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The effect of postfire salvage logging on bird communities in Mediterranean pine forests: the benefits for declining species

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Summary

1. Postfire salvage logging is the most commonly applied forestry practice in burned forests worldwide, mainly for economic reasons. However, it strongly affects bird communities and is generally considered to be detrimental for bird conservation. In Europe, many open-habitat species are currently declining owing to land use changes. Wildfires, which are common disturbances in the Mediterranean Basin, can create suitable habitat for these species but the effect of postfire salvage logging on bird communities is unknown.

2. We surveyed breeding birds in two burned secondary pine forests from the western Mediterranean Basin and analysed the effect of salvage logging and vegetation regeneration as determinants of individual species and community parameters. We used a pseudoexperimental before-after-control-impact approach to study the changes in the bird community during the first three springs after fire.

3. Most bird species were affected by salvage logging (measured by snag density), a relationship that was positive for forest birds and negative for open-habitat species. Species linked to shrub and edge habitats were positively affected by vegetation regrowth. Bird communities in logged areas held more species of conservation concern than those in unlogged areas. Species richness and overall density tended to decrease from the first to the second year after fire and to increase from the second to the third.

4. Salvage logging benefits a number of open-habitat species, although its effect on bird conservation depends strongly on the specific threats that birds face in each region or ecosystem.

5. *Synthesis and applications*. In the Mediterranean Basin, some postfire salvage logging of pine forests can be compatible with bird conservation. We recommend that managers retain some standing dead trees during logging operations and that logged forest is interspersed with unlogged stands. This will provide suitable habitat for the widest range of species.

Key-words: colonization, conservation, disturbance, fire, forest management, open-habitat birds, wood harvesting

Introduction

Salvage logging has traditionally been the most common management practice in forests affected by severe wildfires worldwide (Lindenmayer *et al.* 2004; Hutto 2006; Lindenmayer & Noss 2006). The main goal of postfire salvage logging is to minimize or recoup the economic loss caused by fire by selling surface-charred logs before they start to deteriorate and become unsalable. However, other justifications have been given for removing dead wood, such as speeding forest recovery, avoiding the proliferation of xylophagous insects, reducing fuel for future fires, making travel within the burned area easier and safer, reducing erosion with log barriers and even improving the aesthetic appearance of the area (Ne'eman, Lahav & Izhaki 1995; Martínez-Sánchez *et al.* 1999). There has been very little social resistance to these justifications because the

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prevailing public perception is that wildfires are catastrophic events that are not part of the natural dynamics of ecosystems and that burned areas have little value to wildlife, even though many authors have said otherwise (Hessburg & Agee 2003; Lindenmayer & Noss 2006; Pausas *et al*. 2008).

Postfire logging has a strong impact on ecosystem processes including soil, nutrient and hydrological cycles, and also on the ecosystem's physical structure, because the removal of snags (i.e. standing dead trees) is a drastic habitat change (Beschta *et al*. 2004; Karr *et al*. 2004; Dellasala *et al*. 2006). This habitat transformation has major effects on the biota living in burned areas. Studies carried out on birds show a reduction in the number of forest species living in logged areas compared with those in unlogged ones, because of the removal of snags that provided them food and nesting opportunities (Llimona, Matheu & Prodon 1993; Morisette *et al*. 2002; Hutto 2006; Castro, Moreno-Rueda & Hódar 2010). In western North American forests, salvage logging is especially detrimental for certain woodpeckers that are considered fire specialists because of their strong dependence on severely burned stands (Hutto & Gallo 2006; Koivula & Schmiegelow 2007; Hutto 2008).

In the Mediterranean basin, bird communities occupy intensely managed landscapes characterized by a dynamic fine-grained mosaic of forest, shrubland and farmland areas (Farina 1997; Covas & Blondel 1998; Moreira *et al*. 2001). Such mosaic landscapes are far from being static, and the area of different habitat types has changed considerably through history, mostly due to human activities that include induced fires (Pausas *et al*. 2008). Through time, socioeconomic factors have constrained human land uses and, consequently, modified the extent of the habitat patches that constitute the rich Mediterranean mosaic landscape (Blondel & Aronson 1999). For instance, although there was a general process of deforestation from the Middle Ages to the 19th century, in the early 20th century rural depopulation, farmland abandonment and the substitution of wood and charcoal by fossil fuels reversed this trend in many parts of the region, causing an overall increase in forest area (Blondel & Aronson 1999). This led to the expansion of secondary pine forests dominated by early colonizer tree species, of which the most representative is probably the native Aleppo pine *Pinus halepensis*, a species that has also been actively planted in certain areas.

Reforestation, which occurred mainly in abandoned areas, combined with agricultural intensification, led to significant changes in the population levels of several bird species. This has been documented since the 1970s in many European countries (BirdLife International 2004). Forest bird populations have increased, while the number of open-habitat species has declined steadily (Preiss, Martin & Debussche 1997; Sirami, Brotons & Martin 2007). As a result, several open-habitat bird species linked to farmland and sparsely vegetated habitats, which avoid well-developed shrublands or young forests, are currently of conservation concern all over Europe, while few forest birds are classified as threatened (BirdLife International 2004).

Lowland secondary pine forests are one of the most frequently burned habitats in the Mediterranean basin and are usually affected by severe crown wildfires (Pausas *et al*. 2008). Once burned, these forests can maintain high snag densities until a few years after fire, which allows some forest birds to persist until snags start to fall over (Izhaki 1993; Izhaki & Adar 1997; Rost *et al*. 2010). However, a high snag density hinders those species that prefer a more open environments (Izhaki & Adar 1997; Rost *et al*. 2010), even though they would be capable of colonizing burned areas almost immediately after fire from nearby shrubland and farmland patches. Therefore, salvage logging could benefit several open-habitat birds whose numbers are declining, suggesting that the effect of postfire salvage logging on bird conservation need not always be detrimental.

The main objective of this study was to assess the role of postfire salvage logging on the composition of breeding bird communities in burned pine forests in the first 3 years after fire. We aimed to separate the effects of habitat features closely associated with salvage logging (i.e. snag density) from those derived from vegetation postfire succession on bird community composition and bird species occurrence. We also took advantage of areas that were logged during the study period to perform a before-after-control-impact (BACI) analysis of the bird community's response to the impact of salvage logging, using those areas that remained either logged or unlogged as controls.

Materials and methods

STUDY AREA

The study was conducted at two sites, 25 km apart, that burned in August 2006, Ventalló (henceforth VE; 3°2′E, 42°7′N) and Cistella (CI; 2°50′E, 42°17′N), in Catalonia (NE Iberian Peninsula) (see Fig. S1 Supporting Information for further details). Both areas are characterized by a low hilly landscape (maximum elevation of 155 m a.s.l. at VE and 210 m a.s.l. at CI), with limestone substrate and meso-Mediterranean climate conditions (mean annual rainfall ~700 mm; mean annual temperature ~16 °C). Wildfires affected mainly Aleppo pine forest at both sites, burning 1011 ha in VE (613 forest ha) and 268 ha in CI (170 forest ha). The fire burned both the forest canopy and the undergrowth and the majority of pines were killed, although some individuals survived in a few small patches where fire was less severe. The postfire habitat was composed of Aleppo pine snags and an undergrowth of regenerating shrubs (*Quercus coccifera*, *Phillyrea angustifolia*, *Cistus* spp.), herbs (mainly *Brachypodium* spp.) and pine saplings.

Salvage logging operations started during the first winter after fire and lasted for 3 years, by which time almost all the burned area had been cleared. Approximately one-third of the burned forest was logged each year. Not commercially profitable wood debris (the thinnest branches) were left *in situ*, scattered on the ground or heaped up in low piles. However, even clear-cut stands kept a few standing snags. Holm oaks *Quercus ilex* and the few surviving pines were not logged.

BIRD DATA

We sampled birds by conducting 5-min line transects (average length of transects 183·7 ± 4·3 m SE; max. 244 m, min. 129 m) at 58 sampling stations distributed evenly across the burned areas (42 stations in VE and 12 in CI; Fig. S1b). Sampling stations were at least 150 m apart. One observer (J. R.) performed all the surveys, which were conducted within the first 5 h after sunrise. All birds seen or heard within 100 m from the observer were recorded and separated into three counting bands (0–25, 25–50 and 50–100 m), to account for potential differences in detectability among bird species. We did not record individuals seen flying overhead, as they were not considered to be using the sampled habitat, with the exception of birds detected while performing a display or seen actively hunting. We carried out censuses in the first three breeding seasons after the fires (2007, 2008 and 2009). We surveyed each station twice in each breeding season (once at the end of May and once 2 weeks later) to maximize the number of species and bird contacts at each station.

We calculated four bird community variables from the bird data: species richness, overall bird density, conservation index and a compound index of community structure. We calculated richness as the total number of species detected at each station after pooling the two visits. We used Distance 5.0 software (Thomas *et al.* 2006) to calculate the density of each species as well as the total density from the detections of each species at each distance interval. We selected the most appropriate detection function from three possible key functions (half-normal, uniform and hazard-rate), choosing the model with the lowest AIC. We used multiple covariate distance sampling (MCDS) to assess the effect of habitat covariates (PCveg and snag density: see the 'Habitat data' section below for further details) on species detectability. With the previously selected key function, we ran four models for each species: without covariates, with PCveg, with snag density and with both. We considered the effect of the covariate to be significant whenever the AIC of a model including covariates was at least 2 units smaller than that of the null model (Burnham & Anderson 2004) and used this model to calculate density. This happened only for two species, the wood lark *Lullula arborea* and the subalpine warbler *Sylvia cantillans*. We calculated species' density as the product of the maximum number of individuals recorded after the two visits, multiplied by the f(0) parameter estimated for each species (a unique value for all stations, except for the wood lark and the subalpine warbler, for which we estimated a specific f(0) for each station applying the model with covariates for these two species, resulting in a different f(0) between stations according to the value of the covariates at each station), and divided by the transect area, which varied according to the transect length (Buckland *et al.* 1993; Pons, Bas & Estany-Tigerström 2010). For species where the number of recorded individuals was too low to obtain a reliable f(0), we used the f(0) of a similarly detectable species that was sufficiently abundant to have a reliable estimated detection function. We also used the conservation index proposed by Pons *et al.* (2003), which takes into account the European conservation status of each species (the SPEC status, which is divided into five categories according to each species threat status in Europe and whether or not its population is concentrated in Europe: see BirdLife International 2004 or Appendix S1 Supporting Information for further details). This was then weighted by the species' log-transformed density, adding all the specific values for each station to calculate the index. Thus, stations with higher values in the conservation index held more species and individuals of conservation concern. In order to generate a compound index of community structure to describe the associations among species, we performed a partial detrended correspondence analysis (DCA) on a matrix of 174 samples and the occurrence of 31 species (those species present in more than 5% of the samples, i.e. in more than nine stations), including the fire site as a covariate to control for possible spatial autocorrelation at this stage. We ran the DCA with the CANOCO program (ter Braak & Smilauer 1998).

HABITAT DATA

We sampled six habitat quadrats at each station (348 plots in all) to characterize habitat structure and link it to bird variables. We placed three quadrats on each side of the transect, 15, 35 and 70 m away and at 40-m intervals from the transect beginning (see Fig. S2 in Supporting Information). Quadrats measured 10 × 10 m, within which we measured snag density and live undergrowth plant cover. Snag density was the number of standing burned and dead trees taller than 2 m and with diameter at breast height higher than 10 cm in an area of 100 m^2. We estimated live undergrowth plant cover (expressed as a percentage) for the same quadrat by visual comparison with the template described by Prodon & Lebreton (1981). We estimated four different vegetation layers: bare ground, vegetation between 0 and 0·5 m, vegetation between 0·5 and 1 m and vegetation taller than 1 m. For each sample, each vegetation layer value was the mean cover of that layer in the six quadrats; snag density was calculated in the same way. We carried out a principal component analysis (PCA) to unify the data from the four vegetation layers into a single gradient. We used CANOCO to perform this analysis (ter Braak & Smilauer 1998), including the site (CI or VE) as a covariate. The first axis of the PCA (eigenvalue: 0·89, percentage of explained variance: 89·5) created a gradient negatively related to bare ground and positively influenced by the three vegetation layers (Table 1), and which is interpreted as a vegetation successional gradient from the early to the more advanced stages, in the short time after fire. We used the sample scores on this axis (PCveg) for further analyses.

Finally, we estimated the length of the streams in each transect census area (100 m from each side of the transect) from aerial photographs in ArcView 9.2 (Redlands, CA, USA). We used the same software to calculate the proportion of logged area to the entire census area along each transect, by drawing the logged area in the field on aerial photographs and converting it into a GIS shape file.

DATA ANALYSES

We used generalized linear mixed models (GLMM) to analyse the effect of the three habitat variables, vegetation gradient (PCveg), snag density and stream length (fixed effect factors) on species richness, overall bird density and conservation index using Poisson error distributions and a log link function, which we determined after checking the error distribution of the model. For the community structure, we used linear mixed models with normal error distribution and identity link function with the same fixed effect factors as for the GLMMs. We also tested the effect of the three habitat variables on the occurrence of 31 species (those appearing on more than 5% of the transects), using GLMMs with binomial error and logit link function. We included the calendar year as a random factor in all mixed-effect

Table 1. PCA first factor (PC1) scores of the four vegetation variables included in the principal components analysis

Vegetation variable	PC1 score
Bare ground cover	−0·98
Vegetation 0–0·5 m cover	0·98
Vegetation 0·5–1 m cover	0·88
Vegetation > 1 m cover	0·63

analyses because of its influence on both the vegetation cover (because of postfire succession) and on the density of snags (because of logging). We also used station (nested within site) as a random factor in the analyses to minimize pseudoreplication problems associated with repeated sampling at the same stations over a 3-year period.

In addition, we were interested to know whether the rapid transformation of burned areas caused by salvage logging produced changes in bird community characteristics. We used a BACI approach, taking advantage of the fact that some stations changed from unlogged to logged between two consecutive breeding seasons, while others remained either unlogged or logged during the 3 years of the study. We defined impacted stations (IM) as those that changed from burned forest (unlogged stations, or stations logged over < 20% of their area) to open areas (logged over more than 50%). We compared IM stations with two different controls: (i) burned forest control stations (FC, also with < 20% of their area logged); and (ii) logged control stations (LC, with more than 50% logged). We also classified annual changes according to the year transition (first breeding season to second, 1–2; second to third, 2–3) to assess whether the time because fire had any influence on bird groups. The number of stations considered in each category was not equal because of the spatial and temporal variability in the logging operations ($FC_{1–2}$, $N = 24$; $FC_{2–3}$, $N = 7$; $IM_{1–2}$, $N = 15$; $IM_{2–3}$ $N = 16$; $LC_{1–2}$, $N = 5$; $LC_{2–3}$, $N = 22$).

For each station, we calculated the annual change in species richness, total density, conservation index and community structure, as the difference between the values in 1 year and the corresponding values in the previous year (hereafter a year transition). We also classified bird species into two main groups (forest and farmland) according to their habitat preferences, adopting the classification used by the European Bird Census Council (Voříšek & Klvaňová 2010; see Appendix S2 Supporting Information for details). We then calculated the annual change in the density of both groups of species, excluding those stations at which any bird group was absent for both years of a transition. We used linear mixed models to analyse whether the annual change in the community parameters and density of different groups of species varied across the three BACI categories and the 2 year transitions, as well as their interaction. Transect nested within site was always included as a random factor. We performed all analyses using SAS 9.1 software (SAS Institute Inc., Cary, NC, USA), and effect significance was determined by *F* tests with a statistical significance threshold at $P < 0{\cdot}05$.

Results

We detected a total of 1526 birds belonging to 55 species (see Appendix S1, Supporting Information for details), 20 of which (36·4%) have an unfavourable conservation status in Europe (BirdLife International 2004). The first axis of the partial DCA (DC1; eigenvalue: 0·53, 11·5% of variance) ordered stations roughly in relation to the preference of bird species for different snag densities (confirmed by the GLMM results: see below). At the negative extreme of DC1, stations were characterized by the presence of forest birds such as the winter wren *Troglodytes troglodytes* and the chaffinch *Fringilla coelebs*, while at its positive end stations included species associated with treeless environments, such as the tawny pipit *Anthus campestris* and shrubland species such as the Dartford warbler *Sylvia undata*. The biplot of the partial DCA is shown in Supporting Information (Fig. S3).

Snag density had a significant effect on the conservation index, with higher conservation values where the snag density was low (Table 2), and it was also negatively related to DC1. In addition, a long stretch of stream had a positive effect on the number of species occurring in sampled areas. Finally, neither species richness nor overall bird density was affected by snag density and PCveg. Snag density had a significant effect on the occurrence of 16 of the 31 most frequent species (Appendix S2, Supporting Information). It was highly correlated with the extent of logged area in each station ($R^2 = 0{\cdot}72$), which highlights the important effects of salvage logging on bird species occupying postfire habitats. Among those 16 species, seven were positively affected by high snag densities, while nine benefited from low snag densities. PCveg showed a significant positive effect on the occurrence of Sardinian warbler *Sylvia melanocephala*, Dartford and subalpine warblers, which were related to dense shrublands. On the other hand, the effect was negative for goldfinch *Carduelis carduelis* and the chaffinch, which preferred areas with poorly developed shrub layers. Finally, the presence of streams had a positive effect on the occurrence of common nightingales *Luscinia megarhynchos*, melodious warblers *Hippolais polyglotta*, cirl buntings *Emberiza cirlus* and winter wrens.

The annual change in species richness and the overall density was significantly different between year transitions ($F = 11{\cdot}27$, $P = 0{\cdot}002$ and $F = 7{\cdot}95$, $P = 0{\cdot}007$, respectively). Both variables increased between the second and third years in relation to the first- to second-year transition (Fig. 1) but we did not find significant differences between BACI categories for these variables. In turn, DC1 annual change in IM was significantly higher than in forest (FC) and logged controls (LC) ($F = 6{\cdot}54$, $P = 0{\cdot}003$), irrespective of the year transition. Annual change values were always positive in DC1, that is with increasing time after fire, bird communities tended to include more open-habitat species. Annual changes in the conservation index were not significant in any case, despite showing positive values in LC and in the 2–3 transition of IM. Interactions were never significant.

Focusing on the two habitat groups (Fig. 2), forest birds showed negative annual changes, without important differences between BACI categories, while farmland species did show a significant effect of the BACI treatment on annual

Table 2. Results of the GLMM analyses of the effect of vegetation (PCveg), snag density and stream length on four bird community variables. The sign of the estimate of significant relationships is shown, and significant results are highlighted in bold

	PCveg		Snags		Streams	
Community variable	*b*	*P*	*b*	*P*	*b*	*P*
Species richness		0·777		0·268	+	**0·013**
Overall bird density		0·417		0·654		0·116
Conservation index		0·558	–	**0·001**		0·549
Community structure (DC1)		0·223	–	**0·000**		0·240

GLMM, generalized linear mixed models.

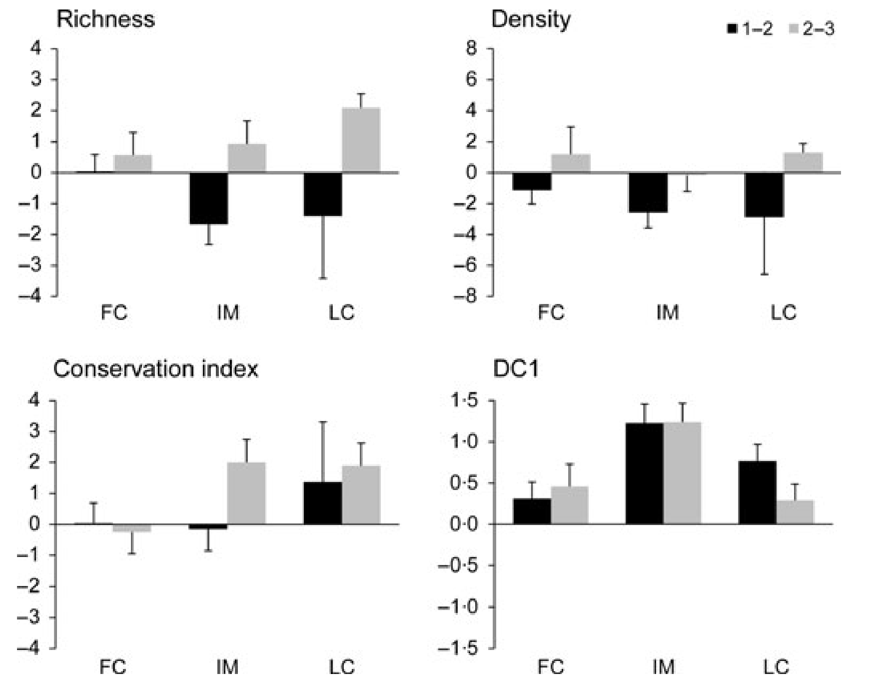

Fig. 1. Bird species richness, overall density, conservation index and community structure (DC1) annual changes, in control stations (forest control, FC and logged control, LC) and in impacted stations (IM) that were transformed from forest into logged areas IM. Black bars show differences in the transition between the first and the second year after fire (1–2) and grey bars between the second and the third year (2–3). Error bars represent the standard error.

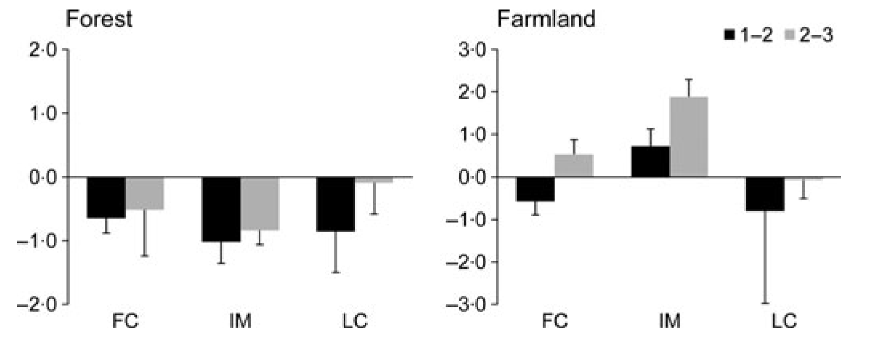

Fig. 2. Annual changes in density of forest, shrubland and open-habitat bird species in control stations (forest control, FC and logged control, LC) and in impact stations that were transformed from forest into logged areas impacted stations. Black bars show differences in the transition between the first and the second year after fire (1–2) and grey bars between the second and the third year (2–3). Error bars represent the standard error.

change, being higher in IM (F = 5·09, P = 0·011). We did not find any significant effect of year or interaction.

Discussion

The results of this study highlight that salvage logging is the main factor determining the composition of postfire bird communities in burned Mediterranean lowland pine forests. For most species, occurrence was greatly affected by the density of snags, which is determined by logging activities. The change from forest foliage-gleaners, canopy and cavity-nesting species to open-habitat, farmland, and ground-dwelling species is consistent with the findings of other authors in relation to burned and logged coniferous forests (Llimona, Matheu & Prodon 1993; Izhaki & Adar 1997; Kotliar *et al.* 2002; Morisette *et al.* 2002). Unlike these previous studies, however, our pseudoexperimental approach revealed that recently logged (impact) stations had a higher rate of replacement of forest species by open-habitat species than any of the control situations. This change took place quite soon after salvage logging and was already apparent in the first breeding season after the removal of snags.

Species turnover caused changes in overall community parameters, because we observed some variation in species richness and overall density during the first 3 years after fire (Fig. 1). Interestingly, these changes were influenced by temporal factors more than by salvage logging and are mainly explained by the dynamics of forest and open-habitat/farm-land birds. Forest species decreased in all situations, while open-habitat species increased in those stations converted from burned forest to logged areas (Fig. 2). The increase in open-habitat species was most obvious when logging occurred between the second and third breeding season, which may be due to colonization from nearby areas that had been logged the previous year and were already occupied.

Despite interannual differences, the drastic change in habitat characteristics because of the removal of snags did not lead to any variation in species richness or overall density within the 3-year period. Similar results were found by Izhaki (1993), also in Aleppo pine forests in the eastern Mediterranean basin (300 m a.s.l.). In turn, Castro, Moreno-Rueda & Hódar (2010) observed that in burned montane (1500-2000 m a.s.l.) Mediterranean pine forests in southern Spain, bird species richness and density decreased significantly after severe logging following fire. These differences could be explained by the slow recovery of the vegetation after fire in montane environments, which limits bird abundance and richness in the first years after fire (Pons & Clavero 2010).

Plant regeneration and succession determined the occurrence of several bird species. *Sylvia* warblers, which are a typical shrubland species, were more abundant in locations with increasing vegetation cover and height, while ground-dwelling granivore finches preferred uncovered areas. Higher vegetation regeneration near small streams probably provided more food resources and nesting opportunities immediately following fire, being a key habitat when vegetation cover elsewhere is low.

From a conservation perspective, the removal of snags by salvage logging was more favourable than unmanaged burned areas for open-habitat early successional colonizers (Fig. 3). Salvage logging also helped these species by facilitating their colonization of burned forests located in mosaic landscapes. However, the spatial scale at which fire and salvage logging occur is very likely to have a strong influence on bird community dynamics. Wildfires of limited spatial extent, such as those in this study, contribute to the creation of heterogeneous landscapes that improve biodiversity levels in Mediterranean areas in areas where rural depopulation has led to secondary forest expansion (Moreira & Russo 2007). However, when wildfires affect very large areas, complete snag removal could have detrimental impacts on the biodiversity. Moreover, the colonization of burned and logged areas by farmland birds is highly constrained by the characteristics of the surrounding landscape, such as the presence of source populations nearby (Brotons, Pons & Herrando 2005).

Our results contrast with the general view that postfire salvage logging is always harmful for bird conservation. For instance, in north-western North America where the landscape has been much less shaped by human activities, there is a greater cover of continuous forest and a more natural fire regime (Hessburg & Agee 2003) than in the Mediterranean basin. In these areas, managers advise against salvage logging in severely burned conifer forests (Kotliar *et al.* 2002; Hutto & Gallo 2006; Hutto 2008).

Salvage logging did not have consistently positive effects for all threatened birds in our data set. The turtle dove, for example, showed a negative response to the removal of snags but this may be because it is not particularly linked to forests, but prefers fragmented woodlands near cultivated areas (Snow & Perrins 1998; Vořišek & Klvaňová 2010). The retention of some snags immediately following fire may be important not

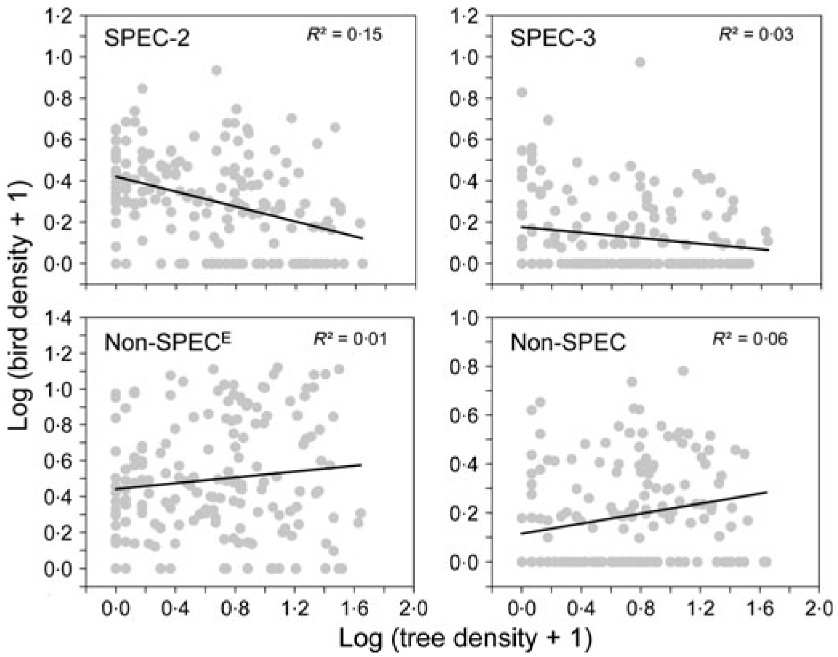

Fig. 3. Relationships between the density of birds of each SPEC category (BirdLife International 2004), calculated as the sum of all species densities of the same SPEC category in a given station and snag density, a proxy variable of salvage logging intensity. SPEC-2 and 3 correspond to unfavourable conservation status, while Non-SPEC^{E} and Non-SPEC denote a favourable conservation status.

only for species such as the turtle dove, but also for those species that usually perch on trees to sing and/or to hunt by sit-and-wait (e.g. corn bunting, wood lark, linnet and shrike). Therefore, combining salvage logging in certain areas (while leaving some snags as perches) with nonintervention in others should improve the conservation of individual species in both open-habitat and forest environments. This could be especially critical after large wildfires, where snag-dependent species that are of conservation interest could disappear from very large areas.

Salvage logging in burned Mediterranean pine forests is a forestry intervention intended to recoup the value of burned timber for sale. Any conservation benefit is secondary to the harvesting operation. Nevertheless, conservation objectives should be included in postfire timber harvesting guidelines, especially considering that such management is often supported by public funds, or undertaken in public forests in which environmental restoration is a stated objective. Management guidelines should be as broad-based as possible. The available evidence suggests that salvage logging can encourage other taxa besides birds, when wood debris is not removed (e.g. terrestrial gastropods, Bros, Moreno-Rueda & Santos 2011; European rabbit *Oryctolagus cuniculus*, Rollan & Real 2010). There is no evidence that salvage logging negatively impacts vegetation or soil significantly in the mid-term (Ne'eman, Lahav & Izhaki 1995; Inbar, Wittenberg & Tamir 1997; Spanos *et al.* 2005).

We are aware that conservation of open-habitat birds in Spain depends not only on postfire forest management factors but also on the wider socioeconomic policies that influence changes in land use across Europe. We hoped that this study provides a comprehensive understanding of the effect of postfire salvage logging on bird conservation, and, in particular, the potential for positive outcomes. However, it is important that management recommendations are made on the basis of the specific threats that birds face in each particular region. The information provided here should help to improve postfire forest management strategies so that salvage logging is compatible with the creation of suitable habitat conditions for bird species of conservation concern as well as the preservation of the ecosystem's ecological functionality after fire. Following large wildfires in Mediterranean pine forests, the combination of salvage logging in some areas (while retaining some standing dead trees) with nonintervention in others should maximize the conservation value of these areas.

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Supporting Information

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

Fig. S1. Study areas.

Fig. S2. Distribution of the plots of habitat sampling within a station.

Fig. S3. Partial DCA biplots of species and stations.

Appendix S1. Species detected during the study.

Appendix S2. Effect of the three habitat variables on the occurrence of the 31 most common species.

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