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Chapter 5

ECOLOGY AND MANAGEMENT OF NATURAL AND REFORESTED CANARY ISLAND PINE STANDS

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ABSTRACT

Pinus canariensis Chr. Sm. Ex DC in Buch is an endemic conifer tree of the Canary Islands archipelago and its stands occupied much larger areas in the past. Plantation programs have been very common in the Canary Islands since the 1940s. The main objective of the plantations analyzed in this study is to restore the canarian pine forest which was heavily disturbed and eliminated during the last 5 centuries after the European colonization of the Canary Islands and reforestation with exotic species.

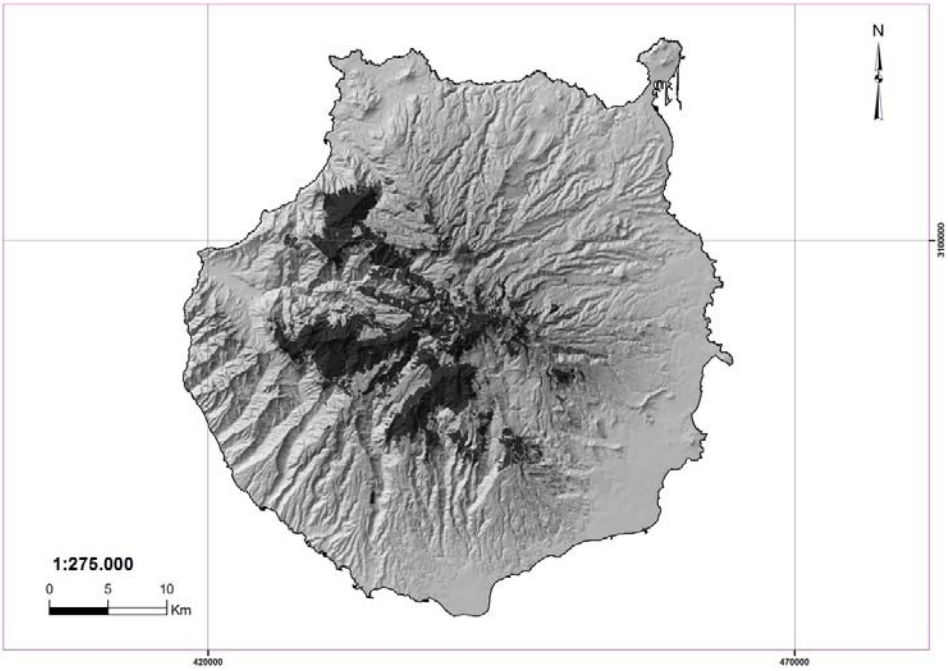
There is not a general agreement in the plantation technology or the management of these plantations, probably due to the low number of studies related with the ecology of this forest stand. In this chapter, we will evaluate the ecological studies carried out with P. canariensis and analyze the management practices followed by the authorities. We will analyze the valuable aspects of this management and suggest, if possible, new alternatives for forest restoration. The impact of fire and the introduction of exotic species in the potential area for P. canariensis is also analyzed and evaluated. We finish the chapter with some concluding remarks based in the information provided by different sources found during this review.

INTRODUCTION

Pinus canariensis Chr. Sm. Ex DC in Buch is the most abundant tree in the Canary Islands, with more than half of the tree population of the archipelago, including both exotic and native trees, belonging to this species, occupying more than 60% of the total forest surface of the islands (120,000 ha approx.) (Sánchez-Pinto 2007). Canary Island's pine, considered a model of evolution and adaptation to different environments (Climent et al. 2007), is thought to be a living fossil of a subtropical mountain pine type, which was widespread along the Tethys seaway in the Tertiary Period (Klaus 1989). Nowadays, the natural distribution of P. canariensis is exclusively restricted to the western Canary Islands, having one of the most restricted distributions of all the species of this genus (Parsons 1981). The outstanding values of these species have made the protection, reforestation and recovery of the disturbed areas one of the main tasks of the local authorities of the Canary Islands, which have the competence in conservation matters at present, and the central government, which had them in the past.

First island inhabitants, who probably arrived to the Archipelago two thousand years ago from North Africa, are thought to have had a very low and reduced impact in the extension of vegetation (Parsons 1981), although recent studies suggest there was significant effect from aboriginal populations in the ecosystems, causing even the extinction of important forest species suggesting also an earlier arrival (de Nascimento 2009). It was after the European colonization of the islands in the XV century when the Canary Island pine forest started to be intensely exploited (Galván 1993). Forest exploitation to get pine tar, wood, for agricultural and farming use and the necessity of space for the increasing population, lasted until the XX century, being much more intense between the conquest and the XVIII century (del Arco *et al.* 1992). At the beginning of the XX century the reduction of the forest surface was really alarming, and reforestation plans were carried out, mainly between 1930 and 1960 (del Arco *et al.* 1992). The main objective of these plantations was to restore the Canarian pine forest, heavily disturbed as a result of intense exploitation over the last five centuries, following the European colonization of the Canary Islands, and to get protection against erosion and ravines overflowing (Parsons 1981). As a result, the primary species used in afforestation was *P. canariensis*, although some areas were planted with exotic species (i.e. *Eucalyptus globulus*, *Castanea sativa*, *Pinus radiata, P. halepensis,* etc.).

Nowadays, Canary Island pine forest occupies around 70% of its potential area at present (Fernández 2002), and the general opinion is that it has a good conservation status, especially after the sixties, as a result of both the intense programs of reforestations, and the lack of exploitation of its habitat at present times just reduced to very restrict logging and needles collection for cattle use (Arévalo and Fernández-Palacios 2009). Moreover, for the conservation of the Canarian pine stands, also contributes the high level of protection, being included in the Annex I of the EU Habitat Directive and having more than 97% of its extension included under different protection laws. All these facts have determined the classification of *P. canariensis* as of Least Concern into the IUCN Red List of Threatened Species. However, it is worth pointing out that some threats remain for these habitats at present time, as the increase of population in the islands, illegal settlement (poorly controlled by authorities due to the unpopular view of the police forces), rates of fires far away from the natural ones (Arévalo *et al.* 2001) and genetic variability lost (Vaxevanidou *et al.* 2006).



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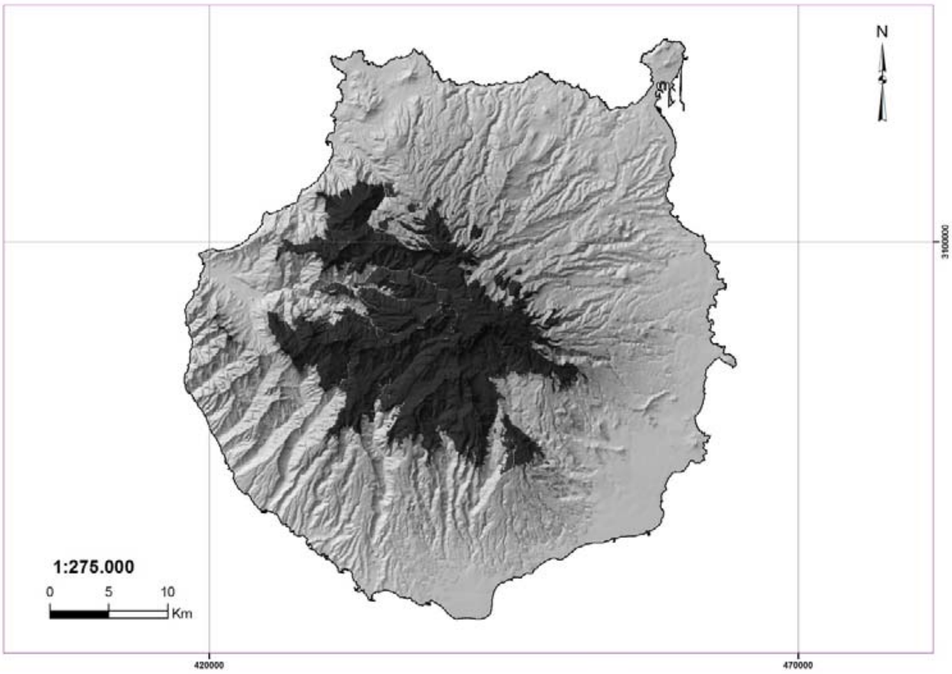

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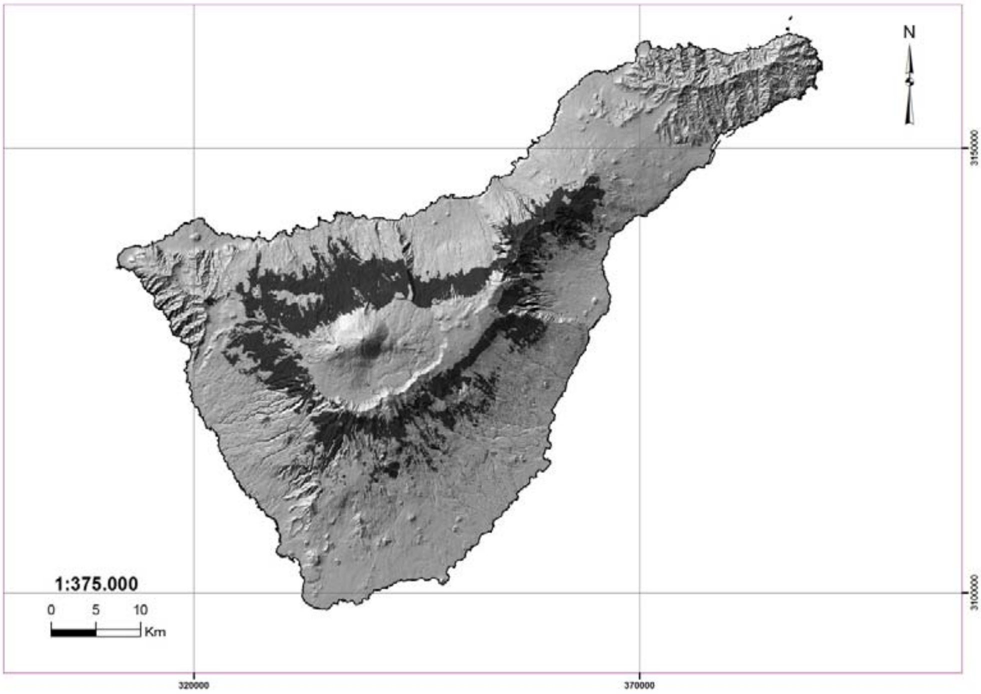
Figure 1. Distribution of the Canary Island pine forest in the island of Gran Canaria, adapted from del Arco (2006). (a) Actual distribution. (b) Potential distribution.



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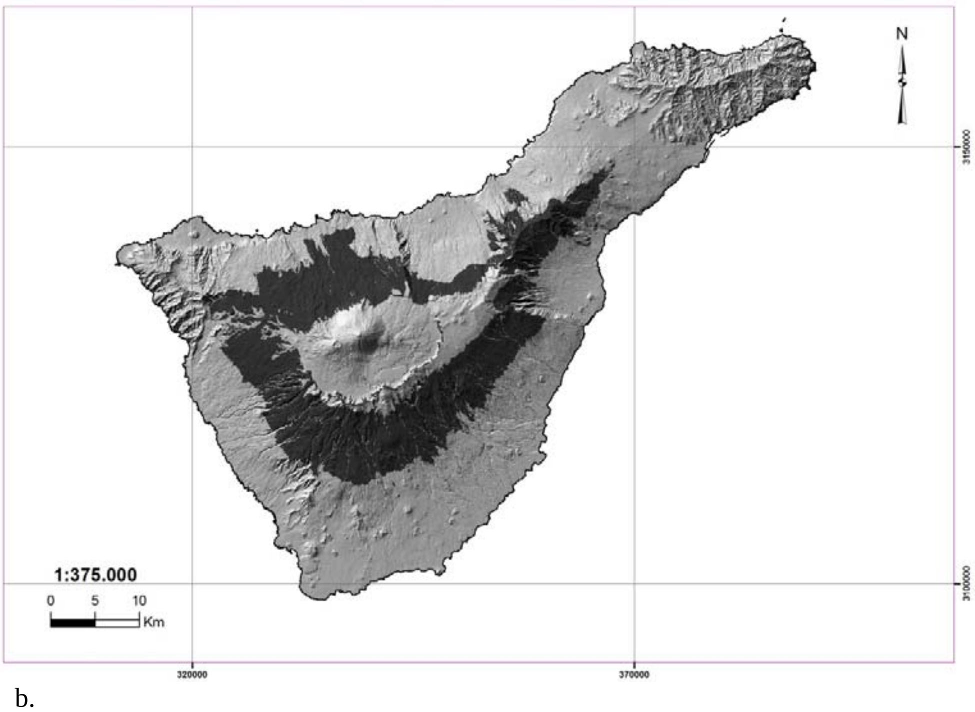

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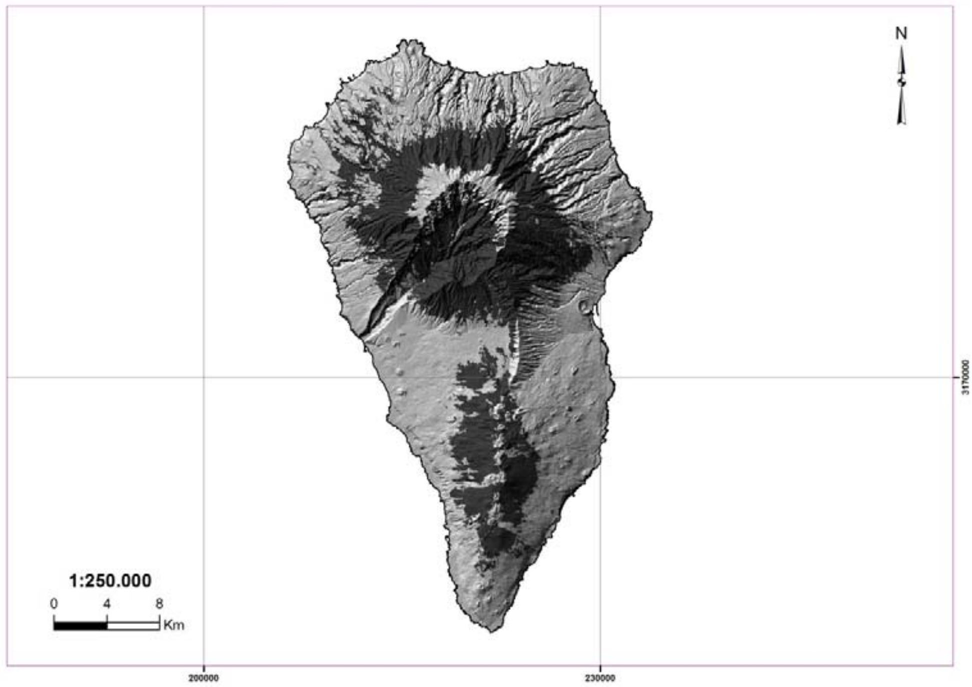
Figure 2. Distribution of the Canary Island pine forest in the island of Tenerife, adapted from del Arco (2006). (a) Actual distribution. (b) Potential distribution.



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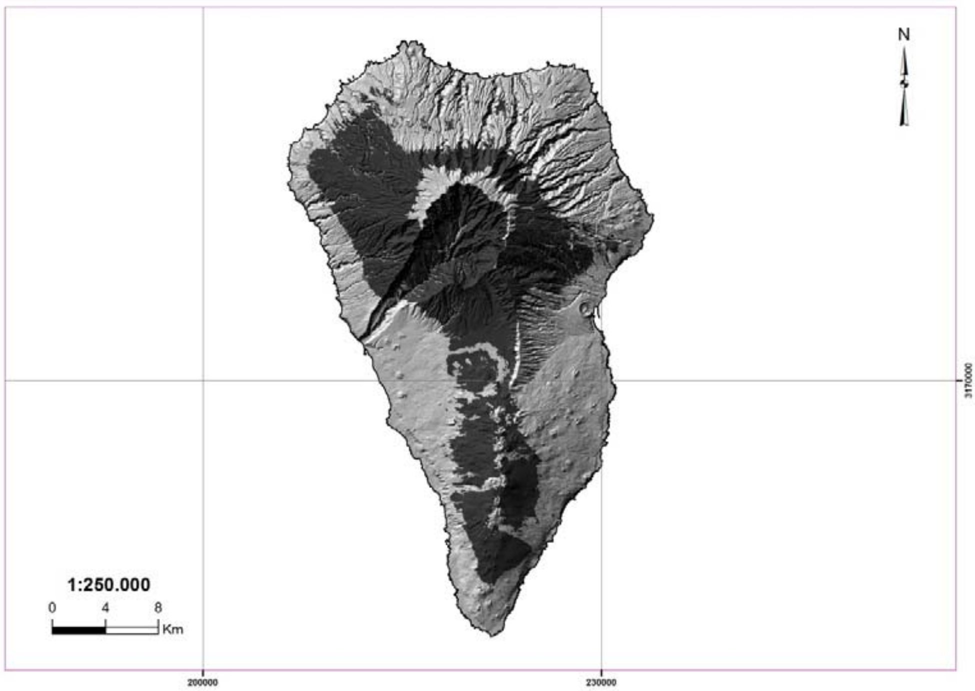

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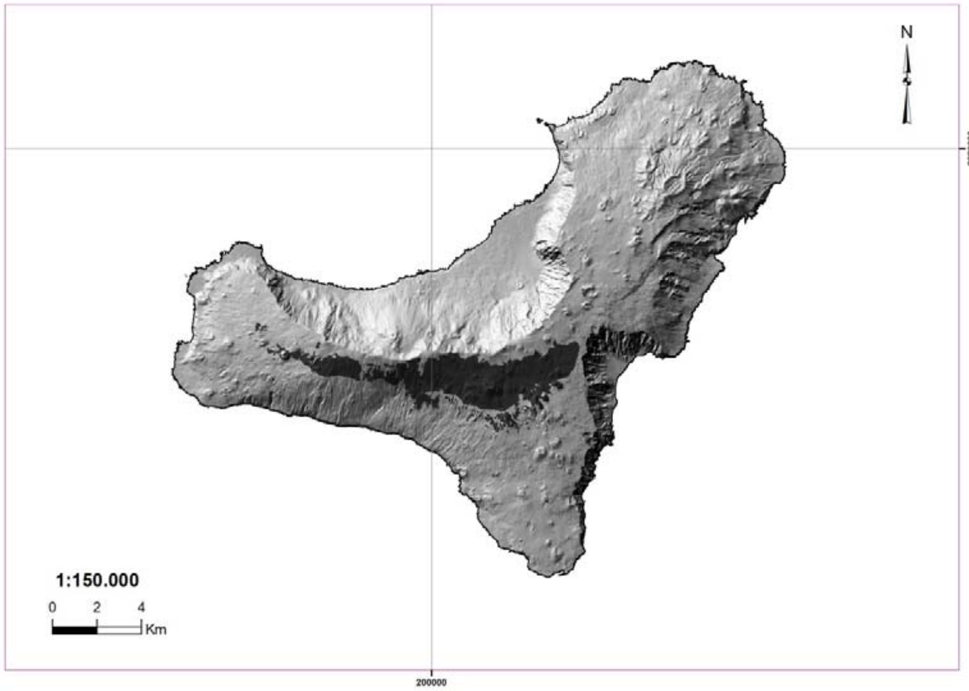
Figure 3. Distribution of the Canary Island pine forest in the island of La Palma, adapted from del Arco (2006). (a) Actual distribution. (b) Potential distribution.



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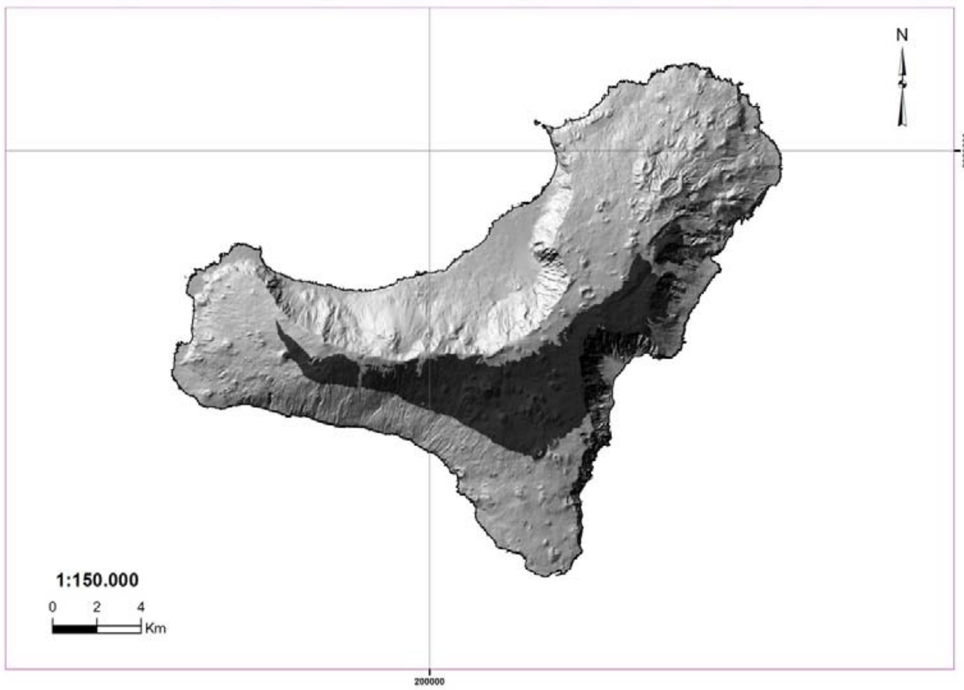

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Figure 4. Distribution of the Canary Island pine forest in the island of El Hierro, adapted from del Arco (2006). (a) Actual distribution. (b) Potential distribution.

In this review we selected a group of papers published about *P. canariensis* stands management and reforestation techniques, analyzing the valuable aspects of its management and suggesting, if possible, new alternatives for forest restoration. The impact of fire and the introduction of exotic species in the potential area for *P. canariensis* are also analyzed and evaluated, as well as some aspects concerning its phylogenetic classification and gene pool. We finish the chapter with some concluding remarks based on the information provided by the different sources consulted during this review.

EXTENSION OF THE PINE FOREST

P. canariensis stands are adapted to the archipelago environmental conditions, but its potential distribution is restricted to the western islands, excluding the ones farther east, Lanzarote and Fuerteventura, due to their particular dryer conditions. However, some evidence of its presence in these more arid eastern islands in historical times has been found (Climent *et al*. 1996). Some paleobotanical studies are analyzing this situation and although they agree that these islands did not have big stands of *P. canariensis*, isolated individuals were present in a natural way (Atoche 2009).

For the other islands (Tenerife, Gran Canaria, El Hierro, La Gomera and La Palma), the bioclimatical and archeological studies allowed to determine the potential distribution of the stand. Also, documents from after the XV century allow us to know the main changes that occurred in respect of the extension.

In Gran Canaria the potential distribution of *P. canariensis* is related to the soil characteristics and with the ecological requirements of the species, and it is basically restricted to the central part of the island, reaching lower altitudes in some southwest areas. 20% of the total area of the island can be considered pine forest. Due to the extensive use in the XVI-XVII centuries, much of the extension was reduced, but after the XX century, large reforestation programs recovered part of the lost forest, and at present time we consider it is occupying almost 50% of its potential area (Figure 1).

Table 1. Surface occupied for *P. canariensis* forest in each island

Island	Potential (km^2)	Actual (km^2)	Actual* (km^2)	Total island	Potential (%)	Actual (%)	Actual* (%)
EH	49.31	20.42	14.88	269.00	18.33	7.59	5.53
GO	5.66	6.10	0.38	370.00	1.53	1.65	0.10
LP	276.96	232.83	232.53	708.00	39.12	32.89	32.84
TF	505.69	242.31	229.99	2,034.00	24.86	16.83	11.31
GC	308.86	160.94	135.76	1,560.00	19.80	10.32	8.70
FV	0.00	0.53	0.00	1,660.00	0.00	0.03	0.00
LZ	0.00	0.02	0.00	846.00	0.00	0.00	0.00
Total	1,146.49	763.14	613.53	7,447.00	15.40	10.25	8.24

EH: El Hierro; GO: La Gomera; LP: La Palma; TF: Tenerife; GC: Gran Canaria; FV: Fuerteventura; LZ: Lanzarote. *Excluding *P. canariensis* plantations.

In Tenerife, the pine forest is occupying the altitudinal band 1800-2300 m, 25% of the total island area. Although, as in Gran Canaria, these stands suffered extensive use and deforestation, but at present time the recovery is very extensive and almost complete (Figure 2).

We can consider that it is in the island of La Palma where the Pine forest has the most important extension of plant vegetation community, with a potential distribution of almost 40% of the whole island, from central points were the volcanic caldera (and the Caldera de Taburiente National Park) is located, and also reaching some areas in the north at low altitude, almost reaching the coast (Figure 3).

In El Hierro, the smallest island, the potential area is around 20% of the whole island, restricted also to central areas, but at present time and due to extensive use, it remains at around 8% (Figure 4).

The reduction of the Canarian pine forest since the XV century has been studied well (Santana 2001; González 2005; Rodríguez and Naranjo 2005; Lobo *et al.* 2007; etc.). Although some early conservative policies were implemented since the beginning of the forest exploitation, they only delayed the extensive destruction of the *P. canariensis* stands, and as we mentioned above, it was not until mid XX century that extensive reforestation programs were carried out. At the moment, only a few hectares of old growth forest can be considered natural remains in the archipelago (although it was even worse for other woody stands as the laurel forest) (Table 1).

REFORESTATION AND MANAGEMENT

Forest stands that have been subject to long-term degradation and soil loss will face many difficulties for its natural regeneration, if it is even possible. In these conditions, the only way to provide the area with some tree regeneration is to grow seedlings in a protected environment and later plant them where they will grow (Smith *et al.* 1997). Although the main objective of a plantation is the optimization of survival, growth and stability of the plants (Long 1991), successful establishment of plants for reforestation depends upon a wide range of interacting factors including: climate, soil, competing species and post-plantation care (Luis *et al.* 2004), which can lead to low survival rates in some areas, especially in the most disturbed and extreme environments.

Plantation programs have been very common in the Canary Islands since 1930. The main objective of these plantations was to restore the Canarian pine forests that were heavily disturbed from logging and intensive human use during the last five centuries, after the European colonization of the Canary Islands (Parsons 1981), although in some cases reforestation was carried out with exotic species (Arévalo *et al.* 2005). In recent years, authorities have re-considered the usefulness of the plantations, moving away from the idea of using them solely as exploitable natural resources towards a management practice that will restore the native pine forest. However, the large areas reforested in the last sixty years have not been followed by an appropriate management and monitoring activities, and some remaining areas of potential Canary Island pine forest have been planted with poor results (Luis *et al.* 2001).

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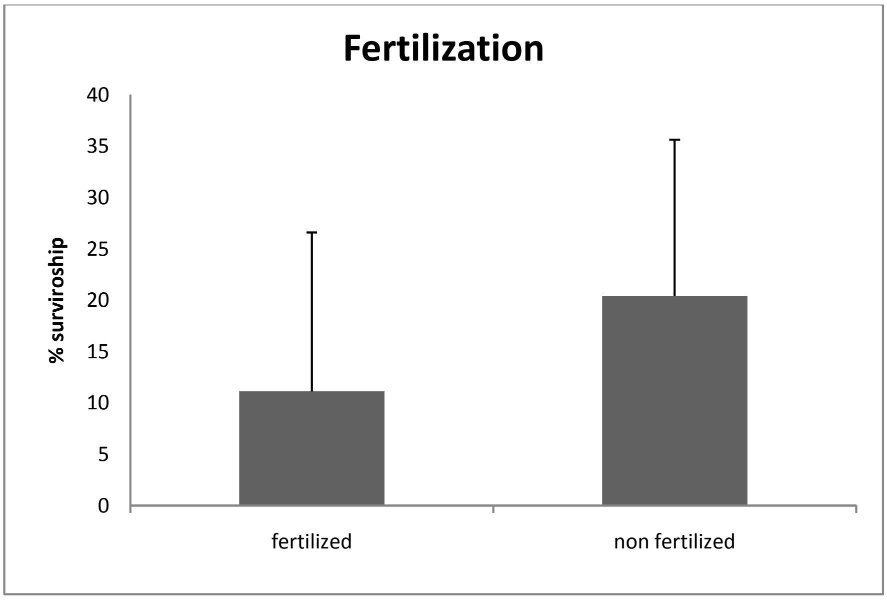

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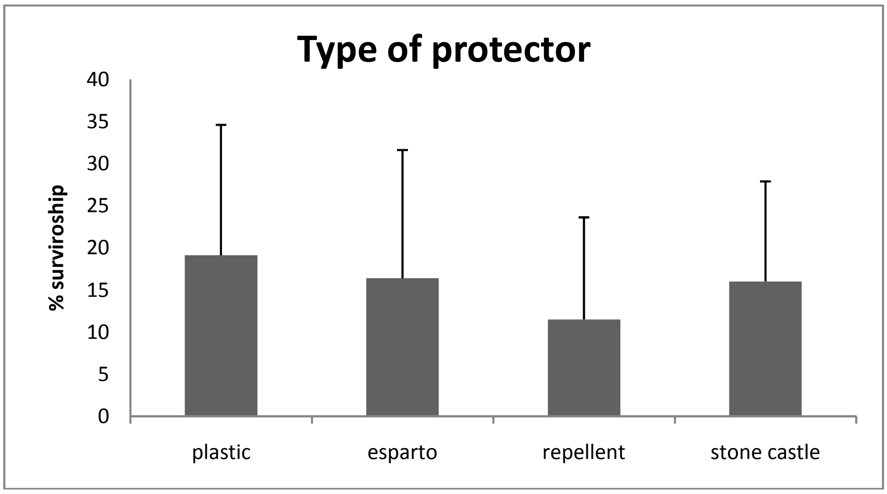
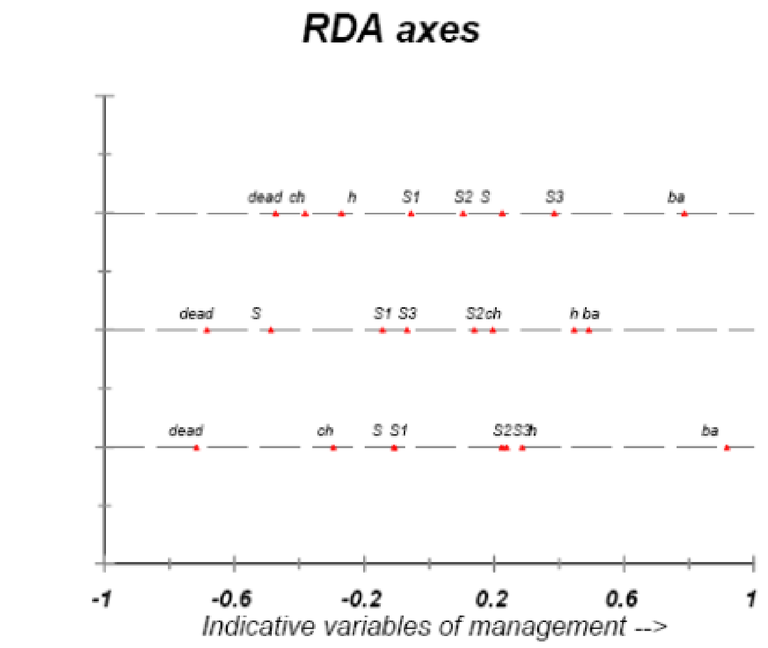


Figure 5. It shows some of the results obtained for Arévalo (2009) with respect to the success of different plantation techniques on the survival of *P. canariensis* seedlings. (**a**) Mean values and standard deviation of percentage of survivorship of fertilized and non fertilized seedlings; (**b**) Mean values and standard deviation of percentage of survivorship of the seedlings with each type of protector.

Nowadays an aspect that any reforestation plan should take into account is that the genetic variability of the species is required to be conserved through the "Original regions" of *P. canariensis* legally established by the Spanish government (Martín *et al*. 1998). Moreover it has been proved that the genetic origin of the plants is a very important factor to get a successful reforestation. Climent *et al*. (2002) demonstrated that the use of *P. canariensis* plants obtained from seeds with similar climatic original region to those of the area to reforest, increases short term survivorship, results explained by the authors as a consequence of the adaptation of the populations of the Canary Island's pine to the different climatic condition included in its natural range of distribution.



Plot comparisons	Monte Carlo Test
Axis Analysis I.- Treatment thin20%-Treatment thin50%	ns.
Axis Analysis II.- Control-Treatment thin20%	ns.
Axis Analysis III.- Control-Treatment thin50%	$p<0.01$

Figure 6. Result of the multivariate analysis (Redundancy analyses; RDA) of the species composition carried out in Arévalo *et al.* (2001). The variables used in this analysis were the following: mean percentage increase in the basal area (ba); mean percentage increases in height (h); mean depth of the canopy (ch); density of dead trees (dead); density of seedlings (S); density of saplings less than one year old (S1); density of saplings between 1 and 2 years old (S2); density of saplings older than two years (S3). In the figure each horizontal line represents the axis of a different analysis, the first one corresponds with the comparison between thinning treatments (thinning 50%-thinning 20%) and the last two correspond with the comparison between control and each thinning treatment, on the right of the graph it is specified the plots used in each analysis. Differences in the studied variables were only found between control and thinning of the 50% of the basal area of the plantation.

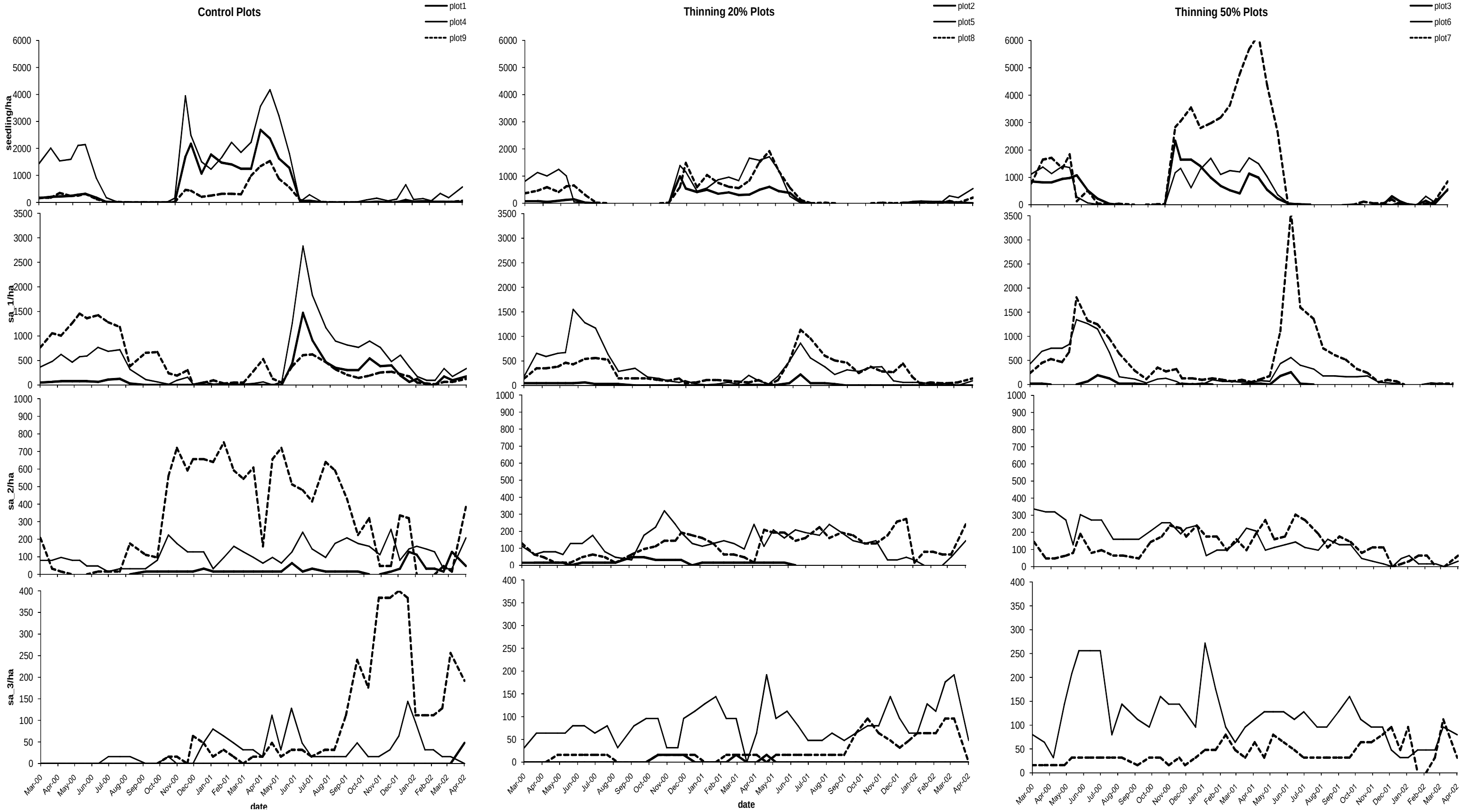


Figure 7. Density values (per ha) of seedlings of P. canariensis found by Arévalo and Fernández Palacios (2008) after silvicultural thinning of the plantations; sa_1 (saplings less than one year old), sa_2 (saplings between 1-2 years old) and sa_3 (saplings older than 2 years old) in the control and treated plots (thinned 20% and thinned 50%).

Other important factors to achieve the success in a reforestation are the preparation of the plants during their time at the nursery and the plantation techniques applied. Luis *et al*. (2004; 2009) demonstrated that the traditional cultivation of the nursery crops with natural soil and no additional fertilization does not offer the highest plant quality and survival rates, but artificial substrates and a correct fertilization do. On the other hand, Arévalo (2009) did a research into the most successful plantation techniques of *P. canariensis* in arid areas, finding that fertilizers, stone castles and hydrogels were negatively associated with plant survivorship while plastic protectors had a high efficiency in survivorship (Figure 5). The author explained some of the results by the high salinity levels of the soils, which heightened the negative effects of fertilization, so that due to the soil and weather conditions of the area, fertilization is not recommended, nor is hydrogels. The plastic protectors offered not only good results in terms of avoiding herbivore grazing pressure (mainly rabbits) but also represented the quickest option in terms of how long it takes to employ the device, a valuable characteristic in this type of forestry activity (Cubbage *et al*. 1991).

The works above described cope with the objective of keeping high levels of survivorship of the *P. canariensis* seedlings, but once the plants have been established it is also necessary to recreate natural stands, as long as the main purposes of the restoration activities are the reestablishment of the structure and function of native ecosystems (Moore *et al*. 1999). Plantations generally present a plant density higher than natural stands and subsequent thinning have proven to be an indispensable management tool for the sustainable development and naturalization of forest plantations (Smith *et al*. 1997; Zhu *et al*. 2003). Based on that, Arévalo and Fernández-Palacios (2005a; 2008) analyzed the impact of silvicultural thinning (20% and 50% removal of density) in structure and regeneration of *P. canariensis* plantations. The analysis carried out in these studies revealed that thinning (in particular the removal of the 50% of the basal area of the plantation) help to transform dense stands into natural-like pine forest, having a positive effect in the quality of vegetation structure and enhanced advanced regeneration in comparison with densely planted stands (Figure 6).

The most outstanding results obtained in these research after the thinning management were: 1) a decrease in the number of dead trees, which can increase the health of the plantation, because the presence of sick trees facilitates the spreading of diseases (Dahlsten and Rowney 1983; Smith *et al*. 1997); 2) a reduction in tree density, which can have positive effects avoiding catastrophic fires (Arévalo et al. 2001) and leads to densities closer to natural stands and trees with larger canopy diameters as a result of the extra space, and consequently a large amount of leaves receiving direct solar radiation; and 3) a superior sexual regeneration established, due to a higher seedling density, most likely as a result of a significant influence of light in the germination , which although being higher than those of the natural forest, is followed by high mortality rates and concludes in a successful establishment of saplings older than 2 years, almost absent in dense plantations as a result of the lack of space (Figure 7). These works concluded that although thinning treatments are having a positive effect in the naturalization of the stands, they are not enough to recreate a natural forest, in part due to the fast recovery of the canopy cover which does not allow the growth of the new trees, and consequently, subsequent management is needed to ensure establishment of advance regeneration.

NATURAL DISTURBANCES: WILDFIRES

Although until the sixties, fire was seen as a disaster to be prevented whenever possible (Kornas 1958; Molinier 1968), at the moment it is considered as an endogenous factor in plant communities, an occurrence which may be a result of community structure and composition (White 1979). Negative effects of fire suppression in ecosystems, like excessive fuel build-up, homogeneous age structure and loss of diversity, has been reported (Leopold *et al*. 1963), and it has been confirmed that wildfires should be allowed to play a greater role when possible (Perry 1994; Wright and Bailey 1982).

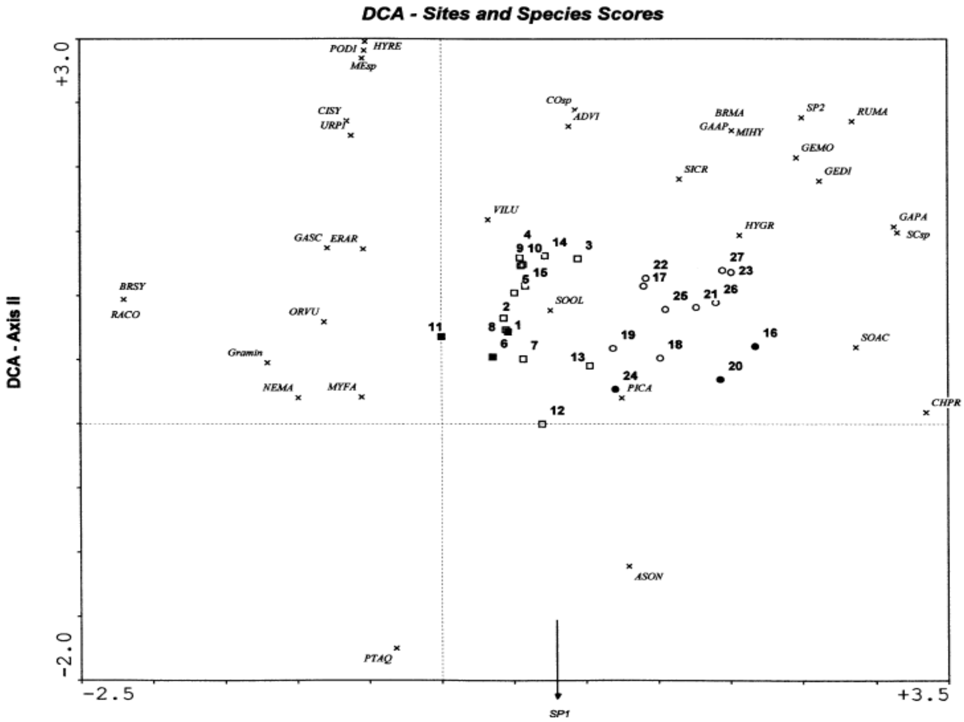


Figure 8. Result of the multivariate analysis (specifically a Detrended Correspondence Analysis, DCA) of the species composition carried out in Arévalo et al. (2001). The main gradient of species composition variation, showed by axis I, was not the fire effect but the situation of the plots at leeward (represented by circles) or windward (represented by squares), which strongly determines the pre-fire and also the post-fire species composition. A second gradient, showed by the axis II, revealed that fire had only a moderate impact on the Canary Island's pine-tree forest. Species abbreviations (ADVI: Adenocarpus viscosus, NEMA: Nemostiles maculata, ASON: Asplenium onopteris, ORVU: Origanum vulgaris, BRMA: Briza maxima, PICA; Pinus canariensis, BRSY: Brachypodium sylvaticum, PODI: Polycarpaea divaricata, CISY: Cistus symphytifolius, PTAQ: Pteridium aquilinum, COsp; Coniza sp., RACO: Ranunculus cortusifolius, CHPR: Chamaecytisus proliferus, RELU: Reseda luteola, DAGN: Daphne gnidium, RUBUS: Rubus mauritanica, DEMY: Descourainia millefolia, RUMA: Rumex mauritanica, ERAR: Erica arborea, SCsp.: Scorpiurus sp., Fusp.: Fumaria sp., SICR: Sideritis cretica, GAAP: Gallium aparine, SMAS: Smilax aspera, GASC: Gallium scabrum, SOAC: Sonchus acaulis, GEDI: Geranium disectum, SOOL: Sonchus oleraceus, GEMO: Geranium molle, SP1: SP1, Graminea: Graminea, SP2: SP2, HYGR: Hypericum grandifolium, HYRE: Hypericum reflexum, ILCA: Ilex canariensis, Mesp.: Medicago sp., MIHY: Micromeria hypssopifolia, URPI: Urospermum picroides, MIVA: Micromeria varia, VILU: Vicia lutea, MYFA: Myrica faya,VITI: Viburnum tinus.

In the Canary Islands, fire has been considered to be an ecological catastrophe that should be prevented. However, there are no doubts that wildfires have played an important role in the evolution of the Canarian pine forest (Höllermann 2000), with *P. canariensis* being a species specially well adapted to fire, having most of the traits associated with fire resistance, such as thick bark, long needles, large buds, a tall growth habit, self-pruning, deeprooting and longevity and/or capacity to resprout (Climent *et al*. 2004). Before the arrival of the first inhabitants to the Archipelago, fires started by volcanic activity and lightning, having a low frequency but spreading over large areas, but after human occupation of the islands, in particular after the Spanish conquest, fire frequency increased, leading to a fire regimen largely different from the natural one (Höllermann 2000). In our time, 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). The fact that wildfires in the *P. canariensis* forest are of ecological has not been studied enough.

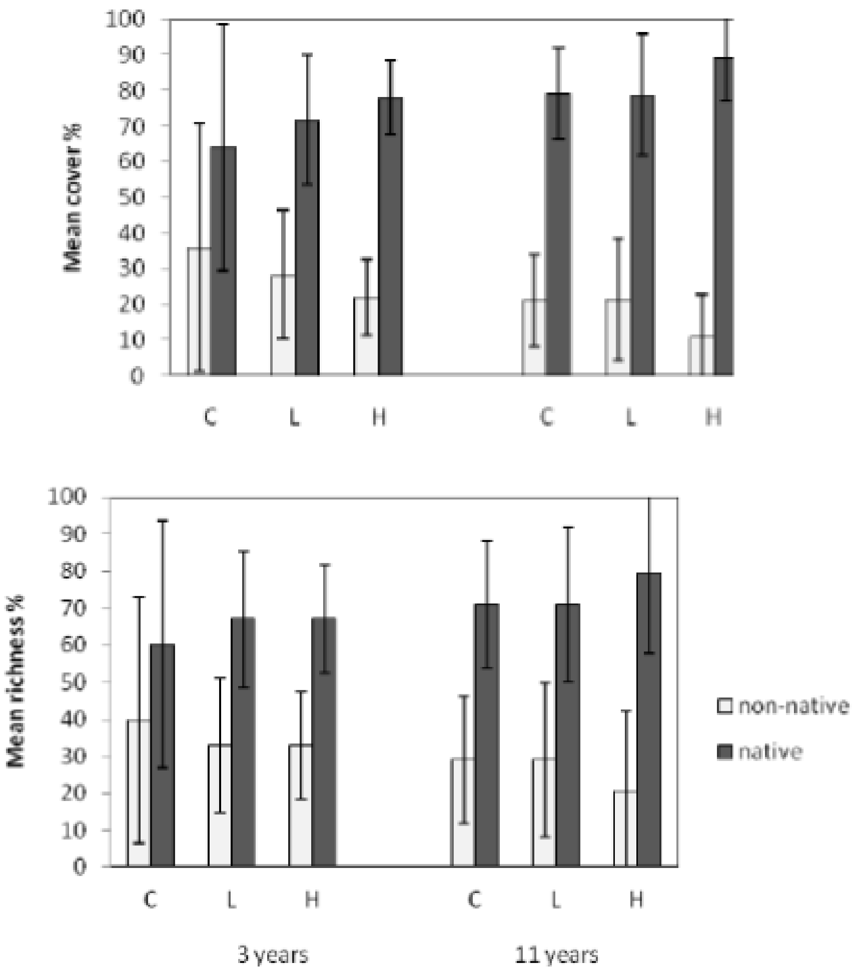


Figure 9. Mean and standard deviation of native and non-native species cover and richness percentage, found by Domínguez and Fernández-Palacios (2009) three and eleven years after fire. C: control; L: low-intensity fire; H: high-intensity fire.

Arévalo *et al*. (2001) designed a study to report and reveal the short term (three years after fire) effects of low and high fire intensity on understory species composition, using multivariate analysis as a mean to evaluate if fire can be considered a real ecological catastrophe in the Canary Island pine forest and to reveal the important aspects about species dynamics with respect to fire that will help in the management of reforestation programs. This study revealed a very low impact of fire in the species composition of the forest stands with a pre-fire composition playing a key role in the regeneration of the burnt areas. The analysis of species composition (Figure 8) indicated that opportunistic species occupied the space immediately after the fire, but as long as the canopy closes up, which can occur very fast (Arévalo and Fernández-Palacios 2005a), other species, related with the understory of the canopy stand displaced these opportunistic ones, showing the fast capacity of post-fire recovery of the *P. canariensis* stands.

In a posterior study, carried out by García-Domínguez and Fernández-Palacios (2009), the same area was evaluated eleven years after the fire. Based on the idea that fire, as a disturbance factor, can promote non-native species, one of the greatest threats to natural ecosystems worldwide (Vitousek 1996). The aim of this study was to compare the richness and cover of native and non-native species in the different wildfire intensities three and eleven years after the fire. This study only found a small number of non-native species, even after high-intensity fire, and no differences were found for cover and richness of these species as a result of the fire severity, neither three or eleven years after the fire (Figure 9), suggesting there is no relationship between fire and the invasion or expansion of these species. On the contrary, an increase of native species cover was detected in areas of high intensity fire after three years, and authors concluded that some native species from the understory adapt to high intensity fire and respond with a fast increase of their cover after fire to the detriment of non-native species.

Other studies have been focused on the post-fire regeneration of *P. canariensis* revealing different results. The importance of fire in pine germination, establishment, and rates of survivorship along a fire chronosequence was evaluated in Méndez (2010), concluding that the sexual regeneration of pine forest cannot be assured to be dependent or favoured by forest wildfires. On the other hand, in the analysis of the first year seedling establishment after fire carried out by Otto *et al*. (2010) an important role of fire intensity in regeneration was found. In the most severely burnt areas of this study a complete lack of regeneration was detected, suggesting that as a result of the damage of the aerial seed bank and/or the unfavourable conditions for seed germination and seedling establishment. Nevertheless, high seedling densities were found at sites with intermediate fire impacts, something attributed to entire liberation of the aerial seed bank (including seeds stored in serotinous cones), as well as a favourable post-fire micro-environmental conditions for seed germination and seedling establishment.

The impact of fire in the soil nutrients of the pine forest has been also analyzed in different studies (Duran *et al*. 2010; Duran *et al*. 2009; Duran *et al*. 2008; Rodriguez *et al*. 2009). Although some of these studies show contradictory results, it can be assumed that fire is an important force affecting soil fertility and that pine forest's wildfires may induce long-term changes in soil properties, especially in relation with nitrogenous (the typical limiting element of these volcanic soils).

EXOTIC PINE SPECIES

Although the primary species used in afforestation of the Canary Islands pine forest was *P. canariensis,* some areas were planted with exotic pine species (*P. radiata, P. pinea, P. sylvestris, P halepensis, P. pinaster*). Under certain circumstances tree species widely planted in alien environments can become naturalized and spread (Richardson *et al*. 2004). The question of whether exotic pine species can compete with Canary Island pine and become an environmental problem was in part discussed in Arévalo *et al.* (2005) where the regeneration of a mixed stand of native *P. canariensis* and introduced *P. pinea* species was studied. Recognizing regeneration characteristics of *P. Pinea* compared to *P. canariensis,* species highly related genetically (Liston *et al.* 1999), can help to predict the ability of this exotic species to invade new areas, as has been seen in other ecosystems of the world (Richardson 1989; Rouget *et al*. 2001). This research reveals a low dispersion rate of *P. pinea* (strongly barochorus) with respect to *P. canariensis* (barochorus and anemochorus), which reduces the invasive capacity of the species, not being at the moment the establishment and regeneration of the species safeguarded and being the presence of *P. pinea* in the stand a function of the past human intervention. Authors concluded that that competition with *P. canariensis* together with the low numbers of *P. pinea* planted (estimated by the authors at around 2000 stems) will not allow the naturalization and spread of the species.

Plantations of exotic species can not be a threat for native forest but instead a way to facilitate forest succession, providing better conditions for native shade-tolerant species, germination and establishment in their understories on sites where disturbances prevented recolonization by native forest species (e.g. Fimbel and Fimbel 1996; Loumeto and Huttel 1997; Parrotta 1995). Reforestation with *P. canariensis* and other exotic pine species were carried out mainly in potential areas of Canarian pine forest, although in some areas the limit of this forest was transfered until areas of potential laurel forest. In this line of work, Arévalo and Fernández-Palacios (2005b) evaluated the regeneration of potential vegetation in the laurel forest and Canarian pine forest under closed canopies of the exotic *P. radiata* D. Don. This study determined that these species have been acting as a nursing plant, providing favorable environmental conditions for the establishment of the native species, providing mainly soil protection and shade. Authors suggest that ecological functions of non-native pine species should be analyzed before starting control or eradication programs of the species, because some degraded areas may benefit from exotic species (Williams 1997). Moreover, in spite of *P. radiata* being a pioneer tree in its natural environment (California, USA), no signs of regeneration for this species were found in the study.

Taking into account that *P. pinea* and *P. radiata* can be classified as invaders species, that *P. pinea* in other areas of the world can be dispersed by squirrels (Grotkopp *et al*. 2004), which at the moment have been intruduced in some of the Canary Islands, and due to the fact that the future ability of both species to disperse, as has been demonstrated in other studies, cannot be predicted, authors propose eradication of these species, together with additional plantings of *P. canariensis* in open areas, to get the restoration of the stands.

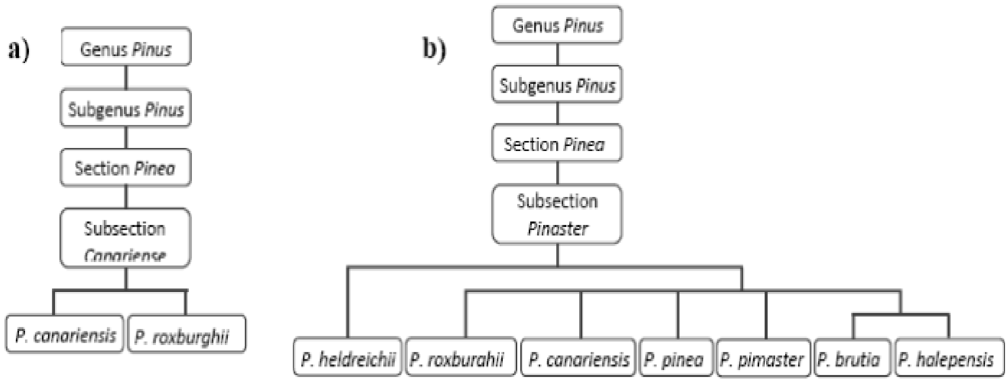


Figure 10. Phylogenetic classification of *P. canariensis*. (a) Adapted from Klaus (1989) and (b) adapted from Gernandt *et al*. (2005).

PHYLOGENY AND GENE POOL

In spite of the fact that the distribution of *P. canariensis* is nowadays exclusively restricted to the western Canary Islands, continental fossils of these species have been described from the Iberian Peninsula to Turkey (Kasapligil 1978), and evidence has also been found of its presence in the more arid eastern islands (Lanzarote and Fuerteventura) in historical times (Climent *et al*. 1996). It was probably the low tolerance of the Canary Island pine to frost events (Farjon 1984) that determined the extinction of the continental population of the species following the dramatic climate changes that took place at the end of the Tertiary (Frankis 1999), whereas populations of the species remained in the Archipelago because they found refuge in the milder climate of the islands, as occurred with the laurel forest, another Tertiary relict vegetation type (Bramwell 1976).

Because of the pine species economic and ecological relevance, an important number of studies have been carried out in order to get a correct classification system of the genus *Pinus*, with approximately 111 species being the largest extant genus of conifers (Price *et al*. 1998). Initially, these studies were mainly based on morphological traits (i.e. Little and Critchfeld 1969; Klaus 1989), and agreed in suggesting a native pine of the Himalayan region, the *P. roxburghii*, as the closest living relative of *P. canariensis* due to the strong morphological resemblance of both species, explained as the result of a common ancestor from a very old Mediterranean evolutionary centre from which both relict species conserve morphology characteristics. Thus, Canary Island and Himalayan pines were traditionally classified as the two only extant members of the subsection *Canarienses* (Figure 10a). Subsequently, phylogenetic classifications improved with development of molecular method, especially after the contributions of DNA analysis (Price *et al*. 1998), and in opposition to morphological based methods, the study of chloroplast (cp) DNA restriction site data and ITS sequences showed that there are high levels of divergence between *P. roxburghii* and *P. canariensis,* typically thought as very closely related (Liston *et al*. 1999; Wang *et al*. 1999). In consequence, these authors removed the subsection *Canarienses* and grouped the Canary Islands pine together with other more related Mediterranean species into the subsection *Pinaster*. However, most recent studies (Geada *et al*. 2002; Gernandt *et al*. 2005) place again both pine species into the same subsection, suggesting that the close relationship existing between Himalayan and Canary Island pine is not well resolved yet. Nevertheless, all these surveys agree in the relationship of *P. canariensis* with other Mediterranean pines (*P. pinaster*, *P. pinea*, *P. halepensis*, etc). Finally, according to Gernandt *et al.* (2005), who made one of the latest phylogenetic classifications of the genus Pinus where inferred the phylogeny for 101 of the approximately 111 species of the genus, *P. canariensis* belongs to the subsection *Pinaster*, together with the Mediterranean *P. brutia*, *P. canariensis*, *P. halepensis*, *P. heldreichii*, *P. pinaster* and *P. pinea*, and the Himalayan *P. roxburghii* (Figure 10b).

Apart from phylogeny, it is worth pointing out specific studies carried out about the genetic characteristic and the gene pool of the population of the Canary Island pine into its natural range by using chloroplast microsatellite markets (cpSSR). In the same line of work Gómez *et al.* (2003) studied the process that has shaped the distribution of gene diversity in this species, obtaining evidence of a common origin of the current populations, and suggesting colonization from a single continental source located close to the Mediterranean Basin through the oldest eastern islands (Fuerteventura 20 Ma and Lanzarote 15-16 Ma), from which it is absent nowadays, to the youngest western islands (Gran canaria 13-14.5 Ma, Tenerife 7.5, La Gomera 12 Ma, La Palma 2 Ma, El Hierro 0.75 Ma). Moreover these authors find a complex population genetic structure with high differentiation amongst populations within islands but not amongst islands, explained by the volcanic history of the islands, which has determined isolation amongst island populations and extinctions and recolonizations from diverse sources, as well as by the long-distance gene flow (favoured by the undetachable seed wing), which allows genetic interchange amongst islands. The survey of Navascués *et al.* (2006) supports this West to East pattern of colonization and the relevance of the volcanic history of the Archipelago in determining the genetic structure of the populations of these species, while the study of Korol *et al.* (1999) confirmed a frequent gene flow amongst native population of different islands.

The detected complex and diverse genetic structure of the Canary Island pine populations highlights the necessity for conservation strategies for these species at the population level (Gómez *et al.* 2003). As a result, from a conservation genetics perspective Vaxevanidou *et al.* (2006) evaluated for the first time, genetic diversity of the Canary Island pine stands through the full range of the species, including the most outstanding Canary Island's pine marginal populations. This survey showed contrasting values of haplotypic genetic diversity in marginal populations of *P.canariensis*, which go from very low to very high genetic diversity of all Canary Island's pine range. Moreover, this study emphasizes the high risk of extinction of marginal populations, with remarkable singularity in their haplotype composition, as a result of its extremely low population numbers and the lack of natural regeneration. Therefore, due to the singularity of these genotypes and to the possibility of containing outstanding and valuable adaptations to extreme environments, authors suggest urgent conservation activities, as the establishment of genetic reserves in situ and multifunctional collections ex situ, in order to preserve the particular haplotypic genetic diversity of these critically endangered marginal populations.

CONCLUSION

Based on the review done from the information provided by the selected research work, we can assume the following facts about *P. canariensis* stand:

- The extension of the stand has been increasing continuously in the last decade thanks to conservation and restoration management, which also helps to increase the continuity of the stand.
- Fires can be considered an endogenous natural process of this pine forest and the main problem can be related with the lack of fire in much of their area. Controlled burning is an excellent restoration and naturalization tool. Unfortunately, the population, the interface area and the topography makes the application of controlled burning very difficult, and although recommended should be applied with caution.
- Restoration has improved its techniques in the last years, as well as preparation of plants in greenhouses, and these advances should be applied in extended programs of reforestation.
- At present time, the introduced exotic species of conifers haven't shown any ability to invade new areas far away from where planted. However, the control of these stands of exotic species is required in order to monitor the possibility of a change in their demography as happens in others areas of the planet with the same species.
- The large amount of comparative systematic surveys agrees in the close relationship existing between the Canary Island pine and genuine Mediterranean pines, although more research should be done to get a consensus about its relationship with the Himalayan pine.

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