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Post-fire salvage logging alters species composition and reduces cover, richness, and diversity in Mediterranean plant communities

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ABSTRACT

An intense debate exists on the effects of post-fire salvage logging on plant community regeneration, but scant data are available derived from experimental studies. We analyzed the effects of salvage logging on plant community regeneration in terms of species richness, diversity, cover, and composition by experimentally managing a burnt forest on a Mediterranean mountain (Sierra Nevada, S Spain). In each of three plots located at different elevations, three replicates of three treatments were implemented seven months after the fire, differing in the degree of intervention: “Non-Intervention” (all trees left standing), “Partial Cut plus Lopping” (felling 90% of the trees, cutting the main branches, and leaving all the biomass *in situ*), and “Salvage Logging” (felling and piling the logs, and masticating the woody debris). Plant composition in each treatment was monitored two years after the fire in linear point transects. Post-fire salvage logging was associated with reduced species richness, Shannon diversity, and total plant cover. Moreover, salvaged sites hosted different species assemblages and 25% lower cover of seeder species (but equal cover of resprouters) compared to the other treatments. Cover of trees and shrubs was also lowest in Salvage Logging, which could suggest a potential slow-down of forest regeneration. Most of these results were consistent among the three plots despite plots hosting different plant communities. Concluding, our study suggests that salvage logging may reduce species richness and diversity, as well as the recruitment of woody species, which could delay the natural regeneration of the ecosystem.

1. Introduction

Predicting the effects of anthropogenic changes mediated by land uses or disturbances has been a central concern of ecological research (e.g. Grime, 1979; Lavorel et al., 1997). Ecosystems show remarkable differences in their capacity to regenerate after disturbance depending on the type of vegetation, disturbance characteristics, and historical background. After disturbance, large amounts of ecological legacies can remain, which play crucial roles in ecosystem recovery and influence ecosystem processes for decades or centuries (Foster et al., 1998). Ecological legacies are the residues left after disturbance, and they are composed of both biological and physical components (Turner and Dale, 1998).

Biological legacies left after a wildfire, such as remaining burnt trees, logs and branches, as well as surviving vegetation, aid ecosystem recovery by retaining soil (Reeves et al., 2006), producing nutrient inputs in the short- and the long-term (Brais et al., 2000; Marañón-Jiménez and Castro, 2013), favoring mutualistic plant–animal interactions (Castro et al., 2012), acting as seed traps (Marzano et al., 2013), facilitating survival and population viability in disturbed areas (Castro et al., 2011; Leverkus et al., 2012), and promoting plant and animal (re) colonization by providing habitat features, substrate, and food for many species (Lindenmayer and Noss, 2006; Lindenmayer et al., 2008). However, the ecological role of these biological legacies in post-fire ecosystems has long been neglected by managers and policymakers, associated with the lack of scientific evidence of their importance (McIver and Starr,

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2001). In fact, the removal of some of the biological legacies (i.e. the burnt biomass) is one of the most common post-fire management strategies worldwide, also called salvage logging (McIver and Starr, 2001; Beschta et al., 2004; Lindenmayer and Noss, 2006; Lindenmayer et al., 2008). Post-fire salvage logging consists in the felling and removal of the burnt trunks, often including the elimination of the remaining woody debris. Major motivations for post-fire salvage logging can differ, although the most important are economic (recovering part of the forest capital) or silvicultural (aiding the management and restoration of the burnt site; Lindenmayer et al., 2004, 2008; Donato et al., 2006; Castro et al., 2010). However, there is increasing evidence that biological legacies are components of natural systems that promote ecosystem recovery and diversity, and that their extraction represents a further disturbance which acts synergistically with the original one and may lead to effects that would not be expected by considering one of the disturbances (i.e. fire or logging) alone (Lindenmayer et al., 2004, 2008; Beschta et al., 2004; DellaSala et al., 2006; Hutto, 2006). As a result, there are growing calls to implement post-fire policies of retention of all or at least part of the biomass (DellaSala et al., 2006; Lindenmayer et al., 2008; Castro et al., 2011; Marzano et al., 2013; Marañón-Jiménez et al., 2013a).

Potential reductions in species diversity and changes in community assemblages are among the major concerns about post-fire salvage logging (Franklin et al., 2000). As this management practice can dramatically change habitat structure and other abiotic conditions (McIver and Ottmar, 2007; Castro et al., 2011), these can in turn alter the composition and relative abundance of species, as well as the successional trajectories of plant communities (Purdon et al., 2004; Macdonald, 2007; Beghin et al., 2010; Marzano et al., 2013). The effect of salvage logging on plant diversity has been addressed in some studies, and it often points to reductions in species richness and/or diversity (Sexton, 1998; Purdon et al., 2004; Bradbury, 2006; Marzano et al., 2013). However, the overall trends on plant species richness and diversity are not clear, as some studies have found no effects (e.g. Macdonald, 2007) or even positive effects of salvage logging (e.g. Ne'eman et al., 1995; Kurulok and Macdonald, 2007).

Differing results for salvage logging effects on species richness and diversity can be explained by several factors related to fire characteristics, the nature and timing of the logging operations, or ecosystem features (Lindenmayer and Ough, 2006; Lindenmayer et al., 2008), but it is hard to draw conclusions because most studies have not been performed under controlled and designed experiments. In fact, part of the scientific literature dealing with ecological consequences of post-fire logging predicts effects but without testing them (Van Nieuwstadt et al., 2001; Reeves et al., 2006; Lindenmayer and Ough, 2006). Among experimental studies, most have sampled salvaged sites without the consideration of unsalvaged controls (Greenberg et al., 1992; Greenberg and Mcgrane, 1995), made use of areas that have been differently managed for reasons other than the experiment itself (e.g. Martínez-Sánchez and Ferrandis, 1999; Purdon et al., 2004; Bradbury, 2006; Foster and Orwig, 2006; Kurulok and Macdonald, 2007; Macdonald, 2007), or carried out unreplicated experiments (e.g. Martínez-Sánchez and Ferrandis, 1999; Spanos et al., 2005; Beghin et al., 2010). Altogether, these studies have provided crucial and urgent information about the potential impacts of post-fire salvage logging. However, problems of lack of proper experimental designs and the imperative need of such an approach have previously been pointed out (McIver and Starr, 2001; Lindenmayer and Noss, 2006; Lindenmayer and Ough, 2006) and are common throughout conservation science in general (Sutherland et al., 2004), but studies with an experimental approach remain scarce (but see Ne'eman et al., 1995; McIver and Ottmar, 2007; Fernández et al., 2008).

In this study we seek to analyze the effects of salvage logging on post-fire plant communities. We made use of a replicated experimental design that was set up in a burnt pine reforestation in the Sierra Nevada National Park (Spain) to study the effects of three burnt-wood management treatments (salvage logging, a partial felling treatment without biomass extraction, and non-intervention) on plant community regeneration two years after fire. This experimental design allowed making rigorous assessments of the working hypotheses that burnt-wood management affects plant communities in terms of: i) species richness and diversity, ii) percent cover, and iii) species composition and abundance. Overall, we aimed to investigate whether this silvicultural practice could change the patterns of regeneration of plant communities in a Mediterranean mountain ecosystem.

2. Methods

2.1. Study area and experimental design

The study site was located in the Sierra Nevada Natural and National Park (SE Spain; 37°N, 3°W), where in September 2005 the Lanjarón fire burned 1300 ha of pine reforestations (3420 ha in total) with 35–45 year-old trees. The fire, moderate to high in severity, consumed or totally scorched most of the tree crown (Marañón-Jiménez et al., 2013b). Climate in the area is Mediterranean, with hot, dry summers and mild, wet winters (see Table 1 for details).

Three plots of *ca.* 25 ha each were established after the fire along an elevational gradient, with similar aspect (SW) and slope (28,7–31,4%). The pine species present in each plot differed according to their ecological requirements along this elevational/moisture gradient (Table 1). All of them are native in the region, although they were extensively planted in the area for soil protection after long-term degradation resulting from human intervention. The area surrounding the plots was dominated by shrublands mixed with scattered individual holm oaks (*Quercus ilex* subsp. *ballota*

Table 1
Main characteristics of the experimental site.

	Plot		
	1	2	3
UTM coordinates (x; y)[a]	456070E–4089811N	455449E–4091728N	457244E–4091551N
Plot area (ha)	17.7	23.9	31.7
Subplot area (ha)[b]	2.0 ± 0.15	2.7 ± 0.18	3.5 ± 0.30
Elevation[a]	1477	1698	2053
Slope (%)[c]	30.3	28.7	31.4
Mean daily min. temp. (°C)[d]	6.8 ± 0.2	5.6 ± 0.2	3.4 ± 0.2
Mean daily max. temp. (°C)[d]	17.1 ± 0.2	16.2 ± 0.2	13.4 ± 0.2
Mean ann. precip. (mm)[d]	501 ± 49	550 ± 40	630 ± 42
Dominant species	*Pinus pinaster*/ *P. nigra*	*Pinus nigra*	*Pinus sylvestris*
Tree density (trees/ha)[e]	1477 ± 46	1064 ± 67	1051 ± 42
Tree basal diameter (cm)[e]	17.7 ± 0.2	18.3 ± 0.1	15.7 ± 0.1
Tree diameter at 1.30 m (cm)[e]	13.3 ± 0.2	14.5 ± 0.2	10.7 ± 0.2
Tree height (m)[e]	6.3 ± 0.1	6.6 ± 0.1	6.2 ± 0.1

[a] Coordinates and elevation measured at the centroid of each plot (UTM zone 30N, Datum: ED-50).
[b] There was no significant difference in subplot area among treatments (Kruskal Wallis test; $P > 0.05$).
[c] Mean slope of the nine subplots.
[d] Data obtained from interpolated maps of Sierra Nevada (1981–2010) created at the Centro Andaluz de Medio Ambiente (CEAMA) except precipitation in Plot 1, which is an empirical value obtained at Plot 1 (1988–2011).
[e] Measured after the fire. Density sampled in each subplot by counting the trees in four randomly placed 25 × 25 m quadrats. Basal tree diameter was measured on 30 randomly chosen trees in these quadrats, thus 120 trees per subplot.