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The effect of fire intensity on the understorey species composition of two *Pinus canariensis* reforested stands in Tenerife (Canary Islands)

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Abstract

Wildfire in the *Pinus canariensis* forest of Tenerife is of ecological significance, but has been little studied. Fire is considered an ecological catastrophe that should be prevented in Tenerife. The present study was designed to report the effects of fire intensity on understorey species composition as a means to evaluate this premise. Due to the effect of the site in the species composition, we suggest the use of multivariate analysis of the species composition under the effect of fire. These methods allow us to eliminate the sources of variability related with the site and to evaluate the fire intensity effect per se on species composition. *P. canariensis* were planted in the sites during the 1940s and 1950s for reforestation purposes, but no other management activities have been carried out in the last 30 years. The pine forest is a fire-prone ecosystem within which species have a high ability to regenerate after fire. Although the rate of fire has on the whole increased in recent years, the affected area is on an average much lower. Knowing this, our results suggest that a regular occurrence of fire as an internal process of the ecosystem, will favour and accelerate the change of the pine stands to more natural forests, as is the aim of the reforestation. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Fire; Multivariate analysis; Forest dynamics; Pine forest; Species composition

1. Introduction

Fire is an endogenous factor of communities and its occurrence may be a result of community structure and composition (White, 1979). Until the 1960s, fire was seen as a disaster to be prevented if possible (Kornas, 1958; Molinier, 1968). Leopold et al. (1963) reported the negative aspects of fire suppression in ecosystems: excessive fuel build-up, homogeneous age structure and loss of diversity. Nowadays, fire is considered a natural force in most plant communities and should be allowed to play a greater role where possible (Wright and Bailey, 1982; Perry, 1994). In Mediterranean ecosystems, fire is considered an important influence on the vegetation structure. After fire, autosuccession leads to a recovery of preburn communities (Naveh, 1975; Trabaud, 1994).

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In the Canary Islands, fires are recurrent in the pine forest, although their occurrence in the same area more than once within a 20-year period is rare (del Arco et al., 1992). There are few sites on the islands with mature stands of *Pinus canariensis* Sweet, ex Spreng forest; they are originally reforestations of 35–40 years old carried-out in potential areas of this forest (pine forest has been extensively logged in the last two centuries). The dominant tree of these reforested areas is *P. canariensis*, but there are small areas (<1% of the total) within of *Pinus radiata* D. Don and *Pinus halepensis* Mill (management plans have been developed to eradicate these species). The main objective is to reforest part of the potential natural pine forest cover of Tenerife.

Fire has been considered to be an ecological catastrophe that should be prevented in Tenerife. The present study was designed to report and reveal the effects of fire intensity on understorey species composition using multivariate analysis as a means to evaluate this premise. Appropriated tools of analysis could reveal important aspects about species dynamics with respect to fire that will help in the management reforestation programmes.

2. Material and methods

2.1. Study site

The present study was conducted in the northeast side of the Corona Forestal Natural Park (28°19′N, 16°34′W) of Tenerife, Canary Islands (Fig. 1). A big fire affected 2709 ha in June 1995 during three days. Although the fire of 1995 affected other protected areas and vegetation, we restricted our study to plantations of *P. canariensis* because it was the community most affected.

Sites of this study were planted during the 1940s and 1950s (del Arco et al., 1992), and some management activities are required for their maintenance. *P. canariensis* was extensively planted as part of a reforestation program. Ecologically, *P. canariensis* is important because it colonizes volcanic soils, maintaining soil stability on the high slopes of the island (Martínez et al., 1990). Old mature pine stands are rarely affected by intense canopy fire. The branching of the adult trees generally begins several metres above the ground, out of the reach of ground fires. Following fire, the Canary pine develops many new sprouts from the base of the stem or from dormant buds of the trunk and branches. Great numbers of pine seedlings follow a burn and find favourable conditions for establishment in the ash bed and upper soil layer where there are high concentrations of available nutrients (Höllermann, 2000). Also, *P. canariensis* has the ability to regenerate both by basal sprouts and seedlings, this capacity being related to its adaptation to different fire regimes.

We selected two sites, at windward and leeward. They maintain some differences in species composition. Due to moisture, the windward site has a more developed understorey than the leeward site. However, at both sites reforestations were made at the same time with the same species, so that the age and density of trees is similar.

The dominant shrub species in the windward site are *Erica arborea* and *Adenocarpus viscosus*, while in the leeward site they are *A. viscosus* and *Chamaecytisus proliferus*. A high number of annual and ruderal species are present at both sites, especially in the plots close to trails or affected by disturbances. All these species are considered adapted to fire.

The annual precipitation of this area of the park reaches 900 mm, but can be twice this amount if fog drip is considered (Kämmer, 1974). The mean annual temperature is approximately 15°C with minimal annual and daily fluctuations. There are no frost events in the study areas, but they are common in some of the highest points of the park. Soils of the study site have been classified in the order Entisol, suborder Orthens (Fernández-Caldas et al., 1985).

Additional information of the area and species is described by Ceballos and Ortuño (1976), Blanco et al. (1989), del Arco et al. (1992), and Fernández-Palacios (1992). Nomenclature follows the check-list of Hansen and Sunding (1985).

2.2. Sampling design

At both sites we selected areas with different fire effects: canopy fire, surface fire and control plots (not burnt). In each site (windward and leeward), we selected a different number of 100 m^2 plots: at the windward site we selected six canopy, six surface and three control plots and at the leeward site we selected

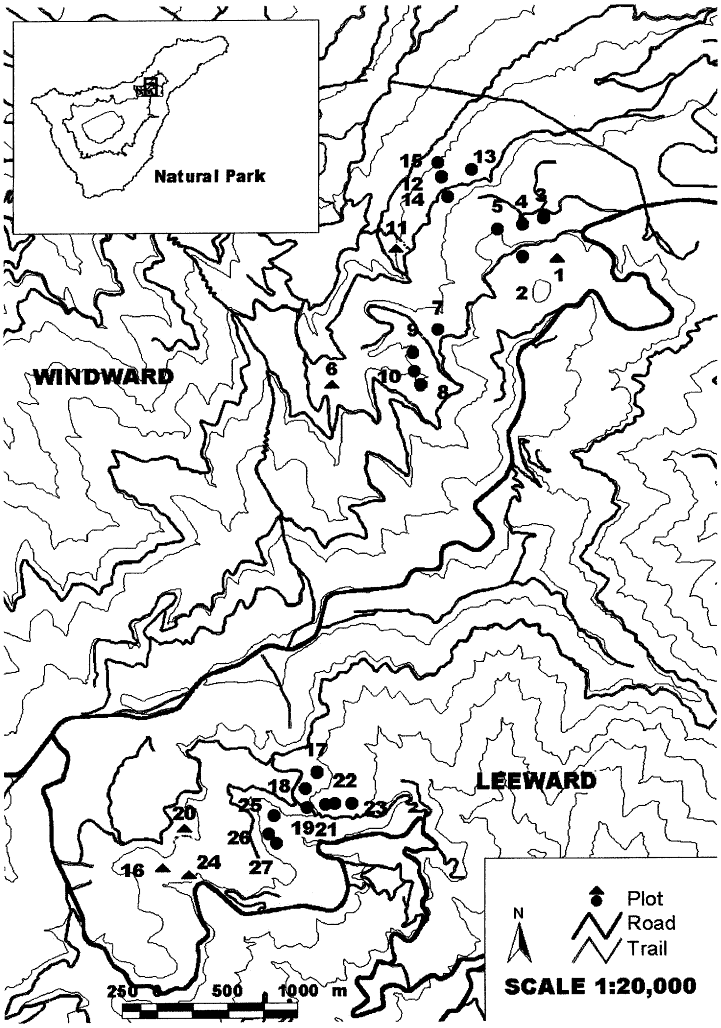

Fig. 1. Tenerife and the study area specifying leeward and windward sites. Control plots at both sites are indicated with a triangle. The area delimited by the lines in the Tenerife island map are the boundaries of the Natural Park "Corona Forestal".

three canopy, six surface and three control. We used a subjective method to choose the plots, because the irregular effect of the fire in the forest required such a method. The plots of each site are located within approximately 2 km^2.

Sampling was conducted between October 1998 and January 1999, approximately three and a half years after the fire (July 1995). The cover of all the species at surface was estimated and noted in a scale from 1 to 9. Environmental characteristics of the plots and levels for cover classes are shown in Table 1.

2.3. Statistical analysis

We used detrended correspondence analysis (DCA) (Hill and Gauch, 1980) to analyse species composition in the 27 plots studied. The purpose of this indirect analysis is to show complete variation in species composition. This helps to reveal any environmental variable not included in the sampling.

We also used canonical correspondence analysis (CCA) (ter Braak, 1986; Palmer, 1993) using the effect of the fire (canopy, surface and control) as a

Table 1
Characteristics of the plots. Diameter in cm, height and altitude in m, regeneration of *P. canariensis* in 100 m^2, stems<25 cm height, slope and canopy cover in percentage are mean values[a]

Effect of fire	Plot Nos.	*P. canariensis*			Cover (%)			Altitude	Slope	Canopy cover
		Diameter	Height	Regeneration	Litter	Rock	Soil			
Windward site										
Control	1, 6, 11	24.3	17.9	0	9	4	3	1420	80	85
Surface fire	2, 3, 7, 8, 12, 13	22.6	16.3	0.4	9	4	2	1435	70	82
Canopy fire	5, 10, 15, 4, 9, 14	22.2	15.6	1	9	4	2	1410	70	65
Leeward site										
Control	16, 20, 24	20.5	12.8	0	9	4	1	1531	100	70
Surface fire	17, 18, 21, 22, 25, 26	19.3	11.7	1.4	9	4	2	1480	95	64
Canopy fire	19, 23, 27	20.5	12.2	2	9	5	2	1485	85	60

[a] Cover classes — 1: traces, 2: >1%, 3: 1–2%, 4: 2–5%, 5: 5–10%, 6: 10–25%, 7: 25–50%, 8: 50–75%, 9: >75%.

"dummy" variable and site (windward or leeward) together with other environmental variables (rock, altitude and slope) as covariables. By testing the significance of the axes with a Monte Carlo test, we can determine if samples are distributed randomly (non-significant eigenvalue) among linear combinations of the explanatory variables (fire intensity: canopy, surface, control). If the eigenvalues of the axes are significant, we can conclude that the axes are useful for separating samples.

With this method, variation produced by the covariables will be eliminated and the analysis will be restricted to the explanatory variables remaining (ter Braak, 1988). Because we only have three "dummy" variables, only two axes will be produced by the CCA. This particular use of the CCA has been shown to be useful to test for significant effects of the variables on species compositions (Arévalo et al., 1999; Arévalo and Fernández-Palacios, 2000).

We performed all multivariate analyses with the CANOCO package (ter Braak and Šmilauer, 1998) and tested the eigenvalue of the first and second axes with a Monte Carlo test using 200 iterations of the samples.

3. Results

The fire intensity was irregular in the affected area, requiring a subjective sampling method of choosing the plots. Plots at the two sites showed some differences in altitude and slope (Table 1) and we did not consider some variables in the analysis such as canopy cover, litter or bare soil, since they can be related to fire intensity.

The DCA (Fig. 2) shows the important gradient in species composition to be differences between the windward and leeward sites. The length of axis I is 6 standard deviation units (std). Since the axis length in DCA has biological meaning (Gauch, 1982), it indicates an important change in species composition (more than three units of differences means that sites do not share any species at all). This change is more important through axis I (related to sites) than II (related to fire intensity).

The shrub layer at the windward site plots is characterized by *Myrica faya* and *E. arborea* while *C. proliferus* dominates the shrub layer at the leeward site. Common grasses and forbs at the windward site are *Brachipodium sylvaticus*, *Ranunculus cortusifolius*, *Origanum vulgaris*, *Nemostiles maculata*, while *Sonchus acaulis* and *Hypericun grandifolium* dominate at the leeward site. Species associated with fire differed between the sites. At the windward site we found *Hypericum reflexum*, *Cistus symphytifolius*, and *Gallium scabrum* to be associated with intensely burnt plots (crown fire), while *Briza maxima*, *Sideritis cretica* and *Geranium dissectum* were associated with intensely burnt plots at the leeward site. *P. canariensis* and *Sonchus oleraceus* are common at both sites, independent of fire intensity, while *A. viscosus*, *S. cretica*, and *Coniza* sp. are associated with intense burning at both sites.

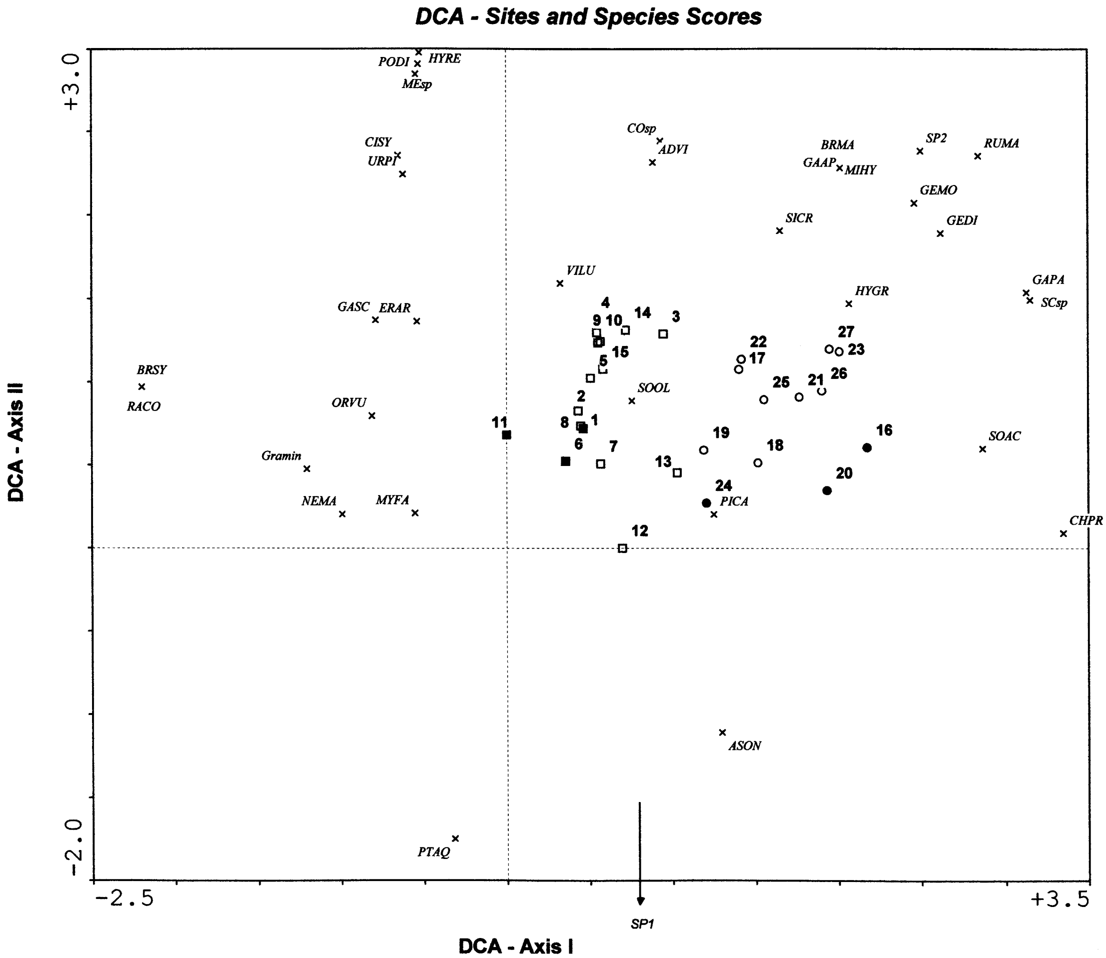

Fig. 2. Species and site scores for the first and second axes of the DCA based on cover of the species (eigenvalues were 0.349 and 0.115, respectively, and the cumulative percentage variance of species data of both axes was 33.4%). Axis I discriminated sites (leeward and windward) while axis II plots different fire intensity. Circles indicate the southern pine forest and squares the northern pine forest (indicating control plots with solid dots and squares). The third axis (not shown) did not reveal interpretable patterns for species or sites and its eigenvalue was 0.060. Species abbreviations: ADVI, *A. viscosus*; ASON, *Asplenium onopteris*; BRMA, *B. maxima*; BRSY, *Brachypodium sylvaticum*; CISY, *C. symphytifolius*; COsp., *Coniza* sp.; CHPR, *C. proliferus*; ERAR, *E. arborea*; GAAP, *G. aparine*; GAPA, *Galium parisine*; GASC, *G. scabrum*; GEDI, *Geranium disectum*; GEMO, *Geranium molle*; *Gramin*, Gramin; HYGR, *Hypericum grandifolium*; HYRE, *H. reflexum*; Mesp., *Medicago* sp.; MIHY, *Micromeria hypssopifolia*; NEMA, *N. maculata*; *MYFA*, *M. faya*; ORVU, *O. vulgaris*; PICA, *P. canariensis*; PTAQ, *Pteridium aquilinum*; PODI, *Polycarpaea divaricata*; RACO, *R. cortusifolius*; RUMA, *R. mauritanica*; SCsp., *Scorpiurus* sp.; SICR, *S. cretica*; SOAC, *S. acaulis*; SOOL, *S. oleraceus*; SP1, SP1; SP2, SP2 (unidentified species); URPI, *Urospermum picroides*; VILU, *Vicia lutea*.

The first gradient indicated in the DCA showed a strong effect of site on the species composition of the plots. We carried out a CCA with the covariables altitude, rock cover and forest type (windward or leeward), and with the dummy variables control, surface fire (moderately affected) and canopy fire (intensely affected). In this way, we restricted our analysis to the residual variance once we eliminated the variance of variables related to the site as it is demonstrated to be the main source of variability. The results of the CCA are shown in Fig. 3. The first axis separated control and crown fire plots,

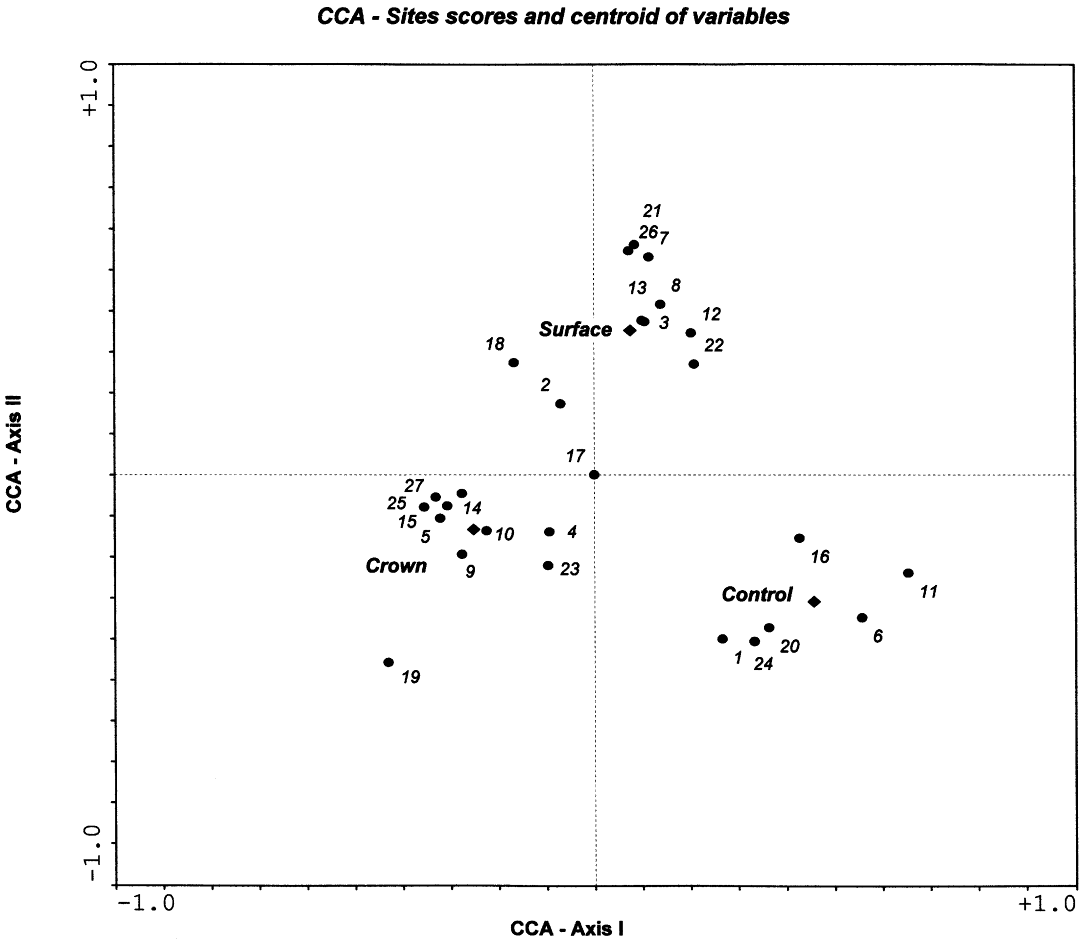

Fig. 3. CCA axes I and II of the plots and the environmental variables. Centroid of environmental variables is shown instead of the typical arrow because of the nominal character of the variables. Symbols follow the same nomenclature as in Fig. 2.

while the second axis separated surface fire plots. Species scores of this CCA are shown in Fig. 4. Results are similar to those from DCA, but when site variables are factored out, the three understorey plot types separate nicely (Figs. 3 and 4, Table 2). *Brachipodium sylvaticum*, *R. cortusifolius*, *N. maculata* and *Galium scabrum* are species associated with control plots, while *Rumex mauritanica*, *Gemostiles maculata*, *H. reflexum*, *C. symphytifolius* and *Medicago* sp. are more associated with crown fire plots. In the surface fire plots, *S. acaulis*, *G. dissectum*, *B. maxima*, *Galium aparine*, *Sonchus* sp. and *Coniza* sp. are the most common species encountered.

4. Discussion

In our study, multivariate analysis revealed some statistically significant patterns of species composition. There is an important effect of the pre-fire species composition in the regeneration of the burnt areas. The effect of the site in the regeneration of communities after fire has been reported in different ecosystems (Johnson and Strang, 1982; Trabaud, 1994). It can be considered a general pattern and this source of variability should be eliminated when studying the effect of fire on the species composition of different sites. Fire effects are difficult to generalize because the biotic and abiotic interactions that influence post-fire effects

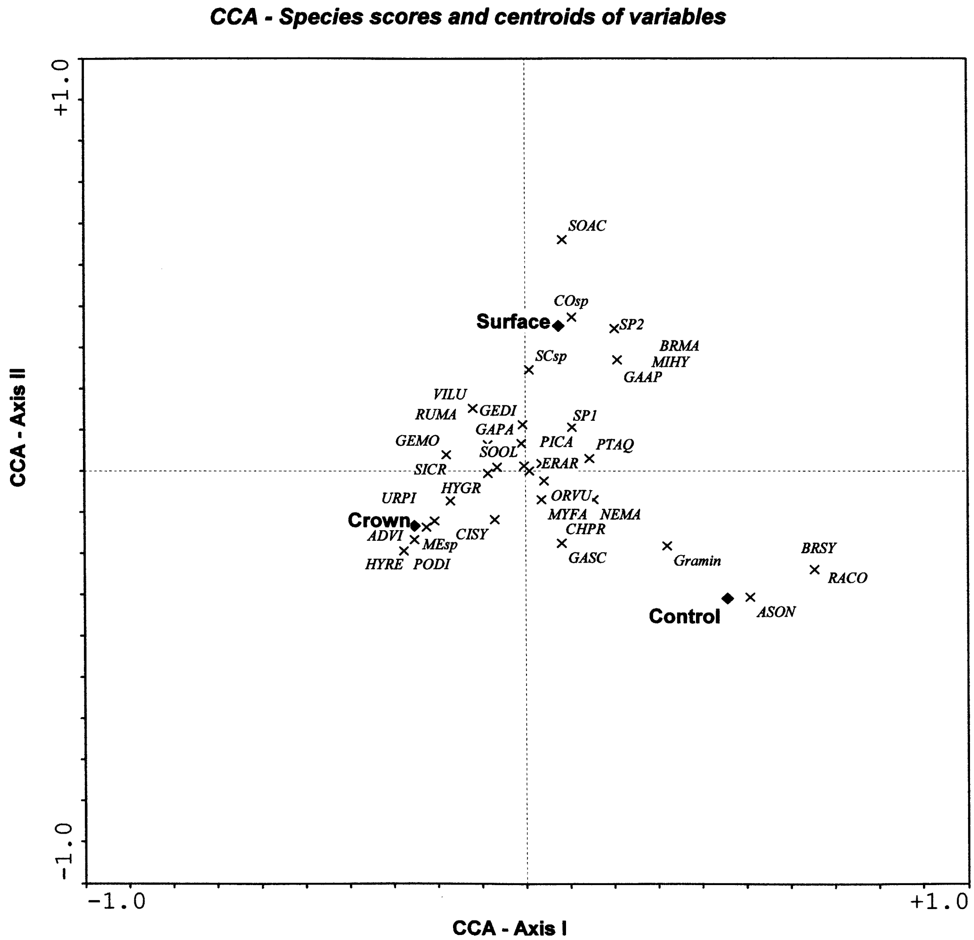

Fig. 4. CCA axes I and II of the species and environmental variables. Species are significatively discriminated by axes I and II of CCA following a gradient from control to canopy fire, indicating the occurrence of a dynamic processes. Species close to the coordinate centre cannot be related with fire intensity.

are complex and not fully understood (Pyne et al., 1997). Studies of the effect of the fire on the understorey communities are not very common because of the high dependence of the species composition on other parameters such as those mentioned above. Multivariate methods can be very useful tools because they can isolate fire effects and extract more general patterns.

Three years post-fire, the species composition of the communities affected by the fire in 1995 can be considered site and fire intensity specific, with site playing a more important role. Both, canopy fires and surface fires increased the number of ruderal species relative to control plots. Establishment of ruderal species may primarily be due to canopy opening as these species are very abundant along the edges of roads and trails. After a process of canopy recovery, the results suggest a decrease in the abundance of ruderal species, mainly annuals. The dynamic processes will not result in important changes in species richness and a "turnover" should be expected from species more ruderal to more specific species of the pine forest in just a few years, showing an autosuccession of the sites.

Fire should be considered an endogenous disturbance enhancing the pine forest community. It has been suggested that in communities where species are adapted to fire, the fire should have a return time of 20

Table 2
CCA eigenvalues and results of Monte Carlo test (weighted correlation indices of fire intensity variables with respect to axes I and II)

	Axis I	Axis II
Eigenvalue	0.09	0.05
Cumulative % variance of species data	10.1	15.4
Monte Carlo test		
F-ratio	2.14	1.27
p-value	0.01	0.44
Weighted correlation matrix[a]		
Control	0.71	−0.4
Surface fire	0.18	0.71
Crown fire	−0.76	−0.34

[a] Correlations are adjusted for the covariables, i.e. they are partial correlations (Kendall and Stuart, 1973).

years or less (DeBano et al., 1998). In the last 50 years, a total of 20 000 ha of pine forest has been affected by fire. Because the total extension of pine forest in Tenerife is >40 000 ha (del Arco et al., 1992), the rate of fire could be considered lower than that expected in an ecosystem with a high adaptation to fire.

No significant increase or decrease in pine mortality was found in the burnt plots (surface or canopy fire); however, a higher germination rate of *P. canariensis* was found in the plots intensively affected by the fire.

The main management goal of the pine reforestation on Tenerife is to create natural forest communities and to restore self-maintaining processes at the same time. However, the low number of fires in some areas of the pine forest of Tenerife has slowed the naturalization of these restorations. Human activities have increased the rate of fire but only locally, and fires nowadays affect less of the pine forest (Höllermann, 2000). Since the reforested areas have coetaneous trees, the low extent of the fires will not allow a patchy community, and succession to a more natural ecosystem will be slowed. The low rate of fires in the area in the recent years (Höllermann, 2000) is having negative effects, creating a system that requires more management as processes responsible for maintaining the ecosystem integrity are impeded (Gilliam and Platt, 1999). Dense forest canopy minimizes the light reaching the forest floor, thus reducing the herbaceous plant communities (Master, 1991; Wilson et al., 1995). Also, wildfire may become more intense if fire is suppressed for long period of time, increasing the danger for this overpopulated island ($400\,\mathrm{km}^{-2}$), mainly concentrated on the coast.

This is the first quantitative study about the effect of fire in the understorey community of the pine forest of Tenerife. In order to understand the dynamics of the pine forest with respect to fire more completely, we realize the necessity of a long-term study with the establishment of representative permanent plots (van der Maarel, 1993). However, knowing that disturbances accelerate succession and dynamics of ecosystems (Lorimer, 1980; Abrams and Scott, 1989; DeCoster, 1996), we suggest that a regular occurrence of fire (<20 years), as an internal process of the ecosystem, will favour and accelerate the evolution of the pine forest to a more natural system as is the purpose of the restoration. We recommend that designated fire control services concentrated their technical and human resources on protecting properties and utilities rather than these reforested areas of pine forest unburnt in the last 20 years.

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