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RESEARCH ARTICLE

Restoring Sage-grouse nesting habitat through removal of early successional conifer

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Conifer woodlands have expanded into sagebrush (*Artemisia* spp.) ecosystems and degrade habitat for sagebrush obligate species such as the Greater Sage-grouse (*Centrocercus urophasianus*). Conifer management is increasing despite a lack of empirical evidence assessing outcomes to grouse and their habitat. Although assessments of vegetation recovery after conifer removal are common, comparisons of successional trends with habitat guidelines or actual data on habitat used by sage-grouse is lacking. We assessed impacts of conifer encroachment on vegetation characteristics known to be important for sage-grouse nesting. Using a controlled repeated measures design, we then evaluated vegetation changes for 3 years after conifer removal. We compared these results to data from 356 local sage-grouse nests, rangewide nesting habitat estimates, and published habitat guidelines. We measured negative effects of conifer cover on many characteristics important for sage-grouse nesting habitat including percent cover of forbs, grasses, and shrubs, and species richness of forbs and shrubs. In untreated habitat, herbaceous vegetation cover was slightly below the cover at local nest sites, while shrub cover and sagebrush cover were well below cover at the nest sites. Following conifer removal, we measured increases in herbaceous vegetation, primarily grasses, and sagebrush height. Our results indicate that conifer abundance can decrease habitat suitability for nesting sage-grouse. Additionally, conifer removal can improve habitat suitability for nesting sage-grouse within 3 years, and trajectories indicate that the habitat may continue to improve in the near future.

Key words: ***Centrocercus urophasianus*, conifer management, Great Basin, *Juniperus occidentalis*, sagebrush, western juniper**

Implications for Practice

- Increased conifer cover in sagebrush ecosystems reduces shrub understory vegetation characteristics important for sage-grouse nesting, thereby limiting habitat suitability and availability for sage-grouse.
- Conifer removal increases herbaceous vegetation in a short time period which increases habitat suitability for sage-grouse nesting habitat. Shrubs may not respond as quickly.
- Different conifer removal methods may have differing impacts on understory vegetation. Managers should consider and attempt to limit potential negative affects, such as decreased shrub cover or increased exotic annual grasses, when planning conifer removal projects.
- Managers should first focus conifer removal efforts in areas with intact shrub and herbaceous composition to achieve the quickest and most complete habitat recovery.

Introduction

Growing concern for Greater Sage-grouse (*Centrocercus urophasianus*; hereafter, sage-grouse), a sagebrush (*Artemisia* spp.) obligate requiring large, contiguous tracts of habitat (Knick & Connelly 2011), has led to a rangewide conservation response to reduce threats to the species and ecosystems upon which they depend (USFWS 2015). Land management agencies (e.g. U.S. Department of Interior's Bureau of Land Management [BLM]) have implemented policy revisions and proactive restoration efforts to address a variety of threats ranging from energy development to wildfire (USFWS 2015). Among the suite of conservation actions, removal of encroaching conifers at landscape scales has been increasing in an attempt to maintain extant sage-grouse populations (Baruch-Mordo et al. 2013). Multiscale monitoring protocols (i.e. habitat assessment framework [HAF]; Stiver et al. 2015) are being implemented on federally administered lands to evaluate land

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uses and conservation actions relative to meeting specific habitat indicators and objectives (e.g. BLM 2015).

Conifer woodlands have been expanding into sagebrush and grassland ecosystems throughout the western United States since Euro-American settlement and are considered a major threat to sagebrush and grassland obligate species (Bragg & Hulbert 1976; Miller & Tausch 2001; Briggs et al. 2002; Grant et al. 2004; Miller et al. 2005, 2011; Davies et al. 2011). The most abundant encroaching conifer species in the northern Great Basin, western juniper (*Juniperus occidentalis*), has increased ~10-fold in abundance during the past 130–150 years and currently occupies ~3.6 million ha in California, Nevada, Oregon, Idaho, and Washington (Miller & Tausch 2001; Miller et al. 2005; Johnson & Miller 2008). Conifer expansion and infill reduces grass and forb abundance and diversity due to competition for nutrients, water, sunlight, and space, increasing surface water runoff and erosion (Pierson et al. 2007, 2013; Petersen & Stringham 2008).

Conifer removal in sage-grouse habitat has been recommended to maintain or recover sage-grouse habitat (Connelly et al. 2000). Removal has accelerated in recent years, especially through the Sage Grouse Initiative (SGI; Baruch-Mordo et al. 2013). For example, from 2010 to 2014 in Oregon, the amount of conifer-encroached lands treated by SGI partners grew 1,411%, addressing roughly two-thirds of the early phase encroachment on priority private lands (NRCS 2015). However, little research exists assessing the spatial and temporal effects of conifer management on sage-grouse habitat quality and use (USFWS 2015).

Monitoring and evaluating ecological restoration projects is crucial to evaluating treatment efficacy and improving future management actions (Michener 1997). One way to assess the potential effects of restoration on a wildlife species is to track short-term changes in habitat, assuming that these will lead to long-term population changes. Effects of conifer removal on vegetation structure in sagebrush communities have been mixed depending on site conditions, woodland phase, residual pretreatment vegetation, time since removal, and management technique (Bates et al. 2005, 2007, 2013, 2014; Roundy et al. 2014a). In general, herbaceous vegetation tends to increase, while shrubs tend to remain stable or, in the case of fire treatment, are reduced in the short term (Bates et al. 2005; Miller et al. 2014; Roundy et al. 2014*a*). While some conifer removal studies have considered sage-grouse habitat characteristics (Miller et al. 2014; Bates et al. 2017), no studies have directly compared the postremoval vegetation successional trajectories to habitat used by local sage-grouse populations.

Using a controlled repeated measures design, we evaluated the effects of conifer encroachment and removal on site-scale vegetation characteristics (fourth order in the HAF; Stiver et al. 2015) in potential sage-grouse nesting habitat in southeastern Oregon using both treatment and control areas. Our objectives were to determine effects of conifer abundance on understory vegetation characteristics important to sage-grouse nesting and whether nesting habitat improved after conifer removal. We then compared these data to published sage-grouse nest habitat guidelines as well as data from 356 nests found locally to assess whether the areas were suitable or progressing toward suitable habitat. As our monitoring data were collected concurrently with a sage-grouse radio-tracking project in the same area, our study was uniquely suited to this comparison. We predicted negative effects of conifer abundance on nesting habitat characteristics including herbaceous and shrub cover and richness and that herbaceous vegetation would begin recovering within 3 years of conifer removal but shrub recovery would be negligible over this short time period.

Methods

Study Area

We collected vegetation data within the South Warner Juniper Removal Project Area (BLM 2011) in southern Lake County in south-central Oregon between the Warner Mountains and the Warner Valley (Fig. 1). We also collected sage-grouse nest habitat data here as well as north to Abert Rim and south of Warner Valley extending into Modoc County, California, and into Washoe County, Nevada (Fig. 1). Average monthly precipitation from January to June in 2012 to 2014 was 1.42, 0.99, and 0.98 cm, which were all below the 15-year average of 1.74 cm (median: 1.91 cm; interquartile range: 1.04–2.17 cm). Only 1 year (2001: 0.77 cm January to June monthly average) was drier than 2013 and 2014 over the last 15 years. The area ranged in elevation from 1,360 to 2,180 m with an average of 1,700 m above sea level and was dominated by low sagebrush (*Artemisia arbuscula*), but other habitat types included mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana*) at higher elevations, Wyoming big sagebrush (*A. tridentata* ssp. *wyomingensis*) at lower elevations, and interspersed shrub species including antelope bitterbrush (*Purshia tridentata*), rabbitbrush (*Chrysothamnus* spp.), saltbrush (*Atriplex* spp.), and mountain mahogany (*Cercocarpus* spp.). Western juniper tended to occur in a patchy distribution from mid to high elevation. Characteristic forb taxa are listed under the section "Vegetation Monitoring." Characteristic perennial grasses included Sandberg's bluegrass (*Poa secunda*), bottlebrush squirreltail (*Elymus elymoides*), bluebunch wheatgrass (*Pseudoroegeneria spicata*), and Thurber's needlegrass (*Achnatherum thurberianum*). The main annual grass was cheatgrass (*Bromus tectorum*), an exotic invasive species.

Conifer Management

Conifer invasion transitions through three successional phases (Miller et al. 2005): In Phase I, conifers are present with shrubs and herbaceous plants still dominant; in Phase II, conifers codominate the vegetation community; and in Phase III, the landscape is dominated by conifers with decreased understory. Most of the treated areas in our study were Phase I to Phase II encroachment with generally intact understory herbaceous and shrub vegetation (Miller et al. 2005, 2008). Treatments occurred from late fall to early spring and were designed to maximize sagebrush retention. All conifer removal treatments were conducted by hand-cutting with brush- and chainsaws. Additional slash treatment of cut conifers was conducted where necessary

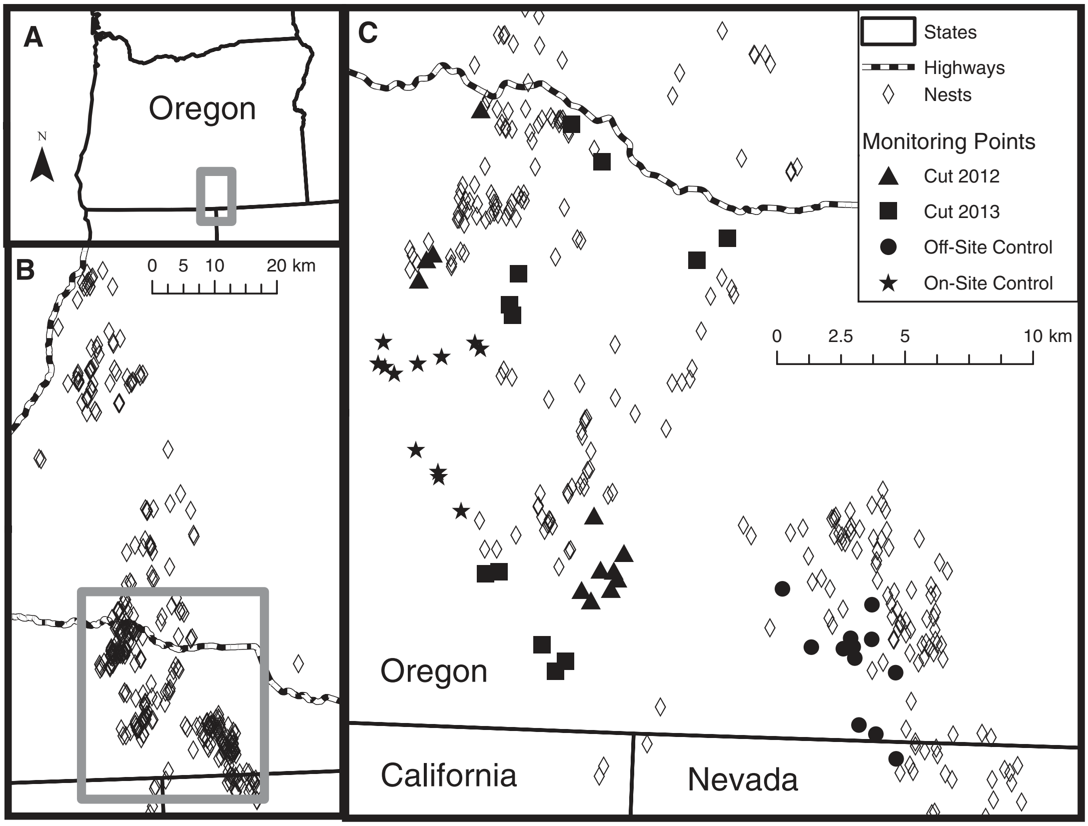

Figure 1. (A) Gray box shows study area location within Oregon. (B) Study area of sage-grouse nesting study from 2010 to 2014. (C) Vegetation monitoring points for conifer removal study from 2012 to 2014.

to reduce woody fuels and vertical structure. Treatments consisted of either cut-and-leave or cut-and-burn. Cut-and-leave involved cutting trees without additional slash treatment and primarily occurred in areas with trees of small size and low density. Cut-and-burn occurred with larger, denser trees to expose the understory and encourage growth. Cut trees were left to dry for ~1 year and then individually burned during the winter to minimize the impact to herbaceous and shrub vegetation. Effort was made to burn only individual trees to minimize shrub mortality and the burn footprint areas. Across all treatments, presettlement trees were left in locations that historically supported juniper, thus some areas still had standing trees after treatment (BLM 2011). We consolidated all sample locations into either cut or not cut. We defined the year of the cut as the year of the first growing season following treatment. We surveyed treatments designated only as cut-2012, cut-2013, or not-cut during the study.

Treatment Monitoring Locations

We established 12 random vegetation monitoring locations in each of four strata using the conifer removal management plan (BLM 2011). Because the plan limited the available strata locations, the treatments were not randomized and the monitoring locations potentially suffered from autocorrelation; we therefore used spatial and temporal controls to minimize these effects. The strata included cut in 2012 (no pretreatment, 3 years posttreatment), cut in 2013 (1 year pretreatment, 2 years posttreatment), an on-site control in close proximity to treated areas but not cut, and an off-site control in an adjacent study area to the southeast (Fig. 1). A total of 26 sampling locations were in low sagebrush, while 22 were in mountain big sagebrush. All areas had greater than 16% conifer cover estimated in the plan (BLM 2011). We buffered the areas 50 m inward to avoid potential edge effects and randomized the 12 points in each strata while restricting points to greater than 200 m apart to minimize spatially correlated vegetation. We monitored vegetation at each of these locations annually from 2012 to 2014.

Vegetation Monitoring

We surveyed vegetation at each of the 48 monitoring points annually from 2012 to 2014. One point in the on-site control was influenced by a natural gas pipeline and was removed from the analysis resulting in a sample of 47 points surveyed annually between late May and early July. We collected vegetation data at nests and at random treatment monitoring points over a site-scale extent (10 × 10-m area) typical of sage-grouse nest habitat studies. An array of two 10-m orthogonal transects was oriented in a random direction centered on the established monitoring point or the nest bowl. We used the line intercept method (Canfield 1941) to estimate the percent cover for each shrub species. We also recorded the cover of each shrub species between 40 and 80 cm tall (determined by the uppermost portion of the canopy; Connelly et al. 2000), which we called medium height. We measured the height of free-standing shrubs not including the flower stalks of sagebrush. Cover data on juniper was collected along with the shrub data to estimate conifer abundance. We removed data within 1 m of the center of the crossed transects from the shrub cover estimate to reduce bias induced by centering on shrubs at nests (Musil 2011). We summarized the data into total shrub richness (i.e. number of species), total shrub cover, total sagebrush cover, medium shrub cover, and medium sagebrush cover. We did not record shrub height at the site-scale directly, but in a concurrent survey, we collected shrub heights at a scale we called stand, which we used to supplement our site-scale data. We collected stand-scale vegetation data from early July to early August when site-scale surveys were completed, and due to time constraints, conducted stand-scale surveys at vegetation monitoring points, but not at nests. We randomly oriented and centered on the survey point an array of four parallel 60-m transects, each 40 m apart (modified from Davies et al. 2006). We identified species and measured height of all shrubs that intersected the transects.

We estimated site-scale grass and forb cover at monitoring points and nests using ten 20 × 50-cm frames placed at 1, 3, 5, 7, and 9 m along each transect (Daubenmire 1959). Forb data included total forb cover, key forb cover, key forb richness (number of species), and tall forb cover (>18 cm; Connelly et al. 2000). We measured total height of free-standing plants. Forbs consisted of 16 taxa that were found to be important for nesting females and broods including desert parsley (*Lomatium* spp.), hawksbeard (*Crepis* spp.), false dandelion (*Agoseris* spp.), milkvetch (*Astragalus* spp.), broomrape (*Orbanche* spp.), clover (*Trifolium* spp.), slender phlox (*Phlox gracilis*), fleabane daisy (*Erigeron* spp.), common dandelion (*Taraxacum officinale*), goatsbeard (*Tragopogon dubius*), yarrow (*Achillea millefolium*), aster (*Aster* spp.), monkeyflower (*Mimulus* spp.), groundsmoke (*Gayophytum* spp.), pussytoes (*Antennaria* spp.), and eyelashweed (*Blepharipappus* spp.; Barnett & Crawford 1994; Drut et al. 1994; Gregg 2006). Grass cover was divided into total cover and tall cover (>18 cm) similar to forbs. Grass height was measured as droop height of the highest leaf. We also recorded total and tall perennial grass cover and total annual grass cover. We combined forbs and perennial grasses to derive total and tall herbaceous cover.

Encroachment Analysis

We assessed the effects of conifer encroachment on vegetation characteristics with data from the cut-2013, on-site control, and off-site control strata collected during 2012 because this provided the greatest not-cut sample. We analyzed relationships for the treatment monitoring plots between vegetation response variables and conifer canopy cover explanatory variable using generalized linear models in the R environment (R Core Team 2014) with a Poisson distribution and log link for key forb and shrub richness and a Gaussian distribution and identity link for all other response variables. We assessed each model individually using p values from the chi-square test for the Poisson regression and the F test for the Gaussian regression. We interpreted the slope as the effect of conifers on the vegetation variables and the y-intercepts as potential estimates of the variable in the absence of conifers.

Conifer Removal Analysis

We assessed effects of conifer removal on the vegetation characteristics using data from all strata and years. In the R environment, we used generalized linear mixed effects models with Poisson distribution and log link for the key forb and shrub richness response variables and linear mixed effects models for all others. We modeled the time trend (i.e. 0 was uncut to 3 years posttreatment) as the fixed effect and time within individual monitoring points as random effects to account for autocorrelation of repeated measures, thereby utilizing spatial and temporal controls to optimize information in the data. We assessed the models using p values of the trend. For significant trends (i.e. treatment effects), we interpreted the slope as the effect size.

Sage-Grouse Nest Habitat Data

To provide local habitat data for comparison, we captured sage-grouse females during winter to spring 2009–2014 in the treatment area and 2010–2014 in the control area using spotlighting techniques (Giesen et al. 1982; Wakkinen et al. 1992) near leks and wintering habitat and fitted them with radio-collars (22-g VHF radio-collars, Advanced Telemetry Systems, Isanti, MN, U.S.A.). We monitored radio-marked females twice per week during the potential nesting seasons from 2010 to 2014. When a grouse was observed in the same place on two consecutive locations, she was then observed visually, without flushing, to verify nesting. Nests were subsequently monitored twice per week until incubation was terminated. We then surveyed nest habitat with the same methods and same time (i.e. late May to early July) as previously described for site-scale vegetation.

We compared the means, standard errors, and y-intercepts of vegetation characteristics affected by conifer encroachment and removal from the aforementioned analyses with nest data. We compared values from nests with cut and not cut samples empirically with one-way analysis of variance with Tukey's honest significant differences for multiple comparisons and an alpha level of 0.05. We then qualitatively compared the monitoring data and nest data to the rangewide nesting habitat guidelines described below.

Sage-Grouse Nest Habitat Guidelines

We compared two sources of rangewide nesting habitat information to the vegetation survey data. The recommendations of Connelly et al. (2000) defined suitable nesting habitat and are the most used and cited sage-grouse habitat guidelines. The HAF (Stiver et al. 2015) modified and expanded those guidelines for more general use, and included an additional category for marginal habitat. Hagen et al. (2007) conducted a meta-analysis on nesting habitat using multiple published studies. We therefore compared our vegetation monitoring data to the HAF guidelines and the estimates of the meta-analysis.

Stiver et al. (2015) recommended nesting suitability values for sagebrush cover (suitable [S]: 15–25%; marginal [M]: 5–15% or >25%; unsuitable [U]: <5%), sagebrush height (S: 40–80 cm; M: 20–40 cm or >80 cm; U: <20 cm), perennial grass cover (S: >15%; M: 5–15%; U: <5%), and perennial forb cover (S: >10%; M: 5–10%; U: <5%). They also suggested greater than 18-cm height as suitable for herbaceous vegetation and the increased forb richness was more suitable. Hagen et al. (2007) assessed 19 studies distributed across the sage-grouse distribution and calculated estimates of 4.02% forb cover (95% confidence interval [CI]: 2.05–5.99), 6.75% grass cover (95% CI: 4.53–8.98), 21.51% sagebrush cover (95% CI: 19.91–23.93), and 25.13% shrub cover (95% CI: 20.35–29.91).

Results

Encroachment Effects

In the encroachment analysis, all slopes were negative indicating reduced abundance and richness with increasing conifer cover for all vegetation characteristics assessed. However, only 6 of the 16 habitat variables had slopes significantly different from zero (key forb richness: $\chi^2_{[1,33]} = 5.95$, $p = 0.015$; total forb cover: $F_{[1,33]} = 5.40$, $p = 0.027$; total herbaceous cover: $F_{[1,33]} = 4.91$, $p = 0.034$; medium shrub cover: $F_{[1,33]} = 5.40$, $p = 0.026$; total shrub cover: $F_{[1,33]} = 11.07$, $p = 0.002$; shrub richness: $\chi^2_{[1,33]} = 4.34$, $p = 0.037$), and two of the habitat variables had marginally significant slopes (perennial grass cover: $F_{[1,33]} = 3.98$, $p = 0.054$; total sagebrush cover: $F_{[1,33]} = 3.20$, $p = 0.083$; Table S1, Supporting Information; Fig. 2). None of the slopes for the tall herbaceous variables or annual grass cover were statistically different from zero. Shrub cover had the most deviance explained by conifer cover with 25.1% (Table S1). Shrub cover decreased by 0.47 percentage point for every one percentage point increase in conifer cover (Table S1; Fig. 2).

Conifer Removal Effects

In the conifer removal analysis, the treatment effect trend was significantly positive for three of herbaceous variables including tall perennial grass cover ($F_{[1,93]} = 7.85$, $p = 0.006$), perennial grass cover ($F_{[1,93]} = 5.94$, $p = 0.017$), and tall herbaceous cover ($F_{[1,93]} = 7.73$, $p = 0.007$), and was marginally significantly positive for tall forb cover ($F_{[1,93]} = 3.72$, $p = 0.057$) and total grass cover ($F_{[1,93]} = 3.63$, $p = 0.060$; Table S1; Fig. 3). As anticipated, we did not observe a significant treatment effect on shrub richness or cover (Table S1). However, sagebrush height increased following treatment ($F_{[1,93]} = 7.17$, $p = 0.009$; Table S1; Fig. 3).

Sage-Grouse Nesting Habitat Comparison

We found and surveyed 356 nests from 2010 to 2014. Our cut monitoring points had lower total shrub (20.8%) and total sagebrush (12.6%) cover than the uncut points (22.9 and 13.3%), but was not a significant difference, while both cut and uncut points had significantly lower cover than the nests (33.3 and 24.1%; Table S2). Cut and uncut estimates were also lower than those reported by Hagen et al. (2007) (25.1 and 21.5%) and fell into the marginal class of Stiver et al. (2015); Table S2; Fig. 3). However, the intercept of sagebrush on conifer cover, at 15.8% (Table S2; Fig. 2), was within the suitable habitat range suggesting that conifer removal could improve conditions for nesting sage-grouse. Although sagebrush heights in uncut areas were within the suitable range, heights increased further into the suitable range after treatment (Table S1; Fig. 3).

Forb and grass cover was greater in areas with less conifer cover (Table S1; Fig. 2) and showed some increases after conifer removal (Fig. 3), suggesting lower conifer cover provided higher quality sage-grouse nesting habitat in terms of herbaceous vegetation. While below the suitable habitat category, the perennial grass cover averages at nests (6.0%) and cut areas (5.3%) were within the marginal range, and both perennial grass and forb cover were close to the meta-analysis values and the nest averages (Table S2). Perennial grass was within the marginal category at less than 10% conifer cover but became unsuitable at higher cover (Fig. 2). Prior to treatment, perennial grass cover was unsuitable, but became marginal at greater than 1-year posttreatment (Fig. 3). Tall (>18 cm) grass and forb cover, recommended as important for nesting cover, was not affected by conifer cover but showed increases after treatment (Table S1; Fig. 3). Values for key forb richness were not given by Stiver et al. (2015), but they noted that increased forb diversity was beneficial. Although conifer removal did not increase forb richness, increased conifer cover negatively impacted forb richness (Table S1; Fig. 2).

In general, the estimated values of the vegetation characteristics at 0% conifer cover were near the local and rangewide nest habitat values, but suitability decreased with increasing conifer cover (Fig. 2). Following treatments, all vegetation characteristics that changed significantly, increased with time (Fig. 3).

Discussion

Our study is the first to compare information on the effects of conifer encroachment and removal on vegetation with local and rangewide sage-grouse nest habitat data and established nest habitat guidelines. We observed negative effects of conifer encroachment on vegetation characteristics important to sage-grouse nesting and positive benefits of conifer removal within 3 years. The years during the study were especially dry (see "Study Area" section) potentially reducing productivity. We would expect even greater herbaceous response after treatments in years with increased precipitation (Sneva 1982).

Negative effects of conifer encroachment on sagebrush vegetation are well documented (Miller et al. 2005, 2011; Coultrap et al. 2008; Roundy et al. 2014*a*). Coultrap et al. (2008) observed negative trends on various richness and cover estimates with increasing conifer cover similar to our observations. In general, as conifer abundance increases, other vegetation decreases (Miller et al. 2011; Roundy et al. 2014*a*), possibly contributing to the avoidance of sage-grouse to trees during every life history stage (Gregg 1991; Doherty et al. 2008,

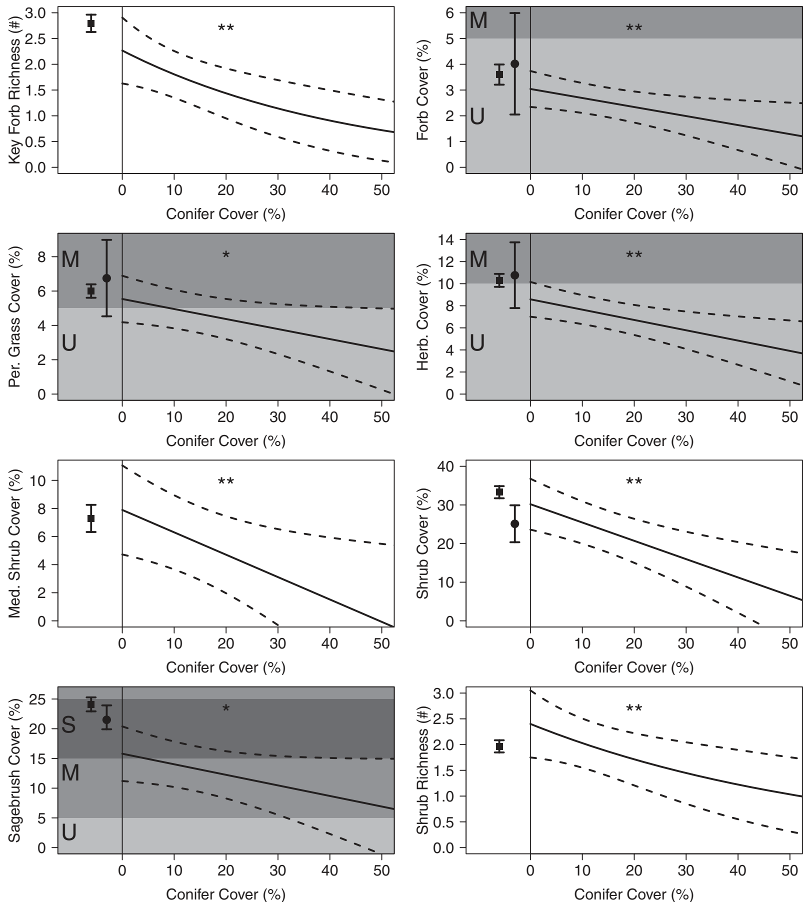

Figure 2. Effects of conifer cover on habitat characteristics of vegetation monitoring plots in southern Lake County, Oregon, during 2012 compared to sage-grouse nesting habitat guidelines (Stiver et al. 2015; S: suitable [dark gray]; M: marginal [medium gray]; U: unsuitable [light gray]), rangewide nest habitat estimates (Hagen et al. 2007; round symbol), and local nesting data (square symbol). Values for guidelines and nest habitat estimates are omitted if unavailable. Error bars and envelopes are ±95% CI. *Marginally significant trend ($0.05 < p < 0.10$). **Significant trend ($p < 0.05$).

2010; Freese 2009; Atamian et al. 2010; Casazza et al. 2011). Vegetation provides necessary benefits to sage-grouse including structure for nesting cover (Gregg et al. 1994; DeLong et al. 1995; Doherty et al. 2014), forbs for food during nesting and brood-rearing (Barnett & Crawford 1994; Drut et al. 1994; Gregg et al. 2008), and sagebrush for food during winter (Patterson 1952). Our nesting habitat assessment demonstrated negative effects of conifer encroachment and benefits of conifer removal on cover and forage required by nesting grouse.

Although several vegetation characteristics did not respond to conifer treatments, we observed increases in multiple measures of herbaceous vegetation, which is consistent with other studies (Bates et al. 2005, 2007; Dodson et al. 2008; Miller et al. 2014; Roundy et al. 2014*a*). Because of our inability to completely randomize the treatments, this may have been due in part to site effects we could not control. Understory vegetation recovery depends on several factors including site conditions, conifer abundance, pretreatment vegetation, time since removal, and management technique (Bates et al. 2000, 2005, 2007; Dodson et al. 2008; Roundy et al. 2014*a*). Many studies have not observed recovery of shrub communities (Miller et al. 2014; Roundy et al. 2014*a*) due to the short monitoring time, while recovery of herbaceous vegetation is common, but may take several years (Bates et al. 2000). Bates et al. (2000) observed effects within 2 years, while Bates et al. (2005) reported maximum herbaceous recovery at 5–6 years. Consistent with those results, we observed effects within 3 years. Additionally, although managers in our area attempted to avoid treating sites at risk of annual grass invasion, we observed a slight positive, but nonsignificant, increase in invasive annual grass cover. Further research is needed to monitor annual grass abundance, evaluate longer time periods, and assess effects of specific site factors.

As expected, shrub cover was unaffected by conifer removal during the short duration of this study, although we observed a nonsignificant negative trend in cover. An effort was made to minimize the impact of the slash burning in this study, but conifer removal and burning have the potential to decrease shrub abundance depending on the methods used. Cutting with machines (e.g. feller buncher) can potentially disturb vegetation, and heat from the slash burning can kill nearby shrubs. Additionally, fire creep occasionally occurred, which may have

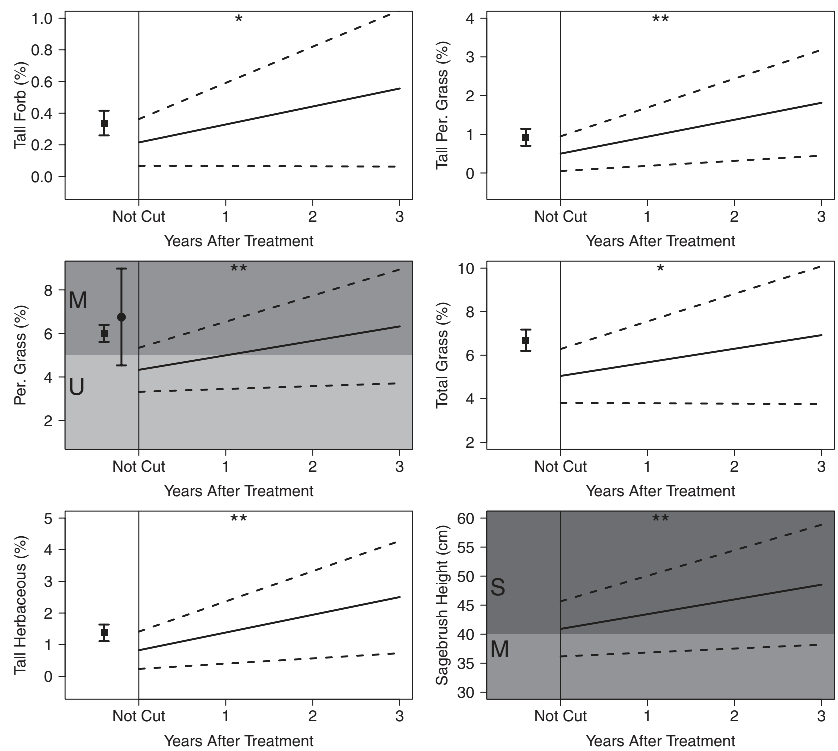

Figure 3. Effect of time since conifer removal on habitat characteristics of vegetation monitoring plots in southern Lake County, Oregon, during 2012–2014 compared to sage-grouse nesting habitat guidelines (Stiver et al. 2015; S: suitable [dark gray]; M: marginal [medium gray]; U: unsuitable [light gray]), rangewide nest habitat estimates (Hagen et al. 2007; round symbol), and local nesting data (square symbol). Values for guidelines and nest habitat estimates are omitted if unavailable. Error bars and envelopes are ±95% CI. *Marginally significant trend ($0.05 < p < 0.10$). **Significant trend ($p < 0.05$).

killed additional shrubs, but this was minimized by burning during the winter with snow on the ground. While negative effects to the understory should be minimized, slight decreases in habitat quality in the short term may be mitigated by increases in the long term as well as increased availability of productive nesting habitat (Severson et al. 2017). As conifer cover was reduced through removal, sagebrush cover shifted almost immediately from codominant with conifer to the dominant cover. Additionally, we observed an increase in sagebrush height. Because the crowns of western juniper are efficient at intercepting precipitation and the extensive tap roots and lateral roots are efficient at removing nutrients and moisture from soil (Miller et al. 2005; Kormos et al. 2017), removal of these trees immediately frees resources for other vegetation (Roundy et al. 2014*b*) which could potentially account for the fast response in sagebrush height and other vegetation. In the long term, we expect shrub abundance to recover given sufficient time. Burning individual fallen trees during the winter to eliminate slash and minimize impact can provide other benefits to posttreatment succession such as increased growth of perennial grass (Bates & Svejcar 2009), but managers should consider potential trade-offs with the approach and make every effort to minimize negative impacts.

Our local nest data and treatment monitoring points were more aligned with the quantitative estimates provided in the meta-analysis (Hagen et al. 2007) than suitable nesting habitat categories defined in the HAF (Stiver et al. 2015). This could be due to lumping different habitat types that have inherently different structure (e.g. Davies & Bates 2010) but is consistent with how the habitat guidelines were constructed and interpreted. Vegetation monitoring points generally had low herbaceous cover that increased posttreatment. Local nesting data indicated sage-grouse readily used sites with lower herbaceous cover than the HAF guidelines consider suitable, suggesting site potential to reach rangewide guidelines may be limited in our study area due to soil type or other ecophysical factors (Davies et al. 2006). Overall, the encroachment and treatment analyses illustrated trajectories of habitat quality with and without conifer removal, which ultimately may be more informative, given local variability and site potential, than whether or not HAF habitat suitability levels were attained. More monitoring is needed and long-term monitoring of these sites is planned over the coming years.

Management Implications

Conifer encroachment has negative impacts on sagebrush vegetation including those characteristics necessary for sage-grouse nesting, but conifer removal can improve nesting conditions given enough time. For sage-grouse nesting habitat improvement, managers should focus on areas that have the greatest potential for nesting. Knowledge of local sage-grouse habitat is beneficial to refine established guidelines and develop realistic recovery goals and expectations. Because we observed relatively quick herbaceous recovery, focusing on treating areas with intact understory communities (Phase I and Phase II) may provide the most immediate benefits. Phase I woodlands may already have an intact understory. In Phase II woodlands, where the understory may be reduced, herbaceous vegetation can recover quickly, while the shrub communities will recover more slowly, but more research is needed to evaluate the specific effects of site conditions and the time frame necessary for recovery. Although annual grass cover did not change significantly after our treatments, managers should consider all possible threats from invasive species based on site characteristics (Chambers et al. 2007, 2013) prior to initiating woodland treatments.

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Supporting Information

The following information may be found in the online version of this article:

Table S1. Effects of conifer canopy cover (%) on understory vegetation response variables during summer 2012 (i.e. encroachment effect) and conifer removal treatment effect from 2012–2014 in southern Lake County, Oregon.

Table S2. Vegetation cover (%) richness (number of species) at conifer removal monitoring points and sage-grouse nests in southern Lake County, Oregon from 2010–2014.

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