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Restoring habitat for the northern Idaho ground squirrel (*Urocitellus brunneus brunneus*): Effects of prescribed burning on dwindling habitat

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ABSTRACT

Land use and fire exclusion have contributed to an increase in ponderosa pine (*Pinus ponderosa*) forest extent and density in west-central Idaho. Open areas within ponderosa pine forests are decreasing, thus reducing habitat for the endemic northern Idaho ground squirrel (NIDGS; *Urocitellus brunneus brunneus*). In 2000, the NIDGS was listed on the Endangered Species Act as threatened in part due to habitat loss. Therefore, recovery plans encourage the use of burning to expand meadows and open corridors. We gathered data on habitat attributes altered by prescribed fall burning at three sites selected for habitat restoration. Each site was divided into two units: a CONTROL unit occupied by the NIDGS and a BURN unit not occupied by the NIDGS. We sought to assess whether the prescribed fall burning fulfilled management goals and generated habitat features similar to CONTROL conditions that are suitable for the NIDGS. Data were collected before the fall prescribed burn and one and two years post-burn. Before the prescribed burn, BURN units had higher tree densities and canopy cover than CONTROL units; however, the prescribed fall burn did not reduce tree density or canopy cover one year later. Understory height in the BURN unit decreased slightly post-burn, approaching CONTROL conditions. Majority of understory characteristics were similar between CONTROL and BURN units before, one, and two years after the burn, but understory community structure remained strongly dissimilar. This study preliminarily examines NIDGS habitat and is the first paper to evaluate the effects of prescribed burning as restoration practices to create NIDGS habitat. Key habitat attributes associated with NIDGS presence include tree canopy cover, understory height and community structure, and litter depth. Management goals were not attained within the stated timeline, one year post-burn, or even two years after prescribed burn was implemented. Based on our results, managers should consider extending the timeframe for restoration goal achievement and perhaps modifying goals to include changes in tree canopy cover, understory height and community structure, and litter depth. Future efforts should monitor beyond two years post-fire, focus on long-term effects of prescribed burning, and examine how repeat burns may help attain habitat restoration goals.

1. Introduction

For the past 100 years, anthropogenic land use has changed the historical occurrence and extent of fire in the western United States (Covington, 2000; Hessburg et al., 2005; Heyerdahl et al., 2008). This reduction in fire has important ecosystem consequences considering fire modifies vegetation structure, promotes herbaceous species production (Endstrom et al., 1984; Laughlin et al., 2004), and alters nutrient cycling (Neary et al., 1999). Fire exclusion has altered ecosystem structure and function, thus affecting wildlife habitat (Fontaine and Kennedy, 2012).

The primary tools used to restore forests that evolved with frequent fire include thinning, burning, or a combination of the two treatments (Brown et al., 2004; Crist et al., 2009; Schwilk et al., 2009). Thinning can reduce crown cover by removing large trees to increase solar infiltration and promote herbaceous plant growth (Agee and Skinner, 2005; Busse et al., 2000). Prescribed burning can reduce understory biomass, promote nutrient cycling, and reduce the intensity and severity of subsequent fires (Wagle and Eakle, 1979; Crist et al., 2009). Thinning to remove smaller and less fire-tolerant trees followed by prescribed burning can be effective for restoring low-severity fire regimes in dry conifer forests (Brown et al., 2004). Across the western United States, managers use these treatments to restore ponderosa pine forests that historically had frequent fires (Stephens et al., 2009). Managers not only apply these practices to restore forest structure and function, but also to restore wildlife habitat (Long and Smith, 2000; Gaines et al., 2007; Lyons et al., 2008; Fontaine and Kennedy, 2012).

There is strong circumstantial evidence that fire exclusion has negatively impacted habitat of the northern Idaho ground squirrel (*Urocitellus brunneus brunneus*, NIDGS; Yensen, 1991; Yensen and

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Sherman, 1997). Contemporary populations of the NIDGS are small and isolated, which is in part attributed to the loss and fragmentation of open habitat due to the growth of ponderosa pine (*Pinus ponderosa*) forest (Truska and Yensen, 1990; Gavin et al., 1999); thus, the NIDGS was listed as threatened under the Endangered Species Act (Clarke, 2000). Authors examining NIDGS demography and genetics concur that habitat restoration efforts should focus on opening habitat for existing populations (Gavin et al., 1999; Sherman and Runge, 2002; Garner et al., 2005). The NIDGS recovery plan indicates that habitat enhancement is necessary and identifies prescribed burning an appropriate tool (USFWS, 2003).

We quantified differences between sites occupied and unoccupied by NIDGS and changes in habitat after prescribed burning, since no study has evaluated the effectiveness of prescribed burning for restoring NIDGS habitat. Three study sites were selected in west-central Idaho. Each site was divided into two units: a CONTROL unit (currently occupied by the NIDGS) and an adjacent BURN unit (unoccupied by NIDGS). BURN units were burned in the fall of 2010. At the CONTROL and BURN units, we measured vegetation structure, understory characteristics, and ground cover before the prescribed burn and one and two years after the prescribed burn.

We had two general hypotheses: (1) habitat attributes would be different between the occupied CONTROL and unoccupied BURN units before the prescribed burn; and (2) the prescribed burn would result in changing BURN unit habitat attributes to be more similar to CONTROL units. Specifically, we predicted that before burning, the BURN units would have greater tree density; higher canopy cover levels; a taller understory; lower understory cover, richness, evenness, and diversity; different understory community structure; and thicker litter depth than CONTROL units. In addition, we predicted prior to burning the BURN units would have a lower percentage of bare ground and higher litter and woody debris coverage than CONTROL units. We predicted that the prescribed burn would decrease BURN unit tree density, canopy cover, understory height, and litter depth, as well as increase herbaceous understory species cover, richness, evenness, and diversity. We also predicted that burning would increase the percent of bare ground cover and lower litter and woody debris cover.

2. Methods

2.1. Sites and experimental design

Experimental sites were located in the mosaic landscape of open meadows and ponderosa pine stands in Adams County, Idaho. The US Forest Service (USFS) selected three sites for NIDGS habitat restoration in 2010: Cap Gun (11T, 523220E 4984658N), Price Valley Guard Station (11T, 544977E 4986841N) and Summit Gulch (11T, 52229E 4982111N). We divided sites into two units: an occupied CONTROL unit and an unoccupied BURN unit (Fig. 1). The unoccupied BURN units were selected based on feasibility to be burned in fall 2010 and whether it was adjacent to an occupied CONTROL unit to allow for potential squirrel dispersal post-burn. At each unit, we randomly distributed six 50-m transects within 100 m of actual squirrel sightings from Idaho Fish and Game monitoring surveys. All sites were approximately 1350 m in elevation and were on south- to east-facing slopes. Average annual high temperatures were 13.7 °C and lows were −3.7 °C in New Meadows (Western Regional Climate Center, 2010). The closest weather station to the sites (roughly 30 miles away), USFS New Meadows District weather station, reported 702 mm of precipitation in 2010, 332 mm in 2011 and 277 mm in 2012, while the average annual precipitation was 591 mm for the last 100 years (Western Regional Climate Center, 2010). Data collection occurred during the peak of the growing seasons in July 2010 (before burning), July 2011 (one year post-burn), and in June 2012 (two years post-burn).

2.2. Prescribed burn treatments

Management goals for prescribed fire used to create NIDGS habitat included: (1) decreasing tree density [trees with a diameter at breast height (DBH)>20 cm], (2) increasing herbaceous community cover by 10–30% one year post-burn, (3) retaining an open understory by reducing fuels with DBH < 8 cm by 50–90%, and (4) decreasing woody debris with DBH > 8 cm by 20–65% (Doane, 2012; Enna and Cobb, 2010). The USFS Council and New Meadows Ranger Districts conducted the prescribed fall burns in September and October 2010 when the NIDGS were hibernating underground to avoid any direct impacts on the NIDGS. The prescribed burn at Cap Gun had 0.3–1.2 m flame lengths, but rising humidity levels resulted in overall low consumption. The prescribed burn at Price Valley Guard Station had flame lengths that ranged from 0.2–3.0 m but were primarily 0.6 m long; Summit Gulch had flame lengths that were intentionally low, 0.3–0.6 m, to protect trees in adjacent timber sales. Additional fire behavior characteristics are found in Table 1 (USFS *per comm*).

2.3. Field measurements

Vegetation structure variables were measured by establishing two 200-m^2 circular plots with an 8-m radius at opposite ends of the 50-m transect to describe tree structure. Every tree within the circular plots was counted and placed into a size category to measure tree density and size distribution. The tree size categories were determined by diameter at breast height (DBH < 8 cm, 8–12 cm, 13–20 cm, >20 cm). The diameter of trees with a DBH > 20 cm was recorded to the nearest 0.1 cm. The percentage of closed canopy cover was measured with a concave spherical crown densiometer one meter above the ground in the four cardinal directions around the center of the plot (Lemmon, 1956). We described understory vegetation height in order to estimate potential cover or visual obstruction for the NIDGS. Along each transect, we recorded vegetation height at three transect points in the four cardinal directions with a meter-high sighting pole 5 m away from a modified Robel pole (Robel et al., 1970). The modified Robel pole had markings every 2 cm from 0–40 cm and measurements above 40 cm were recorded as 41–50 cm, 51–100 cm or >100 cm. Detailed measurements were collected under 40 cm because understory vegetation below that height could help conceal the NIDGS or obstruct the vision of the NIDGS, which are 15–22 cm tall when standing on their hind legs (Yensen and Evans Mack *per. comm.* 2012).

Understory characteristics were quantified with ocular estimates of the percent cover of understory species within a 0.5 × 0.5 m quadrat using Daubenmire (1959) cover class groups (0–5%, 6–25% 26–50%, 51–75%, 76–95%, 96–100%). We quantified understory species cover with ten quadrats along a 50-m transect (60 plots per unit). Some plants were grouped by genus due to similarities between identification features; therefore, richness is slightly underestimated. We also categorized understory vegetation by functional groups: annual forb, perennial forb, annual/perennial forb (species that can take either growth form), annual grass, perennial grass, annual/perennial grass, perennial sedge, perennial rush, and perennial shrub. Voucher specimens were collected for a reference collection of the understory species.

In addition to plant cover, ground cover was recorded. Litter depth (top of litter debris to soil surface) was recorded 30 times along each transect. The percentage of ground that was soil (bare ground), litter, woody debris (branches, pieces of wood, etc.), and rocks (roughly >10 cm in diameter) were recorded along with the

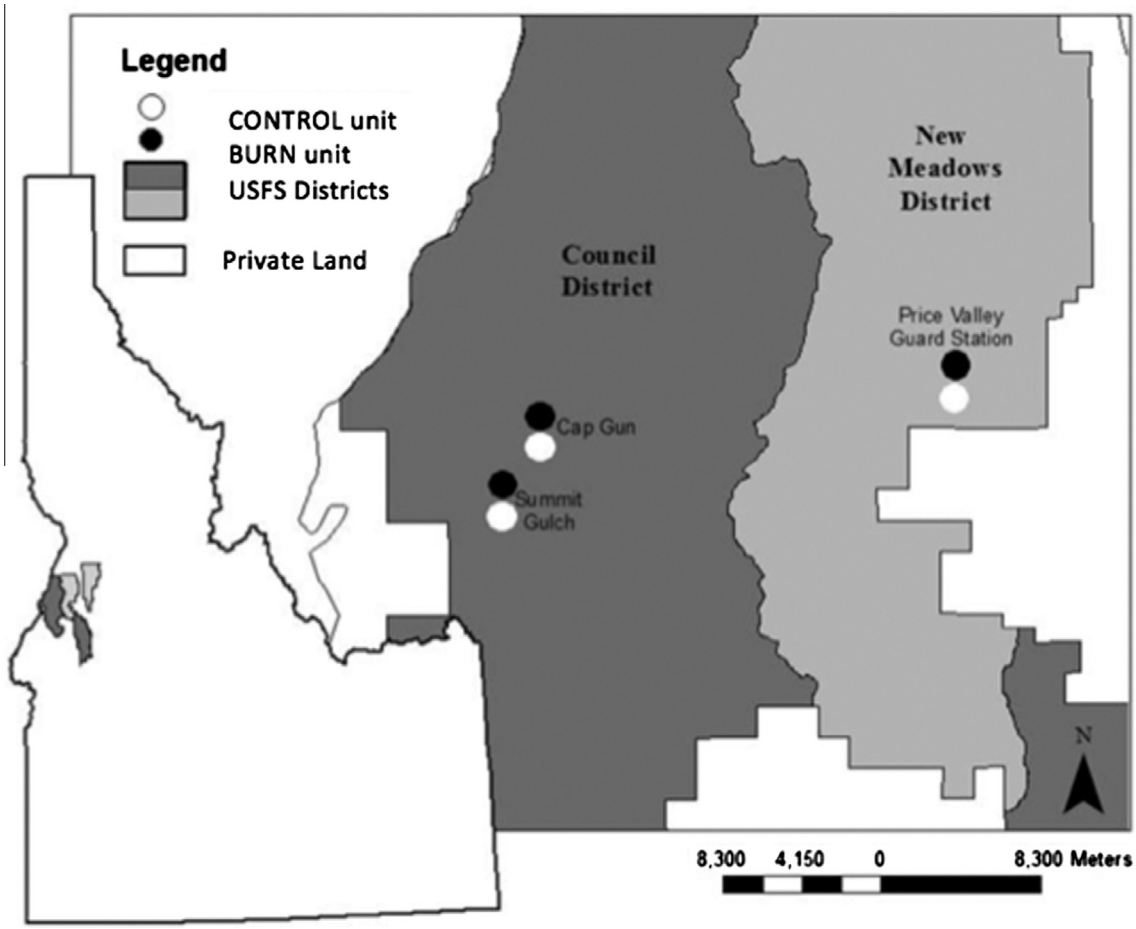

Fig. 1. Restoration sites for the northern Idaho ground squirrel (NIDGS, *Urocitellus brunneus brunneus*) located on the Council and New Meadows Districts of the Payette National Forest. Unfilled circles represent occupied units that were not burned (CONTROL unit), while the filled circles represent unoccupied units that were burned (BURN unit).

Table 1
Fire behavior characteristics of the prescribed burns at Cap Gun, Price Valley Guard Station, and Summit Gulch in the Payette National Forest, Idaho.

Measurement	Cap Gun	Price Valley Guard Station	Summit Gulch
Day	September 8, 2010	October 11, 2010	September 2, 2010
Time of day	0940–1200	1400–1600	1200–1855
Area (ha)	68	64	25
Ambient temp. (°C)	16	6	21–26
Relative humidity (%)	47	19	20
Wind speed (km/h)	1–1.6	1.6–6.4	3.2–9.6
Wind direction	S	SW	SW
Fuel moisture (%)			
1 h	11	7	5–6
10 h	16	9	8-11
100 h	17	10	12–14
1000 h	–	33	–
Fuel consumption (%)			
Litter	–	20–50	–
<2.5 cm	0–20	–	85–90
2.5–7.6 cm	10–30	–	30–60
100–1000 h fuels	–	20	–
Tree mortalitiy (%)	<10	<15	20
Area burned (%)	40	70	60

percentage of moss and lichen cover within each 0.5 × 0.5 m quadrat using Daubenmire (1959) cover class groups (same as listed above).

2.4. Statistical analyses

Vegetation structure, understory characteristics, and ground cover data were tested for differences across two main effects: 'year' (2010 = pre-burn, 2011 = one year post-burn, 2012 = two years post-burn; $n = 3$) and 'unit' (CONTROL and BURN; $n = 2$) in a non-parametric permuted MANOVA (PERMANOVA; McArdle and Anderson, 2001) using DISTLM software (Anderson, 2004). 'Site' (Cap Gun, Price Valley Guard Station, and Summit Gulch; $n = 3$) was treated as a random effect, since preliminary analyses showed little variation between sites. In the PERMANOVA, we also tested for an interaction between 'year' and 'unit' (referred to as

'year × unit'). Since CONTROL and BURN units could have simultaneously changed over time but in the same direction, a 'year × unit' interaction is necessary to signify an effect of the prescribed burn.

For the PERMANOVA analysis, dependent variables were divided into four groups: (1) vegetation structure, (2) understory species cover, (3) understory functional group cover, and (4) ground cover. We log10 + 1 transformed tree density and tree size class data to improve normality and homogeneity of variance. We also excluded rare species from the understory species and functional group cover data. Rare species were classified as those that occurred in five or fewer transects (5% of the 108 transects) (McCune and Grace, 2002).

Each group of dependent variables (1–4 above) was tested in a nested PERMANOVA model: fixed effects and the interaction were nested within site. The nested design was written as an interaction between the fixed and random effect ('fixed' by 'random'): 'year' was tested over the 'year × site' interaction, 'unit' was tested over the 'unit × site' interaction, and the 'year × unit' interaction was tested over the three-way interaction among 'year × unit × site'. The "p" was based on 999 permutations or the Monte Carlo Method (permuted p). The PERMANOVA analysis was performed on normalized data using Euclidean distances for all variables except understory species and functional group cover data for which we used Bray–Curtis distances (Legendre and Legendre, 1998). We did not standardize species composition and functional group cover data by row in the PERMANOVA; therefore, the results depended upon species cover and composition. Significant terms in the PERMANOVA were further explored with univariate mixed model ANOVAs using SAS/STAT® version 9.2 software (SAS; SAS Institute Inc., 2008). We ran Tukey post hoc tests for terms with significant differences in the ANOVA output. Statistical significance was set at an alpha <0.05.

Patterns in the understory community were analyzed using non-parametric multidimensional scaling (NMS) ordination (McCune and Grace, 2002). We grouped understory cover data by 'unit' (CONTROL and BURN) and year (2010 = before burn, 2011 = one year post-burn, 2012 = two years post-burn). Non-parametric multidimensional scaling was run with Sorensen (Bray–Curtis) distance metric in PC-ORD version 6 software (McCune and Mefford, 2011). The NMS ordination ran with 250 runs with real data and 250 with randomized data. Kendall's rank correlation coefficient value (tau) was calculated for each explanatory variable to determine which habitat attributes were strongly correlated (tau > 0.5) with the NMS ordination. PC-ORD software was also used to calculate species richness, evenness, and Simpson's Diversity Index [$1 - sum\ (P_i * P_i)$, where "P_i" equals the importance probability in element "i", a plant species relativized by total species cover within a transect (Simpson, 1949)]. The effects of 'year', 'unit', and 'year × unit' on species richness, evenness, and diversity were tested using univariate mixed model ANOVAs in SAS.

3. Results

3.1. Vegetation structure

For the vegetation structure group of dependent variables, there was a 'year' and 'unit' effect but no 'year × unit' interaction (PERMANOVA; Table 2). In follow-up univariate analyses, tree canopy did not change across years, but canopy cover was significantly greater in the BURN units than in CONTROL units before and one year post-burn but not two years post-burn (2010: $t_4 = 5.80$, $p = 0.03$; 2011: $t_4 = -7.46$, $p = 0.01$; 2012: $t_4 = 5.75$, $p = 0.13$; Fig. 2a). The prescribed burn did not significantly affect tree canopy cover. 'Year' but not 'unit' significantly affected tree density. There was a pattern of greater decrease in tree density over time within the BURN unit (Fig. 2b). Across units tree densities before and one year post-burn were higher than the tree density two years post-burn (2010 vs. 2012: $t_4 = 4.87$, $p = 0.02$; 2011 vs. 2012 $t_4 = 4.44$, $p = 0.02$). Density differences were mostly found in the two largest categories of trees sizes. Trees with a DBH of 13–20 cm significantly decreased in density from 2010 to 2012 ($p = 0.03$). For trees with a DBH > 20 cm, densities were significantly different between 2010 and 2012 ($p = 0.01$) and between 2011 and 2012 ($p = 0.005$). The slight shift in tree density with trees having a DBH > 20 cm was not significantly different between units; however, tree densities in BURN units tended to be higher than CONTROL units [128 ± (49, 80) trees ha-1, 24 ± (10, 16) trees ha-1, respectively (mean ± (SE low, high)].

Understory vegetation height was significantly affected by 'year', but there was no significant effect of 'unit' or 'year × unit' (Table 2). Understory vegetation height decreased over time; pre-burn understory height across units was significantly higher compared to height one year post-burn ($t_4 = 6.39$, $p = 0.007$), but there was no significant difference between one and two years post-burn ($t_4 = 3.19$, $p = 0.07$; Fig. 2c). The height of understory was not significantly different between units; BURN unit vegetation was marginally taller than CONTROL vegetation before the prescribed burn ($p = 0.05$), but there were no differences between units one year ($p = 1.00$) and two years ($p = 0.68$) post-burn. Although there was no significant 'year × unit' effect, BURN units responded differently than CONTROL units based on the Tukey post hoc contrasts. Before the burn, understory height in the BURN units [38.51 ± (3.73) cm, mean ± (SE)] was 42% taller than vegetation in BURN units one year post-burn [22.20 ± (3.73) cm; $p < 0.05$)]. Height slightly decreased in BURN units by 18% from one to two years post-burn [18.51 ± (3.73) cm, $p = 0.61$]. In comparison, the height of vegetation steadily decreased in the CONTROL units over time, but these changes were not significant [2010: 27.10 ± (3.73) cm; 2011: 21.42 ± (3.73); 2012: 14.51 ± (3.73); 2010–2011: $p = 0.35$; 2011–2012: $p = 0.22$].

3.2. Understory characteristics

Understory species and functional group cover were not different among years, between units, and the 'year × unit' interaction was not significant (PERMANOVA, Table 2; Fig. 3, Panel A). Understory species richness was different between years, but there was no effect of 'unit' or 'year × unit'. Species richness before the burn increased significantly one year post-burn in both CONTROL and BURN units (CONTROL: $p = 0.04$, BURN: $p = 0.04$), but there was no change two years post-burn for BURN or CONTROL units (Fig. 3, Panel B). For understory species evenness and diversity, there was no significant effect of 'year', 'unit, or 'year × unit'.

Patterns in understory community structure at CONTROL and BURN units were different before, one and two years after the prescribed burn. A one-axis solution explained 70% ($r^2 = 0.698$) of the variation in community structure after 25 iterations with a final instability < 0.00001 in the NMS ordination (Fig. 4, stress = 0.0002, $p = 0.004$). Axis 1 represented a vegetation structure gradient with a strong positive correlation with tree canopy cover (tau = 0.89) and density (tau = 0.78). In particular, the density of trees in the <8 cm DBH (tau = 0.87) and 8–12 cm DBH size categories (tau = 0.45) were correlated with the separation between the two units.

3.3. Ground cover

Overall, ground cover was significantly affected by 'year', 'unit', and 'year × unit' (PERMANOVA; Table 2). Litter depth was signifi-

Table 2
Results from permuted non-parametric multivariate analysis of variance (PERMANOVA) analyses for vegetation structure, understory species cover, functional group cover, and ground cover. Permuted *p* values are reported for the PERMANOVA analyses. Univariate mixed model analysis of variance (ANOVA) results are presented if statistical significance was detected in the PERMANOVA. Statistically significant '*p*' are bold when $\alpha < 0.05$.

Analysis	Data	Year		Unit		Year × Unit	
		$F_{2,4}$	*p*	$F_{1,2}$	*p*	$F_{2,4}$	*p*
PERMANOVA	Vegetation structure	7.50	**0.001**	9.08	**0.01**	1.91	0.12
Univariate	Canopy cover	14.56	0.17	75.20	**0.01**	1.78	0.28
Univariate	Total tree density	5.70	**0.01**	7.93	0.11	0.63	0.58
Univariate	DBH <8 cm	2.59	0.19	5.86	0.14	0.20	0.82
Univariate	DBH 8-12 cm	5.15	0.08	14.31	0.06	3.59	0.13
Univariate	DBH 13-20 cm	9.17	**0.03**	11.10	0.08	2.84	0.17
Univariate	DBH >20 cm	25.95	**0.005**	12.33	0.07	5.10	**0.07**
Univariate	Understory height	47.55	**0.002**	14.11	0.06	5.11	0.08
PERMANOVA	Understory species cover	0.80	0.74	1.25	0.25	1.43	0.10
PERMANOVA	Understory functional group cover	2.14	0.06	2.78	0.06	1.40	0.22
PERMANOVA	Ground cover	17.37	**0.001**	5.63	**0.003**	4.97	**0.001**
Univariate	Litter depth	46.45	**0.002**	25.65	**0.04**	19.72	**0.009**
Univariate	Bare soil (% cover)	23.23	**0.006**	14.56	0.06	0.33	0.73
Univariate	Litter (% cover)	70.07	**0.0008**	27.81	**0.03**	2.70	0.18
Univariate	Woody debris (% cover)	1.47	0.33	0.11	0.77	1.57	0.31
Univariate	Rock (% cover)	6.23	0.06	0.00	1.00	1.07	0.42

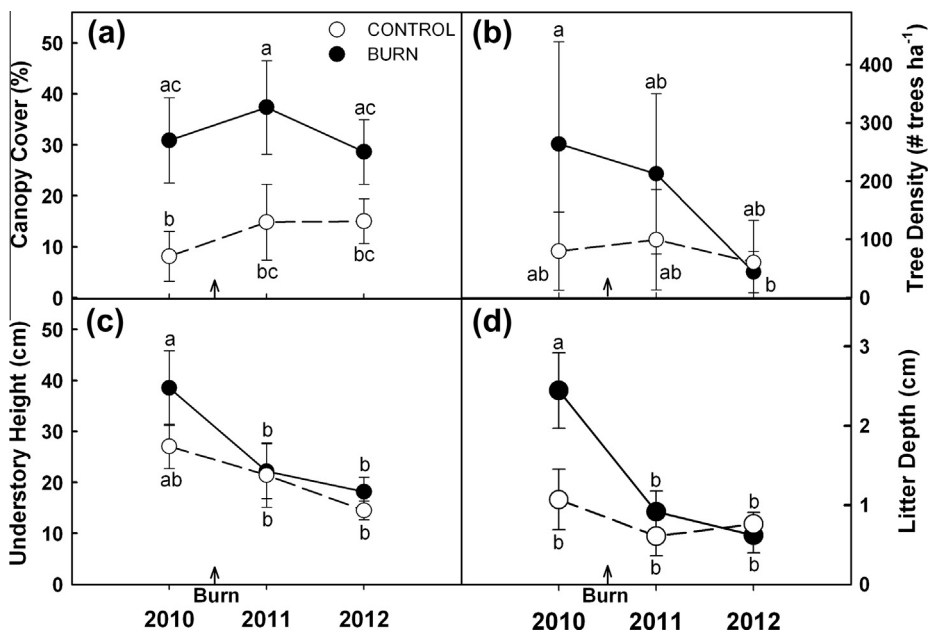

Fig. 2. Tree canopy cover, tree density, understory height, and litter depth at CONTROL (open circles) and BURN (filled circles) units in 2010, 2011, and 2012. Error bars represent standard error of mean. The arrow indicates the fall prescribed burn and letters designate significant differences (alpha <0.5) between and within units over time.

cantly higher in the BURN units compared to the CONTROL units before burning ($t_4 = 7.88$, $p = 0.008$; Table 2; Fig. 2d). One year post-burn, litter depths decreased in the BURN units ($t_4 = 8.76$; $p = 0.005$) but remained the same in the CONTROL units ($t_4 = 2.64$, $p = 0.27$). Litter depths did not change in either CONTROL or BURN units from one to two years post-burn (CONTROL: $t_4 = -0.8$, $p = 0.94$; BURN: $t_4 = 1.67$, $p = 0.60$). Generally, prescribed burning reduced litter depth in the BURN units toward CONTROL unit levels.

The percent of ground covered by bare soil was significantly affected by 'year', litter cover was significantly affected by 'year' and 'unit', and percent woody debris and rock cover were not affected by 'year' or 'unit' (Table 2). Percent bare soil for both BURN and CONTROL units increased over time and the BURN units had slightly less bare ground than the CONTROL units although not significant (Fig. 5a). Litter cover was higher in the BURN units compared to CONTROL units. Percent litter cover increased significantly from before the prescribed burn to one year post-burn in BURN units [2010: 14 ± (4)%; 2011: 35 ± (4)%; $p = 0.02$]. Litter cover also steadily increased in the CONTROL units over time but remained lower than the BURN units (Fig. 5b). Woody debris and rock cover were similar between units over time (Fig. 5c and d).

4. Discussion

4.1. Habitat attributes in occupied versus unoccupied units

We predicted that vegetation structure, understory characteristics, and ground cover would be different in the unoccupied BURN units compared to the occupied CONTROL units before burning. Restoration sites for the prescribed burn were selected because sites were not occupied by the NIDGS. Historical land use has lead to increases in forest density and extent, which has decreased squirrel habitat (Gavin et al., 1999). Therefore, we predicted that the unoccupied BURN units before burns were implemented would have more trees and a denser canopy cover than occupied CON-

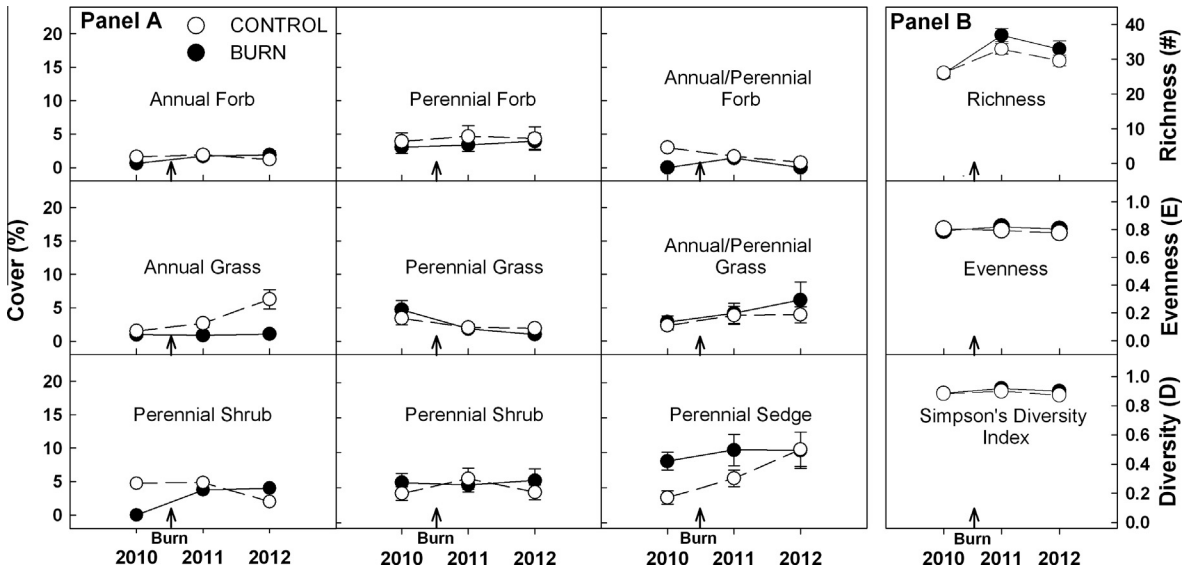

Fig. 3. Understory responses of CONTROL (open circles) and BURN (filled circles) units in 2010, 2011, and 2012. Panel A shows the relative cover of functional groups: annual forbs, perennial forbs, annual/perennial forbs, annual grasses, perennial grasses, and shrubs in each unit over time. Panel B shows average understory species richness, evenness, and Simpson's Diversity Index in each unit over time. Error bars represent standard error of mean. The arrows indicate the fall prescribed burn.

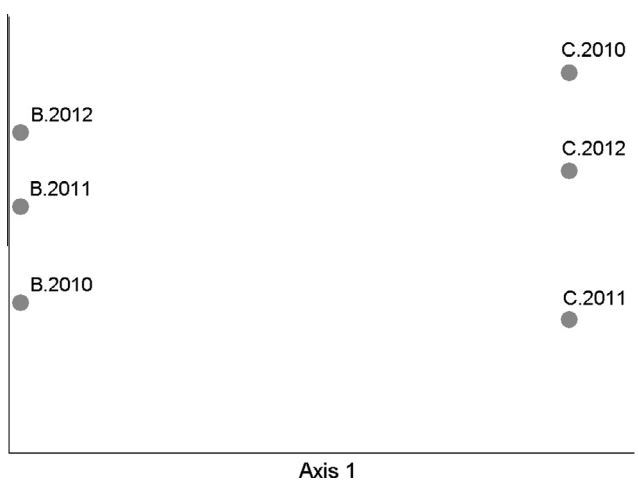

Fig. 4. Single axis ordination of understory community patterns between unit types (C = CONTROL unit, and B = BURN unit) across year (2010, 2011, and 2012). The ordination was derived from a non-parametric multi-dimensional scaling test. Sites are jittered along the single axis solution.

TROL units, which our study confirmed. These results show that the NIDGS favor habitat with an average canopy cover of 8% and an average tree density of 80 trees ha-1 compared to BURN units with an average of 31% canopy cover and 264 trees ha-1. While trees indirectly affect a ground squirrel, trees directly impact understory plants.

We anticipated that understory vegetation height would be greater in the unoccupied BURN units due to light competition with high tree canopy cover and higher soil moisture from thicker needle layer. Understory height in the unoccupied BURN units was taller and the litter depth was thicker (BURN mean = 2.4 cm thick, CONTROL mean = 1.1 cm thick) than the occupied CONTROL units. Results from this study suggest that the NIDGS select for understory height of around 27 cm and avoid habitat with taller visual obstruction of around 38 cm.

The NIDGS are primarily herbivores (Yensen et al., 2010); therefore, the type and condition of the understory within their habitat influences their diet. Ritchie (1990) reported that foraging behavior directly impacted ground squirrel fitness. We predicted the BURN units pre-burn would have lower species and functional group cover, as well as lower species richness, evenness, and diversity; however, there were no significant differences between units for these community characteristics before the burn. Nevertheless, the NMS ordination showed that the CONTROL understory community structure was dissimilar to the BURN units before the burn. The separation between the two units was highly correlated with a gradient in overstory structure. A higher tree cover and density seems to be driving factors in determining NIDGS occupancy and patterns in understory characteristics. We also predicted that the BURN units prior to burning would have a lower percentage of bare ground, higher litter and woody debris coverage but similar percent of ground covered by rock. There were no differences in ground cover between units, thus ground cover was not correlated with NIDGS habitat selection.

Our results quantitatively demonstrate that areas occupied by squirrels have different features than those unoccupied by squirrels. By measuring CONTROL units that are used by the NIDGS and also measuring BURN units that are available to the NIDGS but remain unused by squirrels, the pre-burn data in this study can be used as a first look into NIDGS habitat selection. Quantifying differences between these units helped determine which habitat attributes coincide with NIDGS occupancy (CONTROL unit) and avoidance (BURN unit). Our results suggest restoration treatments should continue targeting tree density and canopy cover, as well as understory height, community structure and litter depth.

4.2. Effects of prescribed burning on habitat attributes

Habitat restoration goals for the NIDGS focused on using prescribed burning to reduce conifer tree density, increase herbaceous community cover, and create an open understory by reducing ladder fuels one year post-burn (Doane, 2012; Enna and Cobb, 2010). We predicted that the prescribed burn would meet these goals along with reducing tree canopy cover, understory height, and litter depth. The data from this study indicate that restoration goals were not achieved within the targeted one-year timeframe. Overstory canopy cover and understory height were also not reduced

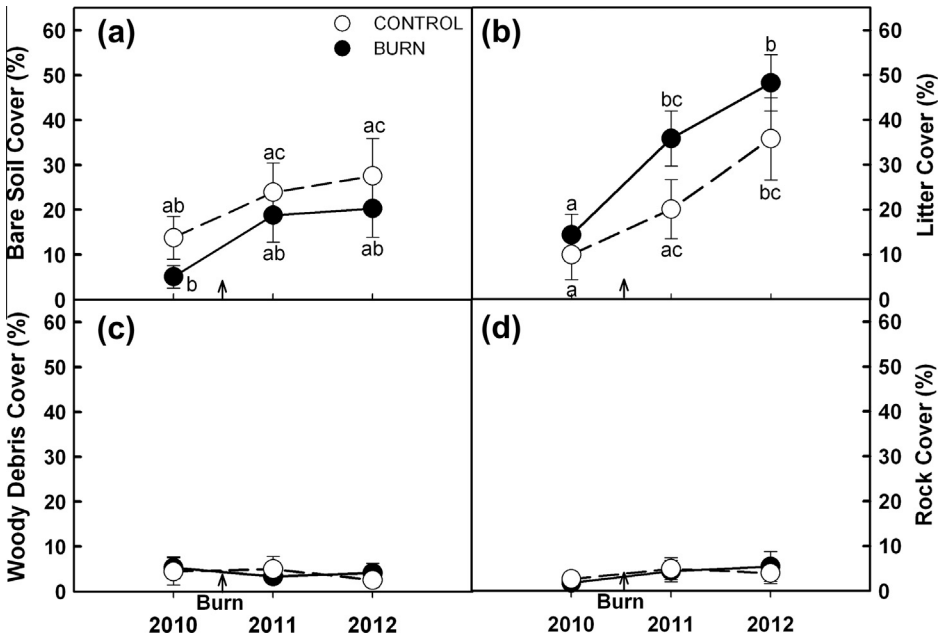

Fig. 5. Ground cover (percent bare soil, litter, woody debris, and rock) at CONTROL (open circle) and BURN (filled circles) units in 2010, 2011, and 2012. Error bars represent standard error of mean. The arrow indicates the fall prescribed burn and letters designate significant differences between and within units over time (alpha <0.5).

one year post-burn, whereas litter depth decreased one year post-burn. However, two years post-burn tree density and understory height decreased in the BURN unit. The prescribed burn did not significantly affect any other attributes that we measured, including ground cover.

We presume that burn treatments were not sufficient to reduce tree density and canopy cover one year post-burn. Weather conditions and concerns about adjacent timber harvests interfered with the intensity of the prescribed burns at Cap Gun and Summit Gulch. While some trees were killed, many dead trees were still standing in the BURN units and retained fire-damaged needles; hence, tree canopy cover in the BURN units remained high post-burn. Tree cover might decrease in subsequent years once needles and dead branches fall. While tree density decreased two years post-burn, density levels were still not as low as CONTROL sites. Tree density may further decrease over time; however, burn-only prescriptions may not be enough to reduce conifer density even three years after a prescribed burn (Fiedler et al., 2010). Thinning by burning is often unpredictable and difficult to control (Harrington and Sackett, 1990). Therefore, mechanical thinning prior to prescribed burning may help achieve a reduced tree canopy cover and density (Sackett et al., 1996; Fiedler et al., 2010). Repeated treatments are likely needed to obtain desired tree density and also for long-term restoration goals (Keane et al., 1990; Fulé et al., 2001; Stephens et al., 2012). In 2012, thousands of tree seedlings (<10 cm tall) sprouted in areas with higher tree densities, further supporting the need to follow up with another burn.

Vegetation height was not a specific restoration goal, but prescribed burning decreased understory height in the BURN units toward CONTROL unit conditions. While both BURN and CONTROL units experienced annual decreases in understory height, there was a larger decrease in understory height in the BURN units. Vegetation height is important because it affects predator avoidance behavior in small rodents (Lima and Dill, 1990). The NIDGS are small rodents whose eye-level is about 4.5 cm off the ground when on all fours and 15–20 cm off the ground when on hind-legs (Yensen and Evans Mack *per. comm.* 2012); thus, an understory of 37 cm in the BURN unit before fire might deter the NIDGS because it could hinder their ability to detect predators. However, the prescribed burn decreased BURN understory height by 16 cm, which resulted in levels similar to CONTROL units. Understory height in CONTROL units could allow a ground squirrel to utilize both anti-predator strategies: cover and visibility (Hannon et al., 2006). In sand shinnery oak habitat, visual obstruction was significantly reduced one year post-burn but recovered to control levels within five years post-burn (Harrell et al., 2001). Therefore, repeat burns may be necessary in NIDGS habitat to maintain understory height.

Another restoration goal for NIDGS habitat was to increase herbaceous community cover; however, individual species cover, functional group cover, richness, evenness, and diversity of the understory was similar between the CONTROL and BURN units before burning, one and two years after burning. Thus, the management goal of increasing herbaceous plant cover by 10–30% one-year post-burn was not reached. Nevertheless, the ordination separated the unit types along a single axis that was highly correlated with a vegetation structure gradient driven by tree density and canopy cover. Since tree canopy cover did not decrease, the intended alteration of environmental conditions to benefit understory species did not occur; therefore, an increase in growth and reproduction by the understory species may be delayed (McConnell and Smith, 1970; Busse et al., 2000; Sabo et al., 2009). Ponderosa pine trees can negatively impact herbaceous species through competition for light and nutrients (Moir, 1996). If the burn intensity had been slightly higher or if all sites were mechanically thinned, the community structure post-burn might have shifted closer to control conditions. The understory community in burned areas might shift over time or with subsequent burns (Busse et al., 2000; Laughlin et al., 2004). The lag time for understory species to respond to changes in the overstory likely takes more than two years, especially when the burn did not immediately alter tree density and canopy cover. The cover of some understory species may increase in subsequent years after a fire (e.g. *Potentilla gracilis*, *Fragaria virginiana, Geum triflorum*, *Elymus elymoides* and *Carex* sp.; Armour et al., 1984; Busse et al., 2000).

The prescribed burn consumed litter, thus decreasing litter depth in BURN units toward CONTROL units one year post-burn. Pre-burn litter depth was greater in the BURN units compared to the CONTROL units, which was likely due to the higher tree density

increasing the needle-load. Forest litter depth is important because it influences the recruitment and development of plants. Litter covers bare soil, serves as mulch (influencing soil moisture and soil temperature), alters chemical inputs, affects water infiltration, and influences the degree of soil heating during a fire (Neary et al., 1999, 2005). Other prescribed burns in ponderosa pine forest have decreased litter depth for habitat restoration (Bock and Bock, 1983). Ponderosa pine trees drop needles at a higher rate compared to other trees, which often creates a thick layer of litter that is slow to decompose and deters herbaceous species growth (Pase, 1958; Hart et al., 1992; Biswell et al., 1966). Thus, conifer density should be decreased to maintain low levels of litter. Once litter levels have been lowered, the herbaceous community will likely respond with increased production (Xiong and Nilsson, 1999; Melten and Fiedler, 2006), which could lead to the desired response of increased understory percent cover.

5. Conclusions

Identifying differences between occupied and unoccupied habitat is fundamental to wildlife research and habitat restoration. In this study, we found that the occupied CONTROL units had fewer trees, lower canopy cover levels, a shorter understory, and a thinner litter layer than the unoccupied BURN units before the burn. Since CONTROL and BURN units were dissimilar, the second part of our study evaluated whether prescribed fire changed these attributes one to two years post-fire. Litter depth was the only attribute to change significantly toward CONTROL levels one year post-burn, while after two years passed changes in tree density and understory height occurred. Based on these results, management goals were not met within the designated timeframe. Managers should consider extending the timeline and potentially include changes in tree canopy cover, understory height and community structure, and litter depth. We also suggest that habitat monitoring should continue past two years in order to determine whether the prescribed burn may eventually create habitat favorable to the NIDGS. Long-term monitoring efforts can reveal the effects of prescribed fire over time to further determine if repeat prescribed burns are appropriate. Indeed, repeat burns are suggested by the recovery plan for NIDGS habitat maintenance (USFWS, 2003). Evaluating prior restoration actions in an adaptive management framework will assist in refining restoration treatments and goals (Block et al., 2001; Boyd and Svejcar, 2009). Restoration treatments and sound management practices are essential for wildlife habitat and the persistence of species at risk (Foin et al., 1998; Anderson and Gutzwiller, 2005).

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