier, drier soils while sagebrush and grasslands occurred on siltier, wetter soils (Clark unpublished data). Prior to burning, bitterbrush areas were commonly dominated by a tall, dense canopy of shrubs which likely competed with herbaceous plants for light, moisture, and nutrients and thus heavily suppressed herbaceous growth and recruitment (Wrobleski and Kauffman, 2003). This brush canopy also contained heavy loads of the woody fuels which generally yielded higher fire severities than those observed in sagebrush or grass-dominated areas. We suspect the combination of less favorable soils, prefire competition with bitterbrush, and higher fire severity with associated grass plant mortality and neutralization of near-surface seed banks resulted in lower grass diversity, cover, and productivity on former bitterbrush areas for the first 3 or more years postfire, relative to sagebrush or grass-dominated areas. In 2008, however, the final model predicted cattle would avoid areas of prefire sagebrush dominance. Cattle in 2008 were predicted to favor areas southwest of the study area center where bitterbrush was dominant prefire (Fig. 4). In 2009, however, the model predicted cattle would again select for areas that were formally dominated by sagebrush. It is unclear what drove this short-term shift in selectivity during 2008 but, in any case, dominance of the sagebrush-snowberry cover type played an important role in cattle resource selection on this rangeland.

Distance to upland water has been documented as an important factor influencing cattle distribution (Ganskopp, 2001; Pinchak et al., 1991; Roath and Krueger, 1982). In our study, however, effects of upland water distance were non-significant in 3 of 5 postfire years and were contradictory between the remaining 2 postfire years. In 2005, cattle use was unexpectedly predicted to increase with distance from upland water while use decreased with distance in 2008, as it did during prefire years, 2003 and 2004. Although cattle certainly made use of some upland water sources during 2005; particularly those on the east side of the pasture, they also made considerable use of lower-elevation, moist meadow areas in the unburned northeastern corner of the study area (Fig. 3). These meadows had also received concentrated use during prefire year 2004 (Figs. 1–2); were closer to streams (50–360 m) than upland water sources (222–408 m); and were about 200–220 m lower in elevation than the upland water sources. Hence, cattle foraging on these meadows were required to either climb back up to upland sources for water or occupy riparian areas and drink from streams. After 2005, these meadows were not used by cattle again until 2008 and 2009 and then only in a much less concentrated fashion (Figs. 3–4). Although not formally tested, these resource-selection patterns suggest fire may have played a role in reducing concentrated cattle use of moist meadows but it appears to have required more than 1 postfire year before the burned area became attractive enough to cause cattle to shift away from using moist meadows.

4.1. Management implications

The scope of inference for this case study was limited to the study area and this ranch-level population of cattle. Additional research in other study areas within the sagebrush steppe during spring and other seasons is needed to broaden the applicability of this information. This case study, however, indicates fall prescribed fire was a viable tool for inducing changes in cattle resource-selection patterns on this mesic sagebrush-steppe landscape during spring and that fire treatments were effective for up to 5 years. If applied under conditions similar to this study, livestock producers and natural resource managers may be able to use fall prescribed fire to shift livestock use away from critical resources such as stream riparian areas and moist meadows for as long as 5 years.

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