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RESEARCH ARTICLE

Avian Response to Mechanical Aspen Restoration in Sierra Nevada Coniferous Forest

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Abstract

Using mechanical treatments to mimic natural disturbances is becoming a standard management and restoration approach. In the Sierra Nevada, as throughout much of western North America, much of aspen habitat is in poor health. Because of the high ecological value of healthy aspen, and its limited extent on the landscape, restoration to reverse the decline and improve stand health has become a management priority in the region. To evaluate the ecological effects of mechanically removing competing conifers to restore aspen in the Sierra Nevada, we compared vegetation characteristics and bird abundance in treated and untreated aspen stands on the Lassen National Forest before and up to 13 years after mechanical conifer removal. Treatments reduced total canopy cover and increased herbaceous cover and the number of aspen stems, while shrub and overstory aspen covers were unchanged. Of 10 aspen focal bird species, 7 increased in abundance following treatment relative to controls, including all species associated with early seral aspen habitat and cavity nesting species; none declined. In contrast, of the six conifer focal species, the four associated with denser conifer habitat declined as a result of the treatments. The two species associated with conifer edges and understory cover increased. Our results demonstrate mechanical conifer removal treatments can provide ecologically meaningful changes in habitat for the avian community and are an effective tool for restoring ecological values of degraded aspen habitat for birds in the Sierra Nevada.

Key words: aspen, birds, conifer encroachment, effectiveness monitoring, focal species, restoration, Sierra Nevada.

Introduction

Ecological disturbance is widely recognized as essential for maintaining biodiversity (Pickett & White 1985; Attiwill 1994; Brawn et al. 2001). In historically fire-prone forest ecosystems, allowing wildfire to burn or using treatments that mimic the natural disturbance (e.g. mechanical thinning, prescribed fire) are becoming standard management and restoration strategies (van Wagtendonk 2007; Sneeuwjagt et al. 2013). The effectiveness of treatments to fully realize the ecological benefits of natural disturbance is variable, as is highlighted by comparative studies of bird community response to wildfire and mechanical treatments in North American forests (Schieck & Song 2006; Fontaine & Kennedy 2012).

Quaking aspen (*Populus tremuloides*) is a disturbance-dependent component of western North American forests, important for its high ecological values relative to adjacent forest types, such as increased water yields (Gifford et al. 1984; LaMalfa & Ryle 2008), higher quality soils (McCullough et al. 2013), and increased diversity of plants, birds, and other wildlife (Flack 1976; Griffis-Kyle & Beier 2003; Kuhn et al. 2011). Restoration to reverse aspen decline has become a management priority in the region (Shepperd et al. 2006) because of aspen's high ecological value and limited landscape extent. Restoration treatments are designed to increase aspen recruitment by mechanically removing encroaching conifers (Jones et al. 2005). This effort represents a larger trend to mitigate the impacts of environmental change using ecological restoration (USDA Forest Service 2011, 2012). In the face of uncertain and rapidly changing environmental conditions, ecological restoration is one tool for increasing the resilience and adaptive capacity of ecosystem services (Harris et al. 2006; Seavy et al. 2009).

To evaluate the ecological effects of mechanical aspen restoration in the Sierra Nevada, we monitored birds in treated and untreated aspen stands in the Lassen National Forest. Previous studies from this region found mechanical treatments are effective at increasing aspen recruitment (Jones et al. 2005), but the degree to which these increases manifest in meaningful changes to aspen-associated wildlife remains untested. To evaluate post-treatment changes to the avian community, we selected two suites of focal bird species, one associated with a broad range of aspen habitat characteristics, and the other associated with coniferous forest habitat, as indicators of ecological change. The objectives of this study were to (1) describe the effects of mechanical aspen restoration treatments on bird abundance and vegetation structure and (2) use these monitoring data to make inferences about the degree to which

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aspen treatments produce ecologically meaningful changes to forest structure and composition.

Methods

Study Area

All data were collected on the Lassen National Forest at the junction of the Sierra Nevada and southern Cascade Mountain Ranges in northeastern California (Fig. 1). We sampled aspen stands ranging in elevation from 1502 to 1896 m within or adjacent to Sierra mixed conifer (predominantly *Abies concolor*, *Calocedrus deccurens*, *Pinus lambertiana*, *Pinus ponderosa*, *Pseudotsuga menziesii*), lodgepole pine (*Pinus contorta*), white fir (*A. concolor*), red fir (*Abies magnifica*), and eastside pine (*Pinus jeffreyi* and *Pinus ponderosa*) cover types (Mayer & Laudenslayer 1988).

Aspen restoration Treatments

Restoration treatments were designed to trigger hormonally stimulated aspen vegetative suckering and increase aspen recruitment by harvesting conifers competing with existing stems for sunlight and water (Shepperd et al. 2006). This entailed removing all conifers around aspen stems at a distance equal to the height of the tallest conifer to the north and 1.5–2 times the height of the tallest conifers in other cardinal directions. Trees were removed using track-laying harvesters and rubber tire skidders to minimize residual woody material. A small number of legacy trees that represented the historic conifer component (generally >76 cm dbh) were maintained at a density generally less than 3/ha. Residual woody material was left in place with the exception of two stands where slash was piled and burned. None of the stands were affected by wildfire or prescribed fire during the study. Where herbivory from ungulates (domestic and wild) was deemed to be a risk to achieving recruitment objectives, fencing or modifications to grazing practices were implemented. All treatments occurred from August to March, outside of the avian breeding season, from 1999–2011.

Sampling Design

To select stands to sample we consulted U.S. Forest Service staff planning treatments to determine stands that had been treated or most likely to be treated during the timeframe of our project and prioritized them for monitoring. As controls, we selected stands where treatment was not likely during our study. Because aspen were scarce on the landscape and because not all stands slated for treatment were treated, some controls were up to 37 km from the nearest treatment stand.

At all stands we sampled birds using point count surveys that were clustered along nonlinear transects. We used GIS layers from the U.S. Forest Service derived by in-field delineation of all of the aspen stands in our study area to select individual point count stations. Point selection was constrained by maintaining a minimum of 220 m spacing between stations and limiting the total sample for any one transect to what could be surveyed in a 4-hour window. We dropped from consideration any potential transect with less than four point count stations, thus, areas with few and dispersed small stands were not sampled. We sampled 104 aspen stands ranging in size from 0.2 to 324.1 ha (median = 2.9 ha). The number of point count stations per transect varied from 4 to 16.

We collected data between 2004 and 2012. Half the transects were first surveyed in 2004 with the other half beginning in 2006 and 2007. By the end of the study, we had data from 180 point count stations at 18 sites. Of the 180 stations, 17 were treated before 2004, 44 were treated from 2004 to 2011, and 119 were never treated. Once established, all stations were surveyed twice between 21 May and 7 July in each year through 2012, except for two control transects that were not surveyed in every year due to heavy snowpack. With variation in the timing of treatment and establishment of survey transects, the number of pre-treatment years of data varied from zero to eight and post-treatment from one to nine. Whether a station was treated and the year of treatment also varied among stations within a transect.

Point Count Surveys

Surveyors conducted standardized 5-minute exact-distance point counts (Ralph et al. 1995) at each point count station. With the aid of rangefinders, surveyors estimated distance to each individual in six distance bins: 0–10, 11–20, 21–30, 31–50, 51–100 m. Counts began after local sunrise and were completed before 10:00 AM. Surveyors received three weeks of training to identify birds and estimate distances and passed a double-observer field test.

Vegetation Surveys

We collected vegetation data across a 50-m radius plot centered on each point count station. On these plots we made ocular estimates of the percent cover of overstory (>5 m) and understory (<5 m) aspen, shrubs, and herbaceous vegetation, and counted all snags greater than 30 cm. Along two 50-m line transects oriented south and east from the plot center, at 3-m intervals starting 3 m from the center, we used a moosehorn densiometer to measure canopy cover (Fiala et al. 2006).

Post-treatment vegetation data were collected from 1 to 13 years following treatment. For post-treatment stations with more than one sample, we used the sample furthest from the year of treatment for the analysis, yielding a dataset with a mean of 5 years following treatment. For pre-treatment stations we used the sample closest to the year of treatment. The 17 stations without pre-treatment data were included in post-treatment vegetation analysis. At the 119 control stations we randomly chose one vegetation survey per station for analysis.

Focal Species

We selected 10 focal species associated with aspen habitat and 6 species associated with conifer habitat in the study area.

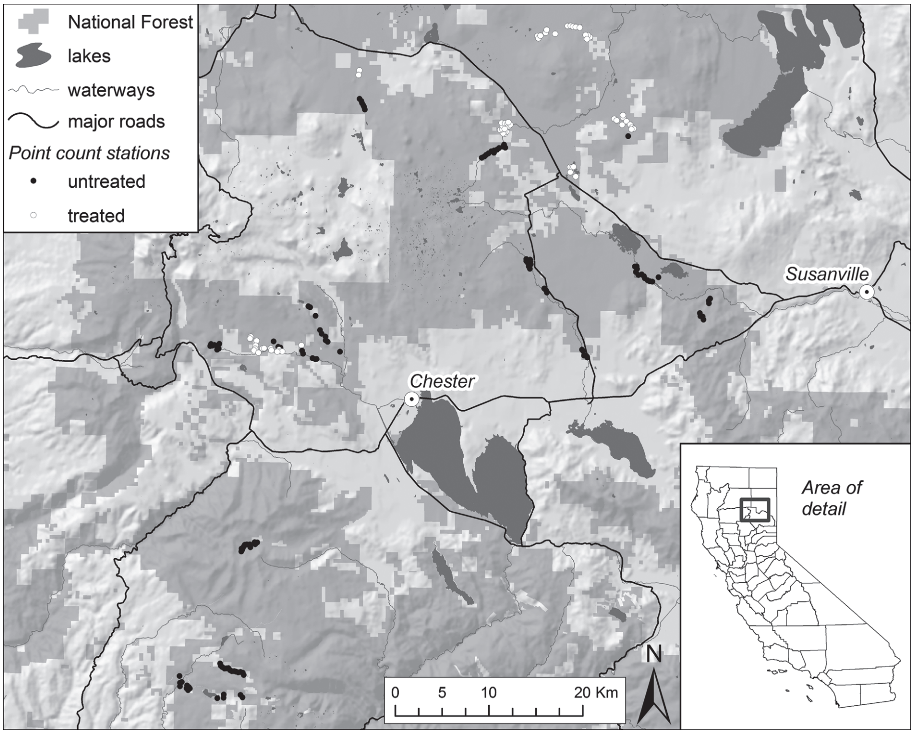

Figure 1. Locations of point count stations in treated and untreated aspen stands surveyed from 2004 to 2012 in the northern Sierra Nevada, California, United States.

We used several criteria to select our aspen focal species: (1) abundant enough to allow for meaningful statistical analysis (Nur et al. 1999), (2) appropriately sampled using the point count method (Ralph et al. 1995), and (3) represented a range of ecological conditions found in aspen habitat throughout the region. For conifer habitat, we used the focal species listed in the California Partners in Flight Coniferous Forest Bird Conservation Plan (CalPIF 2002) that met our above criteria and were not already included in our aspen focal species list.

Aspen focal species were split into three groups that represented a progression of aspen seral conditions expected under a natural disturbance regime based on their foraging and nesting associations and our local knowledge of their habitat associations. Tree Swallow (*Tachycineta bicolor*) and Mountain Bluebird (*Sialia currucoides*) were considered early seral aspen associates because they nest and forage in open habitats with low tree density. Dusky Flycatcher (*Empidonax oberholseri*), MacGillivray's Warbler (*Geothlypis tolmiei*), and Chipping Sparrow (*Spizella passerina*) were considered early to mid-seral associates because they nest and forage in understory shrubs and trees. Red-breasted Sapsucker (*Sphyrapicus ruber*), Hairy Woodpecker (*Picoides villosus*), Western Wood-Pewee (*Contopus sordidulus*), Warbling Vireo (*Vireo gilvus*), and Mountain Chickadee (*Poecile gambeli*) were considered mid- to late-seral associates because they use the boles or foliage of larger trees. Following treatment, we predicted (1) an increase in early seral associates because the treatments created open habitat for foraging, and sufficient retained mature aspen for nesting, (2) little to no response from mid-seral associates because the timeframe of avian sampling for this study averaged 5 years after treatment, hence many of the aspen stands had not yet developed complex understory structure, and (3) declines from late-seral associates because the treatments removed the majority of conifers these species also use.

Of the coniferous forest focal species, Golden-crowned Kinglet (*Regulus satrapa*), Red-breasted Nuthatch (*Sitta canadensis*), and Brown Creeper (*Certhia americana*) are associated with closed canopy conifer stands and we predicted a decrease in their abundance after treatment. Western Tanager (*Piranga ludoviciana*) is associated with open canopy conifer forest and we predicted they would decline but the magnitude of decrease would be less than the closed-canopy group. Dark-eyed Junco (*Junco hyemalis*), an understory generalist, we predicted would increase in abundance following treatment. Finally, Olive-sided Flycatcher (*Contopus cooperi*), which are strongly associated with large trees and post-disturbance habitat, we predicted would increase.

Data Analysis

To analyze changes in vegetation structure, we evaluated the difference between control, pre-treatment, and post-treatment vegetation using a Kruskal–Wallis rank sum test for each of the six vegetation metrics. If significant differences were found, we made pairwise comparisons using a Wilcoxon rank sum test. Our analytical technique effectively compared the median condition just before treatment to a median condition 1–13 years after treatment to a single measurement in time at control stations.

For the bird data, we collapsed the pre-treatment and post-treatment years into binary pre/post-treatment periods. We had insufficient sample sizes to investigate temporal trends in bird abundance following restoration. We assumed the post-treatment time period we sampled was short enough from an avian habitat perspective to warrant pooling and would not overwhelm our ability to detect changes in avian abundance.

Comparisons of point count data collected in different vegetation structure can be confounded by differences in detectability (Buckland et al. 2001). To account for differences in detection between treated and untreated aspen, we estimated the probability of detecting an individual of each focal species within each treatment condition using program Distance 6.0 release 2 (Thomas et al. 2010). Because some species were scarce in either untreated or treated aspen stands, pooling data from all pre- and post-treatment years into two discrete periods was necessary to meet the minimum sample size ($n = 50$) to properly fit detection curves in program Distance. We modeled detection functions using the five distance bins with a uniform key function with a cosine expansion, a half-normal key function with both Hermite and cosine expansions, and a hazard-rate key function with a simple polynomial expansion. All detections within each treatment condition for each focal species were pooled across stations, transects, visits, and years. Top models were selected on the basis of AICc and goodness-of-fit diagnostics provided in Distance (Buckland et al. 2001), resulting in 32 models: one for each focal species in untreated and post-treatment aspen (Table S1).

To evaluate the effects of aspen treatment on focal species abundance, we used a modified before-after control-impact (BACI) analysis. Our sampling unit was a point count station. We defined treated stations as any treated between 1999 and 2011 with at least 1 year of post-treatment data. Control stations were defined as any station not treated. Pre-treatment data was limited to 44 of the 61 treated stations. On the basis of our observations and those of the U.S. Forest Service staff, we assumed the 17 stations without pre-treatment data were comparable in pre-treatment conditions to the other treated stations. Because treated stations were not paired with controls stations at the beginning of the study, nor did all treatments occur in the same year, we could not use a standard before-after control-impact design (McDonald et al. 2000). Alternatively, we randomly assigned a year for each control station. Data collected in years up to and including the random year were defined as before impact and after the random year as after. Random years were drawn from a frequency distribution identical to the frequency distribution of treatment stations. Thus, we generated a random before/after history for control stations analogous to the actual before/after history for treated stations, where the virtual treatment year varied among control stations within transects, as well as among transects.

To estimate the interaction effect between the treatment and time variables on the discrete counts of each focal species, we built generalized linear mixed models with Poisson error and logarithmic link function using the package lme4.0 version 0.9999-1 (Bates et al. 2011) in program R x64 version 2.15.1 (R Development Core Team 2011). Our sample unit was a single point count visit and the dependent variable was the count. Random effects on the intercept parameter included year of survey, transect, and station. There were three fixed effects: treatment (binary: impact/control), time (binary: before/after), and a treatment-by-time interaction. We included as an offset term in the model the estimated mean probability of detection for each species in each treatment type from program Distance (modified from Hedley et al. 2004; Trimble & van Aarde 2011). We interpreted a significant ($p < 0.05$) treatment-by-time interaction as a response to treatment. We checked models for overdispersion, but none was found.

Results

Vegetation Response to Treatment

Changes in vegetation were mostly consistent with desired effects of treatment (Fig. 2). Canopy cover at control stations was 48.4%, and at treated stations it was reduced from 40.6 to 12.5% (Table 1). The cover of aspen stems less than 5 m tall was greater at post-treatment stands compared to pre-treatment and controls, but the cover of overstory aspen did not increase in treated stands. There was a significant difference in snag abundance among treatment conditions, but it was unclear whether the difference was attributable to aspen treatments. There was no evidence shrub cover changed as a result of treatment, but herbaceous cover responded positively, doubling from pre-to post-treatment.

Avian Response to Treatment

Of the 10 aspen focal species, 7 increased in abundance following treatment relative to changes in abundance at control stands (Fig. 3). As predicted, both of the early seral species increased in abundance following treatment. Tree Swallow increased from 0.07 birds/ha pre-treatment to 0.30 birds/ha post-treatment ($p = 0.002$) and Mountain Bluebird increased from 0.01 to 0.15 birds/ha ($p < 0.001$).

The response of the three mid-seral understory aspen species was mixed. MacGillivray's Warbler increased from 0.06 to 0.12 birds/ha post-treatment ($p = 0.027$), while there was no effect for Dusky Flycatcher (pre-treatment, 0.24, post-treatment, 0.25, birds/ha; $p = 0.306$) or Chipping Sparrow (pre-treatment, 0.08, post-treatment, 0.11, birds/ha; $p = 0.202$).

Contrary to our predictions four of the five late-seral aspen species increased as a result of treatment. The abundance of Red-breasted Sapsucker increased from 0.34 to 1.15 birds/ha ($p < 0.001$). Hairy Woodpecker increased from 0.16 to 0.57 birds/ha ($p < 0.001$). Mountain Chickadee increased from 0.87 to 1.23 birds/ha ($p = 0.003$). Western Wood-Pewee increased from 0.19 to 0.25 birds/ha ($p = 0.020$). There was no treatment effect for Warbling Vireo (pre-treatment, 0.48, post-treatment, 0.58, birds/ha; $p = 0.188$).

The change in abundance of coniferous forest focal species in stands following restoration tracked our predictions (Fig. 4).

Figure 2. Aspen stand seven years after restoration by mechanical conifer removal in the northern Sierra Nevada, California, United States.

Red-breasted Nuthatch decreased from 0.24 to 0.11 birds/ha ($p < 0.001$), Brown Creeper decreased slightly from 0.24 to 0.22 birds/ha while the abundance in the control sample increased from 0.22 to 0.30 birds/ha ($p = 0.030$), Golden-crowned Kinglet decreased from 0.21 to 0.05 birds/ha ($p < 0.001$), and Western Tanager decreased from 0.10 to 0.05 birds/ha ($p < 0.001$). Dark-eyed Junco increased from 1.53 to 1.95 birds/ha ($p = 0.041$) and Olive-sided Flycatcher increased from 0.004 to 0.024 birds/ha ($p < 0.001$).

Discussion

This is the first published study we are aware of that quantifies the response of wildlife to aspen restoration through mechanical conifer removal. Compared to untreated stands, there was a distinct shift in vegetation cover following mechanical treatments. Two earlier studies in the Sierra Nevada found mechanical aspen treatments significantly increased understory aspen recruitment within 5 years of treatment (Jones et al. 2005; Krasnow et al. 2012). Our results from a larger sample suggest that mechanical treatments can have the same desired effects on aspen recruitment across a broader range of conditions. The change in vegetation was followed by a concurrent change in the abundance of focal bird species. We conclude these mechanical treatments resulted in ecologically meaningful change to aspen habitat because they resulted in greater abundance of the majority of aspen focal species and reduced the abundance of species associated with dense conifer forest.

The response of aspen and conifer focal species suggests the treatments approximated a natural post-disturbance condition. As predicted, species associated with early seral aspen responded positively to treatments because aggressive mechanical conifer removal created the open habitat these disturbance-dependent species prefer while maintaining cavity nesting resources (Robertson et al. 1992; Power & Lombardo 1996). Also consistent with our predictions, only one species

Table 1. Summary statistics for vegetation data collected at point count stations at control and treatment aspen stands in Lassen National Forest from 2004 to 2012.

	Median Values (Lower, Upper Quartiles)			*Kruskal–Wallis Rank Sum Test*			*Pairwise Comparisons: Wilcoxon Rank Sum Test*		
Variable	*Control*	*Pre-treatment*	*Post-treatment*	χ^2	df	*p*	*p: Control Versus Pre-treatment*	*p: Control Versus Post-treatment*	*p: Pre-treatment Versus Post-treatment*
Canopy, percent cover	48.4 (34.4, 59.4)	40.6 (30.5, 50.0)	12.5 (6.3, 21.9)	92.78	2	<0.0001	0.0242	<0.0001	<0.0001
Aspen <5 m tall, percent cover	2.4 (0.2, 7.5)	5.3 (1.8, 8.0)	12 (3.6, 19.6)	24.9	2	<0.0001	0.0813	<0.0001	0.0013
Aspen >5 m tall, percent cover	3.5 (1.0, 9.0)	4.5 (1.9, 8.9)	3 (0.7, 8.3)	1.74	2	0.4199	—	—	—
Shrubs, percent cover	10 (4, 24)	6 (5, 10)	5 (2, 10)	20.24	2	<0.0001	0.0033	<0.0001	0.3311
Herbaceous plants, percent cover	12 (6, 22)	13 (7, 28)	25 (10, 60)	12.06	2	0.0024	0.5938	0.0008	0.0131
Number of snags >30 cm	6 (2, 11)	1 (0, 4)	3 (2, 6)	27.28	2	<0.0001	<0.0001	0.0162	0.0008

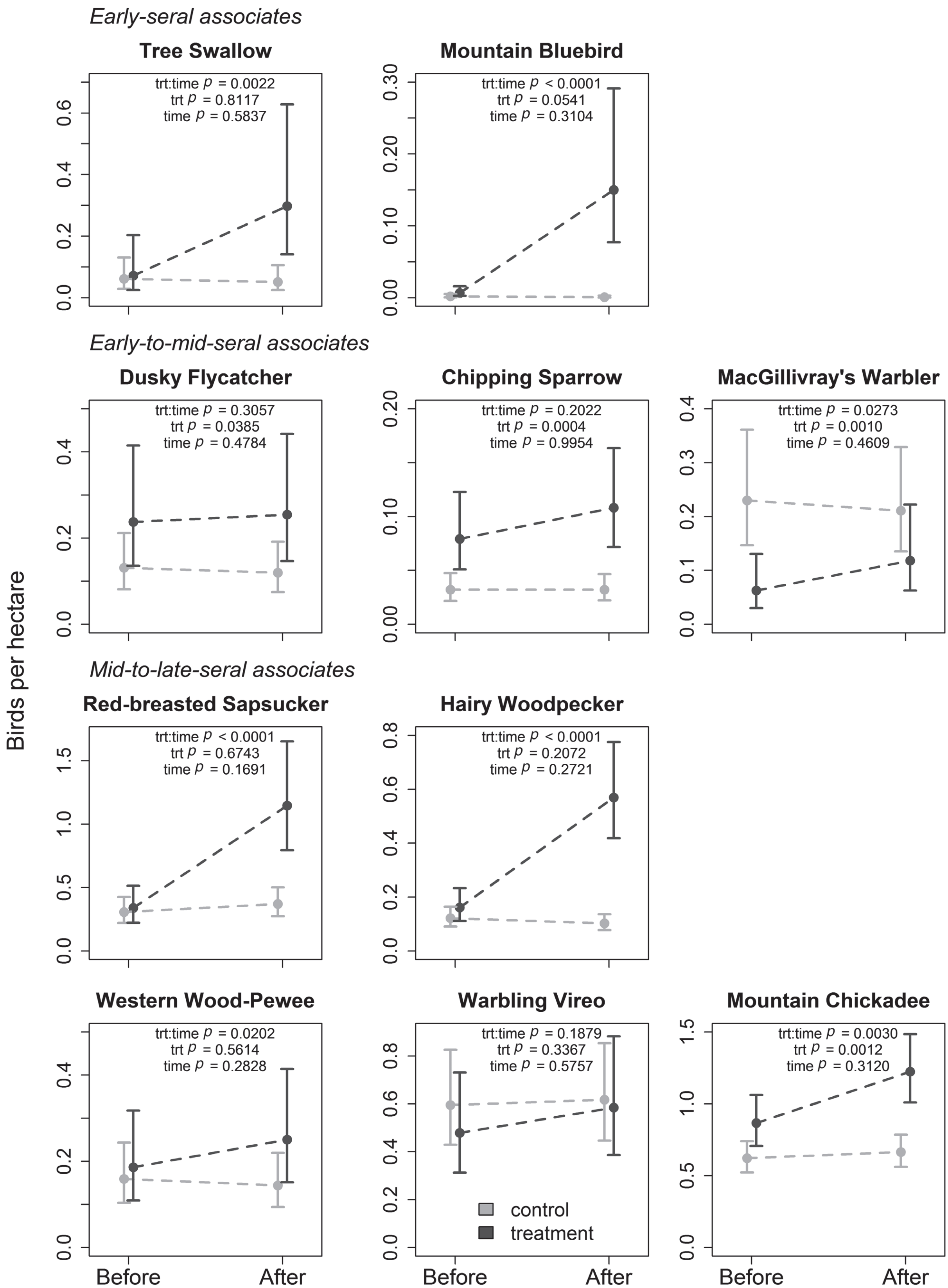

Figure 3. Predicted abundance of aspen focal species from GLMMs in treatment and control plots before and after aspen restoration treatments on Lassen National Forest. The dots represent the estimated abundance from the models, and the vertical lines represent the 95% confidence intervals around the mean estimates.

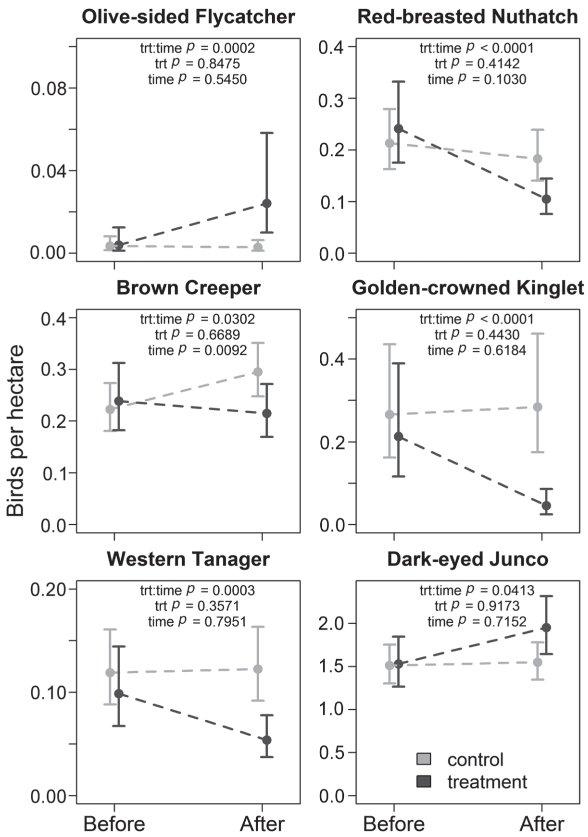

Figure 4. Predicted abundance from GLMMs of conifer focal species in treatment and control plots before and after aspen restoration treatments on Lassen National Forest. The dots represent the estimated abundance from the models, and the vertical lines represent the 95% confidence intervals around the mean estimates.

associated with mid-seral aspen, which primarily use small trees and shrubs for foraging and nesting, responded positively to treatment. This result suggests that the understory structure these species use had not yet developed or the mechanical treatments were not conducive to creating them. Prescribed burning after mechanical conifer removal results in higher densities of aspen regeneration than mechanical treatments alone (Shepperd 2004; Krasnow et al. 2012), and could produce better habitat for mid-seral aspen associates in a shorter timeframe after treatment. Contrary to our hypotheses, most species associated with late-seral aspen showed a positive response to treatment and none exhibited a negative response. We suspect in formulating our hypotheses for late-seral aspen associates, we overestimated the importance of conifer cover and underestimated the importance of retained legacy habitat structure and surrounding intact forest. Many of the late-seral aspen associates that responded positively in our study were more abundant in early seral boreal forest clear cuts that retained similar legacy structures than those that did not retain these structures, and were also similarly abundant in early seral habitat after fires (Schieck & Song 2006). Forest thinning prescriptions that most closely mimic habitat structure and patch sizes created through natural disturbance may promote conditions for a wide range of wildlife.

Five of seven aspen associates that responded positively to treatment were cavity nesters. The importance of aspen as nest trees for cavity nesting birds is well established (Martin & Eadie 1999; Aitken & Martin 2004). However, our results suggest that cavity nesting species respond positively to the removal of conifers even before there is an increase in nest-tree availability. At the time of this study, the only structure within restored aspen that were large enough for cavity nests were also available pre-treatment. We suggest instead of nest site availability, either preference for aspen stands with minimal conifers and/or selection for nest placement in open habitat likely explains the increase in abundance of cavity nesting birds.

Our results should be interpreted with respect to the age of the aspen treatments in this study. While enough time had passed to see a positive response in the herbaceous layer and aspen less than 5 m tall, there was no evidence of shrub regeneration or an increase in overstory aspen. In the future we expect many of the more recently treated stands will have an increase aspen canopy cover as the young aspen stems recruit into larger size classes. This change in stand structure may benefit some species (Earnst et al. 2012), but may result in decreases of birds associated with open aspen habitat (Lawler & Edwards 2002).

Focal species monitoring should continue at regular intervals to ensure the habitat requirements of all aspen-associated birds and other wildlife are met. Ecological effects monitoring focused on groups of organisms, such as in this study, can provide cost-effective information about ecological conditions of interest (Gram et al. 2001). With knowledge of their natural history, comparing individual species responses within and among multi-species groups may help explain why responses did not fit predictions and help guide recommendations to adjust future treatment prescriptions.

Conducting this study on actively managed public lands, where we had little experimental control, presented significant challenges, including the variable timing of treatment and variation between pre-treatment and control conditions. Our before-after control-impact approach was selected to help overcome these issues. We believe the value of the inference gained by evaluating real-world treatments across a relatively large spatial scale outweighs the limitations.

Implications for Practice

- Practitioners should consider the role of aggressive mechanical thinning in the restoration of disturbance-dependent habitats.
- With a thorough understanding of their biology, monitoring groups of focal species with similar resource requirements can be valuable for evaluating restoration activities.
- Retain legacy structures to increase the diversity of wildlife associated with post-disturbance habitats.
- Ecological monitors should work closely with agencies planning and executing treatments to ensure a robust before/after-treatment time series of data.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Table S1. Summary of model results from program Distance for aspen and conifer focal species. Models in bold indicate the selected model for inclusion in the before-after control-impact analysis. An asterisk indicates models for which a goodness of fit analysis (GOF) could not be performed.