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Prescribed fire effects on resource selection by cattle in mesic sagebrush steppe. Part 2: Mid-summer grazing

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ABSTRACT

Prescribed fire can release herbaceous forages from woody plant competition thus promoting increased forage plant production, vigor, and accessibility. Prescribe fire also consumes standing litter thereby improving forage quality and palatability. Consequently, prescribed fire is commonly considered an effective tool for manipulating livestock distribution on rangelands. Efficacy of this tool on mesic sagebrush steppe, however, has received little research attention. Beginning in 2001, resource selection by beef cows under a mid-summer (July) grazing regime was evaluated using global positioning system (GPS) collars for 2 years prior to and for up to 5 years after a fall prescribed fire was conducted on mesic sagebrush steppe in the Owyhee Mountains of southwestern Idaho, USA. Cattle selected for burned areas during the first, second, and fifth postfire years. Cattle had exhibited neutral selectivity towards these areas, during one of the two prefire years. Burning in the uplands reduced cattle use of near-stream habitats but only during the second postfire year. Differences in phenological timing of grazing may account for differences in cattle response to burning noted between this study and one conducted nearby under a spring (May) grazing regime. This is a case study and caution should be taken in extrapolating these results.

1. Introduction

Fire plays an important ecological role as a disturbance agent which promotes successional cycling (Christensen, 1985; Keane et al., 2004; Turner et al., 1997). Many woody plant species are killed or reduced by fire. Western juniper (*Juniperus occidentalis* Hook.) is one such species and fire serves to control the extent of this invasive native plant and its encroachment into sagebrush steppe rangelands (Burkhardt and Tisdale, 1976; Miller and Rose, 1999). Burning of shrubs and/or trees also releases associated herbaceous plants from woody competition (Bates et al., 2011; Miller et al., 2000; Wrobleski and Kauffman, 2003). Fire consumes standing litter accumulations in herbaceous plants, often without unduly compromising plant vigor (Willms et al., 1980a). Removal of standing litter from forage species like bunchgrasses can increase nutritional quality and palatability to grazing wildlife and livestock (Cook et al., 1994; Hobbs and Spowart, 1984; Willms et al., 1980a, 1980b, 1981; Young and Miller, 1985). Exotic plant invasions, poorly-managed livestock grazing, and wildfire suppression, however, have drastically altered the historic fire regimes on many rangelands of the world (Brooks et al., 2004; D'Antonio and Vitousek, 1992). While some systems, like those converted to exotic annual grasslands, now have too much fire (Brooks et al., 2004), others often have too little (e.g., higher-elevation, mesic sagebrush steppe; Miller and Rose, 1999). In the later case, in the absence of fire, fuels have accumulated to excessive and hazardous levels. Stands of shrubs and trees have become exceptionally dense and decadent. Competition from these woody plants and physical obstruction by their canopies have depressed the presence, vigor, and/or production of herbaceous forage plants and reduced forage accessibility to wildlife grazers and livestock (Miller et al., 2000). Consequently,

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there is a critical need on many rangelands, where fire has been wrongly excluded, to re-establish an appropriate fire cycle. Hazardous fuel accumulations and proximity to human settlement, infrastructure, or valuable commodities (e.g., flammable crops or timber); however, commonly prohibit the use of "let-burn" wildfire management policies on these rangelands. Fortunately, it is often possible to use carefully-managed, prescribed fire as a safe and effective means of re-initiating and/or maintaining an appropriate fire cycle.

Prescribe fire can promote increased forage production, quality, and palatability while also opening up new foraging areas where wildlife and livestock grazing was previously excluded by dense shrub canopy (Cook et al., 1994; Davies et al., 2012; Hobbs and Spowart, 1984; Willms et al., 1980a, 1981; Young and Miller, 1985). Research in a number of rangeland ecosystems; including montane and prairie grasslands, shrub steppe, and savanna, have demonstrated prescribed burns are highly attractive to grazing animals and, in some cases, can be used to manipulate animal distribution (Augustine et al., 2010; Bates et al., 2009; Hobbs and Spowart, 1984; Klop et al., 2007; Peek et al., 1979; Van Dyke and Darragh, 2007; Vermeire et al., 2004). As such, it is reasonable to hypothesize prescribed burning could be used to manage cattle resource-selection patterns on sagebrush-steppe rangelands.

The sagebrush-steppe ecosystem occurs on about 44.4 million ha of western North America. A higher-elevation, more mesic portion of this ecosystem is dominated by mountain big sagebrush (*Artemisia tridentata* Nutt. ssp. *vaseyanna* Beetle), with antelope bitterbrush (*Purshia tridentata* [Pursh] DC) and/or mountain snowberry (*Symphoricarpos oreophilus* A. Gray) often occurring as co-dominants. The mesic sagebrush steppe represents a considerable proportion of the sagebrush-steppe ecosystem and is a principal habitat of many wildlife species, some of which are threatened or endangered (e.g., greater sage-grouse [*Centrocercus urophasianus* Bonaparte]. Mesic sagebrush steppe is also important livestock grazing land in several western regions. The ability of exotic annual grasses, such as cheatgrass (*Bromus tectorum* L.) and medusahead (*Taeniatherum caput-medusae* [L.] Nevski) to invade and, through repeated burning, convert sagebrush steppe into annual grassland is a considerable threat in the drier, lower-elevation portions of the sagebrush-steppe ecosystem (Brooks et al., 2004; Chambers et al., 2007). Mesic sagebrush-steppe rangelands, however, are currently much less susceptible to exotic annual grass conversion. Mesic sagebrush steppe is susceptible, however, to invasion by native woody plants like western juniper (Burkhardt and Tisdale, 1976; Miller and Rose, 1999; Miller and Wigand, 1994). Long-term absence of fire can promote conversion from mesic sagebrush steppe to juniper woodland which can often have adverse consequences to rangeland hydrology, soil stability, wildlife habitat, and livestock grazing (Noson et al., 2006; Pierson et al., 2010, 2013; Wall et al., 2001).

While prescribed fire is widely considered to be an effective tool for controlling western juniper encroachment in the mesic sagebrush steppe, claims about its efficacy for also managing livestock distribution have received comparatively little research attention. It has been found; however, under a spring (May) grazing regime, that fall prescribed fire in mesic sagebrush steppe can promote increased use of burned areas by cattle for up to 5 years postfire (Clark et al., 2014). The longevity of this cattle resource-selection response to fire is quite unprecedented even in other rangeland types. The phenological timing of grazing, however, may influence both, the efficacy of prescribed fire for manipulating cattle distribution and the longevity of this effect. In addition, site factors including slope, distance to water, and vegetation composition and structure affect cattle distribution and may interact with or cancel out fire-related effects (Bailey, 1995, 2005; Cook, 1966; Ganskopp, 2001; Ganskopp and Vavra, 1987; Howery et al., 1996, 1998; Loza et al., 1992; Mueggler, 1965; Pinchak et al., 1991; Roath and Krueger, 1982; Senft et al., 1985). As such, additional research was required to investigate the efficacy of fall prescribed fire for manipulating cattle resource-selection patterns under different site conditions and grazing regimes (e.g., mid-summer [July] grazing) than those used by Clark et al. (2014).

Objectives of this study were to: i) Evaluate whether fall prescribed fire affected cattle resource-selection patterns under a mid-summer (July) grazing regime; ii) if fire effects on cattle resource selection were detected, determine how long these effects persisted postfire; and iii) compare and contrast findings with those obtained by Clark et al. (2014). This study was conducted within the scope of a larger research project intended to evaluate spatiotemporal effects of prescribed fire on resource selection, activity budgets, and movement path characteristics of beef cattle in mesic sagebrush-steppe rangelands. A series of 3 papers was the intended product from this project with Clark et al. (2014) being the first paper in the series, the present paper on mid-summer resource selection as the second, and a third paper on cattle activity budget and movement path responses to prescribed fire is in preparation.

2. Methods

2.1. Study area

The study was conducted at the Breaks study area (176 ha), a fenced rangeland pasture within the Reynolds Creek Experimental Watershed (43° 6′ 29″ N, 116° 46′ 37″ W) located 80 km south of Boise in southwestern Idaho (Fig. 1). Climate is continental with maritime influences. Winters are cold and wet while summers are warm and dry. Long-term (1966–1975, 2002–2013) mean annual precipitation at the Breaks gauges (145) was 588 mm (NWRC, 2014) with typically about 1/3 of the precipitation occurring as snow (Hanson, 2001). Annual precipitation during the study (2001–2007) varied from a low of 421 mm in 2002, 463 mm in 2007, 542 mm in 2003, 543 mm in 2004, 655 mm in 2006, and a high of 773 mm in 2005. Precipitation data from the Breaks gauges was not available for 2001, but data from the nearby Tollgate gauges (116c) indicated precipitation in 2001 was below the long-term mean (1962–2013) for Tollgate (NWRC, 2014). The growing season is about 100 days in length 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, 2014). Mean daily air temperature varied during the study from a low of 8.3 °C in 2002, 8.6 °C in 2005, 8.7 °C in 2001, 8.8 °C in 2004 and 2006; 9.4 °C in 2003, and a high of 9.6 °C in 2007. Note that mean annual air temperatures for all study years, except 2002, were warmer than long-term mean.

Topography of the study area is an east-facing hillslope ranging from 1547 to 1761 m in elevation. Slope ranges from flat to very steep (107.5% or 47.1° 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 (Seyfried et al., 2001).

Three vegetation cover types; including mountain big sagebrush – mountain snowberry, antelope bitterbrush – mountain big sagebrush, and native bunchgrass types, dominate the study area as they do in the mid- and higher-elevation portions of the sagebrush

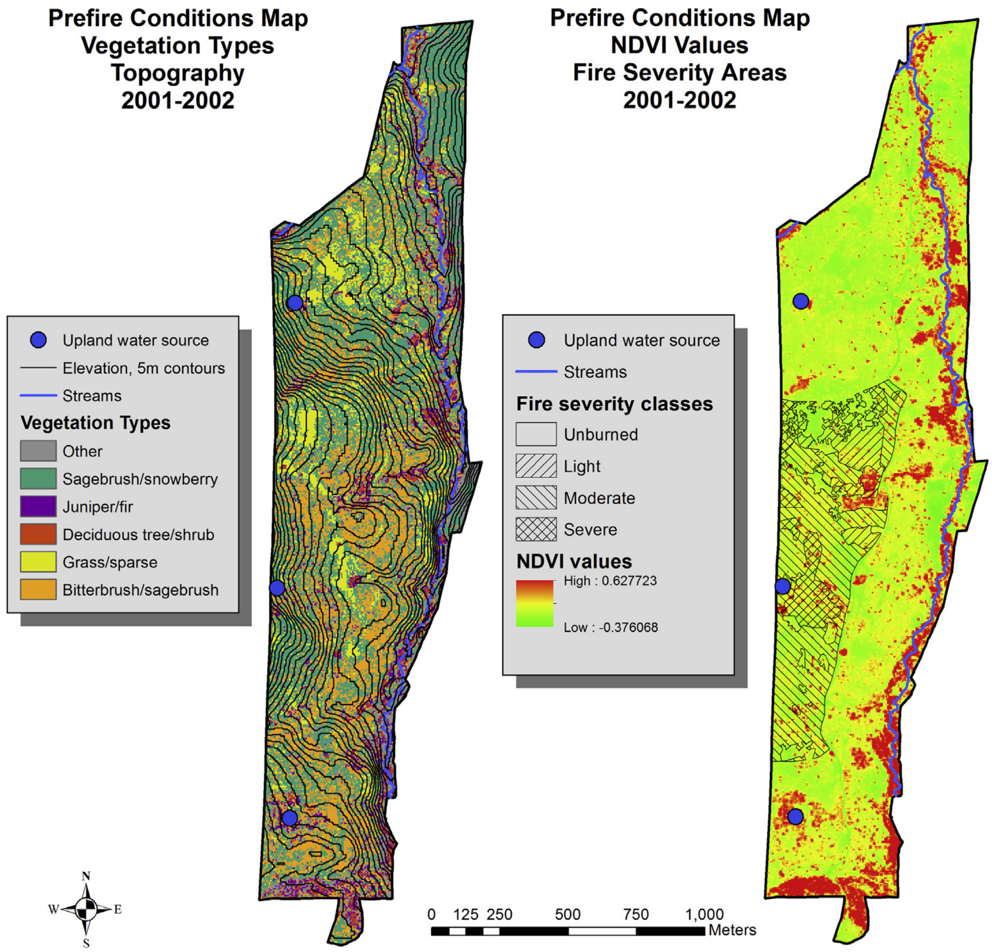

Fig. 1. A map (left) illustrating the dominant prefire vegetation (6 types) which occurred at the Breaks prescribed fire study area (176 ha) in the Owyhee Mountains of southwestern Idaho. This map (left) also includes an overlay of elevation contours (5-m intervals) illustrating study area topography. A second map (right) displaying Normalized Difference Vegetation Index (NDVI) or vegetation greenness values throughout the study area. The map on the right also illustrates the distribution of fire severity (4 classes) which occurred as a result of the Breaks prescribed fire (34 ha) on 24 September 2002.

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. Lö ve), 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.). When contrasted, the mountain big sagebrush-mountain snowberry type generally had the more herbaceous cover, both in the interspaces and under the shrub canopy than the antelope bitterbrush-mountain big sagebrush type (Clark unpublished data). 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.

Cattle had access to two perennial streams, Reynolds Creek and Dobson Creek, while in the study area. The riparian zones of both streams were dominated by a black cottonwood (*Populus balsamifera* L. ssp. *trichocarpa* [Torr. & A. Gray ex Hook.] Brayshaw) overstory, a peachleaf willow (*Salix amygdaloides* Andersson), redosier dogwood (*Cornus sericea* L. ssp. *sericea*), and rose (*Rosa woodsii* Lindl.) shrub layer, and a sedge (*Carex* spp.) and Kentucky bluegrass (*Poa pratensis* L.) understory. Small, dry meadows typically less than 0.25 ha in size and dominated by Kentucky bluegrass and rushes (*Junus* spp.) where located on the stream terrace and in upland swales. Willow (*Salix* spp.), quaking aspen (*Populus tremuloides* Michx.), and black cottonwood occurred as occasional, small clumps or groves (0.001–1 ha) near upland surface-water sources and in other upland areas where the water table was shallow. Occasional, small groves (1–2 ha) of Douglas-fir trees (*Pseudotsuga menziesii* [Mirb.] Franco) occurred in the southern end of the study area where the elevation was highest.

2.2. Fire treatment

About 34 ha of the central portion of the study area were burned during the Breaks prescribed fire conducted on 24 September 2002. 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 areas of low (6 ha), moderate (23 ha), and high (5 ha) fire severity (Fig. 1). About 6 ha of unburned areas also remained within the outer perimeter of the fire.

Unburned areas, inside and outside the fire perimeter represented 142 ha or 80.7% of the total pasture area. 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 in sparsely vegetated areas where fine fuels were limited and where stands of mature western juniper or aspen had sufficient canopy closure to exclude shrub and herbaceous understory thus limiting the amount of fuels, particularly ladder fuels, available to the fire. Polygon data for areas of low, moderate, and high fire severity as well as unburned areas within the fire perimeter were acquired immediately after the prescribed fire using a dual-channel GPS unit (Trimble Pro XRS, Trimble Navigation, Inc., Sunnyvale, California). These GPS data were post-differential corrected to an expected accuracy of ±0.73 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. Perennial forbs and grasses, particularly squirreltail, increased cover in formerly shrub-dominated areas during the first year postfire relative to prefire conditions. (Clark unpublished data). The resultant postfire landscape was a perennial grassland with occasional inclusions of unburned shrubs and trees. Areas dominated by bitterbrush or juniper prefire tended to contain persistent, burned shrub and tree skeletons postfire.

2.3. Cattle GPS tracking

During each of the 6 study years, 10 lactating, mature beef cows were randomly selected from a larger, total ranch population of about 750 cows. Starting 27 June 2001, the 10 selected cows of the year were fitted with GPS tracking collars (model 2200 LR: Lotek Wireless, Inc., New Market, Ontario, Canada) programmed to collect and store GPS locations every 10 min. These collared cows were then grazed with their suckling calves and 4 additional, uncollared cow–calf pairs for 15 days within the fenced study area. A second, 15-day prefire grazing trial was conducted with a new sample of 10 collared cows, their suckling calves, and 4 uncollared cow–calf pairs beginning 26 June 2002. Postfire, 15-day grazing trials were conducted in late June/early July of 2003, 2004, 2005, and 2007 using a combination of Lotek model 2200 LR GPS collars and Clark ATS+ GPS collars (Clark et al., 2006a). New, randomly-selected cattle were collared in each of these post-fire years. All trials generally started just after peak production for the dominant perennial grasses on the study area. A grazing trial was not conducted during 2006 because cattle were not available from the producer cooperator during that postfire year. Assuming each cow and her calf represented 1.15 metabolic animal unit equivalents (AUEs), the stocking rate in the pasture was about 0.091 AUEs ha^{-1} or 21.9 ha AUM^{-1} each trial. This is a very light stocking rate for mesic sagebrush steppe rangelands during mid-summer. Based on a 2014 review of allotment management plans in the region, we found the USDI Bureau of Land Management (BLM) typically stocks unburned, mesic sagebrush steppe at about 4–7 ha AUM^{-1} during mid-summer. 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 the first 2 postfire years. This postfire grazing-rest guideline is intended to allow burned vegetation to recover vigor before being grazed. This guideline is just that, a guideline not a strict rule or law, and it still awaits rigorous scientific evaluation on mesic sagebrush steppe and many other rangeland types. Consequently, our intent here was to use a very light stocking 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 GPS locations per collar varied among years due to equipment failures and malfunctions (Table 1). However, because collar malfunctions were random and not related to resource selection or cow movement (Nielson et al., 2009), differing cow sample sizes across years did not confound our results. Collar data sets 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 ±3.2 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. Complete behavioral independence among collared cows was not necessary for our resource selection analyses which were conducted using pooled data (see below). Nevertheless, confirmation of a high level of independence among cows was still important. An association 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. While a temporal threshold like ≥50% could have been used to define associations, we chose to use the ≥75% temporal threshold for a more conservative analysis. Our choice of the ≥75 m spatial separation threshold was based on the complexity of the terrain, vegetation patch size, and our expert opinion of their effects on typical line-of-sight distances between individual collared cattle. 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

Fire treatment and environmental effects on the probability of resource use by cattle were evaluated using the multiple regression

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 cow^{-1}	Minimum cow^{-1}
2001	7	14,750	2158	2002
2002	8	17,418	2203	2116
2003	4	8350	2112	2068
2004	10	21,489	2191	2070
2005	6	12,848	2161	2109
2007	4	6633	1955	1305

approach described by Sawyer et al. (2006, 2007, and 2009) and Nielson and Sawyer (2013). A generalized linear model (GLM; McCullagh and Nelder, 1989) was used as a resource selection probability function (RSPF; Manly et al., 2002) 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, and 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 model coefficients (Nielson and Sawyer, 2013; Manly, 2009).

Basically, our analysis approach consisted of 5 steps where we: 1) measured predictor variables at 1177 randomly-selected, circular plots with 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 RSPF model.

First, a set of 1350 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, 173 plots with center points located <50 m of the fence were removed from the selection leaving 1177 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 (Nielson and Sawyer, 2013). 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/sparse, deciduous tree/shrub (which combined aspen, cottonwood, and willow-dominated areas), juniper/fir, sagebrush/snowberry, or bitterbrush/sagebrush cover types in each plot were derived using a supervised classification of airborne hyperspectral imagery (5-m ground sample distance [GSD]) (Earth Search Sciences, Inc., Lakeside, Montana) acquired August 8, 2001. Mean and standard deviation values for the Normalized Difference Vegetation Index (NDVI) or vegetation greenness in each plot were also derived from the hyperspectral imagery. Postfire cover percentages for unburned and low, moderate, high, and burned (i.e., all fire severities combined) fire-severity classes in each plot were derived from the fire-severity polygons described above. Of the 1177 plots, 778 were entirely unburned, 1 was classified entirely as low fire severity, 3 as entirely moderate fire severity, 2 as entirely high fire severity, and the remaining 393 plots were a mixture of unburned and/or differing fire severities. Distance (m) to fences, trails, 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 centroids and these cultural linear and point features.

Each viable collar data set from each study year was then subset by randomly selecting 75% of the locations for RSFP model development and reserving the remaining 25% for model validation. The relative frequency of cattle use for each of the 1177 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 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):

$$\ln(E[l_i]) = \ln(total) + \beta_o + \beta_1 X_1 + \cdots + \beta_p X_p, \tag{1}$$

which is equivalent to

$$\ln(E[l_i/total]) = \ln(E[\text{Relative Frequency}_i]) = \beta_o + \beta_1 X_1 + \cdots + \beta_p X_p, \tag{2}$$

where, l_i is number of GPS locations within sampling unit i ($i = 1, 2, \ldots, 1177$), $total$ 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 (Manly et al., 2002) for the sample of animals.

An *a priori* set of 32, 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, trails, 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 4-variable, 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 high fire-severity polygon boundary (m) or moderate fire-severity cover (%), to the best fitting prefire model. The performance of these 5-variable models was evaluated for all 4 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 study years were evaluated using the 90% confidence intervals derived by bootstrapping for individual animals.

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., elevation + slope + distance to upland 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 data sets reserved from each animal for each study year. The number of GPS locations were 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.

An unbalanced, one-way analysis of variance (ANOVA) was conducted using a general linear model (GLM) to test for differences among years in cattle use (i.e., counts of GPS locations) of areas within 50 m of upland water sources. A similar GLM was used to test for differences in cattle use of areas within 50 m of perennial streams among years.

The GIS analyses were conducted using ARCGIS ArcMap 10.0 (ESRI, Redlands, California) and Geospatial Modelling Environment 0.7.2.0 (Spatial Ecology LLC, Glasgow, Scotland). All statistical analyses were performed in the R Language and Environment for Statistical Computing v3.0.0. Population-level RSPF model coefficients were reported as significant when bootstrapped 90% confidence intervals for coefficient estimates did not include zero. Statistical significance was reported at the 0.05 alpha level for the two ANOVA results.

The spatial scope of inference for this study is confined to the 176 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. Elevation, slope, NDVI standard deviation (i.e., variability in vegetation greenness at 5-m GSD), and distance to upland water sources were important factors affecting cattle

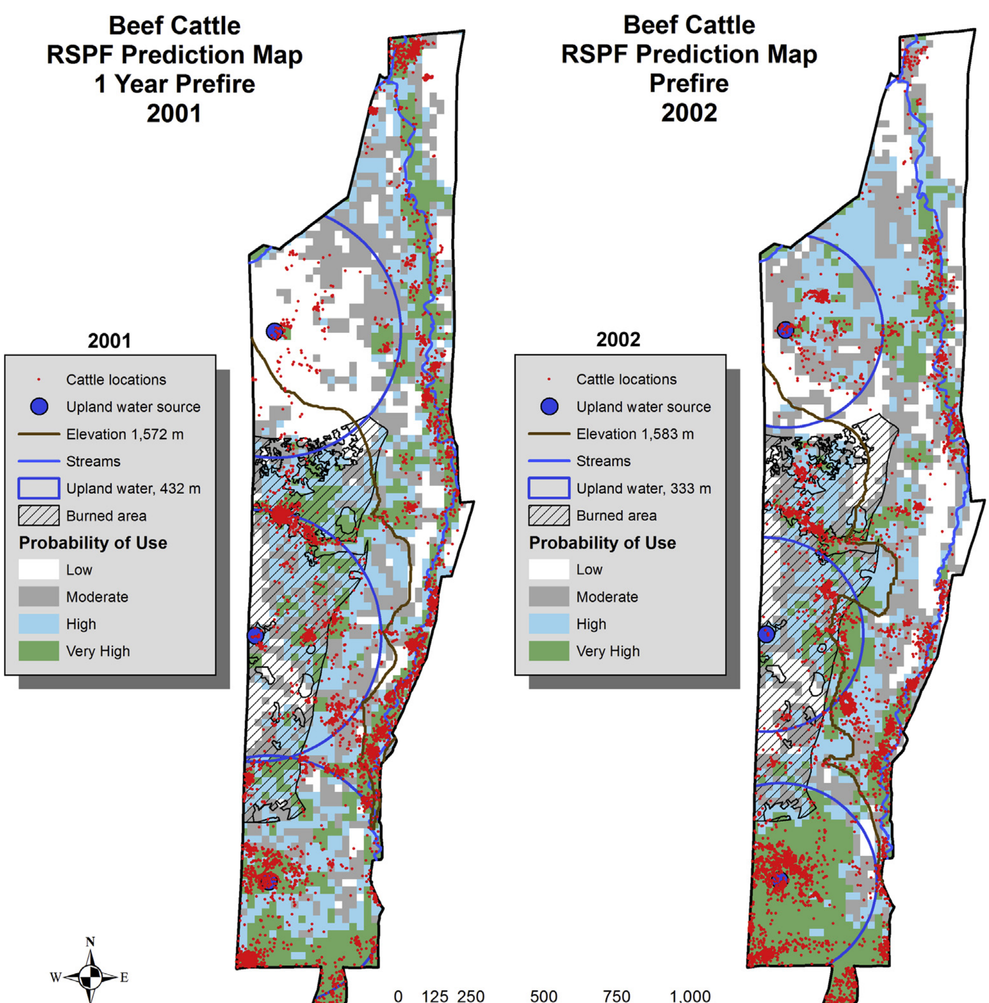

Fig. 2. Maps illustrating predicted cattle use patterns (Prefire), derived with a population-level resource selection probability function (RSPF), relative to burned areas and actual cattle GPS collar locations at the Breaks prescribed fire study area (176 ha) in the Owyhee Mountains of southwestern Idaho during 2001 (1 year prefire) and 2002 (prefire). Both maps display blue arcs representing the distance (m) at which the RSPF predicted cattle were most likely to be found from upland water sources during the respective years. Both maps also show the elevation (m), as a brown contour line, at which the RSPF predicted cattle were most likely to occur during each year. Red areas (dots) on the maps represent all the GPS-collared cattle locations used to develop or validate the respective RSPF models.

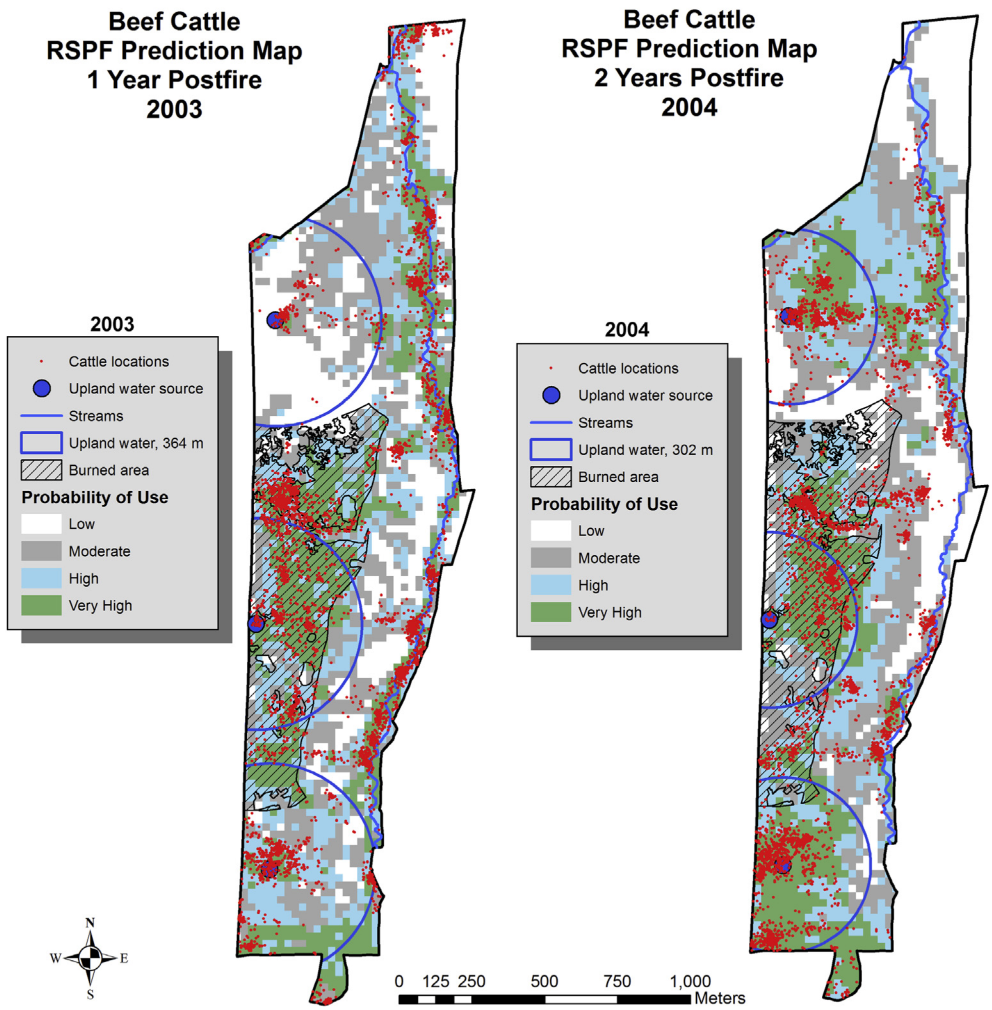

Fig. 3. Maps illustrating predicted cattle use patterns (Postfire), derived with a population-level resource selection probability function (RSPF), relative to burned areas and actual cattle GPS collar locations at the Breaks prescribed fire study area (176 ha) in the Owyhee Mountains of southwestern Idaho during 2003 (1 year postfire) and 2004 (2 years postfire). Both maps display blue arcs representing the distance (m) at which the RSPF predicted cattle were most likely to be found from upland water sources during the respective years. Red areas (dots) on the maps represent all the GPS-collared cattle locations used to develop or validate the respective RSPF models.

resource-selection patterns during both prefire years (Fig. 2). With each 10 m increase in elevation, the predicted level of cattle use increased by 7.85 and 6.19 percentage points during 2001 and 2002, respectively. Elevation in the study area tends to increase primarily from north to south (i.e., upstream) and, secondarily, from east to west as one moves perpendicularly from the stream (Reynolds Creek) into the uplands (Fig. 1). Areas with mean elevations of 1572 and 1583 m had the highest levels of predicted cattle use for 2001 and 2002, respectively (Table 3; Fig. 2). In both prefire years, these areas of highest predicted cattle use occurred at moderate elevations which were either near or above the median elevation of the study pasture (1573 m) but below the median elevation of burned areas (1606 m). Cattle use near the 1572 m elevation contour during 2001 occurred primarily along the upper (southern) section of Reynolds Creek (Fig. 2). In 2002, cattle use near the 1583 m contour mostly occurred along the eastern boundary of the prescribed fire (future) and near where Reynolds Creek entered the southern end of the study pasture.

With each degree increase in slope, the predicted level of cattle use during 2001 and 2002 decreased by 10.8 and 17.0 percentage points, respectively. Areas with mean slopes of 9.21° and 7.92° had the highest predicted level of use in 2001 and 2002, respectively (Table 3). Areas with relatively gentle slopes, ranging from 8 to 9°, tended to be prevalent and well dispersed across the uplands within the study area. In some cases, gentle terrain was actually less prevalent near streams than it was in the uplands (Fig. 1). For example, the southern section of the Reynolds Creek was confined within steep canyon walls. Stream terraces here were quite narrow (e.g., <50 m in width) and sparsely distributed along the stream. Prefire cattle use in the southern section tended to be concentrated on these narrow stream terraces. In the northern section of Reynolds Creek, the canyon was less confining and the stream terraces were broader and more prevalent than in the southern section. Near-stream cattle use in the northern section, occurred on both the gently sloping canyon walls and broad stream terraces and thus was more dispersed than in the southern section.

Areas with substantial, fine-scale variability in NDVI or greenness values were selected for by cattle prior to the fire. Prefire standard deviation of NDVI values (NDVI SD) ranged from 0.0231 to 0.276. With each 0.01 unit increase in NDVI SD, the predicted level of cattle use increased by 15.6 and 14.4 percentage points in 2001 and 2002, respectively. Areas with NDVI SD values of 0.163 and 0.145 had the highest predicted use in 2001 and 2002, respectively (Table 3). Areas with these relatively high NDVI SD values tended to

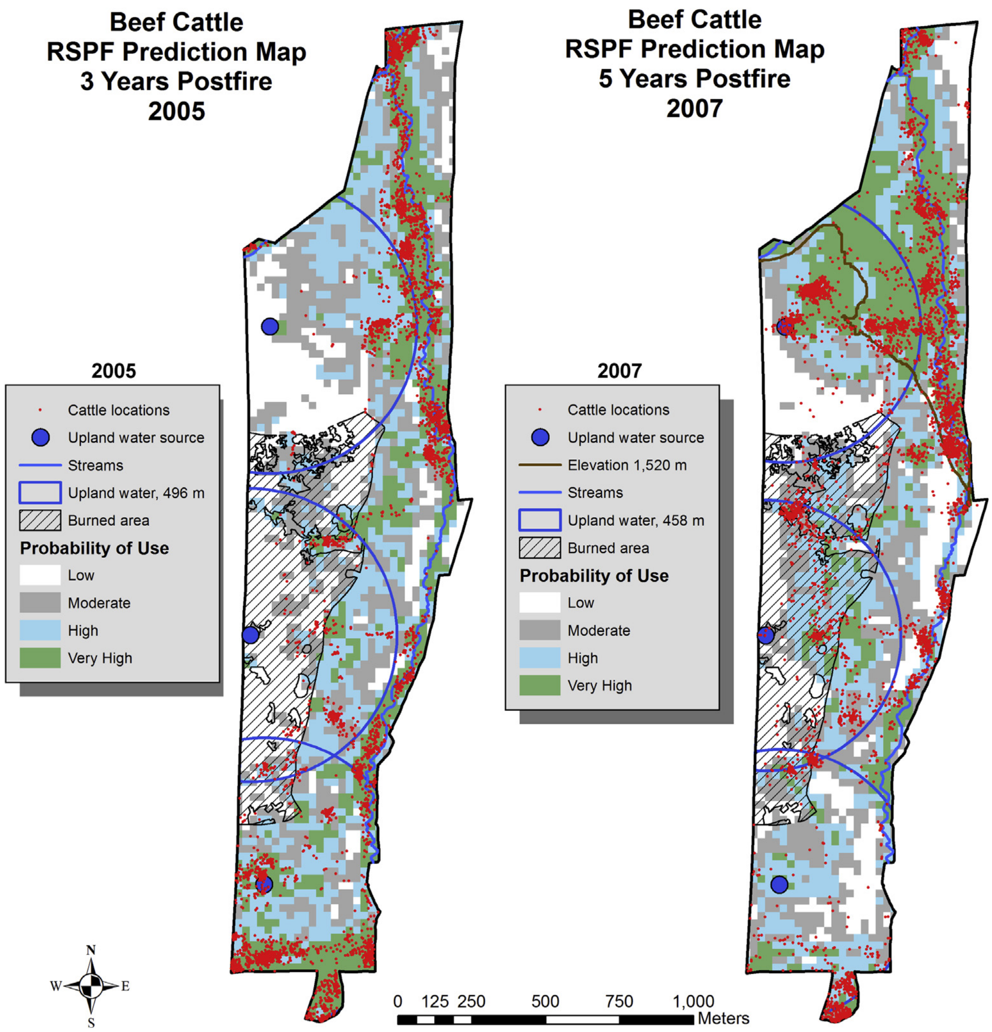

Fig. 4. Maps illustrating predicted cattle use patterns (Postfire), derived with a population-level resource selection probability function (RSPF), relative to burned areas and actual cattle GPS collar locations at the Breaks prescribed fire study area (176 ha) in the Owyhee Mountains of southwestern Idaho during 2005 (3 years postfire) and 2007 (5 years postfire). Both maps display blue arcs representing the distance (m) at which the RSPF predicted cattle were most likely to be found from upland water sources during the respective years. The map on the right also shows the elevation (m), as a brown contour line, at which the RSPF predicted cattle were most likely to occur during 2007. Red areas (dots) on the maps represent all the GPS-collared cattle locations used to develop or validate the respective RSPF models.

occur as a broken, linear band along the perennial streams where the green, leafy canopy of black cottonwood trees and riparian shrubs occurred immediately adjacent to the much sparser canopy of sagebrush-steppe plant communities occurring on the stream terraces and canyon slopes. Areas of high NDVI SD also occurred in the uplands as tight clumps near upland water sources and at the boundary of moist areas where the green canopies of quaking aspen, black cottonwood, Douglas-fir, and willow were immediately adjacent to sagebrush-steppe vegetation. It is useful to note, however, that the effects of NDVI SD on cattle resource selection were not collinear with the effects of upland water distance (Pearson $|r| < 0.60$).

There was some discrepancy between prefire years in how distance to upland water affected cattle resource selection. With each 100 m increase in distance from upland water sources, predicted cattle use increased by 8.96 percentage points in 2001 but decreased by 13.2 percentage points in 2002. Areas with a mean distance to upland water of 432 m and 333 m had the highest predicted use in 2001 and 2002, respectively (Table 3). Areas 432 m from upland water sources occurred as arcs which approached (e.g., <100 m) or crossed over Reynolds Creek (Fig. 2). Arcs representing areas 333 m from upland water sources generally occurred well up into the uplands except in the southern most portion of the study area where an arc approached to within 55 m of Reynolds Creek. Generally, cattle made somewhat greater use of upland areas (i.e., areas > 50 m from streams) and lesser use of near-stream areas during 2002 than 2001. About 78% of cattle GPS locations acquired during 2002 occurred in the uplands while 67% of locations occurred in the uplands during 2001.

Burned Cover, the fire-related factor in the model, did affect prefire cattle resource selection but the effect was fairly small and occurred during only one prefire year, 2001 (Table 2). In other words, during 2001 but not 2002, prefire conditions (e.g., fuel load, type, continuity, or moisture) which typically affect susceptibility to burning and fire severity (Sapsis and Kaufmann, 1991) appeared to increase cattle selectivity for areas later burned by fall prescribed fire. During 2001, with each percentage point increase in future burned cover, predicted cattle use increased by 0.440%. Areas which later had mean burned cover of 21.3% had the highest predicted cattle used during 2001 and these areas tended occur along

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 (2001 and 2002; Prefire) and for up to 5 years after (2003–2005 and 2007; 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)	Slope (deg)	NDVI[a] (SD)	Distance to upland water (m)	Burned cover[b] (%)
2001	β	**−19.1**[c]	**7.82E-3**	**−0.114**	**14.5**	**8.95E-4**	**4.39E-3**
	LCL	−24.6	4.93E-3	−0.140	14.1	5.68E-4	2.24E-3
	UCL	−14.3	0.0112	−0.0878	15.1	1.29E-3	6.44E-3
2002	β	**−14.5**	**6.18E-3**	**−0.186**	**13.5**	**−1.32E-3**	−7.50E-5
	LCL	−19.7	3.75E-3	−0.217	12.4	−1.91E-3	−1.75E-3
	UCL	−10.6	9.42E-3	−0.157	14.7	−7.40E-4	1.56E-3
2003	β	−2.83	−2.79E-3	**−0.0912**	**22.4**	**−1.81E-3**	**0.0233**
	LCL	−7.61	−4.67E-3	−0.114	21.2	−2.21E-3	0.0210
	UCL	0.188	1.43E-4	−0.0712	23.8	−1.24E-3	0.0245
2004	β	−2.61	−1.06E-3	**−0.167**	**11.7**	**−2.56E-3**	**9.37E-3**
	LCL	−6.94	−3.70E-3	−0.188	10.5	−2.81E-3	8.41E-3
	UCL	1.62	1.68E-3	−0.152	13.1	−2.27E-3	0.0105
2005	β	**−6.57**	−4.30E-4	**−0.186**	**24.8**	**4.96E-4**	**−4.74E-3**
	LCL	−8.83	−1.37E-3	−0.206	24.3	2.60E-4	−6.42E-3
	UCL	−5.01	9.61E-4	−0.171	25.4	7.55E-4	−2.79E-3
2007	β	**24.6**	**−0.0192**	**−0.122**	**11.8**	**−1.79E-3**	**0.0129**
	LCL	21.6	−0.0225	−0.127	9.87	−2.79E-3	0.0119
	UCL	29.7	−0.0172	−0.115	14.5	−1.08E-3	0.0140

[a] Standard deviation for Normalized Difference Vegetation Index (NDVI) values occurring within the 100-m dia. circular sample plots.
[b] Percentage of sample unit area classified as Burned during the prescribed fire on 24 September 2002.
[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 (2001 and 2002; Prefire) and for up to 5 years after (2003–2005 and 2007; 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)	NDVI[a] (SD)	Distance to upland water (m)	Burned Cover[b] (%)
2001	Very high	1572	9.21	0.163	432	21.3
	High	1580	10.2	0.114	407	37.0
	Moderate	1567	11.4	0.0980	421	18.7
	Low	1549	12.8	0.0650	353	11.9
2002	Very high	1583	7.92	0.145	333	NS[c]
	High	1570	8.77	0.102	385	NS
	Moderate	1557	11.4	0.103	421	NS
	Low	1557	15.5	0.090	465	NS
2003	Very high	NS	9.80	0.150	364	45.2
	High	NS	11.3	0.126	443	32.0
	Moderate	NS	10.4	0.0985	396	8.53
	Low	NS	12.0	0.0660	401	3.00
2004	Very high	NS	7.84	0.131	302	38.5
	High	NS	8.74	0.104	369	24.0
	Moderate	NS	11.6	0.104	423	17.7
	Low	NS	15.4	0.101	511	8.57
2005	Very high	NS	10.2	0.179	496	3.72
	High	NS	9.66	0.110	398	15.1
	Moderate	NS	9.70	0.0832	385	32.1
	Low	NS	14.0	0.0678	325	38.0
2007	Very high	1520	8.39	0.139	458	13.5
	High	1567	9.98	0.110	389	36.5
	Moderate	1581	11.3	0.105	410	23.1
	Low	1599	13.9	0.0853	348	15.8

[a] Standard deviation for Normalized Difference Vegetation Index (NDVI) values occurring within the 100-m dia. circular sample plots.
[b] Percentage of sample unit area classified as Burned during the prescribed fire on 24 September 2002.
[c] Effect was non-significant at the 0.05 alpha level.

the eastern and northern boundaries of the prescribed fire (Table 3).

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, burned cover was a dominant factor affecting cattle resource-selection patterns during all postfire years (Figs. 3–5). There was, however, some discrepancy among postfire years as how burning influenced cattle resource selection. The third postfire year, 2005, stands out as an oddity (Fig. 5). During 2003, 2004, and 2007, with each percentage

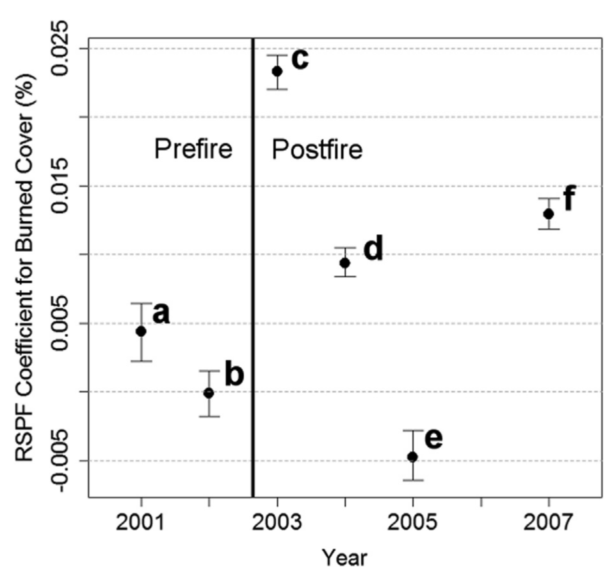

Fig. 5. Coefficient estimates for the Burned cover effect (i.e., the combined cover of all 3 burned fire severity classes) on population-level, cattle resource-selection responses among 6 study years and between prefire (2001–2002) and postfire (2003–2005 and 2007) periods where, differing letter labels indicate the 90% confidence intervals (bars) for the estimates did not overlap and the estimates were different.

point increase in burned cover, predicted cattle use increased by 2.36, 0.942, and 1.01 percentage points, respectively. Conversely, predicted cattle use during 2005 actually decreased by 0.473 percentage points with each percentage point increase in burned cover. Areas classified as having 45.2, 38.5, 3.72, and 13.5% burned cover had the highest predicted use in 2003, 2004, 2005, and 2007, respectively (Table 3). Strength of the burned-cover effect on cattle resource selection peaked during the first postfire year (2003) but then was substantially reduced during the second and fifth postfire year (Fig. 5). During the third postfire year (2005); however, cattle selectivity for burned areas was not only less than it had been during prefire but there was actually a tendency for cattle to avoid burned areas during 2005 (Fig. 4). Only 3.5% of cattle locations occurred in burned areas during 2005 in contrast to 15.9 and 10.8% of cattle locations occurring in these same areas during prefire years 2001 and 2002, respectively (Fig. 2). For comparison, during 2003, when cattle resource selection was most effected by burned cover, 27.7% of cattle locations occurred in burned areas (Fig. 3).

Contrary to its effect prior to burning, elevation was a significant predictor of cattle resource selection during only the fifth postfire year, 2007 (Table 2). In this postfire case, rather than increasing, predicted cattle use actually decreased by 1.67 percentage points with each 10 m increase in elevation. Areas with the highest predicted cattle use in 2007 occurred at a mean elevation of 1520 m which is considerably lower than the median elevations of both the study pasture (1573 m) and the burned areas (1606 m). These areas of highest predicted use occurred in the northern third of the study area and well north of the prescribed fire boundary (Table 3; Fig. 4).

Slope affected cattle resource selection during all postfire years (Table 2). Predicted cattle use decreased by 8.71, 15.4, 17.0, and 11.5 percentage points for each degree increase in slope during 2003, 2004, 2005, and 2007, respectively. Areas with mean slopes of 9.80, 7.84, 10.2, and 8.39° had the highest predicted cattle use in 2003, 2004, 2005, and 2007, respectively (Table 3). Areas with this range of relatively gentle slopes (i.e., 8–10°) were well distributed throughout the uplands and in riparian areas along the northern section of Reynolds Creek. Slopes along the southern section of Reynolds Creek were steeper due to confining canyon walls and resulting scarcity of the stream terraces.

During all postfire years, cattle tended to select for areas which had had substantial fine-scale variability in prefire NDVI or greenness. Predicted cattle use increased by 25.1, 12.4, 28.5, and 12.5 percentage points, for each 0.01 unit increase in the standard deviation of prefire NDVI, during 2003, 2004, 2005, and 2007, respectively. Areas with NDVI SD values of 0.150, 0.131, 0.179, and 0.139° had the highest predicted cattle use in 2003, 2004, 2005, and 2007, respectively (Table 3). Areas with NDVI SD values ranging from 0.130 to 0.180 tended to occur at the interface between stream riparian areas and drier upland plant communities and near upland water sources and moist areas.

Distance to upland water influenced cattle resource selection during all postfire years (Table 2). Upland water effects during the third postfire year (2005), however, differed from those occurring during the remaining postfire years. With each 100 m increase in distance from upland water sources, the probability of cattle use decreased by 18.1, 25.5, and 17.9% in 2003, 2004, and 2007, respectively, but increased by 4.96% in 2005. Areas 364, 302, 496, and 458 m from upland water source had the highest predicted cattle use in 2003, 2004, 2005, and 2007, respectively. These areas of highest use were located well up into the uplands in 2003 and 2004, for at least 2 of the 3 upland water sources (Fig. 3), but encompassed both upland and near-stream habitats (i.e., <50 m from perennial streams) during 2005 and 2007 (Fig. 4). Based on actual GPS tracking locations, cattle visited all 3 upland water sources in the study pasture during 2003 and 2004 (Fig. 3). In 2005, cattle upland watering visits were confined to the southern-most source and during 2007, primarily limited to the northern-most source (Fig. 4). The upland water source located within the burned area received little or no collared cattle visitation during 2005 and 2007.

3.3. Model validation

The final 5-variable model was validated for each study year using the randomly-selected and reserved subset (25%) of the location data acquired for each collared animal. Spearman rank correlations (r_s) calculated between the prediction-class ranking and animal-location counts within each class for prefire years 2001 and 2002 were 0.971 and 0.946, respectively. Spearman correlations for postfire year models 2003, 2004, 2005, and 2007 were 0.943, 0.952, 0.955, and 0.892, respectively. These consistently high Spearman scores indicate this single model was quite robust (Wiens et al., 2008) in accurately predicting cattle resource-selection responses to environmental variation and fire treatment effects for all 6 study years.

3.4. Actual cattle use near water

Counts of cattle GPS locations within 50 m of upland water sources represented 3.1 and 4.3% of total locations acquired during prefire years 2001 and 2002, respectively; and 5.0, 5.1, 3.0, and 2.0% of total locations acquired during postfire years 2003, 2004, 2005, and 2007, respectively. Based on the ANOVA involving all study years, actual cattle use near upland water sources did not differ between 2003 and 2004 ($P > 0.05$) but, in both cases, was higher than during years 2001 (prefire), 2005, and 2007. Cattle use near upland water during 2002 (prefire) did not differ from that of all other study year except 2007. It was noteworthy that cattle use within 50 m of upland water was greater during the first two postfire years (2003 and 2004) than at least one of the prefire years (2001).

Cattle location counts within 50 m of perennial streams represented 32.8 and 22.0% of total locations acquired during prefire years 2001 and 2002, respectively; and 36.2, 12.8, 39.8, and 36.6% of total locations acquired during postfire years 2003, 2004, 2005, and 2007, respectively. Actual cattle use of near perennial streams during years 2002 (prefire) and 2004 (postfire) did not differ ($P > 0.05$) but, in both cases, was lower than that of any remaining study year. No differences in near-stream use were detected among postfire years 2003, 2005, and 2007. Cattle use within 50 m of streams was higher during postfire year, 2005, than during prefire year, 2001.

Generally, these two ANOVA results indicated that as cattle use near upland water sources increased, use near perennial streams declined. This tendency was most clearly illustrated during the second year postfire (2004) when use within 50 m of upland water sources was among the highest levels of the study while use near perennial streams was at its lowest level.

4. Discussion

Fall prescribed fire influenced resource selection by mature, lactating beef cows on this mesic sagebrush-steppe rangeland for up to 5 years postfire. Research in other rangeland systems (e.g., Peek et al., 1979; Hobbs and Spowart, 1984; Coppedge and Shaw, 1998; Biondini et al., 1999; Van Dyke and Darragh, 2007) indicated selectivity by grazing animals for burned areas generally declines over time and becomes similar to prefire levels within 3–5 years after burning. At the Breaks study area, GPS-collared cattle exhibited their greatest selectivity for burned areas during the first postfire year (2003). Selectivity for burned areas declined somewhat during 2004 but remained elevated above prefire levels. By the third postfire year (2005), in agreement with the literature, cattle selectivity for burned areas substantially declined. In fact, selectivity for burned areas in 2005 was actually less than it had been during prefire. Five years after application of prescribed fire, however, cattle selectivity for burn areas was again elevated above prefire levels.

4.1. Response longevity

The summary above raises two obvious questions. First, if findings in the literature suggest burned areas are initially attractive to grazing animals but selectivity for these areas declines to prefire levels within 3–5 postfire years, then what caused cattle in this study to exhibit elevated selectivity for burned areas even after 5 years postfire? Second, the response during 2005 seems different from the other postfire years, did something anomalous happen during that year? We address the first question here and will address the second question in its own subsection below. Prescribed fire may enhance the quality (Hobbs and Spowart, 1984; Cook et al., 1994), quantity or production (Bates et al., 2009; Davies et al., 2012), palatability (Peek et al., 1979; Willms et al., 1980a), and accessibility (Blaisdell, 1953; Davies et al., 2012) of herbaceous forages. We suspect the increased selectivity for burned areas exhibited by cattle in our study was initially driven by fire-induced improvements in forage quality and palatability lasting 1–2 postfire years. Later, it is likely cattle selectivity for burned areas was principally driven by longer-term enhancements in forage production and accessibility lasting more than 5 years postfire.

Fire-induced improvements in forage quality and palatability of graminoid forages like bluebunch wheatgrass and squirreltail typically only last for 1–2 postfire years (Hobbs and Spowart, 1984; Willms et al., 1980a; Young and Miller, 1985). Fire removes accumulations of old, standing litter from bunchgrass plants; consequently, forage available from these burned plants during the first postfire growing season is generally of higher nutritional quality and palatability than forage from unburned plants. Prescribed fire, however, can dramatically increase shoot production in perennial grasses like squirreltail. During the first postfire year, burned squirreltail plants may produce 5 times more reproductive shoots or culms than unburned plants (Young and Miller, 1985). Without grazing, standing litter may rapidly begin to accumulate in burned bunchgrass plants following the first and second postfire growing seasons (Uresk et al., 1980). These litter accumulations can become self-perpetuating thus resulting in the formation of “wolf” plants or individual bunchgrass plants that are strictly avoided by grazing cattle and other ungulates because of heavy, standing litter accumulations (Ganskopp et al., 1992). Grazing during the first postfire year; however, depending on its timing and intensity, may remove a substantial proportion of the leaf material and reproductive culms produced during that growing season thus slowing re-accumulation of standing litter. Consequently, forage available from burned bunchgrass plants during the second postfire year may continue to be of higher nutritional quality and palatability than forage from unburned plants. Cattle can detect and avoid grazing bunchgrass plants with even a very limited accumulation of reproductive culms (Ganskopp et al., 1992, 1993). Hence, bunchgrass plants with little or no standing litter accumulations, due to removal by fire and/or grazing, will tend to be grazed and re-grazed by cattle while plants with some litter accumulation will be repeatedly avoided and continue to accumulate more standing litter (Ganskopp and Bohnert, 2006). Because of this patchy grazing behavior, even under moderate or moderately-heavy grazing, re-accumulation of standing litter will likely occur in a substantial proportion of burned bunchgrass plants and the nutritional quality and palatability of these forage plants will probably return to prefire levels on or before the third postfire growing season.

Sagebrush is competitive with bunchgrass forage species for nutrients (Caldwell et al., 1985, 1991) and soil moisture (Cook and Lewis, 1963; Seyfried and Wilcox, 2006). Fire reduces shrub and/or tree cover thereby decreasing competition and allowing increased production by forage species. Herbaceous forage production generally peaks 2–3 years postfire in burned sagebrush steppe communities (Bates et al., 2009, 2011; Davies et al., 2012). In some cases, bluebunch wheatgrass production may initially decline during the first postfire year relative to unburned plants (Mueggler and Blaisdell, 1958). By the 2nd postfire year, however, burned bluebunch wheatgrass plants in sagebrush communities can exhibit higher productivity through increased shoot production compared to unburned plants (Willms et al., 1980a). By 3 years postfire, bluebunch wheatgrass production in mesic sagebrush steppe may increase by more than 300% relative to prefire levels (Harniss and Murray, 1973). At some sites, perennial grass cover on burned sagebrush steppe can remain elevated above that of adjacent unburned areas for at least 7–8 years postfire (Wambolt et al., 2001). Long-term increases in perennial grass biomass are likely associated with these fire-induced increases in grass cover. In our study, elevated cattle selectivity for burned areas more than 5 years postfire suggests these cattle may have been responding, at least in part; to long-term increases in bunchgrass forage production.

Fire in sagebrush steppe can completely consume shrub and tree canopies and/or it can reduce the size and interconnectivity of these canopies (Sapsis and Kaufmann, 1991). In areas where the prefire shrub and tree canopies are dense enough to substantially inhibit cattle movement, fire-induced removal or reduction of this inhibiting vegetation structure can potentially influence cattle resource selection. Prior to burning, a dense canopy of bitterbrush dominated much of the uplands within the Breaks study area (Fig. 1). Prefire reconnaissance indicated this vegetation was stiff and unyielding enough that cattle movement through it was largely limited to just a few established trails bisecting the area. Foraging opportunities within these dense bitterbrush stands were quite limited. The Breaks prescribed fire greatly reduced the bitterbrush canopy (Clark, unpublished data) thereby opening up many new movement corridors and foraging areas within the burned areas. Postfire recovery of shrub canopies in sagebrush steppe generally requires many years to several decades to occur (Wambolt et al., 2001; Baker, 2006; Lesica et al., 2007). Consequently, the new movement corridors and foraging areas opened up by fire on our study area remained available to cattle for more than 5 years postfire. Close examination of Figs. 1–3 provides confirmation that collared cattle did indeed respond to increased accessibility to areas formerly dominated by dense bitterbrush stands. Looking at the prefire vegetation type map in Fig. 1, the reader can identify a large bitterbrush stand (coded in orange) near the geographic center of the study area. If the reader then identifies this same general area in the RSPF maps of Fig. 2, few actual cattle locations (red dots) will be noted in this area during the prefire years. A comparison to the postfire RSPF maps of Fig. 3, reveals many, well-dispersed cattle locations across this formerly bitterbrush-dominated area. The reader will also note that most of this area is now classified by the RSPF model as has having the greatest level predicted cattle use (i.e., “Very High”) for both postfire years 2003 and 2004. These fire-induced increases in availability and accessibility of new foraging areas, combined with the increases in forage production discussed above, likely explain why cattle selectivity for burned areas remained elevated for more than 5 years postfire at Breaks.

4.2. An anomalous year – 2005

Avoidance of burned areas by collared cattle at Breaks during the third postfire year, 2005, was unexpected and inconsistent relative to the other postfire years. This inconsistency may be related to substantial differences in growing season precipitation and forage production which existed between 2005 and the other postfire years. Precipitation in May and June of 2005 was greater than that of any other study year (NWRC, 2014) (Fig. 6). Graminoid production in burned and unburned upland areas at Breaks during 2005 was generally more than twice that of 2003 and 2004 (Fig. 6). In 2005, graminoid biomass samples, particularly in burned areas, contained considerably more bunchgrass culms and inflorescences than any other study year (Clark unpublished data). Furthermore, the month of July 2005 was the driest July of the entire study which likely caused forages on these relatively coarse-textured soils to senesce and become less palatable more rapidly than during the other postfire years. As noted above, utilization of bunchgrass forages decreases relative to increasing presence of reproductive culms (Ganskopp et al., 1992, 1993) and standing litter accumulations (Ganskopp and Bohnert, 2006). Given the dry, wolfy condition of upland forages in both burned and unburned areas during 2005, it is likely that foraging cattle tended to avoid the uplands and fed primarily in stream riparian areas of Reynolds Creek where Kentucky bluegrass and sedges were still green and palatable. These differences in precipitation and forage conditions would explain why collared cattle shifted from selecting for burned areas during postfire years 2003 and 2004, to avoiding burned areas and the uplands altogether in 2005, and then back to selecting for burned areas 5 years postfire in 2007.

4.3. Mid-summer vs. spring grazing

The cattle resource-selection response to prescribed burning at the Breaks study areas under mid-summer (July) grazing (Fig. 5) differed somewhat from the selectivity exhibited cattle during a study at the nearby Whiskey Hill study area under a spring (May) grazing regime (see Clark et al., 2014). At Whiskey Hill, GPS-collared cattle selectivity for burned areas during the first postfire year was higher that it had been prefire but selectivity did not peak during that first year as it did at Breaks. Instead, cattle selectivity for burned areas at Whiskey Hill was highest and similar during the second, third, and fourth postfire years (Clark et al., 2014). Cattle selectivity for burned areas at Whiskey Hill attenuated during the fifth postfire year but at both Breaks and Whiskey Hill, selectivity 5 years postfire was still higher than prefire.

Differences between Breaks and Whiskey Hill in terms of the strength and temporal attenuation patterns of cattle selectivity for burned areas are likely related to the difference in phenological timing of grazing between these two study areas. Grazing at Breaks occurred in July when forages such as bluebunch wheatgrass were in the seed-formation to seed-ripened phenological stages. Consequently, even under a sustained, moderate level of grazing intensity, cattle at Breaks, prior to the prescribed fire, were confronted with bunchgrass forages that contained an accumulation of reproductive culms from both the current and previous years' growth. Prescribed fire substantially reduced the wolfiness of these forages by removing this accumulation of reproductive culms and other standing litter. As described above, however, this reduction in wolfiness probably did not last into the second postfire year (2004). Grazing with very light cattle stocking rates during late phenological stages likely promoted selective foraging behavior which allowed ungrazed culms to accumulate in bunchgrass forages, beginning during the first postfire grazing season. Consequently, cattle selectivity for burned areas at Breaks was strongest during the first postfire year, when forage palatability was highest, but substantially declined during later postfire years as the wolfiness of the burned forages increased.

Grazing at Whiskey Hill occurred in May when bluebunch wheatgrass was in the boot to inflorescence-emergence phenological

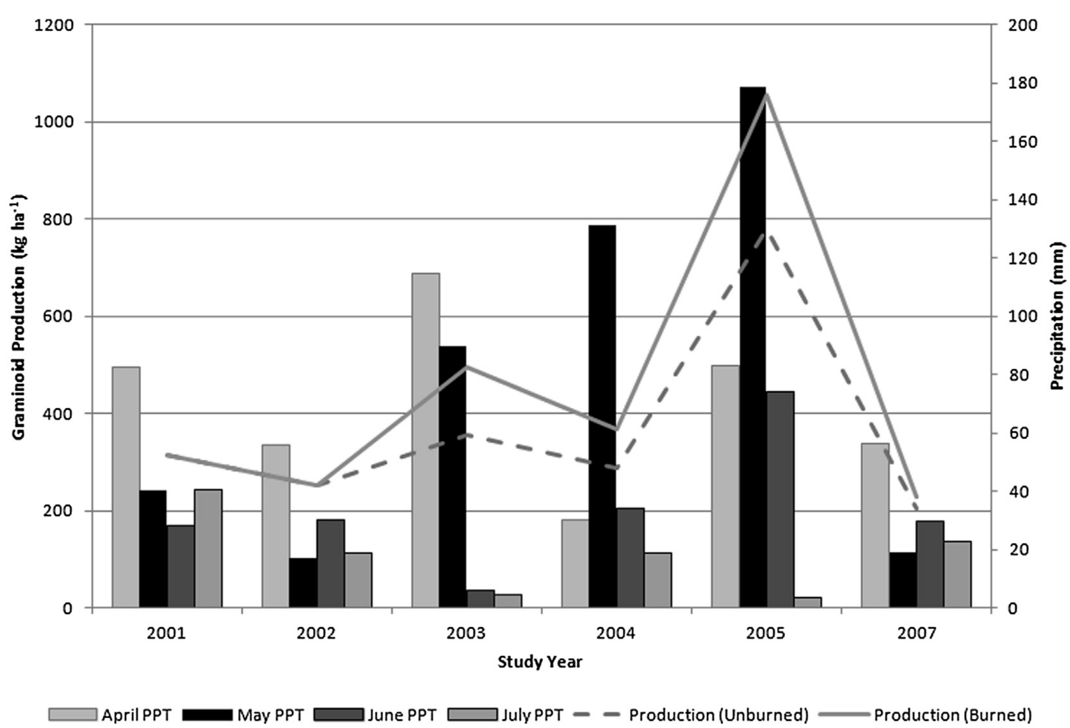

Fig. 6. Graminoid biomass production (kg ha^{-1}) in the burned and unburned areas relative to monthly growing season (April–July) precipitation (mm) for study years 2001–2005 and 2007 at the Breaks prescribed fire study area (176 ha) in the Owyhee Mountains of southwestern Idaho.

stages (Clark et al., 2014). During prefire years, bunchgrass forages contained some reproductive culms from previous years' growth but culms from the current year were not yet present when cattle were grazed in May. Consequently, the wolfiness of forages at Whiskey Hill was less pronounced than at Breaks. Prescribed fire at Whiskey Hill did initially reduce the amount of residual reproductive culms in bunchgrass forages but the sustained strength of cattle selectivity for burned areas seems to be driven more by longer term, fire-induced increases in forage availability and accessibility than by increases in palatability.

4.4. Other factors affecting cattle resource selection

Elevation affected cattle resource selection at Breaks during both prefire years but not during any of the postfire years except the fifth year (Fig. 2). Significance of elevation as a factor in the prefire RSPF models was likely due to heavy concentrations of prefire cattle use at the highest elevations in the pasture (i.e., in SE corner). Cattle tended to use aspen and Douglas-fir stands in this corner of the pasture for bedding and rumination activities and thus spent a great deal of time there. During the first two postfire years (2003 and 2004), the influence exerted by elevation during prefire was eclipsed by fire-related effects (Fig. 3). Cattle use of the highest elevations, consequently, decreased somewhat in 2003 and 2004 while use in burned areas with moderate elevations increased. The strongest elevation effect of the entire study occurred during the fifth postfire year (2007). Cattle used a much narrower range of elevations during 2007 than any other study year. Although a fire-effect was evident in 2007, there was a general northward shift in cattle use, towards the lowest elevations in the study pasture, during that year. Air temperatures during 2007 were the highest of all study years. Data collected as part of an air temperature mapping study (Clark et al., 2006b) indicated, despite their relatively low elevation, the uplands in the northern 1/3 of the pasture tended to have the lowest maximum daily air temperatures in the study area. These northern uplands occurred at the confluence of two major drainages. Converging airflow from these drainages may have made these uplands cooler than other areas. Under high ambient temperatures, range cattle will tend to seek out and occupy the coolest areas available to them (Smith, 2006). Consequently, it is likely that cattle in 2007 were responding to a favorable convergence in topography that made the northern uplands a cooler place to be during hot days.

A number of studies have concluded that cattle use levels tend to decline with increasing slope (Mueggler, 1965; Cook, 1966; Gillen et al., 1984; Ganskopp and Vavra, 1987). Consistent with these earlier reports, cattle use at Breaks during all study years decreased as slopes became steeper. Managers are often interested in whether prescribed fire in the uplands can entice cattle to use steeper slopes than they would otherwise use. We did not find a distinct difference in slope use between prefire and postfire. Our study area was not well suited, however, for evaluating the effects on upland fire on cattle slope use. Slopes in the burned areas ranged from 0 to 33° with a mean of 12° while slopes ranged from 0 to 47° with a mean of 11° in the unburned portion of the study area. About 90% of the steepest slopes (>25°) in the study area were located in unburned areas. Consequently, there really was not any fire-related incentive for cattle to use steeper slopes because most of the steep slopes were located in unburned rather than burned areas.

While NDVI-SD was a significant factor in the cattle RSFP model during all study years, NDVI-SD effect sizes were largest during postfire years 2003 and 2005. According to the ANOVA, actual cattle use near (<50 m) perennial streams was also among the highest levels during 2003 and 2005. Consequently, increased NDVI-SD effect sizes during 2003 and 2005 are likely related to increased cattle use of near-stream habitats. Cattle are attracted to near-stream areas and other habitats with high NDV-SD because they typically offer a desirable combination of nearby shade, green forage, and drinking water. During 2003, it appears that even though cattle were strongly attracted to the uplands by the prescribed fire, their resource-selection patterns were still being partially shaped by the attractiveness of near-stream habitats. During 2005, as discussed above, excessively wolfy upland forages, in both burned and unburned areas, likely promoted increased cattle use of near-stream habitats and, in turn, increased NDVI-SD effect size.

Excessive cattle occupation of near-stream areas can adversely impact riparian vegetation, stream-water quality, and other critical resources (Kauffman and Krueger, 1984). Existence of drinking water sources in the uplands can reduce the need for cattle to go to perennial streams to drink (Bailey, 2004). Many studies have shown distance to upland water sources affects cattle distribution patterns (e.g., Cook, 1966; Ganskopp, 2001; Porath et al., 2002; Valentine, 1947). In our study, distance to upland water sources had its largest effect on cattle resource selection during the second postfire year (2004). Conventional wisdom suggests if prescribed-fire treatments attract cattle to the uplands and if sufficient upland water sources are present near burned areas to allow cattle to remain there more or less indefinitely, then cattle use of perennial streams as drinking water sources and riparian zones as foraging areas should substantially decrease postfire. Based on our ANOVA, cattle use within 50 m of upland water sources at Breaks increased during postfire years 2003 and 2004 relative to at least one prefire year (2001). A corresponding reduction in cattle use within 50 m of perennial streams, however, only occurred during 2004. In this study, consequently, it appears the attractiveness of the burned area to cattle, combined with ready availability of upland water, only exceeded the attractiveness of near-stream habitats during the second postfire year, 2004.

4.5. Management implications

This was a case study; consequently, the scope of inference was limited to the Breaks study area and this ranch-level population of cattle. Additional research in other study areas within the sagebrush steppe is needed to broaden the applicability of this information. Nevertheless, our findings demonstrate fall prescribed fire can be effective for managing cattle distribution in mesic sagebrush-steppe landscape under a mid-summer (July) grazing regime. Results regarding the longevity of prescribed-fire effects on cattle resource selectivity seem to be less clear-cut under this mid-summer grazing study than under a nearby study conducted during spring (May). Burned areas grazed during mid-summer when forage bunchgrasses are in the seed-formation to seed-ripe phenological stages may be less attractive to cattle than when grazed during spring when forages are in the boot to inflorescence-emergence stages. Differing phenological timing of grazing can contribute to differing rates of postfire accumulation of standing litter and consequent impacts on bunchgrass forage palatability which would likely explain differences in the nature of fire effects on cattle behavior observed between these two studies. Despite this palatability disadvantage, however, the present study demonstrated cattle resource-selection patterns under a mid-summer grazing regime can be influenced by prescribed fire even after 5 years postfire.

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References

Augustine, D.J., Derner, J.D., Milchunas, D.G., 2010. Prescribed fire, grazing, and herbaceous plant production in shortgrass steppe. Rangel. Ecol. Manag. 63, 317–323.
Bailey, D.W., 1995. Daily selection of feeding areas by cattle in homogeneous and heterogeneous environments. Appl. Anim. Behav. Sci. 45, 183–200.
Bailey, D.W., 2004. Management strategies for optimal grazing distribution and use of arid rangelands. J. Anim. Sci. 82, E147–E153.
Bailey, D.W., 2005. Identification and creation of optimal habitat conditions for livestock. Rangel. Ecol. Manag. 58, 109–118.
Baker, W.L., 2006. Fire and restoration of sagebrush ecosystems. Wildl. Soc. Bull. 34, 177–185.
Bates, J.D., Davies, K.W., Sharp, R.N., 2011. Shrub-steppe early succession following juniper cutting and prescribed fire. Environ. Manag. 47, 468–481.
Bates, J.D., Rhodes, E.C., Davies, K.W., Sharp, R., 2009. Postfire succession in big sagebrush steppe with livestock grazing. Rangel. Ecol. Manag. 62, 98–110.
Biondini, M.E., Steuter, A.A., Hamilton, R.G., 1999. Bison use of fire-managed remnant prairies. J. Range Manag. 52, 454–461.
Blaisdell, J.P., 1953. Ecological Effects of Planned Burning of Sagebrush-grass Range on the Upper Snake River Plains. USDA Technical Bulletin No.1075. U.S. Department of Agriculture, Washington, D.C.
Boyce, M.S., Vernier, P.R., Nielsen, S.E., Schmiegelow, F.K.A., 2002. Evaluating resource selection functions. Ecol. Model. 157, 281–300.
Brooks, M.L., D'Antonio, C.M., Richardson, D.M., Grace, J.B., Keeley, J.E., DiTomaso, J.M., Pellant, M., Pyke, D., 2004. Effects of invasive alien plants on fire regimes. Bioscience 54, 677–688.
Burkhardt, J.W., Tisdale, E.W., 1976. Causes of juniper invasion in southwestern Idaho. Ecology 57, 472–484.
Burnham, K.P., Anderson, D.R., 2002. Model Selection and Multimodel Inference: a Practical Information-theoretic Approach, second ed. Springer-Verlag, New York, NY.
Caldwell, M.M., Eissenstat, D.M., Richards, J.H., 1985. Competition for phosphorus: differential uptake from dual-isotope-labeled soil interspaces between shrub and grass. Science 229, 384–386.
Caldwell, M.M., Manwaring, J.H., Jackson, R.B., 1991. Exploitation of phosphate from fertile soil microsites by three Great Basin perennials when in competition. Funct. Ecol. 5, 757–764.
Chambers, J.C., Roundy, B.A., Blank, R.R., Meyer, S.E., Whittaker, A., 2007. What makes Great Basin sagebrush ecosystems invasible by Bromus tectorum? Ecol. Monog. 77, 117–145.
Christensen, N.L., 1985. Shrubland fire regimes and their evolutionary consequences. In: Pickett, S.T.A., White, P.S. (Eds.), The Ecology of Natural Disturbance and Patch Dynamics. Academic Press, Inc., New York, pp. 85–100.
Clark, P.E., Johnson, D.E., Kniep, M.A., Huttash, B., Wood, A., Johnson, M.D., McGillivan, C., Titus, K., 2006a. An advanced, low-cost, GPS-based animal tracking system. Rangel. Ecol. Manag. 59, 334–340.
Clark, P.E., Johnson, D.E., Harris, N., Thomas, D.R., 2006b. Low-cost radiation shielding for use in mapping the thermal environments of rangeland animals. Rangel. Ecol. Manag. 59, 674–679.
Clark, P.E., Lee, J., Ko, K., Nielson, R.M., Johnson, D.E., Ganskopp, D.C., Chigbrow, J., Pierson, F.B., Hardegree, S.P., 2014. Prescribed fire effects on resource selection by cattle in mesic sagebrush steppe. Part 1: spring grazing. J. Arid Environ. 100–101, 78–88.
Cook, C.W., 1966. Factors affecting utilization of mountain slopes by cattle. J. Range Manag. 19, 200–204.
Cook, C.W., Lewis, C.E., 1963. Competition between big sagebrush and seeded grasses on foothill ranges in Utah. J. Range Manag. 16, 245–250.
Cook, J.G., Hershey, T.J., Irwin, L.L., 1994. Vegetation response to burning on Wyoming mountain-shrub big game ranges. J. Range Manag. 47, 296–302.
Coppedge, B.R., Shaw, J.H., 1998. Bison grazing patterns on seasonally burned tallgrass prairie. J. Range Manag. 51, 258–264.
D'Antonio, C.M., Vitousek, P.M., 1992. Biological invasions of exotic grasses, the grass/fire cycle, and global change. Annu. Rev. Ecol. Syst. 23, 63–87.
Davies, K.W., Bates, J.D., Nafus, A.M., 2012. Comparing burned and mowed treatments in mountain big sagebrush steppe. Environ. Manag. 50, 451–461.
Ganskopp, D., 2001. Manipulating cattle distribution with salt and water in large arid-land pastures: a GPS/GIS assessment. Appl. Anim. Behav. Sci. 73, 251–262.
Ganskopp, D., Angell, R., Rose, J., 1992. Response of cattle to cured reproductive stems in a caespitose grass. J. Range Manag. 45, 401–404.
Ganskopp, D., Angell, R., Rose, J., 1993. Effect of low densities of senescent stems in crested wheatgrass on plant selection and utilization by beef cattle. Appl. Anim. Behav. Sci. 38, 227–233.
Ganskopp, D., Bohnert, D., 2006. Do pasture-scale nutritional patterns affect cattle distribution on rangelands? Rangel. Ecol. Manag. 59, 189–196.
Ganskopp, D., Vavra, M., 1987. Slope use by cattle, feral horses, deer, and bighorn sheep. Northwest Sci. 61, 74–81.
Gillen, R.L., Krueger, W.C., Miller, R.F., 1984. Cattle distribution on mountain rangeland in northeastern Oregon. J. Range Manag. 37, 549–553.
Hanson, C.L., 2001. Long-term precipitation database, Reynolds creek experimental watershed, Idaho, United States. Water Resour. Res. 37, 2831–2834.
Hanson, C.L., Marks, D., Van Vactor, S.S., 2001. Long-term climate database, Reynolds creek experimental watershed, Idaho, United States. Water Resour. Res. 37, 2839–2841.
Harniss, R.O., Murray, R.B., 1973. 30 years of vegetal change following burning of sagebrush-grass range. J. Range Manag. 26, 322–325.
Harris, N.R., Johnson, D.E., McDougald, N.K., George, M.R., 2007. Social associations and dominance of individuals in small herds of cattle. Rangel. Ecol. Manag. 60, 339–349.
Hobbs, N.T., Spowart, R.A., 1984. Effects of prescribed fire on nutrition of mountain sheep and mule deer during winter and spring. J. Wildl. Manag. 48, 551–560.
Howery, L.D., Provenza, F.D., Banner, R.E., Scott, C.B., 1996. Differences in home range and habitat use among individuals in a cattle herd. Appl. Anim. Behav. Sci. 49, 305–320.
Howery, L.D., Provenza, F.D., Banner, R.E., Scott, C.B., 1998. Social and environmental factors influence cattle distribution on rangeland. Appl. Anim. Behav. Sci. 55, 231–244.
Kauffman, J.B., Krueger, W.C., 1984. Livestock impacts on riparian ecosystems and streamside management implications…a review. J. Range Manag. 37, 430–438.
Keane, R.E., Cary, G.J., Davies, I.D., Flannigan, M.D., Gardner, R.H., Lavorel, S., Lenihan, J.M., Li, C., Rupp, T.S., 2004. A classification of landscape fire succession models: spatial simulations of fire and vegetation dynamics. Ecol. Model. 179, 3–27.
Klop, E., van Goethem, J., de Iongh, H.H., 2007. Resource selection by grazing herbivores on post-fire regrowth in a West African woodland savanna. Wildl. Res. 34, 77–83.
Lesica, P., Cooper, S.V., Kudray, G., 2007. Recovery of big sagebrush following fire in southwestern Montana. Rangel. Ecol. Manag. 60, 261–269.
Loza, H.J., Grant, W.E., Stuth, J.W., Forbes, T.D.A., 1992. Physiological based landscape use model for large herbivores. Ecol. Model. 61, 227–252.
Manly, B.F.J., 2009. Statistics for Environmental Science and Management, second ed. CRC Press, New York, NY.
Manly, B.F.J., McDonald, L., Thomas, D., McDonald, T., Erickson, W., 2002. Resource Selection by Animals: Statistical Design and Analysis for Field Studies, second ed. Kluwer Academic Publishers, Boston, MA.
McCullagh, P., Nelder, J.A., 1989. Generalized Linear Models, second ed. Chapman and Hall, Boca Raton, FL.
Miller, R.F., Wigand, P.E., 1994. Holocene changes in semiarid pinyon-juniper woodlands. Bioscience 44, 465–474.
Miller, R.F., Rose, J.A., 1999. Fire history and western juniper encroachment in sagebrush steppe. J. Range Manag. 52, 550–559.
Miller, R.F., Svejcar, T., Rose, J.A., 2000. Impacts of western juniper on plant community composition and structure. J. Range Manag. 53, 574–585.
Mueggler, W.F., 1965. Cattle distribution on steep slopes. J. Range Manag. 18, 255–257.
Mueggler, W.F., Blaisdell, J.P., 1958. Effects on associated species of burning, rotobeating, spraying, and railing sagebrush. J. Range Manag. 11, 61–66.
Nielson, R.M., Manly, B.F.J., McDonald, L.L., Sawyer, H., McDonald, T.L., 2009. Estimating habitat selection when GPS fix success is less than 100%. Ecology 90, 2956–2962.
Nielson, R.M., Sawyer, H., 2013. Estimating resource selection with count data. Ecol. Evol. 3, 2233–2240.
Noson, A.C., Schmitz, R.A., Miller, R.F., 2006. Influence of fire and juniper encroachment on birds in high-elevation sagebrush steppe. West. N. Am. Nat. 66, 343–353.
NWRC, 2014. Public Database for the Reynolds Creek Experimental Watershed. Northwest Watershed Research Center, U.S. Department of Agriculture, Agricultural Research Service, Boise, Idaho. Available at: ftp://ftp.nwrc.ars.usda.gov/publicdatabase/reynolds-creek/ (accessed 22.01.14.).
Peek, J.M., Riggs, R.A., Lauer, J.L., 1979. Evaluation of fall burning on bighorn sheep winter range. J. Range Manag. 32, 430–432.
Pierson, F.B., William, C.J., Hardegree, S.P., Clark, P.E., Kormos, P.R., Al-Hamdan, O.Z., 2013. Hydrologic and erosion responses of sagebrush steppe following juniper encroachment, wildfire, and tree cutting. Rangel. Ecol. Manag. 66, 274–289.
Pierson, F.B., William, C.J., Kormos, P.R., Hardegree, S.P., Clark, P.E., Rau, B.M., 2010. Hydrologic vulnerability of sagebrush steppe following pinyon and juniper encroachment. Rangel. Ecol. Manag. 63, 614–629.
Pinchak, W.E., Smith, M.A., Hart, R.H., Waggoner Jr., J.W., 1991. Beef cattle distribution patterns on foothill range. J. Range Manag. 44, 267–275.
Porath, M.L., Momont, P.A., DelCurto, T., Rimbey, N.R., Tanaka, J.A., McInnis, M., 2002. Offstream water and trace mineral salt as management strategies for improved cattle distribution. J. Anim. Sci. 80, 346–356.
Roath, L.R., Krueger, W.C., 1982. Cattle grazing and behavior on a forested range. J. Range Manag. 35, 332–338.
Sapsis, D.B., Kaufmann, J.B., 1991. Fuel consumption and fire behavior associated with prescribed fires in sagebrush ecosystems. Northwest Sci. 65, 173–179.
Sawyer, H., Nielson, R.M., Lindzey, F., McDonald, L.L., 2006. Winter habitat selection of mule deer before and during development of a natural gas field. J. Wildl. Manag. 70, 396–403.
Sawyer, H., Nielson, R.M., Lindzey, F.G., Keith, L., Powell, J.H., Abraham, A.A., 2007. Habitat selection of Rocky Mountain elk in a nonforested environment. J. Wildl. Manag. 71, 868–874.
Sawyer, H., Kauffman, M.J., Nielson, R.M., 2009. Influence of well pad activity on

winter habitat selection patterns of mule deer. J. Wildl. Manag. 73, 1052–1061.
Senft, R.L., Rittenhouse, L.R., Woodmansee, R.G., 1985. Factors influencing patterns of cattle grazing behavior on shortgrass steppe. J. Range Manag. 38, 82–87.
Seyfried, M.S., Harris, R., Marks, D., Jacob, B., 2001. Geographical database, Reynolds creek experimental watershed, Idaho, United States. Water Resour. Res. 37, 2825–2829.
Seyfried, M.S., Wilcox, B.P., 2006. Soil water storage and root depth: key factors controlling recharge on rangelands. Hydrol. Process. 20, 3261–3275.
Smith, K.R., 2006. Temperature Influences on Cattle Distribution and Behavior in the Central California Foothills. Oregon State University, Corvallis, p. 86. M.S. thesis.
Turner, M.G., Romme, W.H., Gardner, R.H., Hargrove, W.W., 1997. Effects of fire size and pattern on early succession in Yellowstone National Park. Ecol. Monogr. 67, 411–433.
Uresk, D.W., Rickard, W.H., Cline, J.F., 1980. Perennial grasses and their response to a wildfire in south-central Washington. J. Range Manag. 33, 111–114.
Valentine, K.A., 1947. Distance from water as a factor in grazing capacity of rangeland. J. For. 45, 749–754.
Van Dyke, F., Darragh, J.A., 2007. Response of elk to changes in plant production and nutrition following prescribed burning. J. Wildl. Manag. 71, 23–29.
Vermeire, L.T., Mitchell, R.B., Fuhlendorf, S.D., Gillen, R.L., 2004. Patch burning effects on grazing distribution. J. Range Manag. 57, 248–252.
Wall, T.G., Miller, R.F., Svejcar, T.J., 2001. Juniper encroachment into aspen in the northwest Great Basin. J. Range Manag. 54, 691–698.
Wambolt, C.L., Walhof, K.S., Frisina, M.R., 2001. Recovery of big sagebrush communities after burning in south-western Montana. J. Environ. Manag. 61, 243–252.
Weber, K.T., Burcham, M., Marcum, C.L., 2001. Assessing independence of animal locations with association matrices. J. Range Manag. 54, 21–24.
Wiens, T.S., Dale, B.C., Boyce, M.S., Kershaw, G.P., 2008. Three way *k*-fold cross-validation of resource selection functions. Ecol. Model. 212, 244–255.
Willms, W., Bailey, A.W., McLean, A., 1980a. Effects of clipping or burning on some morphological characteristics of *Agropyron spicatum*. Can. J. Bot. 58, 2309–2312.
Willms, W., Bailey, A.W., McLean, A., Tucker, R., 1980b. The effects of fall grazing or burning bluebunch wheatgrass range on forage selection by deer and cattle in spring. Can. J. Anim. Sci. 80, 113–122.
Willms, W., Bailey, A.W., McLean, A., Kalnin, C., 1981. Effects of clipping or burning on the distribution of chemical constituents in bluebunch wheatgrass in spring. J. Range Manag. 34, 267–269.
Wrobleski, D.W., Kauffman, J.B., 2003. Initial effects of prescribed fire on morphology, abundance, and phenology of forbs in big sagebrush communities in southeastern Oregon. Restor. Ecol. 11, 82–90.
Young, R.P., Miller, R.F., 1985. Response of *Sitanion hystrix* (Nutt.) J.G. to prescribed burning. Am. Midl. Nat. 113, 182–187.