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Short-term effects of low-intensity prescribed fire on ground-dwelling invertebrates in a Canarian pine forest

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Abstract

The effects of prescribed fire on the forest upper ground layer can have consequences for invertebrate communities. In the Canary Islands, prescribed fire is starting to be used as a tool to reduce wildfire risk, but the impacts of this management practice on the Canarian pine forest have not been investigated. The aim of this study is to explore the short-term effects of prescribed burning on the most abundant groups of ground-dwelling invertebrates. Three of six plots were randomly burnt and the other three were used as controls. Pitfall trapping was used to collect the ground-dwelling invertebrates four months after burning. No differences were found in total richness, diversity, evenness and total abundance between treatments. Only Psocopteran abundance increased after fire. Litter depth, total vegetation cover and decayed wood cover were different between treatments. Canonical Correspondence Analyses (CCA) revealed differences in species composition between treatments using these environmental variables. It is concluded that the use of low-intensity prescribed burning in this stand did not have an important impact on the structural parameters of the ground-dwelling invertebrate community, but species composition changed. Care shoud be taken with valuable endemic, rare or sensible species.

Key words: prescribed burning, invertebrate community, pine forest, *Pinus canariensis*, fire, soil ecology.

Resumen

Efectos a corto plazo de una quema prescrita de baja intensidad sobre los invertebrados epiedáficos de un pinar canario

Los efectos del fuego prescrito sobre la capa superficial del suelo pueden tener consecuencias para las comunidades de invertebrados. Las quemas prescritas se están empezando a aplicar en las Islas Canarias como una herramienta para reducir el riesgo de incendios forestales, pero el impacto ecológico de estas prácticas aún no ha sido estudiado en el pinar canario. El objetivo de este trabajo es explorar los efectos a corto plazo de las quemas prescritas sobre los grupos más abundantes de invertebrados epiedáficos. Se establecieron seis parcelas, de las que tres fueron quemadas al azar y las otras tres se usaron como controles. Los muestreos de invertebrados se realizaron cuatro meses después de la quema mediante trampas de caída. No se encontraron diferencias entre tratamientos en riqueza, diversidad, equitatividad y abundancia total de invertebrados. En cuanto a los grupos, Psocoptera fue el único que incrementó su abundancia tras el fuego. Se encontraron diferencias significativas entre tratamientos en profundidad de mantillo, cobertura total de vegetación y cobertura de madera muerta en descomposición. Dichas variables se incluyeron en un Análisis Canónico de Correspondencia (CCA) revelando diferencias entre tratamientos en composición de especies. Se concluyó que, aunque las quemas prescritas no tienen un impacto notable sobre los parámetros estructurales de la comunidad de invertebrados, sí provocan cambios en la composición de especies, que deben ser valorados en presencia de especies endémicas, raras o sensibles.

Palabras clave: quemas prescritas, comunidad de invertebrados, pinar, *Pinus canariensis,* fuego, ecología del suelo.

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Introduction

Invertebrates are critical components of forest ecosystems, especially those that live in the ground, as they act as predators and prey and contribute to nutrient cycling and decomposition (Petersen and Luxton, 1982; Lattin, 1993). Based on that, they have to be taken into account when testing forest management treatments and may also serve as sensitive indicators of habitat quality (Kremen *et al.,* 1993).

The current large fuel load accumulations in forests cause greater intensity and different behaviour of wildfires (Fababú *et al.,* 2007) and, thus, some management is needed to control for these accumulations. Prescribed burns are one of the alternative forest management methods to be applied and are relatively new in the Canary Islands and some other areas of Spain. Low-intensity prescribed fires can be useful in some ecosystems to reduce fuel loads by decreasing low vegetation and small decayed wood (Phillips and Waldrop, 2008; Youngblood *et al.,* 2008) without negative effects on soil conditions (Úbeda *et al.,* 2005). However, there is no consensus about the effects of prescribed fire on the vegetation in Spain. While some authors have found positive effects on both vegetation and soil (Botelho *et al.,* 1994; Molina and Bardají, 1998; Piñol *et al.,* 2005; Úbeda *et al.,* 2005), others have found changes in plant species composition and dominance after the fire treatment (Baeza and Vallejo, 2008). Despite these contradictory results, there is increasing consensus that prescribed fire will be important in restoring ecosystem processes and reducing fire risk at least in conifer forests (Stephens and Moghaddas, 2005).

On a smaller spatial scale, fire management may affect many of the forests' structural elements on which ground-dwelling invertebrates are heavily dependent (*e.g.* dead wood, litter layer), so that they may be very sensitive to this treatment. Many studies have examined the effects of burning on different arthropod groups and found these communities to be highly resilient (Niwa and Peck, 2002; Collett, 2003; Baker *et al.,* 2004). However, there is no consensus about the effects of fire on arthropod communities in conifer forests and only a few specific groups have been studied (Santalla *et al.,* 2002). Some researchers have showed only slight short-term changes (Baker *et al.,* 2004), or even increases in biodiversity (Villa-Castillo and Wagner, 2002), while others have showed a decline of some arthropod groups (Apigian *et al.,* 2006).

Most of the Canarian pine forest is constituted by young (50-60 years old) reforested stands that have been little managed since they were planted for restoration. As a result, they are dense stands with tall, thin, weak trees, and a continuous fuel ladder from the ground to the canopy. Little is known about historic fire regimes in the Canary Islands, but contrary to other pine species in Spain, *Pinus canariensis* is an extremely well fire-adapted species (Arévalo *et al.,* 2001). It rapidly regenerates canopy cover even after severe fire and dead leaves are shed starting the first month after fire, creating a new litter layer.

Community-level ecological studies on invertebrate assemblages in the Canary Islands are very rare. This is the first study to examine the effects of a perturbation on the invertebrate community of a particular ecosystem, in this case, pine forest. It is part of a larger study about the value of introducing fire as a management tool in Canary pine forests. Vegetation structure and cover and soil characteristics of the study area showed few differences between burned and unburned plots (unpubl.), so this study was designed to assess whether the same pattern is evidenced in the invertebrate community. The aim of the study is to explore the short-term effects of prescribed burning on the most abundant groups of the ground-dwelling invertebrates, as there is no consensus within the available research about their response to this management tool.

The tested hypotheses were:

1. Low-intensity prescribed fire alters some environmental variables, upon which ground-dwelling invertebrates depend.
2. Abundance, richness or diversity of ground-dwelling invertebrate community will be affected by the changes in environmental variables due to the fire treatment.
3. Invertebrate species composition will be different in each treatments due to the new microhabitat conditions created by the fire.

Material and methods

Study site

The study was conduced at one area of approximately 50 ha in the Canarian pine forest of Artenara, in Gran Canaria (Longitude 19° 38' 2" W; latitude 27° 56' 37" N). This area, potential Canarian pine forest, was used for cultivating fruit trees and vegetables after cutting down all the pines. About 60 years ago, the already abandoned area was planted with *Pinus canariensis* for restoration and has hardly been managed or burned since then. The area is located between 1,400-1,600 m and faces the prevailing north-easterly winds. The dominant tree species is *P. canariensis* (approximately 600 trees per ha), although the area includes other planted exotic pine species such as *P. halepensis* and *P. radiata*. The understory is dominated by a variety of shrub and herb species, most notably *Chamaecytisus proliferus, Teline microphylla, Bystropogon origanifolius,* and *Micromeria* spp. A deep litter layer, with an average thickness of 5.7 cm, typically covers the entire site.

Plot set-up and treatments

The study area was divided into six plots of between 7-9 ha each. Woody understory vegetation was cut in all plots to break the fuel continuity between the ground and the canopy before burning. The slash was not removed from the plots. Three of these plots were chosen at random and burnt in June 2006 by a low intensity prescribed fire. Burning was carried out under specific temperature, humidity and wind conditions to maintain a flame at less than 1.5 m. Strip fire and backing fire were the ignition patterns used. The other three plots were used as a control.

Ground-dwelling invertebrate collection

Invertebrate sampling was carried out in October 2006, four months after fire. Sampling was carried out during October since, in the Canary Islands, arthropod activity is limited during summer by low humidity. From October until June this activity increases (Delgado J.D. unpubl.), so invertebrate sampling was designed to coincide with the beginning of the moist period and invertebrate activity.

Invertebrates were collected using pitfall traps, an efficient way to collect ground-dwelling fauna, despite the known disadvantages of the technique (Spence and Niemelä, 1994). This trapping method has been found to provide reasonable activity-density estimates for groups such as carabid beetles (Baars, 1979), spiders and ants (Wang *et al.,* 2001).

The traps consisted of 5 cm diameter plastic cups containing a small amount of propylene glycol as a preserving agent. Three 50 m transects were placed in each plot perpendicular to the slope, separated by approximately 25 m, with four traps at 10 m intervals along each transect, always 10 m away from the edges of each treatment plot. They were buried and kept open for a week. Not a pitfall trap was lost during the sampling period. Invertebrate samples were placed in vials of 70% ethanol for storage. They were identified to order level (García Becerra *et al.,* 1992; McGavin, 2002), except in case of the Acari Infraclass. And they were also all further classified into morphospecies, except for Collembola and Psocoptera. Larvae and juveniles were not considered in this study.

Environmental measurements

In order to study the environmental variables a sampling unit of 5 × 5 m was set up around each pitfall trap, so a total of twelve sampling units were set in each plot. In each sampling unit we measured the main environmental variables that could affect the invertebrate community: litter depth in cm; cover percentage of rock, decayed wood, and tree, herb and shrub layers; and total vegetation cover, including the three layers. Percentage covers were visually estimated. Elevation in meters (GPS), slope in degrees sexagesimal (clinometer) and aspect in degrees sexagesimal (compass) were measured once per plot.

Data analysis

Morphospecies-level was used to calculate invertebrate community structural parameters: total abundance, richness, the Shannon diversity index (H') (Elliott, 1990) and evenness (J). We used nine replicates (transects) per treatment to apply these analyses. Each transect can be considered as a replicate as they are separated by 25 m, a distance which has been shown to assure statistical independence of ground dwelling invertebrate samples (Ward *et al.,* 2001). Psocoptera and Collembola richness could not be calculated as we did not sort these groups into morphospecies. The David *et al.* (1954) test was used to check normality and the Cochran (1941) test was used to check homocedasticity of the data. A Mann-Whitney U test was used to analyze the variance of the total abundance, richness, diversity and evenness to test for differences between treatments. We used a non-parametric test because of the small number of samples (nine per treatment). These same analyses were performed for each of the most abundant orders separately (Acari, Araneae, Coleoptera, Collembola, Diptera, Hemiptera, Hymenoptera, Psocoptera), but only abundance and richness were calculated, as the other indices were often not applicable. Statistical tests were carried out using Statistical Program for the Social Sciences 11.5 (SPSS Inc., 1989-2002)

All nine replicates per treatment were used to perform the analyses of variance of the environmental variables. After testing the normality and homocedasticity of the data, a Mann-Whitney U test was used to compare means between treatments for each variable. This test was performed with the SPSS package.

Ordination techniques were used to analyze the assemblage-level response of invertebrates to the fire treatment. They were performed using nine replicates per treatment. Abundance data of invertebrates were transformed using Ln(X+1) before their inclusion in these analyses to give less weight to dominant species (Jongman *et al.,* 1995), as invertebrate catches were characterised by few abundant species and a great number of rare ones. Two Canonical Correspondence Analyses (CCA) (Ter Braak, 1986) were performed: one using order-level abundance per transect and the other using morphospecies-level abundance per transect to see if the classification level influences the results.

The environmental variables used for CCA were those found to be significantly different between treatments and also important for the ground-dwelling fauna from the ecological point of view, according to the literature. They were: litter depth, decayed wood cover and total vegetation cover. Aspect was also found to be significantly different between treatments, which is not a result of fire, so we included it as a covariable for all the multivariate analyses. Using it as a covariable we eliminate from the analysis the variability created by this variable that could mask real treatment effects.

All multivariate analyses were performed with the CANOCO package (Ter Braak and Šmilauer, 1998), using logistic regression (SPSS) to assess whether the samples were distributed along axes I or II in a function of the treatment (control = 0, burn = 1). We performed logistic regression using treatment as the dependent variable and sample coordinates in one axis as the independent variable.

Results

A total of 858 adult invertebrate individuals were captured, covering 17 orders and 64 morphospecies. Diptera was the order with the greatest richness (16 morphospecies in total) while Collembola and Acari were the orders with the greatest abundance in both control and burned plots (Table 1). We collected eight unique morphospecies from varied orders exclusive to control plots (Diptera 5 and 6, Hymenoptera 4 and 7,

Table 1. Mean and standard deviation of abundance, richness, diversity and evenness for the most abundant orders, total morphospecies and total orders per transect. Differences between treatments were tested with a Mann-Whitney U test. Statistic (Z) and significance (sig.) shown in the table. Statistically significant differences in bold type

	Abundance				Richness			
	Control	Burned	Z	sig.	Control	Burned	Z	sig.
Acari	7.22 ± 5.04	7.89 ± 11.67	–0.71	0.48	3,56 ± 0,88	3,56 ± 1,01	–0.09	0.93
Araneae	2.89 ± 1.54	2.22 ± 1.39	–0.77	0.44	5,33 ± 0,71	5,56 ± 0,88	–0.53	0.57
Coleoptera	1.78 ± 2.22	2.11 ± 1.05	–1.13	0.26	6,89 ± 1,05	6,22 ± 1,09	–1.26	0.21
Collembola	16.89 ± 15.68	24.33 ± 15.80	–0.93	0.35	—	—	—	—
Diptera	6.78 ± 2.59	5.44 ± 2.79	–0.94	0.35	12,11 ± 1,83	12,78 ± 1,39	–0.72	0.47
Hemiptera	0.78 ± 1.99	0.89 ± 0.93	–1.26	0.21	7,44 ± 1,33	3,00 ± 0,83	–1.21	0.23
Hymenoptera	3.33 ± 3.91	4.22 ± 3.87	–1.04	0.30	7,00 ± 1,50	7,44 ± 0,53	–0.52	0.61
Psocoptera	0.67 ± 1.41	4.22 ± 2.86	–2.87	**0.00**	—	—	—	—
Total morphospecies	49.56 ± 26.18	59.11 ± 24.57	–1.06	0.29	54.56 ± 4.90	54.89 ± 2.42	–0.311	0.76
Diversity (H')	3.43 ± 0.12	3.08 ± 0.61	–0.66	0.51	—	—	—	—
Evenness (J)	0.74 ± 0.08	0.66 ± 0.10	–1.09	0.28	—	—		
Total orders	49.56 ± 26.18	59.11 ± 24.57	–1.06	0.29	9.67 ± 1.66	9.00 ± 0.87	–0.83	0.42
Diversity (H')	2.72 ± 0.07	2.70 ± 0.46	–0.66	0.51	—	—	—	—
Evenness (J)	0.78 ± 0.07	0.76 ± 0.08	–0.22	0.83	—	—	—	—

Table 2. Mean and standard deviation of environmental variables per plot. Differences between treatments were tested with a Mann-Whitney U test. Statistic (Z) and significance (sig.) shown in the table. Statistically significant differences in bold type

	Control	Burned	Z	Sig.
Altitude (m)	1,576.67 ± 12.58	1,545.00 ± 61.44	–0.44	0.66
Aspect (°sex)	**23.33 ± 25.37**	**45.00 ± 8.66**	**–2.43**	**0.04**
Slope (°sex)	28.50 ± 10.01	37.47 ± 5.77	–1.55	0.12
Litter depth (cm)	**5.73 ± 0.80**	**2.13 ± 0.59**	**–1.96**	**0.05**
Total vegetation cover (%)	**43.23 ± 12.77**	**26.83 ± 2.24**	**–1.96**	**0.05**
Herb cover (%)	0.73 ± 1.18	0.50 ± 0.35	–0.45	0.65
Shrub cover (%)	7.43 ± 11.35	0.03 ± 0.06	–1.16	0.25
Tree cover (%)	35.97 ± 17.97	26.83 ± 2.24	–0.22	0.83
Decayed Wood cover (%)	**18.47 ± 12.61**	**2.27 ± 2.03**	**–1.96**	**0.05**
Rock cover (%)	5.73 ± 6.83	7.60 ± 5.46	–1.09	0.28

Pseudoscorpiones 1, Hemiptera 1, Julida 1 and Pulmonata 1), and four exclusive to burned plots (Orthoptera 1, Acari 5, Diptera 13 and Hemiptera 5). Morphospecies collected only in one trap during the study were excluded from the analyses.

For most orders, no significant differences were found in mean abundance between treatments (Table 1). Only Psocoptera abundance was significantly higher in burned plots than in control plots. Prescribed fire did not have a significant effect on the richness of the different orders found in the study area (Table 1). Neither the structural parameters of the invertebrate community (total abundance, richness, Shannon diversity and evenness) were significantly affected by prescribed fire (Table 1).

A total of four environmental variables were found to be statistically different between control and burnt plots (Table 2): litter depth, decayed wood, total vegetation cover and aspect. The first three were used as the explanatory variables of the CCA ordinations. Aspect was used as covariable for all the ordination analyses.

In Figure 1, CCA performed with orders as variables, samples were sorted as a function of the treatment along axis I, fact that was confirmed by logistic regression (Wald = 5.076, sig. = 0.024). The environmental variables included explained a great amount of variability of the orders: 86.1% for the two axes. Control samples (grey circles) were grouped in the positive side of axis I, and were related with a larger litter depth, vegetation cover and decayed wood cover. Burnt plot samples (grey squares) were grouped in the negative side, with the opposite environmental characteristics. Most of the collected orders were located near to the centre of the graph. This means that their presence is not strongly related with the environmental variables or the samples. Orthoptera is the only order exclusive to burnt plots and was more related to burnt samples in the analysis.

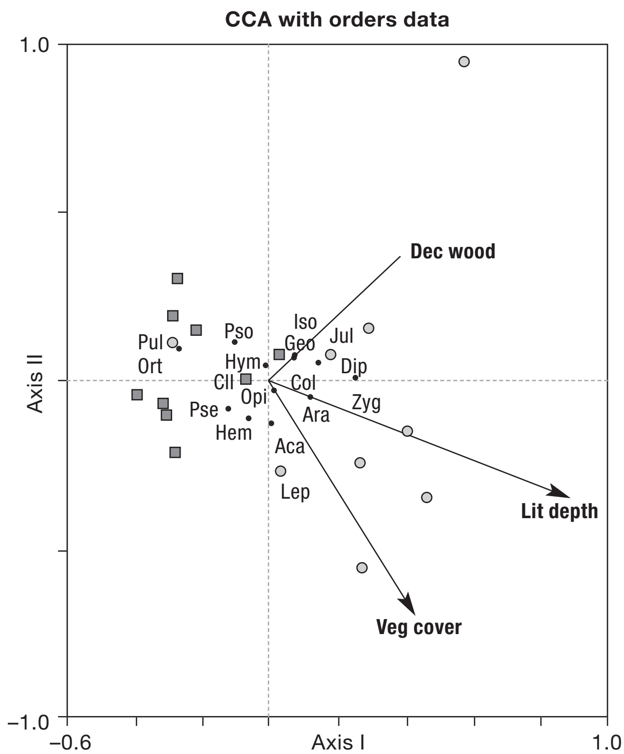

Figure 1. CCA axes I and II for the samples (transects), orders and environmental variables (Eigenvalues were 0.072 and 0.041, respectively, and cumulative percent variance of the relationship between orders and environmental variables for both axes was 86.1%). Circles are control samples, squares are burnt samples, and points are orders. Environmental variables: total vegetation cover, decayed wood cover and litter depth. Order names: Aca, Acari; Ara, Araneae; Col, Coleoptera; Cll, Collembola; Dip, Diptera; Geo, Geophilomorpha; Hem, Hemiptera; Hym, Hymenoptera; Iso, Isopoda; Jul, Julida; Lep, Lepidoptera; Opi, Opiliones; Ort, Orthoptera; Pse, Pseudoscorpiones; Pso, Psocoptera; Pul, Pulmonata; Zyg, Zygentoma.

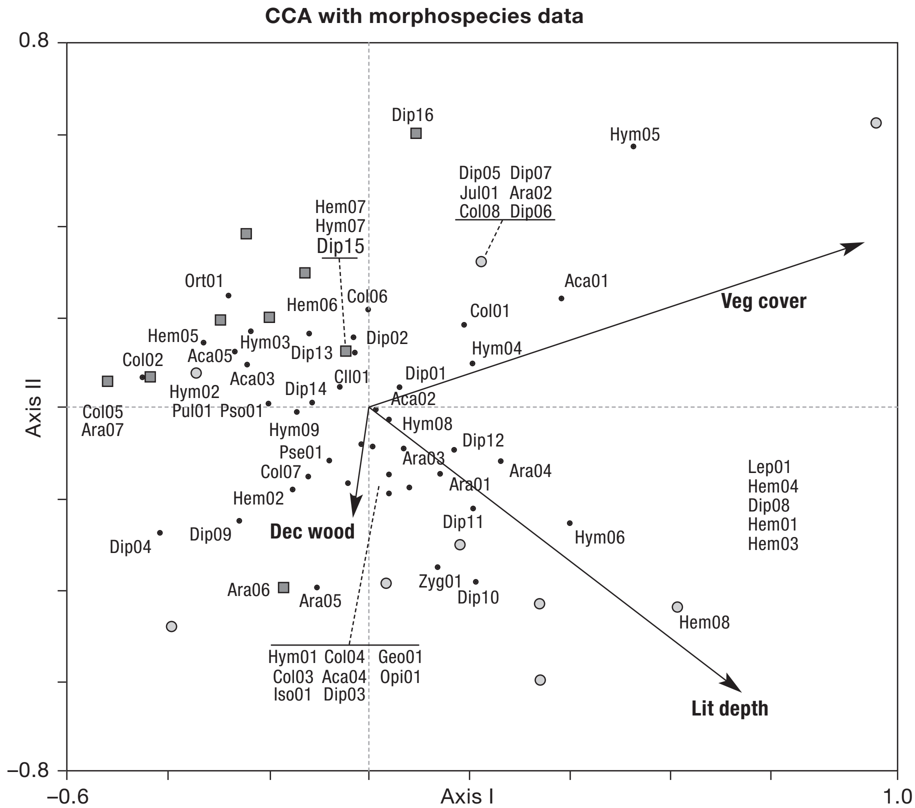

Figure 2. CCA axes I and II for the samples, morphospecies and environmental variables (Eigenvalues were 0.137 and 0.116, respectively, and cumulative percent variance of species-environment relation for both axes was 76.7 %). Circles are control samples, squares are burnt samples and points are orders. Morphospecies names are a combination of the abbreviated order name plus a number. See Fig. 1 for abbreviated order names and environmental variables.

The same analysis performed with morphospecies data revealed similar results (Fig. 2). Slightly greater distance between samples was shown using morphospecies-level instead of orders-level as variables, but the main results obtained were the same. Logistic regression confirmed the relation between axis I coordinates and the fire treatment (Wald = 4.287, sig. = 0.038). The environmental variables explained 76.7% of the morphospecies variability for the two axes. Burnt samples were more closely grouped than control ones, and related with the presence of the four morphospecies exclusive to the burnt plots (Dip13, Ort01, Aca05 and Hem05). Indeed, more variability was shown within the control samples species composition.

Discussion

In general, low-intensity fires do not have a great impact on the forest structure on a large scale, as they do not significantly reduce coarse decayed wood amounts (Stephens and Moghaddas, 2005) , tree or shrub cover (Phillips and Waldrop, 2008) . However, low-intensity fire has smaller scale impacts on environmental variables that could have important effects on the invertebrate community. These impacts include a reduction of leaf-litter depth and lower-canopy cover described by Coleman and Rieske (2006), which are in concordance with the results found in our study. Besides, thin decayed wood debris in the 100 hour timelag size class has been shown to decrease in biomass after low-intensity prescribed fire (Youngblood *et al.,* 2008). In our study, we found a decrease in the cover of decayed wood debris after fire. Although we did not classify size, most of the decayed wood debris in the study plots was also in this same size class, a result of the previous understory cut treatment.

Total vegetation cover was measured to get an idea of the real change in sun exposure after fire. Total vegetation cover might not be expected to decrease, as none of the single vegetation layers significantly did after burning. However, as each layer was slightly reduced, and as most of the herbs and some shrubs grew outside the canopy's shade influence, the slight decrease in each of them resulted in significant differences in total vegetation cover between treatments. A reduction of vegetation cover and the associated increase in ground light exposure is one of the other possible changes after fire, which could attract invertebrate species known to be favoured by sun-exposed conditions (Selonen *et al.,* 2005).

The direct effects of these environmental changes caused by fire on the invertebrate community are not very clear. Responses have been shown to be positive (Villa-Castillo and Wagner, 2002), negative (Apigian *et al.,* 2006) or only relevant at short-term scale (Baker *et al.,* 2004). Many of these studies did not differentiate between leaf-litter and ground-dwelling invertebrates, which have been found to respond in different ways to the fire treatment (Coleman and Rieske, 2006). In our study, using only pitfall traps as the sampling method, the leaf-litter invertebrate community, which was the only group found to decrease in richness after fire in previous studies, may not be strongly represented.

Some groups of invertebrates, such as beetles and some spiders, have been shown to increase after fire treatment (Sullivan *et al.,* 2003). This is likely because their activity can increase due to changes in the microclimate at the litter surface (Andersen and Yen, 1988; Neumann and Tolhurst, 1991), resulting in an increase of catches. In our study, only Psocoptera abundance was significantly higher after fire. Collembola mean abundance also increased, although not significantly. The increase in abundance of these two groups (mostly fungivores) could be associated with the increase of fungi after fire, as it was shown by Coy (1994) in a study carried out with low-intensity fire in the Australian forest. In contrast, other authors have found a decrease in the abundance of Psocoptera (Taber *et al.,* 2008) and Collembola (Coleman and Rieske, 2006) after prescribed fire, which may be due to differences in humidity between study sites.

Total abundance and richness did not change after fire, in concordance with other studies (Bailey and Whitham, 2002; Taber *et al.,* 2008). This was probably due to the rapid recovery of the litter cover (but not depth) and herb cover after burning. However, CCA showed differences in invertebrate species composition related to the environmental variables that significantly changed after fire. These community differences might be due to differences in the number of individuals collected for particular morphospecies (Jongmann *et al.,* 1995). Also a few rare species were probably contributing to these community dissimilarities, as they have either disappeared or appeared after the prescribed burn. Common morphospecies did not change significantly as a result of fire because they recovered in a short-time after the prescribed burning. However, there can be also an inadvertent reduction of more habitat-restricted species after fire, whose recovery may take much longer (Swengel, 2001).

It is necessary to mention some of the limitations of the present study. First, many of the arthropod species inhabiting the Canarian pine forest have not been well studied yet, and, thus, only a morphospecies-level approach was possible.Species identification might have allowed knowledge on ecological requirements and habitat specialization of each species and, thus, a better interpretation of the effects of fire on the ground-dweling invertebrate community. Indeed, studies examining particular species with conservation concerns have had more conclusive results (Swengel, 2001).

Second, this study was carried out in one single stand. Although it is very difficult to find replicate sites with similar environmental conditions in the Canary Islands, replication is needed to extend these results from the stand level to the forest. It is also important to notice that the stand studied is approximately 50-60 years old, and, thus, the invertebrate species composition may not be the same as those in mature stands (Taboada *et al.,* 2008). The invertebrate community sampled may be characterised by generalist species, invaders from the surroundings or that may be using the pine forest as secondary habitat because of the recent plantation of the stand. Specialist species are reported to be more strongly affected by the management of old-growth stands in other conifer forests (Niemelä *et al.,* 1996). As such, care should be taken when extrapolating these results to natural stands on the Canary Islands. It is also important for future studies to check for the presence of sensitive, rare or endemic species that may be affected by low-intensity fires (Swengel, 2001) in this type of forest, characterised by a high percentage of endemism.

In conclusion, low-intensity prescribed fire affects some environmental variables upon which the invertebrate community depends. The fire did not have an important impact on the structural parameters of the ground-dwelling invertebrate community, but species composition changed. The invertebrate fauna of this ecosystem must be better studied and care should be taken when managing areas with sensitive or rare species. Furthermore, in order to suggest management recommendations, more than one-week sampling would be possibly needed to confirm the effects of prescribed burning on the invertebrate fauna, mainly because the components of this fauna change through time due to the different phenology of the different groups.

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