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Effects of light/darkness, thermal shocks and inhibitory components on germination of *Pinus canariensis, Pinus halepensis* and *Pinus pinea*

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Abstract Knowledge of the germination characteristics of *Pinus* species can help in the understanding, prediction and management of the regeneration of pine forests. In the Canary Islands, several exotic pines (*Pinus halepensis L.* and *Pinus pinea L.*) were planted with *Pinus canariensis* Chr. Sm. Ex DC, the only native pine species, and there is now an interest in controlling these exotic species to restore the original forest. The main objective of the present study is to determine the germination response of *P. canariensis, P. halepensis* and *P. pinea* to different light regimes (darkness and light/darkness), thermal shocks and the presence of inhibitory substances from the leaves and litter of *P. canariensis. P. halepensis* seeds showed the highest viability and germination rate. Darkness accelerated *P. halepensis* germination, while exudates accelerated *P. canariensis* germination. Only treatments of 200 °C for 5 min and 300 °C for 5 min significantly decreased the germination of all three pine species. In the absence of strong differences in germination among species after treatments, the key for fire management or prescribed burning in this case may be the sprouting ability of *P. canariensis*. A possible management strategy to control the two obligate seeder exotic species could be to use one intense prescribed fire followed by a low-intensity prescribed fire after seed bank germination in the field, so in this way, only *P. canariensis* could resprout after fire and it would eliminate only the exotic pines in a mixed stand.

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Introduction

Post-fire regeneration is a complex and widely studied process that depends upon the survival of individuals from the direct effects of fire and tolerance of the changed post-fire conditions (Whelan 1995). Fire intensity is one of the most important factors influencing post-fire regeneration (Malanson 1984) and is characterized by two factors: exposure time and the temperature attained (Nuñez and Calvo 2000). Vegetation communities use two main strategies to recover after fire: vegetative reproduction and sexual reproduction (Nuñez and Calvo 2000). In general, species that resprouting from fire-resistant structures are more resilient and show greatest speed of regeneration than non-sprouting species (Lloret 1998; Vallejo and Alloza 1998; Calvo et al. 2002). In the case of the obligate seeders, many Mediterranean species need to be exposed to high temperatures in order to germinate (Trabaud 1995). Most Mediterranean conifers are obligate seeders (Escudero et al. 1997); however, on many experimental laboratory germination test, pine seeds have shown not significant stimulation by high temperatures (Tárrega et al. 1992; Martinez-Sanchez et al. 1995; Escudero et al. 1999). There were other factors that affect their regeneration in the field like post-fire conditions, such as seed rain, an increase in

available nutrients and reduced competition (Whelan 1995). So, fire is required by some species to maintain their position in the ecosystem, as is the case for *Pinus ponderosa* Dougl. ex. Laws (Cooper 1961) or *Pinus halepensis* L. (Trabaud 1989), among others. However, fire is not a constant phenomenon, and each species is adapted to a specific fire regime that may not be suitable for another fire-adapted species (Whelan 1995).

Among the Mediterranean conifers, *Pinus canariensis* Chr. Sm. Ex DC is very resistant to fire and not only germinated after fire but it is the only conifer species that can resprout from trunk and branches (Climent et al. 2004) even after 100 % of the canopy has been burnt, whereas in other Mediterranean pine species such as *P. halepensis*, *Pinus pinaster* and *Pinus pinea* L., their regeneration depends exclusively upon their seeds (Skordilis and Thanos 1997; Alvarez et al. 2005, 2007).

One of the factors that probably influence *Pinus* seed germination is the temperature to which seeds were subjected during a fire. Thermal shock produces an alteration in the embryo and so influences germination. However, larger seeds resist high temperatures better (Escudero et al. 2000; Reyes and Casal 2001). Alvarez et al. (2007) have demonstrated that *Pinus* with larger seeds (e.g. *P. pinaster* in comparison with *P. halepensis* and *Pinus sylvestris*) have a higher probability of survival at high temperatures. In this sense, some authors (Escudero et al. 2000; Climent et al. 2004) have shown that *P. canariensis* seeds resist heat better than the small seeds of other pine species.

On the other hand, as occurs in other Mediterranean species, germination can also be limited by the presence of chemical substances that act as inhibitors (Gallet and Pellissier 1997; Weir et al. 2004). Thus, leaf exudates from different species that are characteristic of the Mediterranean environment have an inhibitory effect on the germination of their own seeds (Peñuelas and Llusiá 1998) or in the undergrowth of mature forests (Fernández de Simón et al. 2001). Substances such as phenolic compounds (Gallet and Pellissier 1997), which can act as germination inhibitors, are also produced in the acicular decomposition process.

Differences in the germination behaviour after fires to which these species are adapted could be a key factor for eliminating the exotic species by fire management. In addition, knowledge of the germination characteristics of each species can help in the understanding, prediction and manipulation of the regeneration of the pine forest (Escudero et al. 2002). The main objective of the present study is to determine the effect of light/darkness, humus and leaf exudates of *P. canariensis*, the native and dominant species of the forest, and thermal shock on the germination of the three pine species (*P. canariensis*, *P. halepensis* and *P. pinea*), in order to suggest possible management approaches.

The Canarian pine forest was heavily disturbed as a result of intense logging following the European colonization of the Canary Islands in 1496 (Parsons 1981; del Arco et al. 1992). Large areas of potential *P. canariensis* forest in Tenerife, the largest of the seven Canary Islands, were reforested during the last century with *P. canariensis* and other exotic pine species (mostly *P. halepensis* and *P. pinea* L.) (del Arco et al. 1992). The recent policy of restoring native pine forest has led to a desire to eliminate these exotic pines from the Canarian pine forest. *P. halepensis* and *P. pinea* are two of the planted species that are scattered within many areas dominated by *P. canariensis*. *P. halepensis* produces a high number of cones, but it is not regenerating very well in the field (personal observation). Also, spreading has been found in previous studies to be very limited for *P. radiata* and *P. pinea* (Arévalo and Fernández-Palacios 2005, Arévalo et al. 2005). As occurs in other Mediterranean *Pinus* species (Fernández et al. 2008; Peñuelas and Llusià 1998), natural regeneration of these species could be affected by the production of allelopathic substances of the litter layer of *P. canariensis*. On the other hand, *P. pinea* has large seeds that could be attractive to and mainly dispersed by birds or other animals, so increasing its invasiveness.

So, the knowledge of the behaviour of the germination after fire of *Pinus* species that appear at the same forest would be one of the basic analyses to define an adequate management strategy of restoring native pine forest and control the alien species.

The main hypothesis of this work is that seeds of *P. canariensis* resist a wide range of temperatures because in its distribution area (Canary Islands), fire may undoubtedly be considered the principal long-term perturbation influencing the main traits that allow the species to regenerate easily after fires (Climent et al. 2004). The greater seed size of *P. canariensis* and *P. pinea* in relation to *P. halepensis* (García-Fayos et al. 2001) could favour their resistance to high temperatures. Exudates from the leaves and humus of *P. canariensis,* as dominant species in the community, could negatively affect the germination of the other two alien *Pinus* species. Seed germination of the two alien species could be negatively affected by the reduction in the incident light beneath the litter on the understory of the *P. canariensis* forest.

Materials and methods

Pinus halepensis and *P. canariensis* seeds were harvested during summer 2007 in Gran Canaria, Canary Islands. *P. pinea* seeds were obtained from the Centre for Forestry Improvement 'El Serranillo' (General Office for Nature Conservation, Ministry of the Environment) with the origin

from Spain and harvested in 2008. The seeds were stored in opaque paper bags at a constant temperature of 20 °C until the experiment.

In order to study the effects of darkness, simulating the reduction in incident light under litter in the understory of the forest, thermal shocks simulating the effects of fire and inhibitory components on germination, well-established methods were applied (Tárrega et al. 1992; Martinez-Sanchez et al. 1995; Escudero et al. 1999). A total of 100 seeds per treatment were placed on Petri dishes. There were 4 replicates of 25 seeds for each treatment.

Experimental design

Seeds were subjected to the following experimental treatments in 2009: (1) darkness: the Petri dishes were completely covered with 'aluminium paper' so that no light could enter and were watered with demineralized water; (2) effect of leaf exudates: the seeds of each species were watered with an aqueous extract obtained by macerating *P. canariensis* leaves for 48 h. The same treatment was repeated using macerated *P. canariensis* humus; (3) thermal shocks: the seeds were exposed to high temperatures for short periods of time to simulate the effects of fire under natural conditions (Nuñez and Calvo 2000; Escudero et al. 2002; Herrero et al. 2007). We carried out the following combinations of temperature and exposure time using a dry air oven: 60, 100, 150, 200 and 300 °C, for two exposure times: 1 and 5 min. We selected these combinations of temperature and exposure time according to Trabaud (1979), who indicated that the heat in a fire operates on a concrete point for only a short period of time (between 1 and 15 min) and the temperatures reached at 2.5 cm below the soil surface vary between 44 and 150 °C, and Valbuena (1995), who found in field experiments that temperatures reached in the soil surface during fire were 300 °C for 1 min.

Control samples received no heat treatment and seeds were watered with demineralized water. These control samples were subjected to photoperiods of 15 h light/9 h dark.

Immediately after the treatment, the seeds were sown in 8.5-cm-diameter Petri dishes on four layers of filter paper saturated with demineralized water, except for the exudates treatments, where filter paper was saturated with the aqueous extract. The dishes were placed in a controlled environment cabinet at a temperature of 20 ± 1 °C with photoperiods of 15 h light/9 h dark. A temperature of 20 °C was used, comparable with other germination studies where temperatures have varied between 20 and 23 °C (Trabaud and Oustric 1989). The seeds were examined weekly. A seed was considered to have germinated when the radicle could be seen with the naked eye (Côme 1970).

The experiment was continued for 8 weeks, using the method proposed by Martinez-Sanchez et al. (1995), according to which the experiment ends after 15 days without germination.

Viability tests were carried out using the Tetrazolium test (Benister Romero 1989) on a total of four replicates of 25 seeds, giving a total of 100 seeds for each species.

Statistical analysis

Total percentage of seed viability was calculated for each species using the data obtained from the Tetrazolium test. Total percentage of seed germination and average germination times were also calculated for each of the experimental treatments. The average germination time was estimated using the following equation:

$$t_m = \frac{N_1 T_1 + N_2 \cdots + N_n T_n}{N_1 + N_2 \cdots + N_n},$$

where N_1 is the number of seeds that have germinated between time T_1 and T_2, and so on (Côme 1970).

The effects of thermal shock, darkness and inhibitory components on the germination of each species were analysed by a one-way analysis of variance. Similarly, the effects of different experimental treatments among the three pine species were analysed by factorial analysis of variance, considering treatment and species as factors and germination as the dependent variable. The Tukey test was performed to determine which treatments were significantly different. Prior to this, sampling normality (David et al. 1954) and the homogeneity of the variances (Cochran 1941) were checked. For statistical analyses, data expressed as germination percentage were log-transformed before the analysis.

Results

Pinus halepensis seeds showed 98 % ± 2.3 viability, *P. canariensis* 73 % ± 6.8 and *P. pinea* 94 % ± 4.0. This indicates that most seeds were able to germinate and that possible delays in germination may be due to the existence of factors extrinsic to the seed itself.

The percentage of germination differs among the species in the control treatments from 90 to 25 % (approximately for *P. halepensis* and *P. pinea*). Representing individually the results, *P. halepensis* showed no significant differences between percentage of germination in the control and in the seeds kept in total darkness (Fig. 1a). In both cases, high germination percentages (90 %) were observed. Similarly, no negative allelopathic effects on germination were observed from the pine leaves or the humus extracts, and there were no significant differences compared with the
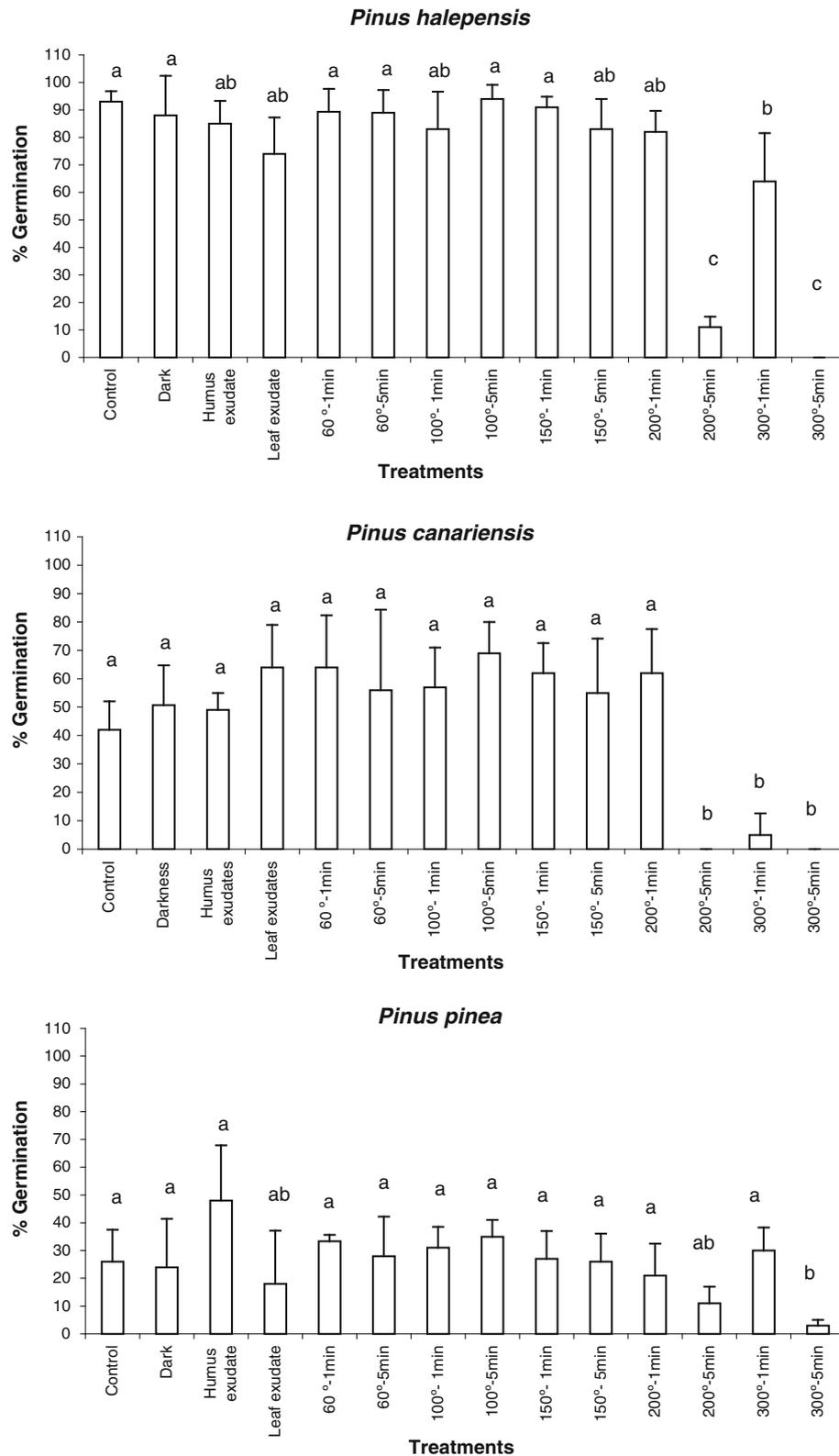
Fig. 1 Percentage of germination for *Pinus halepensis*, *Pinus canariensis* and *Pinus pinea* seeds in the control situation and after all treatments: dark, humus and leaf exudates and thermal shock treatments: 60, 100, 120, 200, 300 °C for 1 and 5 min exposure times (*different letters* represent significant differences ($p < 0.05$) between experimental treatments)

control. As regards thermal shocks, there were no significant differences relative to the control when temperatures and/or exposure time was low (1 min).

Pinus canariensis showed a positive effect of thermal shocks in the germination, although this was not significantly different from the control (Fig. 1b). Only the treatments of 200° C for 5 min and 300° C for 1 and 5 min significantly reduced germination relative to the rest of the treatments ($F_{13, 42} = 12.85$; $p < 0.001$). There were no significant differences between the other treatments.

Highest average germination was found in *P. pinea* after watering with humus exudates, although this was not significantly different from the control (Fig. 1c). Only germination after the 300° C for 5-min treatment (where germination was suppressed) was significantly different from control ($F_{13, 42} = 4.37$; $p < 0.001$). *P. pinea* was the only species of the three examined, where germination after 300 °C for 1 min was not significantly lower than the control. Darkness and exudates treatments did not significantly affect *P. pinea* germination.

In the comparison of the behaviour of the three *Pinus* species studied, we observed significant differences (Table 1) in the total germination after experimental treatments and also significant differences in the interaction between species and treatments. In general, *P. halepensis* is the species with higher percentages of germination (over 80 %) after experimental treatments, except for the 200 and 300 °C, 5-min treatments in which germination was suppressed, and also in the control situation (Fig. 1a), while *P. pinea* showed the lowest germination rate, which was below 50 % in all the treatments, including the control (Fig. 1c). In the case of *P. canariensis* seeds, the total percentage of germination in most treatments was lower than in *P. halepensis*, which can partly be attributed to lower viability (Fig. 1b). In general, all species showed no significant effects on total percentage of germination from darkness or from leaf and humus exudates, while high temperatures (over 200 °C) and long exposure times (5 min) produced significant reductions in percentage of germination ($F_{13, 126} = 310.0$; $p < 0.001$).

For all three species, most seeds germinated during the second week of incubation. The darkness treatment significantly reduced the average germination time in

Table 1 Results of analysis of variance for the germination of the three *Pinus* species after experimental treatments

	Sum of square	d.f.	F-ratio	P value
Main effects				
Species	3885.14	2	215.08	0.0000
Treatments	4030.24	13	34.32	0.0000
Interaction				
Species × Treatments	1279.19	26	5.44	0.0000

Table 2 Average germination time (weeks) and standard deviation for *Pinus halepensis*, *Pinus canariensis* and *Pinus pinea* for each treatment

Treatments	*Pinus halepensis*	*Pinus canariensis*	*Pinus pinea*
Control	2.3 ± 0.4	2.2 ± 0.1	2.4 ± 0.1
Darkness	1.5 ± 0.2*	2.4 ± 0.4	2.2 ± 0.9
Humus exudate	2.2 ± 0.3	1.8 ± 0.2*	2.3 ± 0.2
Leaf exudate	2.1 ± 0.31	1.8 ± 0.1*	2.2 ± 0.3
60° C for 1 min	2.4 ± 0.4	2.3 ± 0.4	2.2 ± 0.3
60° C for 5 min	2.5 ± 0.4	2.2 ± 0.4	2.1 ± 0.3
100° C for 1 min	2.4 ± 0.5	2.4 ± 0.4	2.0 ± 0.1
100° C for 5 min	2.5 ± 0.5	2.2 ± 0.4	2.1 ± 0.2
150° C for 1 min	2.4 ± 0.1	2.1 ± 0.2	2.4 ± 0.6
150° C for 5 min	3.2 ± 0.3	2.4 ± 0.3	2.0 ± 0
200° C for 1 min	3.3 ± 0.8	2.1 ± 0.3	2.1 ± 0.4
200° C for 5 min	5.6 ± 0.6*	–	2.6 ± 0.7
300° C for 1 min	2.8 ± 0.1	3.2 ± 0.3	2.4 ± 0.4
300° C for 5 min	–	–	2.7 ± 1.1

* Significant differences with the control ($p < 0.05$)

P. halepensis, while the 200 °C, 5-min thermal treatment significantly increased this time (Table 2). In addition, in *P. halepensis*, the thermal shocks above 150 °C, 5-min delayed average germination times. In the case of *P. canariensis* (Table 2), in general it showed the lowest average germination times and a significant reduction after treatment with leaf and humus exudates. Delayed germination in the case of *P. canariensis* only occurred after the 300° C, 1-min thermal shock treatment. In contrast with these two species, average germination times for *P. pinea* seeds were not affected by any treatment and had mean germination times of between 2 and 3 weeks. In general, 300° C for 5-min treatment produced a reduction in germination to zero in *P. halepensis* and *P. canariensis*, and only *P. pinea* seeds germinated.

Discussion

The Canary Islands pine (*P. canariensis*) is an endemic species to the Canary archipelago, where it is the only existing native pine. In these Islands, the non-native pine species *P. halepensis* and *P. pinea* have been introduced (del Arco et al. 1992) and appear in the same forest. In general, species are not adapted to fire itself, but to a specific fire regime (Whelan 1995). In Canary Island, natural fires (caused by lightning) are infrequent, but human activities (arson fires) have led to frequent fires, which could favour species such as *P. halepensis*, which is naturally distributed in fire-prone areas (Hanley and Fenner 1998). These reasons indicate the need to know the

germination behaviour of these species in order to control the spread of exotic species in *P. canariensis* forests.

The effects of temperature on pine seed germination have been widely studied and conclude that germination is not positively stimulated in most pine species after thermal shocks, but that they tolerate considerable high temperatures (Tárrega et al. 1992; Martinez-Sanchez et al. 1995; Escudero et al. 1999). However, this resistance is not the only factor influencing fire survival as the soil seed bank has a transient character (Baskin and Baskin 1998); however, the insulation provided by a canopy seed bank in different conifer forests, such as *P. canariensis* (Tapias et al. 2001), is also highly relevant for seed survival during a fire (Fravers 1994). Additional factors, such as seed size, light levels to incident under litter in the understory of the forest and allelopathic substances, have also been found to affect pine seed germination (Alvarez et al. 2005, 2007). So, the germination inhibitors present in the *P. pinea* coat are involved in the regulation of its seed germination (Martinez-Honduvilla and Santos-Ruiz 1978) and could explain the low germination percentage of this species in this study. The ability to tolerate high temperatures is related to seed size (Escudero et al. 2000; Alvarez et al. 2007). In this sense, *P. pinea* seeds are larger than seeds of the other two species studied and showed highly resistant to thermal shocks with the ability to germinate after exposure to 300° C for 5 min. That seems to support the idea proposed by Reyes and Casal (1995) that larger seeds are more resistant to fire. Furthermore, many authors explained the high temperature resistance of *P. pinea* seeds conferred by the thick seed coat (Escudero et al. 1999).

Germination was not significantly inhibited by darkness in any of the studied species; thus, all of them could germinate without a fire event in the understory of the forest with a reduction in incident light, as have been found by other authors in *P. pinea* (Skordilis and Thanos 1997) and *P. pinaster* (Alvarez et al. 2005). In the case of *P. halepensis*, we observed a significant acceleration of its germination in darkness. These results do not agree with those obtained by other authors (Thanos and Skordilis 1987; Skordilis and Thanos 1997), where this species was characterized by low germination in the dark. The differences in the darkness effects on *P. halepensis* germination could be explained by population variability as this is the main source of variation in germination response (Escudero et al. 2002; Vasques et al. 2012; Valbuena et al. 2013).

Patterns of seedling distribution following fire are influenced not only by soil temperatures during fire, but also by the competitive interactions between seedling species emerging in the post-fire environment (Ne'eman et al. 1992). Without a fire or with seeds that were buried in soil before a fire, the more rapid germination of *P. halepensis* in darkness could give this species a competitive advantage over the other species in terms of regeneration. However, *P. halepensis* seedlings are poor competitors in unburned situations (Hanley and Fenner 1998) and grow better under burned canopies, because of reduced competition and better mineral nutrition (Ne'eman et al. 1992). In this sense, total percentage of germination of the *P. halepensis, P. canariensis* and *P. pinea* studied was not negatively affected by the inhibitory effects of allelopathic substances from leaves or humus of *P. canariensis* as have been found in other studies (Alvarez et al. 2005). However, *P. canariensis* showed the significant lowest average germination time after the treatment of leave and humus exudates. This could provide an advantage without fire in these ecosystems because *Pinus* germination problems could be related either to the loss of viability due to abiotic factors or to consumption by seed predators. The negative effects of seed predators on *Pinus* species have been demonstrated in several studies carried out on *Pinus nigra* populations, whose seeds are consumed by mice and ants (Ordóñez García 2004), in common with other *Pinus* populations (Reed et al. 2004).

Pinus halepensis' regeneration strategy is based on taking advantage of the post-fire environment, on the existence of a large canopy seed bank and a certain degree of serotiny (Escudero et al. 1999). This species is considered an obligate seeder (Martinez-Sanchez et al. 1995), but the viability of dispersed seeds is only about 2 years (Ceballos and Ruiz de la Torre 1971). However, seeds stored in the canopy for up to 20 years are capable of germination (Daskalakou and Thanos 1996). They are dispersed by wind, but most of the seeds are not dispersed further than 24 m away from the parent tree (Acherar et al. 1984).

Martinez-Sanchez et al. (1995) found that *P. halepensis* seeds die after a treatment of 150 °C for 5 min, in concordance with Nuñez and Calvo (2000) and with the model of germination probabilities calculated by Escudero et al. (1999). In contrast, we found a high germination rate after the 150° C, 5-min treatment. These differences could be due to the effects of population interaction with temperature, as described by Escudero et al. (2002) for *P. halepensis* seeds or could be related with the different moisture content of seeds that influence the ability to survive high temperature treatments. Thermal treatments tend to delay germination in this species. Escudero et al. (1999) found that control seeds germinate more rapidly than seeds submitted to any heat treatment, although in our study as well as that of Nuñez and Calvo (2000), this occurred only after the most severe treatments.

Both *P. halepensis* and *P. canariensis* disperse seeds to similar distances and tolerate high temperatures. Thus, the higher percentage viability and germination rate of *P. halepensis* seeds relative to *P. canariensis* could give it an

advantage in post-fire regeneration dynamics. However, it is likely that the number of seeds produced by each species is also relevant for making predictions about regeneration success. Alternatively, species that can regenerate by both resprouting and seeding tend to reproduce by resprouting, since it allows them to rapidly recover the available space (Naveh 1975). *P. canariensis* is a resprouter and is therefore likely to compete effectively with new *P. halepensis* seedlings in mixed stands.

Pinus pinea seeds are wingless, dispersing only beneath the canopy of parent trees (Skordilis and Thanos 1997). However, once established, the seedling survival rate is the same for *P. pinea* and *P. canariensis* in Gran Canaria (Arévalo et al. 2009), thus contributing to *P. pinea* population stability. This limited dispersal capacity contributes to the low invasiveness of this species. However, this situation could change with the introduction of dispersal vectors like the African squirrel (*Atlantoxerus getulus*), which has already been introduced to the Canary Islands (Fuerteventura), with a wide diet and in expansion based on climatological models (López-Darias et al. 2008). Although due to the small stand of *P. canariensis* on this island, the effect of the African squirrel has not been tested, other studies in different areas (i.e. South Africa) indicate that these seeds are well dispersed by squirrels and jays (Grotkopp et al. 2004). The high resistance of this species' seeds to high temperatures (300 °C for 1 min) could affect the fast germination response of those seeds present in the seed bank after a prescribed fire and before others are released from serotinous cones (Torres et al. 2006).

Conclusion

There were significant differences in the total germination among the three *Pinus* species. *P. halepensis* was the species with higher percentages of germination and *P. pinea* showed the lowest germination. In general, global percentage of germination of all the species was not significantly affected by the experimental treatments of darkness, washing with leaf and humus exudates or thermal shocks below 200 °C for 1 min. Differences were only observed when the seeds were subjected to 200 and 300 °C for 5 min. The species with greatest seed size *P. pinea* showed the resistance to the highest temperature and exposure time 300 °C for 5 min. There was a reduction in the mean germination time in *P. canariensis* when watered with leaf and humus exudates. The germination of the seeds of the two alien species was not negatively affected by the reduction in the incident light beneath the litter on the understory of the *P. canariensis* forest.

Fire has long been used as a tool in land management, even high-intensity fires (Hermann et al. 1991). In Spain,

the use of prescribed burning is limited due to social concerns about forest fires. However, in Gran Canaria, this practice is gaining popularity for reducing fire hazards. According to these results, a single fire would not be useful for controlling regeneration dynamics of the three *Pinus* species, as the seeds of all three species tolerate high temperatures. The key factor to take into account for fire management in this case may be the resprouting ability of *P. canariensis* in the field (Arevalo et al. 2001). So, one of the possible methods for controlling the exotic pines from mixed stands in Gran Canaria could consist of a first fire, intense enough for the adult trees of both exotic species to die. After this fire, *P. canariensis* would then resprout and the seeds of all three species stored in the canopies would be released to the soil and germinate. A subsequent low-intensity prescribed fire, before the saplings develop a thick protective bark, would then control the exotic species. Prescribed fires of various levels of intensity have been used to control overstory trees without significantly modifying soil characteristics and favouring the stand replacement (Waldrop and Brose 1999; Elliott et al. 2009; Harrod et al. 2009). However, it could be necessary to know the effects of repeated fires on *P. canariensis* to assure the survival of the native pine before performing any fire-related management programs. In addition, the resprouting ability of adult *P. canariensis* trees is one of the main traits related to fire resistance (Ceballos and Ortuño 1976) in contrast with *P. halepensis* and *P. pinea*. This trait allows this species to recover in just a few years following fires (Climent et al. 2004).

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