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Technical Note

Prescribed Burning Effect on the Richness, Diversity and Forest Structure of an Endemic Reforested *Pinus canariensis* Stand (Canary Islands)

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Abstract: Forest fires are considered to play a fundamental role in structuring many forest plant communities. Prescribed burning is a useful tool to reduce fire risk by reducing the amount of fuel. Our main objective was to analyse the effects of prescribed burning on undergrowth species richness and diversity as well as on other characteristic variables in a reforested *Pinus canariensis* stand. In areas where prescribed burning had been performed in the last 10 years, we established 8 plots of 900 m^2. Their respective control plots were in nearby unburned and environmentally similar areas. We systematically selected 10 points in each plot and sampled the presence, richness and diversity of species in 1 m^2 grids. For each plot, the basal area, mean canopy height and average height of individuals were measured. In centred 10 × 10 m plots, shrub species were counted as well as the litter depth, litter cover and herb cover. There was no significant change in the number of species richness found when comparing burned vs. control plots. Additionally, we did not find any differences in diversity or shrub composition, nor were we able to determine the species associated with any of the treatments. The basal area and litter depth were the only parameters that revealed significant differences. Ecologically, prescribed fire is a good practice to reduce biomass accumulation in *P. canariensis* plantations, with little effect on species richness and forest structure but with positive effects for stand management, insofar as biomass reduction can help control summer wildfires.

Keywords: fire; fuel-load management; pine forest; reforestation; vegetation dynamics

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1. Introduction

From the early 20th century, fire was viewed as a disaster that needed to be prevented as much as possible [1,2]. Nowadays, this perception has changed and fire is recognised as a driver of ecosystem dynamics [3] following Leopold et al.'s [4] identification of the negative consequences of fire suppression. Today, fire is considered to be a natural driver in most plant communities and should be allowed to play a more significant role whenever possible [5,6]. In Mediterranean ecosystems, fire is considered to be an influential factor in vegetation structure [7,8].

In the pine forests of the Canary Islands, fires tend to occur with a certain frequency and it is uncommon for the same area to burn in fewer than 20 years [9]. The impact of fire is neither long-lasting nor detrimental to the natural ecological process (as regeneration, maintenance of species richness or species composition), according to a 15-year study in the Canary Islands [10].

Fire has long been a subject of debate due to the contradiction between its controlled use and the threat to life when uncontrolled. One of the most disturbing elements is fire suppression applied specifically to non-commercial protected forest areas. The paradox is that “natural” fires burn a small number of hectares per year; on the contrary, with current fire management, fires are attempted to be controlled when possible. This results in catastrophic forest fires of more than 1000 hectares occurring after 10–15 years, endangering properties and the local population [11,12]. This has also been observed, although to a lesser extent, in the case of the Canary Islands [13].

In Mediterranean countries, pine forests are managed by pruning shrub understory species before prescribed burning, eliminating fuel continuity in the canopy [14]. Burning without clear-cutting is not possible due to the danger of a canopy fire under the current fuel model. Cutting reduces understory cover and the abundance of vertical fuel ladders. However, debris in the field after the slash treatment leads to high fuel loads and light availability at the soil surface is reduced, which may also affect species composition.

Our objective was to analyse the effects of prescribed fire treatments on the forest structure, species diversity and evenness index. The hypotheses tested were that burning would have different effects on species richness and that different species would be identified as descriptors of each treatment (control vs. burned). In addition, the impact of prescribed burning on the forest structure and environmental characteristics of the plots, such as litter cover, shrub cover and litter depth, would be revealed.

For the proper management of restored pine forest areas, it is crucial to use correct analysis tools that reveal the dynamics of species in prescribed burning situations. In addition, few studies have analysed the medium–long-term impact of prescribed burning on species composition or plant species richness.

2. Materials and Methods

2.1. Study Site

Our study areas were located in the pine forests of Gáldar, Artenara, Valleseco and Mora on Gran Canaria Island, Canary Islands, Spain. These plots are included in the Protected Landscape of Las Cumbres [15], between 1400–1600 m a.s.l., and were within environmental conditions of 17.7 °C temperature, 52.2% humidity and 500 mm annual precipitation for the period 2006 to 2008. *Pinus canariensis* is the predominant tree species, accompanied by an understory of species such as *Chamaecytisus proliferus*, *Teline microphylla* and *Micromeria benthami*. In the area, there are also other exotic pine species from plantations such as *Pinus halepensis* or *Pinus radiata*.

The potential vegetation in the area is Canarian pine forest. However, logging and deforestation has occurred in the past. These have affected the studied area and these forest stands have been reforested or the density of pine has been increased through plantation since the 1960s. At the present time, these reforestation programs can be considered successful, as long as the area of pine forest is extended.

2.2. Design of the Experiment

We established 8 plots of 900 m^2 in areas where prescribed burns had been conducted within the last 10 years (see Figure 1). One month before burning, we cleared all woody material in the understory as well as the basal branches of the pines, except in the control plots. This dead biomass was left on the ground to ensure even combustion within the plot and flame heights of less than 1.5 m [16]. Fires were conducted in strips at temperatures ranging from 18 to 26 °C, with humidity between 30 and 70% and wind gusts below 15 km/h. This burning method promotes ignition, generating parallel and backward fire lines. The fire line was established on the downwind side of the fuel and the fire moved slowly upwind. Under these conditions, prescribed burning is considered to have a low to medium intensity, affecting the stand understory and occasionally reaching the canopy.

The control plots were established in the same environmental conditions, close to the burned plots but in unburned areas. One of the main objectives of this study was to analyse the impact of prescribed burning whilst avoiding the effect of environmental variability.

These unburned plots had not been affected by prescribed burning or wildfire for more than 20 years prior to the prescribed burning in the affected plots (Table 1).

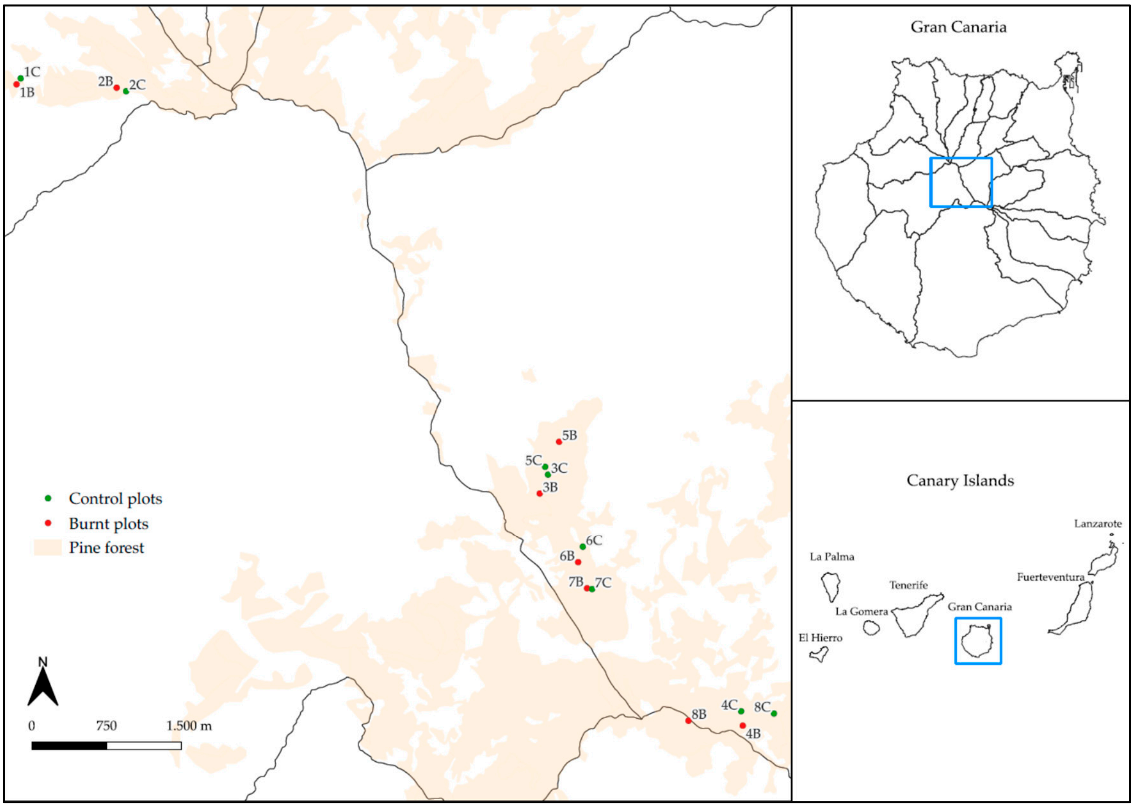

Figure 1. The Canary Islands archipelago, Gran Canaria Island and plot location (red for burned (B) plots and green for control (C) plots). The distribution of the pine forest is in shadow.

Table 1. Site description, cover type and years from the last prescribed burning.

	Altitude	Slope	Aspect	Rock	Litter	Herbs	Litter Depth	
Plot	(m)	(°Sex.)			(% Cover)		(cm)	Years
1B	1449	5	N	5	16.8	53.8	1.0	9
1C	1453	5	N	5	25.3	56.0	5.4	
2B	1480	30	S	4	86.5	1.0	3.4	9
2C	1480	30	S	0	74.7	9.3	6.6	
3B	1580	10	N	10	91.9	1.9	4.2	9
3C	1712	12	N	10	86.6	2.4	5.3	
4B	1750	12	N	30	79.6	0.6	1.7	4
4C	1800	14	N	8	74.6	8.5	4.1	
5B	1615	13	N	0	32.0	61.0	2.3	3
5C	1686	20	N	0	86.7	7.0	7.7	
6B	1750	5	N	25	86.4	2.6	2.6	5
6C	1739	5	N	0	93.2	0.5	5.9	
7B	1793	10	S	1	69.8	1.3	1.1	2
7C	1770	9	S	2	66.8	1.0	5.4	
8B	1888	8	N	10	22.8	62.3	2.1	6
8C	1934	8	N	18	61.8	10.5	4.6	

For these plots, the trees were sampled (>2.5 cm diameter breast height (DBH)) and for each individual, the diameter, height and height of the first green branch over 2.5 cm in diameter were recorded.

In each of the burned and control plots, 10 subplots of 1 m^2 were established in which all the plant species present were recorded in addition to the percentages of soil, rock, leaf litter cover, altitude, aspect and slope. This information is included in Table 1 (the last prescribed burning of the sample area was also included).

Plots of 10 × 10 m were established in the centre of the plot to determine the shrub species composition (less than 2.5 cm diameter and over 0.5 m high) and density. We divided these plots into 1 square meter subplots and estimated the herb cover, litter cover and measured litter depth to estimate the average value for the whole plot.

2.3. Statistical Analyses

We assessed the factor effect (control vs. burning) of the species richness and Smith and Wilson evenness (E) [17], with the main factor as the fixed effect (burned vs. control) and the pairs of plots as the random factor, according to the GLM procedure. Data homoscedasticity was checked with the Bartlett test (for a $p < 0.05$).

$$E = 1 - \frac{2}{\pi arctan\left\{ \frac{\sum_{i=1}^{s} \left(ln\ n_i - \frac{\sum_{j=1}^{s} ln\ n_i}{S} \right)^2}{S} \right\}}$$

where n_i is the number of individuals in species i, n_j is the number of individuals in species j and S is the total species number.

To detect the differences in species composition between the control and burned plots based on a matrix of the species cover, we applied a multi-response permutation procedure (MRPP) using the Bray–Curtis distance [18]. This non-parametric method was appropriate to detect the significant differences among the defined groups based on the species presence and cover. To determine the significant representative species in each group from the same data matrix, we used an indicator species index (ISI) [19]. This non-parametric procedure determined the species preference for specified groups of plots through random analyses. The statistical analyses were performed using the Vegan R Package [20].

We compared the basal area, density and first green branch height using the same GLM procedure, with these variables as factors and pairs of plots as a random factor. We followed the same procedure for the average values of the herbs, litter cover and litter depth.

3. Results

A total of 26 species were recorded (Appendix A). A few of these species, such as *Argyranthemum adauctum*, *Ferula linkii* or *Pteridium aquilinum*, were only found in the prescribed burn plots. In contrast, other species only appeared in the control plots, with *Asphodelus ramosus* being the most frequent. However, when we compared the understory species richness (using a GLM analysis with the treatment as the main factor and the pair of plots as the random factor), the analysis revealed no significant differences (Z = 0.44, n = 8, with mean values and standard deviation for the control = 4.07 ± 1.04 SD; burn = 4.20 ± 1.48 SD). The Wilson and Smith evenness index indicated no significant differences (Z = 0.86, n = 8; control = 0.13 ± 0.05 SD and burned = 0.15 ± 0.06 SD) between the burned and control plots (only for those plot pairs with more than one species).

The MRPP results revealed a T = −0.6684 and a group probability correction of A = 0.0128 (p = n.s.). The ISI base in 1000 permutations indicated that only 1 species was revealed to be an indicator for burned plots: *Argyranthemum adauctum* ($p < 0.05$). For the rest of the species, the differences were considered to be non-significant.

For several of the stand structure parameters, differences were found in the case of the basal area (Z = −2.1, n = 8, $p < 0.05$) whereas they were non-significant for the height of the first green branch and height of the trees (Z = −1.12, n = 8, p = n.s. and Z = −1.4, n = 8, p = n.s., respectively; Figure 2).

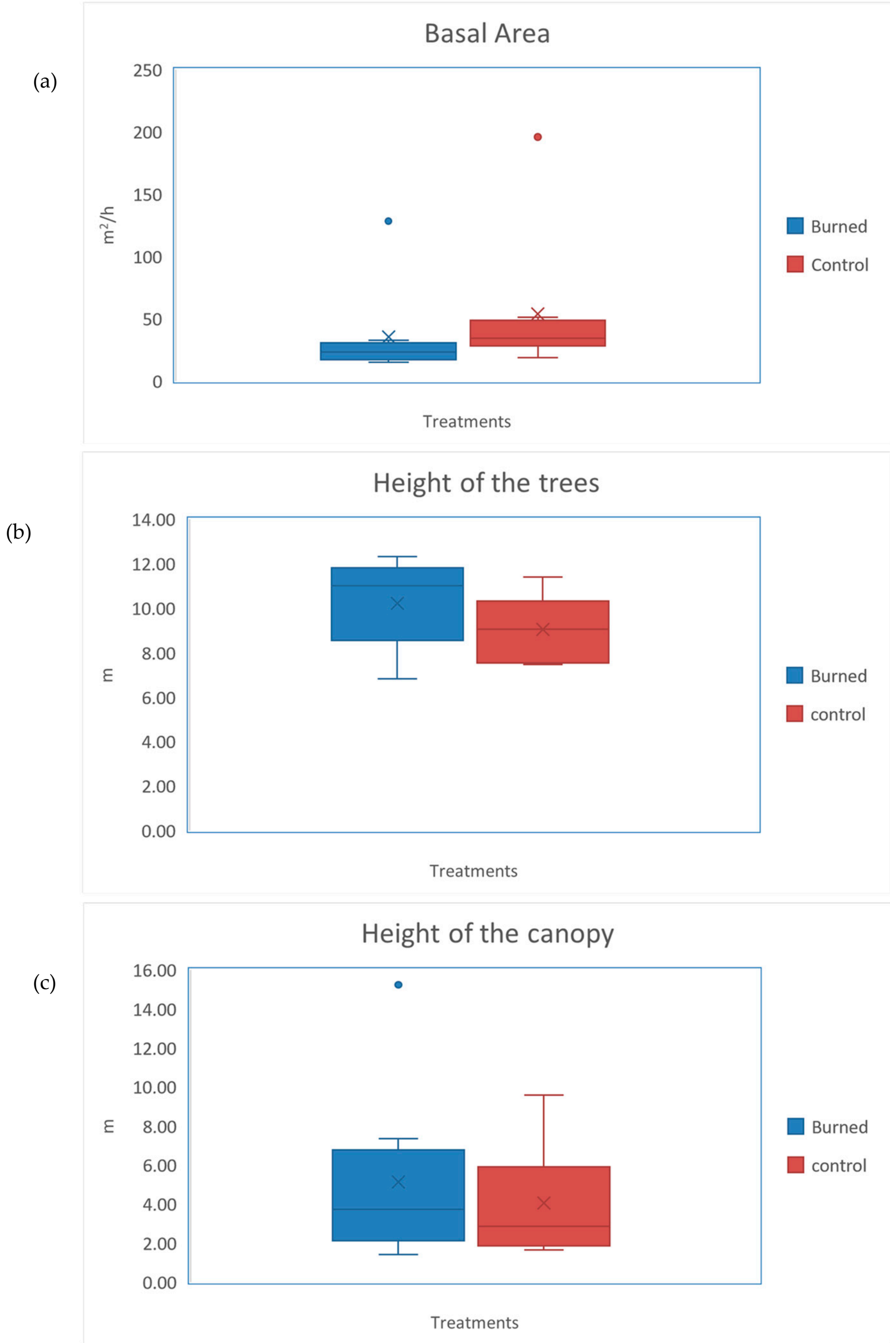

Figure 2. (**a**) Box plots of basal area values for the 8 plots of the burned and control treatments; (**b**) average height of the trees; (**c**) canopy height.

At the shrub level, four species were found; namely, *Adenocarpus foliolosus*, *Chamaecytisus proliferus*, *Pinus canariensis* and *Teline canariensis*. Only *C. proliferus* was present in several plots, not revealing any pattern of distribution with respect to the prescribed burning. In the case of *T. canariensis*, it was only found in two of the burned plots. These forests are relatively poor in shrub species; therefore, these results could not have been related to the treatment.

Non-significant differences were found for herb cover or litter cover on these plots ($Z = -0.280$ and $Z = -0.840$, respectively, and p = n.s.), but the results were significant for litter depth, with higher values in the control plots ($Z = -2.51$ for $p < 0.01$; control = 71.2 ± 21.3 SD; burned = 60.71 ± 31.4 SD).

4. Discussion

Since the 1930s, various restoration programs have resulted in 15,103 hectares of Canary Island pine plantations, which require management tools such as prescribed burns for fire prevention and to achieve a more natural state [21,22]. The low-intensity effect of prescribed burning (understory fire, generally avoiding reaching the canopy) has no significant impact on species richness, evenness or other stand parameters, as confirmed by these results. The absence of differences in species richness or evenness between plot groups was due to the recovery time of the plots, which is faster when the prescribed burning is of low–medium intensity, as explained in the Section 2.

Numerous studies suggest a general trend of increasing species richness and diversity with prescribed fire [23,24] and rapid recovery after low to moderate-intensity fire [25]. The increase in richness occurs mainly during the first to second year after the fire and is more noticeable in annual and herbaceous species [24], related to the canopy opening and higher light availability at the soil surface after a fire [26].

The increase in richness after a fire is primarily due to the germination of pioneer species [27] and even intense fires in *Pinus canariensis* stands have revealed no significant impact on species richness 2–10 years later [28]. Rapid recovery means the impact on species richness is not significant and the same is true for evenness. *Teline canariensis*, a highly adapted leguminous plant, only appeared in the burned plots, but its presence was not universal in all plots. In our study, the plant community could not be distinguished in the burned vs. control plots, as evident in other studies [23,28], suggesting that the impact of prescribed burning should be considered at a more intense level. The only statistically significant indicator species found was *Argyranthemum adauctum*, a species associated with pine forests and whose abundance has been linked to the frequency of fires. As a pyrophytic species, fire can help increase its abundance along the affected area [23].

For the forest structure, we observed significant differences in the basal area, with higher values in the control plots. However, these were general results as even low-intensity prescribed burns can cause intense defoliation [29,30]. The recovery of these leaves can reduce the growth ability of trees for several years as more energy is used to recover the photosynthetic tissues. Studies have shown that growth is more sensitive than photosynthesis in moderate shortages of essential macronutrients [31].

Litter is one of the parameters affected by fires and we found significant differences. However, these differences did not discriminate between the richness or species indicators, except for *Argyranthemum adauctum*, which appeared more frequently in the burned plots. This species is an asteracea, highly adapted to fire and more common in drier areas of the pine forest [32]. Apparently, low-intensity fires can have a positive impact on its distribution.

Ferula linkii was found only in the burned plots, but its presence may have been related to the increase in incident solar radiation in the understory rather than the fire. This plant has a wide distribution on the island and is not exclusively linked to pine forest environments, occurring in a high number of ecosystems, both natural and anthropised [33,34], as long as there is a high contribution of light. A similar situation occurs with the fern *Pteridum aquilinum*. A greater contribution of light due to forest felling as well as the effect of intense forest fires or at a certain time of the year gives ferns a competitive advantage [35]. More in-depth studies on the effect of fires on this species in the Canary Islands would be interesting. However, none of these results were statistically significant based on the ISI analyses.

5. Conclusions

Prescribed fire can be a useful and cost-effective forest management practice to reduce understory and litter fuel, as supported by ecological research [36,37]. Its overall impact cannot be considered to be negative and it is a valuable tool for managing fire-prone ecosystems [38–40]. Several years after the application of prescribed burning, ecological data revealed no significant differences between control and burned plots and only slight differences in parameters such as the basal area or litter depth after more than five years.

As fuel reduction is crucial for effective wildfire management, we recommend extending the use of prescribed burning, provided that safety and control measures are in place.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. List of species indicating family, life form and origin (sampled in the 1 × 1 m plots).

Species	Family [41]	Life form [42]	Origin * [42]
Adenocarpus foliolosus (Aiton) DC.	*Fabaceae*	Phanerophyte	NS*
Allium sp.	*Amaryllidaceae*	Bulb geophyte	
Argyranthemum adauctum (Link) Humphries	*Asteraceae*	Chamaephyte	NS*
Asphodelus ramosus L.	*Xanthorrhoeaceae*	Bulb geophyte	NP
Avena sp.	*Poaceae*	Therophyte	
Carduus tenuiflorus Curtis	*Asteraceae*	Therophyte	NP
Convulvulus canariensis L.	*Convolvulaceae*	Epiphyte	NS
Erysimum virescens (Webb *ex* Christ) Wettst.	*Brassicaceae*	Nanophanerophyte	NS*
Ferula linkii Webb	*Apiaceae*	Bulb geophyte	NS*
Galium aparine L.	*Rubiaceae*	Therophyte	NP
Geranium dissectum L.	*Geraniaceae*	Therophyte	NP
Geranium molle L.	*Geraniaceae*	Therophyte	NP
Hirschfeldia incana (L.) Lagr.-Foss.	*Brassicaceae*	Hemicryptophyte	NP
Hordeum murinum L.	*Poaceae*	Therophyte	NP
Hypericum grandifolium Choisy	*Clusiaceae*	Phanerophyte	NS
Juncus acutus L.	*Juncaceae*	Chamaephyte	NP
Lavandula canariensis Mill. subsp. *canariae* Upson & S. Andrews	*Lamiaceae*	Nanophanerophyte	NS*
Marrubium vulgare L.	*Lamiaceae*	Nanophanerophyte	ISN
Micromeria canariensis (P. Pérez) Puppo	*Lamiaceae*	Chamaephyte	NS*
Pteridium aquilinum (L.) Kuhn in Von der Decken	*Dennstaedtiaceae*	Rhizome geophyte	NP
Ranunculus cortusifolius Willd.	*Ranunculaceae*	Hemicryptophyte	NS
Sideritis dasygnaphala (Webb & Berthel.) Clos *emend.* Svent.	*Lamiaceae*	Nanophanerophyte	NS*
Silene vulgaris (Moench) Garcke	*Lamiaceae*	Therophyte	NP
Sonchus acaulis Dum. Cours.	*Asteraceae*	Hemicryptophyte	NS*
Trifolium sp.	*Fabaceae*	Therophyte	
Vicia lutea L.	*Fabaceae*	Therophyte	NP

* Origin: ISN: introduced, surely non-invasive; NP: native, probably; NS: native, surely; NS*: endemic.

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