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Experimental Test of Postfire Management in Pine Forests: Impact of Salvage Logging versus Partial Cutting and Nonintervention on Bird-Species Assemblages

JORGE CASTRO,*§ GREGORIO MORENO-RUEDA,†‡ AND JOSÉ A. HÓDAR*

*Grupo de Ecología Terrestre. Departamento de Ecología, Universidad de Granada, E-18071 Granada, Spain
†Konrad Lorenz Institut für Vergleichende Verhaltensforschung, Österreischische Academie der Wissenschaften, Savoyenstraße 1a, A-1160, Wien, Austria
‡Departamento de Biología Animal, Facultad de Ciencias, Universidad de Granada, E-18071, Granada, Spain

Abstract: *There is an intense debate about the effects of postfire salvage logging versus nonintervention policies on regeneration of forest communities, but scant information from experimental studies is available. We manipulated a burned forest area on a Mediterranean mountain to experimentally analyze the effect of salvage logging on bird–species abundance, diversity, and assemblage composition. We used a randomized block design with three plots of approximately 25 ha each, established along an elevational gradient in a recently burned area in Sierra Nevada Natural and National Park (southeastern Spain). Three replicates of three treatments differing in postfire burned wood management were established per plot: salvage logging, nonintervention, and an intermediate degree of intervention (felling and lopping most of the trees but leaving all the biomass). Starting 1 year after the fire, we used point sampling to monitor bird abundance in each treatment for 2 consecutive years during the breeding and winter seasons (720 censuses total). Postfire burned-wood management altered species assemblages. Salvage logged areas had species typical of open- and early-successional habitats. Bird species that inhabit forests were still present in the unsalvaged treatments even though trees were burned, but were almost absent in salvage-logged areas. Indeed, the main dispersers of mid- and late-successional shrubs and trees, such as thrushes (*Turdus *spp.) and the European Jay (*Garrulus glandarius*) were almost restricted to unsalvaged treatments. Salvage logging might thus hamper the natural regeneration of the forest through its impact on assemblages of bird species. Moreover, salvage logging reduced species abundance by 50% and richness by 40%, approximately. The highest diversity at the landscape level (gamma diversity) resulted from a combination of all treatments. Salvage logging may be positive for bird conservation if combined in a mosaic with other, less-aggressive postfire management, but stand-wide management with harvest operations has undesirable conservation effects.*

Keywords: clearcutting, postfire burned wood management, postfire forest restoration, salvage harvesting, salvage logging, Sierra Nevada National Park, snags

Prueba Experimental del Manejo Post-Fuego en Bosques de Pino: Impacto de la Tala de Salvamento Versus el Corte Parcial y la No Intervención sobre Ensambles de Especies de Aves

Resumen: *Hay un intense debate sobre los efectos de la tala de salvamento post-fuego versus las políticas de no intervención en la regeneración de las comunidades forestales, pero se dispone de poca información de estudios experimentales. Manipulamos un área de bosque quemado en una montaña Mediterránea para*

§*email jorge@ugr.es*
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analizar experimentalmente el efecto de la tala de salvamentos sobre la abundancia, diversidad y composición del ensamble de especies de aves. Utilizamos un diseño de bloques al azar en tres parcelas de aproximadamente 25 ha cada una, establecidas a lo largo de gradiente altitudinal en un área quemada recientemente en el Parque Nacional y Natural Sierra Nevada (sureste de España). En cada parcela establecimos tres réplicas de tres tratamientos diferentes en el manejo post-fuego de madera quemada: tala de salvamento, ninguna intervención y un nivel intermedio de intervención (poda y corte de la mayoría de los árboles pero dejando toda la biomasa). Un año después del fuego, utilizamos muestreo por puntos para monitorear la abundancia de aves en cada tratamiento por años consecutivos durante las temporadas de reproducción e invernal (720 censos en total). El manejo post-fuego de la madera quemada alteró los ensambles de especies. Las áreas con tala de salvamento tuvieron especies típicas de hábitats abiertos y de etapa sucesional temprana. Las especies de aves habitantes de bosques aun estaban presentes en los tratamientos sin salvamento no obstante que los árboles estaban quemados, pero estaban casi ausentes en las áreas con tala de salvamento. De hecho, los principales dispersores de arbustos y árboles de etapas sucesionales medias y tardías, como Turdus *spp. y* Garrulus glandarius, *estuvieron casi restringidos a los tratamientos sin salvamento. Por lo tanto, la tala de salvamento puede obstaculizar la regeneración natural del bosque mediante su impacto sobre los ensambles de especies de aves. Más aun, la tala de salvamento redujo la abundancia de especies en 50% y la riqueza en 40% aproximadamente. La mayor diversidad a nivel paisaje (diversidad gamma) resultó de la combinación de todos los tratamientos. La tala de salvamento puede ser positiva para la conservación de aves si se combina en un mosaico con otras formas menos agresivas de manejo post-incendio, pero el manejo con operaciones de cosecha tiene efectos indeseables para la conservación.*

Palabras Clave: manejo post-incendio de madera quemada, Parque Nacional Sierra Nevada, restauración de bosques post-fuego, tala de salvamento, tala rasa, tocones

Introduction

A current controversial issue among restoration ecologists and forest managers is appropriate management of dead, burned trees after forest fires (e.g., McIver & Starr 2000; Donato et al. 2006; Lindenmayer & Noss 2006). Historically, postfire salvage logging (i.e., the felling and removal of the burned tree trunks, often including elimination of remaining woody debris such as branches, logs, and snags through chipping, mastication, or fire) has been practiced routinely by forest managers worldwide (McIver & Starr 2000; Beschta et al. 2004; Lindenmayer & Noss 2006), particularly in the case of conifer forest fires. Nevertheless, there is an increasing evidence that salvage logging may have negative impacts on ecosystem function and structure and thus affect, for example, vegetation regeneration, animal and plant diversity, watershed runoff and erosion, and nutrient cycling (e.g. McIver & Starr 2000; Karr et al. 2004; Lindenmayer & Noss 2006). As a result, there are increasing calls to implement postfire policies of nonintervention or less-aggressive intervention associated with evidence that snags and decaying burned wood are components of natural systems that promote ecosystem recovery and diversity (Beschta et al. 2004; Lindenmayer et al. 2004; DellaSala et al. 2006).

Several reasons have been proposed to justify salvage logging. In many cases economic reasons are cited to justify the practice so that timber values can be at least partially recovered (McIver & Starr 2000). Beyond that, however, other arguments for salvage logging have been founded on forest–science concepts that have rarely been tested (e.g., McIver & Starr 2000; DellaSala et al. 2006; Lindenmayer & Noss 2006). For example, it is alleged that salvage logging reduces reburn risk and severity relative to nonintervention policies, but results from the few studies conducted on this issue contradict this claim and provide evidence that reasons other than fuel load may be more important for fire risk (Salvador et al. 2005; Kulakowskii & Veblen 2007; Thompson et al. 2007). Defenders of postfire salvage logging also claim it reduces risks of pest problems that could damage surviving trees, but this too is controversial and the available evidence suggests a more complex picture depending on fire severity and pests, which contradicts the general assumption that burned wood has negative effects (Martikainen et al. 2006; Jenkins et al. 2008). Aesthetic reasons for salvage logging also have been proposed, even though these criteria are in many cases subjective, not relevant or important enough to justify management actions that can exert powerful negative impacts on ecosystem properties, and do not require uniform stand-wide management (Lindenmayer & Noss 2006). Indeed, economic considerations of salvage logging that may apply where forests are exploited for timber production may not be important considerations in protected areas where conservation of ecosystem conditions and processes has priority.

Knowledge of the ecological consequences of salvage logging versus less-aggressive management strategies is critical to determine desirable postfire policies of forest management. Despite widespread application of salvage logging actions and the ecological significance of these practices, few studies have experimentally addressed the effects of salvage logging after fire on ecosystems, including such aspects as the regeneration of plant or animal communities. Experimentation is a necessary approach to ascertain the real impact of this activity in forest ecosystems (Greene et al. 2006; Lindenmayer & Noss 2006; Schmiegelow et al. 2006). In September 2005, the Lanjarón fire burned 3500 ha in the Sierra Nevada Natural and National Park (southern Spain), including about 1300 ha of pine plantations. The burned landscape is a mixture of abandoned agricultural lands, shrublands, and pine reforestations that are representative of millions of hectares in the Mediterranean Basin where planted pine stands are subject to intense disturbance from fire (e.g., Moreno & Oechel 1994).

Working with personnel from the Natural and National Park and regional Forest Service of Andalusia (southern Spain), we established experimental treatments in the pine forest burned in the Lanjarón fire to perform long-term research on the relative effects of salvage logging, partial cutting, and nonintervention on postfire ecosystem patterns and processes, ranging from vegetation regeneration and nutrient cycling to faunal communities. Our experimental design allows rigorous assessment of the effects of salvage logging on bird species assemblages after severe wildfires. Here we present and assess the results from a 2-year study on the effects of salvage logging on bird–species abundance, richness, and community composition. In addition, we analyzed specific responses of the most common species to the treatments.

Birds are an appropriate study model because they are sensitive to habitat structure and can move easily, reflecting habitat preferences soon after a fire. Although the results of several studies document that salvage logging has negative effects on bird communities, most research has focused on cavity-nesting species (Haggard & Gaines 2001; Hutto & Gallo 2006; Koivula & Schmiegelow 2007) or on other partial components of bird communities (Izhaki & Adar 1997; Imbeau et al. 1999; Morissette et al. 2002). Few studies on the effect of salvage logging versus other management alternatives in Mediterranean-type ecosystems have been conducted.

Methods

Study Area and Experimental Design

The Sierra Nevada Natural and National Park is in southeastern Spain, where in September 2005 the Lanjarón fire burned 1300 ha of reforested pine trees that were 35–45 years old, depending on the stand. Three plots (blocks) of approximately 25 ha each were established after the fire across an elevational gradient. All plots had a similar orientation (southwesterly) and slope (mean of all replicates 30.1% [SE 1.0]). Plot 1 was at 1477 m asl (UTM x, y: 456070, 4089811), plot 2 at 1698 m (455449, 4091728), and plot 3 at 2053 m (457244; 4091551). Elevation and position were measured at the center of the plot. The pine species present in each plot differed according to their ecological requirements along this elevational and moisture gradient. The cluster pine (*Pinus pinaster*) and black pine (*P. nigra*) dominated in plot 1, black pine in plot 2, and Scots pine (*P. sylvestris*) in plot 3. All three species are native in the region, although they were extensively planted in the area for forestry purposes. The climate in the area is Mediterranean, with hot, dry summers and wet, mild winters. Mean annual rainfall recorded at a meteorological station beside plot number 1 was 487 L / year (1988–2007). The area surrounding the burned site was dominated by shrublands.

Within each plot, we implemented three replicates of the following burned-wood management procedures (hereafter, treatments) in a random spatial distribution: (1) nonintervention (NI), all burned trees were left standing; (2) partial cut plus lopping (PCL), 90% of burned trees were felled and the main branches of felled trees were lopped off, but all the cut biomass was left on the ground; (3) experimental salvage logging (ESL), trees were cut and the trunks cleaned of branches with chainsaws, trunks were manually piled (groups of 10–15) and woody debris was chopped with a mechanical chopper. For treatment 3, we planned to extract the trunks with a log forwarder, but this step was canceled by the Forest Service because of the difficulties of operating machinery within the spatial arrangement of experimental replicates.

The experimental setup corresponded to a randomized complete block design with replication. The resulting 27 experimental replicates had an average (SE) size of 2.7 ha (SE 0.18), and there were no differences among treatments ($p > 0.05$). Salvage logging is the usual postfire action taken by the local Forest Service, and it was fully implemented throughout the rest of the burned area where the three experimental plots were located and included the removal of trunks with a log forwarder. We considered this matrix of salvage-logged area surrounding our experimental plots a fourth treatment (MSL). It differed from ESL in that cut trunks were removed and the spatial scale of implementation was much larger. Thus, in addition to the experimental treatments within the plots (NI, PCL, ESL), we established three replicates of the MSL around each plot (each of approximately 3 ha in size) that were randomly selected and at least 150 m from the other three treatments. These MSL treatment samples allowed us to detect possible scale and edge effects (from adjoining NI and PCL treatments) on the within-plot replicates of ESL and thus may be considered as a procedural control for the ESL (Quinn & Keough 2002). The four treatments differed in the degree of intervention (maximum: ESL and MSL; intermediate: PCL; minimum: NI) and in the habitat structure generated (minimum complexity, ESL and MSL).

All postfire management treatments were implemented during March to May 2006 (approximately 7 months after the 2005 forest fire). The fire was moderate to severe and consumed or scorched most of the tree crown, although some individuals and small patches of burned trees survived. Surviving trees were not cut by the Forest Service during postfire management treatments, irrespective of the assigned experimental treatment. Live trees covered about 6% of the total surface area within the three experimental plots and were haphazardly distributed across treatments. Mean tree density was 1477 individuals/ha (SE 46) for plot 1, 1064 (SE 67) for plot 2, and 1051 (SE 42) for plot 3. Mean basal tree diameter was 17.7 cm (SE 0.2) in plot 1, 18.3 (SE 0.1) in plot 2, and 15.7 (SE 0.1) in plot 3. Herbaceous vegetation dominated the understory during the study: mean 72.3% (SE 1.4) of cover in NI, 72.3% (SE 1.4) in PCL, 69.3% (SE 1.6) in ESL, and 63.2% (SE 1.7) in MSL (data sampled 2 years after the fire; J. C. et al., unpublished data).

Bird Sampling

For bird sampling, we established one sampling point per replicate for each treatment, located at the center of the replicate with a geographic positioning system ($n = 36$; 4 treatments × 3 plots × 3 replicates). We conducted surveys for two winters (2006 and 2007) and two breeding seasons (2007 and 2008). We began surveying the year after the fire and about 6 months after application of experimental treatments. For each sampling period, four to six censuses were carried out (720 total censuses): four censuses the first winter, six censuses the first breeding season, and five censuses the second winter and second breeding season. We conducted winter censuses from November to February and breeding-season censuses in May and June. Censuses were generally carried out by three observers (authors) simultaneously (one observer in each of the three plots except in a few cases in which only two plots were sampled simultaneously). We used point counts to assess abundance of bird species, by either visual or auditory citing (Bibby et al. 1992), noting all individuals recorded within the limit of the experimental replicate during the time of census. We rotated observers in the plots and the order of visits to the sampling points to minimize bias.

Censuses were done in the morning, during the period of maximum avian activity, starting 1 hour after dawn. Counts started 3 min after observer arrival to each of the sampling points, and lasted 6 min. We only counted birds that stopped within the limits of the corresponding replicate at the moment of the census; thus, birds flying over the replicates were not counted. Raptors, aerial feeders (such as swallows and swifts), and crepuscular species were not counted because this method is not appropriate for assessing their abundance (Bibby et al. 1992). In addition, they represent only a small fraction of the bird community in the study area. We performed censuses only in good weather (i.e., no rain and low or no wind).

Abundance, Richness, and Diversity Estimation

Bird abundance and richness were assessed as the total number of individuals and species detected at each sampling point during the 6-min census, respectively. We calculated two different measures of bird diversity (alpha and gamma). Alpha diversity was calculated as the species richness per sampling point for each sampling period (sum of species found during the 4–6 censuses per season and sampling point for each plot and treatment). Gamma diversity was calculated as the total number of species per experimental plot (combined species list from all replicates and treatments within a plot); replicates of MSL treatment were not considered for this calculation of gamma diversity. Instead, gamma diversity of experimental plots (NI, PCL, and ESL) was compared with gamma diversity in the MSL replicates. The MSL treatment was the usual situation encountered after typical Forest Service intervention. Thus our comparison allowed us to analyze bird species diversity under a typical salvage-logging regime with that of a landscape composed of a mosaic of different postfire management options. Gamma diversity of the MSL treatment was calculated for each plot and season as the sum of species in the three replicates of this treatment (sum of alpha diversity of the three replicates within a plot). We constructed species-accumulation curves to test the efficiency of the sampling schedule to detect the diversity present in each treatment. Overall, our results indicated the number of censuses made was appropriate to estimate the richness of species for all the treatments, although the richness found in PCL was underestimated relative to the rest of treatments (see Supporting Information).

Statistical Analyses

We analyzed species abundance and diversity with a three-way factorial analysis of variance (ANOVA) that included plot (block) as a random factor and treatment (four levels of burned-wood management) and sampling period (four levels) as fixed factors. Each of the three replicates per plot of each management treatment (total $n = 36$; i.e., sampling points) was considered the replicate unit for the ANOVAs. For species richness, we considered the sum of the number of species appearing at each sampling point throughout the 4–6 censuses per sampling period as the response variable. For abundance, the response variable was the average number of individuals found per sampling point each season.

We used multivariate analyses (CANOCO; version 4.5; ter Braak & Smilauer 2002) to examine the effect of environmental variables on the composition of the bird community. As with the ANOVA, the average species abundance per sampling point was the dependent variable for each sampling period; thus, we used 144 samples in construction of the species-abundance matrix. Treatment and sampling periods were included as environmental variables, and plot (block) was a covariable. A preliminary detrended correspondence analysis (DCA) showed a maximum gradient length of 6.931 (detrending by segments), which suggested a unimodal distribution of data (ter Braak & Smilauer 2002; Leps & Smilauer 2003). This distribution and the abundance of zeros in the data set required the use of a canonical correspondence analysis (CCA). We used a Monte Carlo test with 999 permutations and unrestricted permutation structure to assess the significance of the environmental variables. Variables were log-transformed [$\log(x + 1)$] and down weighted for rare species, and Hill's scaling was used for the analysis.

The distribution of species along the first canonical axes (which was mostly determined by the experimental postfire treatments of the burned wood; see Results) was fitted with a generalized linear model (GLM). For this, we used the "species response curves" option of the CANOCO software, which allowed us to explore the distribution of particular species along one specified environmental gradient (ter Braak & Smilauer 2002). We used a quadratic adjustment and a Poisson distribution with a log-link function, according to the nature and distribution of the data set (ter Braak & Smilauer 2002). This fitting was restricted to species with at least 15 records in the full data set, as an arbitrary criterion (1% representation; Supporting Information).

Results

Forty-four species were recorded during the two study years (1596 records; Supporting Information). Avian abundance differed according to postfire management treatment (Table 1). The pattern changed among sampling periods (winter vs. breeding season), which resulted in a significant plot × sampling period interaction (Table 1). For both sampling periods, treatments with the lowest management intensity (NI and PCL) had the highest abundance of birds, whereas treatments with more-intense management (ESL and MSL) had the lowest abundance (Fig. 1). Alpha diversity followed the same trend with intervention intensity; it was highest in the NI and PCL treatments and lowest in ESL and MSL, although there were differences in patterns among sampling periods (significant plot × sampling period interaction; Table 1; Fig. 1). Alpha diversity also differed significantly between sampling periods; it was higher during the breeding season (mean = 5.82 species per sampling point [SE 0.28]) than in winter (3.75 [SE 0.24]; Table 1; all treatments pooled).

Gamma diversity (without considering MSL treatment) did not differ among plots (one-way ANOVA; $F = 0.35$; df = 2, 9; $p = 0.71$), with a mean of 15.3 species per plot (SE 1.2). Gamma diversity in the MSL treatment also did not differ among plots (one-way ANOVA, $F = 0.45$; df = 2, 9; $p = 0.65$) and had an overall mean of 7.7 per plot (SE 0.8). Differences in gamma diversity between the combination of treatments in experimental plots (NI, PCL, and ESL) and the MSL treatment were strongly significant ($F = 30.63$; df = 1, 22; $p < 0.0001$; all sampling periods pooled).

The first species axis of the CCA was strongly correlated with the first environmental axis ($r = 0.865$). This environmental axis was primarily determined by treatment, with a transition from a negative correlation with treatment NI to a positive correlation with MSL (Fig. 2).

Table 1. Summary of the three-way analysis of variance on abundance and alpha diversity (species richness) for bird species in relation to postfire management of burned pine forests in Sierra Nevada Natural and National Park.

Variable[a]	*Source*[b]	*df*	*SS*[c]	F	p
Abundance	plot (P)	2	0.134	0.27	0.7755
	treatment (T)	3	2.181	10.35	0.0087
	sampling period (S)	3	1.833	2.27	0.1803
	P × T	6	0.421	0.79	0.5867
	P × S	6	1.613	3.04	0.0312
	T × S	9	0.345	0.43	0.8998
	P × T × S	18	1.592	1.45	0.1265
	error	96	5.857		
Alpha diversity	plot (P)	2	0.027	0.11	0.8930
	treatment (T)	3	1.204	7.92	0.0165
	sampling period (S)	3	1.923	6.13	0.0294
	P × T	6	0.304	1.36	0.2812
	P × S	6	0.627	2.81	0.0412
	T × S	9	0.308	0.92	0.5291
	P × T × S	18	0.669	0.90	0.5753
	error	96	3.947		

[a] *Variability of the response variable explained by the whole model (R^2) was 0.58 for abundance and 0.56 for alpha diversity.*
[b] *Treatments are nonintervention, partial cut, plus lopping; experimental salvage logging; and matrix salvage logging. Sampling periods are two breeding seasons and two winter seasons. The three plots (P) correspond to blocks and are considered a random factor. The effect of treatment and sampling period were tested using their interaction with plot mean square as the error term.*
[c] *Sum of squares.*

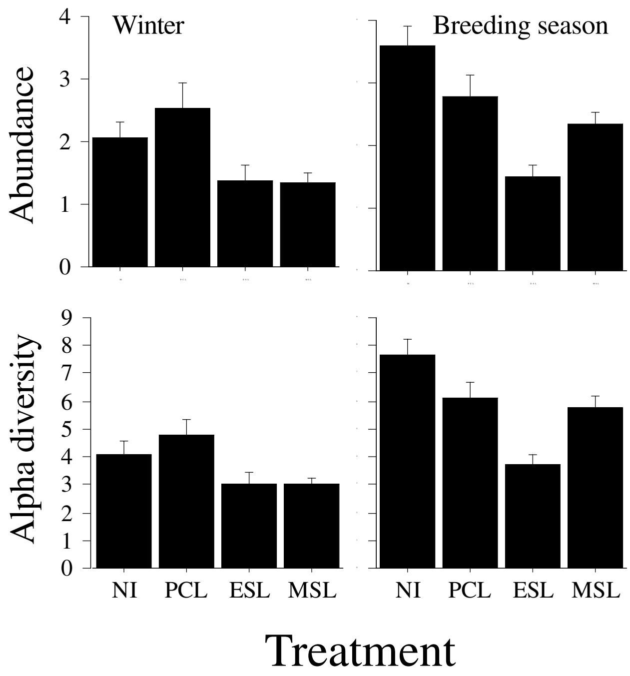

Figure 1. Bird species abundance (mean per census) and richness (alpha diversity) in the four experimental treatments for each season (winter and breeding season) in burned pine forests in Sierra Nevada Natural and National Park. Data from all plots are pooled for simplicity (NI, nonintervention; PCL, partial cut plus lopping; ESL, experimental salvage logging; MSL, matrix salvage logging.

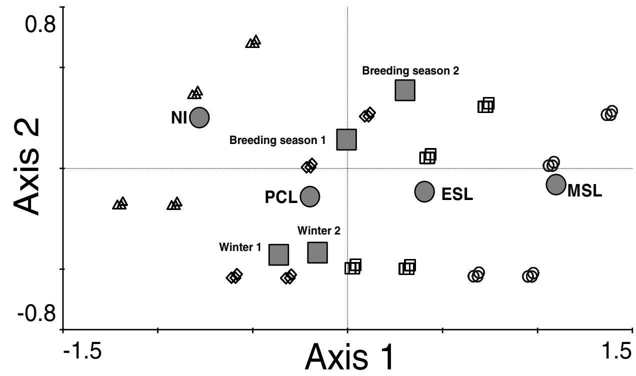

Figure 2. Distribution of categories of the environmental variables along axes 1 and 2, according to the canonical correspondence analysis for bird species composition in the four experimental treatments in burned pine forests in Sierra Nevada Natural and National Park (centroids, initials of the factors; filled circles, treatment: NI, nonintervention; PCL, partial cut plus lopping; ESL, experimental salvage logging; MSL, matrix salvage logging; filled squares, seasons). Sample scores are as follows: open triangles, NI; open diamonds, PCL; open squares, ESL; open circles, MSL. Each score represents the three replicates per treatment within a plot.

The second species axis was correlated with the second environmental axis ($r = 0.755$), primarily determined by the sampling period (winter vs. breeding season; Fig. 2). The first canonical axis explained a large proportion (57.6%) of the variance, and the four first canonical axes explained 93.4% of the variance. The first canonical axis significantly differed from zero (Monte-Carlo permutation test; eigenvalue = 0.355; $F = 14.89$; $p = 0.001$), and all canonical ordination was also significant (eigenvalue = 0.616; $F = 4.69$; $p = 0.001$).

Overall, species assemblages showed a clear transition from nonsalvaged to salvaged treatments (Fig. 3). Bird species that typically inhabit the mature pine forest were more common in the NI treatment. Bird species that typically inhabit early-successional and open habitats were more common in the ESL and MSL treatments. The PCL treatment had species found in both salvaged and nonintervention treatments (Fig. 3; Supporting Information). The species-specific models of distribution across the first canonical axis highlighted this trend across the landscape generated by burned-wood management (Table 2). Common forest or canopy species (sensu lato), such as the Chaffinch (*Frigilla coelebs*), the Chiffchaff (*Phylloscopus collybita*), the Robin (*Erithacus rubecula*), tits (*Parus* spp.), thrushes (*Turdus* spp.), and the European Jay (*Garrulus glandarius*), were found in burned, nonsalvaged treatments, but were almost absent in salvaged areas. By contrast, species typical of open landscapes such as pipits (*Anthus* spp.), Thekla Larks (*Galerida theklae*), and wheatears (*Oenanthe* spp.) were concentrated in logged treatments (Fig. 4; Supporting Information).

Abundance and diversity were higher in MSL than in the ESL treatment (Fig. 1), and species assemblage also differed slightly between the two treatments (Fig. 3; Supporting Information). Species that are characteristic of early-successional and open habitats such as the Linnet (*Acanthis cannabina*), pipits, Quail (*Coturnix coturnix*), Thekla Lark, and wheatears, were more common in MSL than in ESL, which suggests the importance of spatial scale in supporting such open-land birds.

Discussion

Despite the widespread use of postfire salvage logging, such management practices may negatively affect ecosystem regeneration and recovery (Beschta et al. 2004; DellaSala et al. 2006; Donato et al. 2006; Hutto 2006). There are, however, few experimental studies that have addressed this issue (McIver & Starr 2000; Lindenmayer & Noss 2006), and most of the studies that have been performed take advantage of ecologically unplanned natural

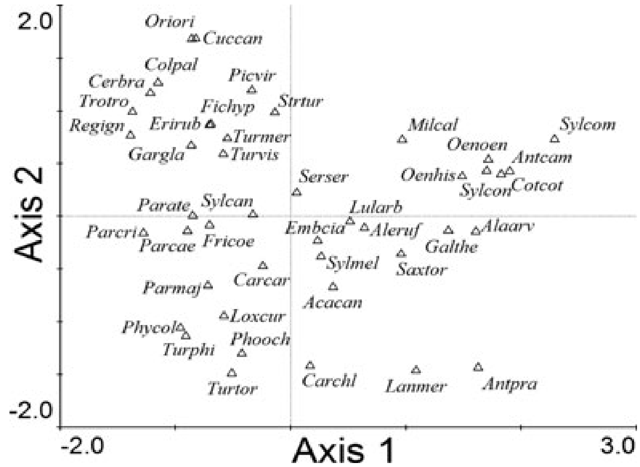

Figure 3. Distribution of the bird species found in the four experimental treatments in burned pine forests in Sierra Nevada Natural and National Park according to the canonical correspondence analysis axes 1 and 2. On axis 1 forestry species are negative values, whereas species from open habitats are positive values. Axis 2 determines overwintering (negative values) and breeding (positive values) species. Species codes: Alaarv, Alauda arvensis*; Antpra,* Anthus pratensis*; Carchl,* Carduelis chloris*; Cerbra,* Certhia brachydactyla*; Colpal,* Columba palumbus*; Cotcot,* Coturnix coturnix*; Cuccan,* Cuculus canorus*; Fichyp,* Ficedula hypoleuca*; Lanmer,* Lanius meridionalis*; Loxcur,* Loxia curvirrostra*; Oenoen,* Oenanthe oenanthe Oriori, Oriolus oriolus*; Phooch,* Phoenicurus ochruros*; Picvir,* Picus viridis*; Regign,* Regulus ignicapillus*; Saxtor,* Saxicola torquata*; Serser,* Serinus serinus*; Strtur,* Streptopelia turtur*; Sylcan,* Sylvia cantillans*; Sylcom,* S. communis*; Sylcon,* S. conspicillata*; Sylmel,* S. melanocephala*; Trotro,* Troglodytes troglodytes*; Turphi,* Turdus phillomelos*; Turtor,* T. torquatus*. Species codes not listed here are provided in Table 2.*

experiments (i.e., comparing some ecosystem properties among salvaged and remnant nonsalvaged areas that usually differ in location, year since fire, treatment sizes, or other uncontrolled site characteristics). In our experimental study burned-wood management was controlled, and the results showed that salvage logging strongly decreased bird–species abundance by approximately 50% and diversity by 40% at the community level (Fig. 1).

The species composition of salvaged treatments was, in addition, similar to that reported in previous studies that addressed bird assemblages in early postfire open habitats in the Mediterranean basin (Herrando et al. 2002; Brotons et al. 2005; Pons & Bas 2005; Ukmar et al. 2007) and differed from forest avifauna. These findings suggest that nonintervention or less-aggressive management of forest after fire could increase richness and abundance of bird species at a regional scale (see also Izhaki & Adar 1997). Furthermore, species richness in the treatment where most trees were cut but all the biomass was left (PCL) was underestimated relative to the rest of the treatments (Supporting Information). This may have been because the PCL treatment harbored species common in the other treatments (probably because it offered intermediate conditions from a habitat–structure standpoint), which increased the variability of species detected through consecutive censuses. Our estimation of species richness in the unsalvaged treatments was thus conservative, but still higher relative to salvaged areas.

The highest species abundance and richness where snags (either standing or partially felled) were present probably occurred for two complementary reasons. First, decaying wood provides a large increase in food supply thanks to the larvae of insects that develop inside the burned trunks, which favors coexistence of a higher number of bird species and individuals (Hutto 2006 and references therein). Second, the more complex habitat structure provided by snags may provide safe sites for foraging, perching, or nesting, which favors selection of these treatments (Llimona et al. 1993; Greenberg et al. 1995; Hutto 2006). In this sense it was notable that species typically inhabiting shrublands were relatively abundant in the NI and, particularly, in the PCL treatment (e.g., Red-legged Partridge [*Alectoris rufa*], Rock Bunting [*Emberiza cia*], Corn Bunting [*Milaria calandra*]). The presence of snags, branches, and other coarse woody debris spread over the ground may have provided the necessary structural complexity for these shrubland-associated birds.

From a community perspective, the effect of salvage logging not only reduced diversity, but also altered the species assemblages. The bird community in the unlogged, burned forest (NI treatment) approached that of unburned pine forests in the Mediterranean basin (e.g., a community composed mostly of forest birds [sensu lato] such as Chaffinch, tits, thrushes, robin, European Jay, or Chiffchaff, as well as other species that appeared sporadically but almost exclusively linked to the presence of burned wood and snags (e.g., Firecrest [*Regulus ignicapillus*], Golden Oriole [*Oriolus oriolus*], Pied Flycatcher [*Ficedula hypoleuca*], Treecreeper [*Certhia brachydactyla*] or Woodpigeon [*Columba palumbus*]; Supporting Information). Similar results have been reported for other Mediterranean areas (Llimona et al. 1993; Izhaki & Adar 1997) and for other forest ecosystems (Imbeau et al. 1999; Morissette et al. 2002; Schmiegelow et al. 2006), which supports the role of nonintervention policies for maintaining species-assemblage characteristics of forest.

Contrarily, the bird species assemblage in salvage-logged areas was similar to that present throughout the landscape in Mediterranean-type ecosystems, namely land-steppe birds that associate with open areas, early-successional shrublands, or cultivated areas (e.g.,

Table 2. Summary of the result of the quadratic generalized linear model for distribution of bird species along the first canonical axis relative to postfire management of burned pine forests in Sierra Nevada Natural and National Park.[a]

Species	Species code	Null model deviance	Fitted model deviance	AIC[b]	F	p	Mean abundance[c]			
							NI	PCL	ESL	MSL
Acanthis cannabina	Acacan	46.41	45.68	53.17	0.29	Ns	0.194	0.222	0.028	0.556
Alectoris rufa	Aleruf	48.80	40.63	43.57	8.33	<0.001	0.111	0.667	0.389	0.583
Anthus campestris	Antcam	13.56	8.81	10.00	12.00	<0.0001	0	0	0.028	0.389
Carduelis carduelis	Carcar	21.19	19.44	22.06	2.01	Ns	0.194	0.222	0.083	0.056
Emberiza cia	Embcia	67.34	53.90	56.27	17.05	<0.0001	1.806	3.194	2.444	2.111
Erithacus rubecula	Erirub	26.20	19.93	21.61	11.16	<0.0001	0.528	0.194	0.028	0
Fringilla coelebs	Fricoe	72.12	31.47	32.95	82.44	<0.0001	3.167	1.556	0.417	0.250
Galerida theklae	Galthe	41.45	18.93	20.39	46.35	<0.0001	0.056	0.111	0.278	1.306
Garrulus glandarius	Gargla	37.94	27.52	29.30	17.57	<0.0001	1.056	0.305	0.083	0
Lullula arborea	Lularb	51.89	44.94	46.89	10.72	<0.0001	0.639	1.778	1.167	1.583
Milaria calandra	Milcal	65.82	52.20	55.54	12.23	<0.0001	0.333	0.722	0.639	1.111
Oenanthe hispanica	Oenhis	14.84	8.13	8.96	24.36	<0.0001	0	0.028	0.139	0.250
Parus ater	Parate	87.25	36.52	38.22	89.67	<0.0001	0.361	1.806	0.472	0.028
Parus caeruleus	Parcae	18.30	15.49	17.17	5.02	<0.01	0.194	0.222	0	0
Parus cristatus	Parcri	22.08	14.88	16.08	18.00	<0.0001	0.278	0.139	0	0
Parus major	Parmaj	33.45	23.99	25.73	16.29	<0.0001	0.333	0.583	0.139	0
Phylloscopus collybita	Phycol	18.73	14.53	16.44	6.62	<0.01	0.222	0.139	0.083	0
Turdus merula	Turmer	25.99	19.66	21.20	12.34	<0.0001	0.639	0.167	0.167	0
Turdus viscivorus	Turvis	16.96	14.44	15.57	6.67	<0.01	0.306	0.222	0	0.028

[a] *The first axis is related to experimental treatments; thus, the models provide information about the distribution of the bird species according to the intensity of burned-wood management. A Poisson distribution with a log-link function was used for all model construction. The analysis was restricted to species with at least 15 records in the whole data set (≈1% of presence). Common names of species are given in Supporting Information.*
[b] *Akaike information criterion.*
[c] *Species mean abundance for each treatment per sampling date. Treatments: NI, nonintervention; PCL, partial cut plus lopping; ESL, experimental salvage logging; MSL, matrix salvage logging.*

Suárez-Seoane et al. 2002; Pons & Bas 2005; Vallecillo et al. 2008). These species are not threatened at the regional scale (Madroño et al. 2004; Burdfield 2005). The maintenance of forest bird species is thus more important at a regional level from a conservation perspective given the relative scarcity of forests in the Mediterranean basin in comparison with the amount of open agricultural landscapes, a situation that is common in many areas of the world. Nonintervention (or partial intervention) policies therefore provide a temporal window for the maintenance of forest birds while the forest recovers and helps keep higher diversity at the landscape level.

The species assemblage in unsalvaged treatments was also critical for natural regeneration of the forest. Most Mediterranean, late-successional, plant species are dispersed by zoochorous vectors that avoid open areas because of the higher predation risk and lower food abundance (Sapir et al. 2004). Thrushes are key vectors for dispersal of late-successional shrubs and trees that produce fleshy fruits in temperate ecosystems (Martínez et al. 2008), and the European Jay is the main disperser of acorns all over the continent (Bossema 1979; den Ouden et al. 2005). The much higher presence of these seed-dispersing bird species in the unsalvaged treatments (Fig. 4; Supporting Information) thus may greatly accelerate forest vegetation succession. The seed-caching (scatter hoarding) activity of jays, in particular, is critical for the natural colonization by native oak species (Hougner et al. 2006; Purves et al. 2007). This bird selectively uses coniferous stands at the landscape level for long-distance dispersal (Gómez 2003; Pons & Pausas 2007) and therefore it is likely that it still uses standing snags as acorn cache sites and thereby promotes recovery of oak forests in burned areas.

Analyses of consequences of salvage logging for ecosystem recovery are critical to ascertain the best restoration policies. Every year forest fires affect large areas all over the world, and the ecological implications of salvage logging are enormous. Some of the classical arguments in favor of conducting salvage logging are being refuted. Nevertheless, even if salvage logging is undertaken after fire, there are management options that can combine harvest with conservation. Keeping a certain density of standing trees or leaving the rest of branches in situ may promote bird diversity. In addition, because (gamma) diversity was higher within a mosaic of different postfire management treatments than in zones where only salvage logging was performed (see also Izhaki & Adar 1997), it may be important to reduce the intensity of postfire intervention, at least in part of the burned area, to promote bird diversity.

In conclusion our experimental results showed that postfire salvage logging greatly reduced the richness and abundance of bird species in the Mediterranean pine

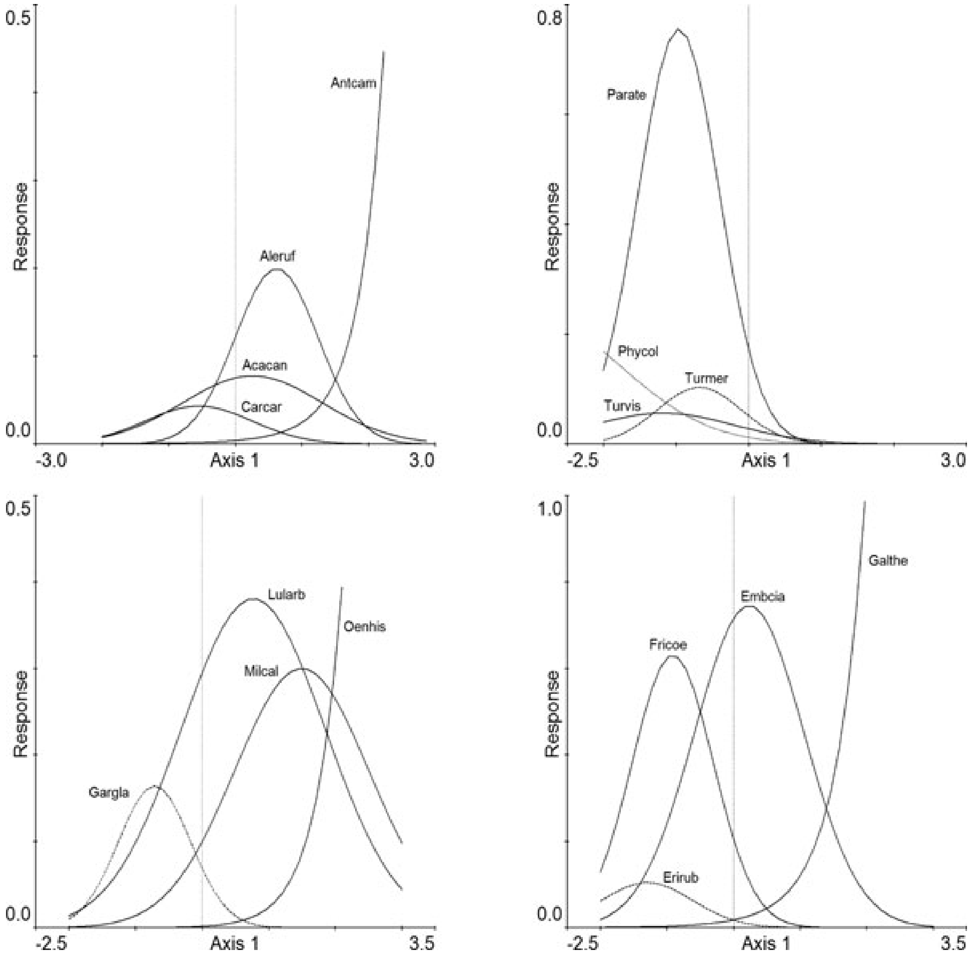

Figure 4. Distribution of bird species with at least 15 records in the full data set (1% representation) along the first canonical axis (which is mostly determined by burned-wood management). Among Parus *spp. (all with ≥1% presence), only* P. ater *is presented for simplicity; the rest of species in this genera have similar distributions across treatments (data not shown). Curves are fitted with a generalized linear model with a quadratic adjustment and a Poison distribution and a log-link function. See Table 2 for details of the models (dotted or dashed lines are used in some cases to help identification of the species; species codes as in Table 2).*

forests in our study area. Our results are in agreement with the increasing recognition that extensive salvage logging has negative effects on ecosystem (McIver & Starr 2000; Lindenmayer et al. 2004; Donato et al. 2006). Salvage logging also affects the maintenance of bird species typical of mature forests, because these birds will still use standing burned trees. Overall, postfire salvage logging has major negative effects on avifauna communities.

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Supporting Information

A list of the species recorded and the number of records per treatment (Appendix S1) and the results of species accumulation curves (Appendix S2) are available as part of the on-line article. The authors are responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

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