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Effects of afforestation with pines on woody plant diversity of Mediterranean heathlands in southern Spain

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Abstract. Open heathlands of the Strait of Gibraltar region constitute a singular vegetation type within the Mediterranean Basin owing to their high biodiversity levels and distinct features in the biological aspects of endemism. However, they have been traditionally depicted as low profitable, tree-less, barren lands and have been either overlooked in conservation policies or included in extensive pine-tree afforestation programmes. Nowadays, most of the existing pine plantations are no longer exploited and have become dense pine woodlands. Here we present the results of a comparative analysis aimed to ascertain the effects of pine stands on the structure and diversity of the woody component of these mediterranean heathlands. Ten sampling sites were located within the study area, each consisting of two adjacent subsamples: an open heathland and a neighbouring heathland under pine-tree cover. Woody species richness and overall shrub cover was much lower in pine-tree heath understoreys. This drop in cover was more marked for short-lived species (seeders and withering resprouters), implying a decrease of the life-history diversity and also having noticeable consequences in homogenizing the floristic composition of heath patches under pine trees. Heathland narrow endemics dropped significantly in pine stands, showing greater sensitivity to afforestation than nonendemics. We suggest that the open heathlands of the Strait of Gibraltar should be given further attention in EU and IUCN conservation policies. Programmes should be implemented to progressively eliminate abandoned pine plantations so as to restore and preserve these highly diverse mediterranean heathlands.

Introduction

Heath-dominated communities (i.e. heathlands) in the northern hemisphere are associated with oceanic areas of temperate latitudes, mainly in western and north-western Europe. These heathlands are found on acid, nutrient-poor, peaty or sandy soils, and under a relatively mild, temperate climate (Gimingham 1972; Gimingham et al. 1979; Rodwell 1991). They are not considered a type of natural vegetation, but associated with cultural landscapes, developing as a result of forest clearance followed by the use of the land by means of burning, cutting and livestock grazing (Webb 1998).

In the Mediterranean Basin, dominated by fine-textured, relatively fertile, nonacid soils, and characterized by a markedly seasonal, mediterranean climate, heathlands are relatively scarce and have subsequently been overlooked in comprehensive reviews of mediterranean vegetation (Quezel 1981; Tomaselli 1981). However, heathland-like communities are dominant in the Strait of Gibraltar region at the western end of the Mediterranean Basin, where they are associated with the acid, nutrient-poor, sandstone-derived soils that are scarce elsewhere in the Mediterranean Basin, and with a relatively mild mediterranean climate (Ojeda et al. 1995, 1996a, 2000a).

Dense, open heathlands, with no tree overstorey, are abundant in this region, and occur mainly on sandstone mountain summits and ridges on poorly developed soils (Ojeda et al. 1996a). Dominant woody species in these communities are heaths (*Calluna vulgaris*, *Erica australis*, and *E. scoparia*), brooms (*Stauracanthus boivinii*, *Genista tridens*, *G. triacanthos*, *G. tridentata*), and rock roses (*Cistus populifolius*, *Halimium alyssoides*). Although these mediterranean heathlands have been traditionally considered as meridional representatives of European temperate heathlands or transitional stages between temperate heathlands and the mediterranean garrigue (de Benito 1948; Rivas-Martínez 1979), they constitute a singular vegetation type within the Mediterranean Basin (Arroyo and Marañón 1990; Ojeda et al. 2000a). Their uniqueness comes not only from their high species richness and levels of endemism (Ojeda et al. 2000a), but also from two distinct features in the biological aspects of endemism: (i) edaphic endemism (associated with acid soil patches), and (ii) association of endemism with the shrub habit (Ojeda et al. 2001).

In contrast with their European temperate counterparts, these mediterranean heathlands can be considered as a natural (as opposed to human-induced) type of vegetation, given the habitat where they are found, their comparatively higher species richness, and the amount of narrow endemic species tightly associated with them (Ojeda et al. 1996a, 2000a). Moreover, the highest diversity of heath species (Ericoideae, Ericaceae) is found in the southwestern end of the Mediterranean Basin (Ojeda et al. 1998). Although palaeoecological analyses are needed, these heathlands are probably older than the 4000 years conferred on European temperate heathlands (Webb 1998).

Despite the singularity and high biodiversity levels of these mediterranean heathlands, and their importance for the wildlife, they have been traditionally depicted as low profit, barren lands, owing to their low fertility status and tree-less features (e.g. Ceballos and Martín-Bolaños 1930). Consequently, they have been either overlooked in conservation policies (e.g. they are not mentioned in Annex 1 of the EU Habitats Directive), or included in extensive afforestation programmes in order to protect soils from erosion, make the heathlands profitable, and 'improve' their physiognomy (Salas et al. 1989; Ibarra 1993). The tree species most frequently used in such afforestation programmes is *Pinus pinaster* (Ibarra 1993).

Nowadays, most of the pine plantations existing in the area are no longer exploited, becoming dense woodlands. Several studies in the western Mediterranean Basin have shown that planted pine woodlands have a negative impact on diversity of the local fauna (e.g. Díaz et al. 1998; Romero-Alcaraz and Ávila 2000) and flora (e.g. Mazurek and Romane 1986; Chiarucci and De Dominicis 1995). In large areas of shrublands of the southern hemisphere vegetation, several *Pinus* species (e.g. *P. pinaster*, *P. radiata*) are problematic invasive aliens, causing severe shifts in plant life-form dominance and reducing diversity (Richardson et al. 1994).

In this article we present the results of a comparative analysis on the life-history diversity, species richness, and endemism level of the woody component between open heathlands and heathlands under *P. pinaster* cover in the Strait of Gibraltar region. Specifically, this study attempts to answer the following questions. (1) Do planted pine woodlands cause changes in plant life-history dominance?, and (2) do pine stands alter species richness and endemism values of these heathlands? The main aim of this study is to ascertain the effects that pine plantations have on the life-history and floristic diversity of these unique, highly diverse mediterranean heathlands.

Methods

Study area

The Strait of Gibraltar region is formed by two small peninsulas, separated by 14 km, and having a rugged topography. These peninsulas show remarkable floristic, biogeographical and ecological affinities (Valdés 1991; Ojeda et al. 1996a; Arroyo 1997). They are characterized by a mild mediterranean climate due to oceanic influences, and by the dominant presence of acid, nutrient-poor, sandstone-derived soils (Ibarra 1993; Ojeda 1995). These soils occur on sandstone mountains and hills, in the form of ‘edaphic islands’ surrounded by more fertile, marly or loamy lowlands (Ojeda et al. 1996a).

The study area lies inside Los Alcornocales Natural Park, at the northern side of the Strait of Gibraltar. This Natural Park covers ca. 1700 km^2 with a maximum elevation of 1092 m, and includes a large amount of the acid, sandstone soils of the northern side of the strait (Figure 1). The vegetation on these acid soils is dominated by evergreen *Quercus suber* woodlands with heath understoreys. Open heathlands cover the more exposed sandstone ridges and summits (Ojeda et al. 1995, 1996a, 2000a).

Sampling

Ten sampling sites were located within the study area (Figure 1). Each site consisted of two neighbouring subsamples: an open heathland and an adjoining heathland under pine cover. Pine cover ranged from 40 to 100% in the 10 pine understorey subsamples. Both subsamples at each sampling site had the same altitude, aspect, and soil bedrock. Care was taken to select sampling sites with no sign of recent (i.e. less than 5 years) management or disturbance events (e.g. slashing, fire) and no visible differences in disturbance levels between subsamples.

Relative abundance (cover) of woody plant species in the shrub layer was recorded in each subsample by the line-intercept method (Kent and Coker 1994) on

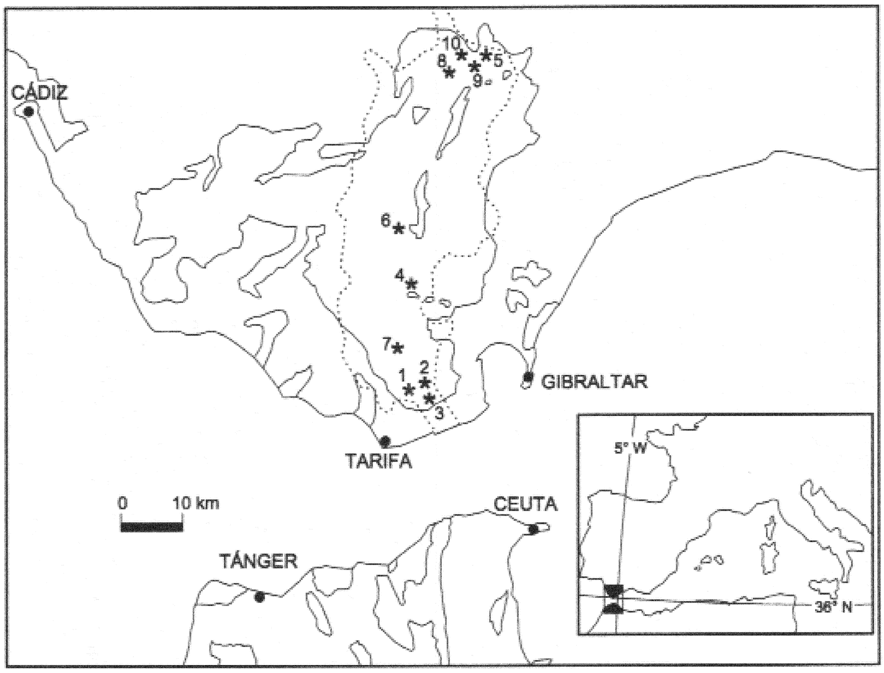

Figure 1. Map of the study area. Solid lines correspond roughly to patches of sandstone-derived soils (see Ojeda et al. 1996a, b). The dashed line in the map represents the boundary of Los Alcornocales Natural Park. Asterisks indicate the location of the 10 sampling sites.

a 50-m line transect. Transects were completed in an area of 0.1 ha (50×20 m^2) by adding those species not recorded in the 50-m line with a predetermined minimum cover value of 0.1%. Both 50-m line transects (one per subsample) at each sampling site were always laid out parallel to each other and 50 m further apart so as to avoid transition zones. Three top soil (0–10 cm) samples were collected randomly along the transect in each subsample and mixed for pH analysis in soil saturated paste.

Species richness was measured in each subsample as the number of woody species recorded by the transect. Plant nomenclature follows Valdés et al. (1987). All recorded species were classified into three life-history categories: *seeders*, *long-lived resprouters*, and *withering resprouters* (Table 1), related to their post-fire regeneration behaviour and according to previous studies (Ojeda et al. 1996a, 2000b; Ojeda 2001), field observations and personal experience (F. Ojeda). The seeder life history includes those species killed by fire, regardless their behaviour as only post-fire recruiters or continuous recruiters. The second category, long-lived resprouters, includes most resprouter taxa, which regrow from lignotubers or root suckers, and are able to live long periods in disturbance-free environments. The withering resprouter life history includes resprouter woody plants that grow and flower vigorously for a number of years, after which their above-ground biomass

Table 1. Life-history classification of the recorded woody species based on their post-fire regeneration behaviour (see text).

Seeders	Long-lived resprouters	Withering resprouters
Calluna vulgaris	*Arbutus unedo*	*Bupleurum foliosum*(*)
Cistus crispus	*Daphne gnidium*	*Genista tridens*(*)
C. ladanifer	*Erica arborea*	*G. tridentata*
C. populifolius	*E. australis*	*Lithodora prostrata*
C. salvifolius	*E. scoparia*	*Polygala microphylla*(*)
Drosophyllum lusitanicum(*)	*Myrtus communis*	*Stauracanthus boivinii*(*)
Erica umbellata	*Phillyrea latifolia*	*Thymelaea villosa*(*)
Genista triacanthos(*)	*Olea europaea*	
Halimium halimifolium	*Pistacia lentiscus*	
H. lasianthum(*)	*Quercus canariensis*	
Lavandula stoechas	*Q. lusitanica*(*)	
Satureja salzmanii(*)	*Q. suber*	
	Rhamnus alaternus	
	Rubus ulmifolius	
	Smilax aspera	
	Teucrium fruticans	

Narrow endemics are marked with (*).

loses vigour progressively, withering in long disturbance-free periods (Ojeda 2001); after fire, they resprout vigorously and start again the same phenological pattern.

Those species whose geographic range is restricted to the southwestern Iberian Peninsula and northwestern Morocco were considered as narrow endemics (cf. Ojeda et al. (1995); see Table 1).

Data analysis

The 20 subsamples were tree clustered so as to detect possible groups among them regarding their floristic composition. In order to do so, a 20 × 20 symmetric matrix of Euclidean distances was created from the subsamples × species cover data matrix, and a dendrogram of the 20 subsamples was subsequently generated by applying UPGMA agglomerative clustering (Sneath and Sokal 1973) to the matrix of Euclidean distances (StatSoft Inc. 1997).

Criteria followed in the sampling method of adjoining subsamples (see above) assimilated our sampling design to a 'before–after' experiment, and allowed us to ascertain the effect of the pine-tree afforestation on heathland features by simple paired comparison tests. Student's *t*-tests for dependent samples were performed to seek out significant differences in (1) soil pH, (2) species richness, (3) overall shrub cover, (4) cover of seeders, (5) cover of long-lived resprouters, (6) cover of withering resprouters, (7) life-history diversity, (8) number of narrow endemic species, and (9) number of nonendemics, between the open heathland subsamples and their pine woodland understorey counterparts. Despite this being a set of repeated analyses to test the same null hypothesis (i.e. there are no significant differences in the mean value between both groups of observations), we considered that it would be overconservative to employ any kind of Bonferroni significance corrections (see Cabin and Mitchell 2000). Instead, we took $\alpha = 0.01$ as the significance level to reject the null hypothesis in all contrasts.

Results

Soil pH did not differ significantly between open heathland (pH = 4.9 ± 0.4, mean ± 1 SD) and tree understorey subsamples (pH = 4.7 ± 0.4; $t = 0.21$, $P = 0.26$, $df = 7$).

Mean species richness decreased significantly in the pine-tree understorey subsamples (11.8 ± 2.3 species/0.1 ha) compared with their open heathland counterparts (16.1 ± 3.1 species/0.1 ha; $t = 4.16$, $P < 0.005$, $df = 9$). Overall shrub cover dropped almost threefold, from 127 ± 34% in open heathland subsamples to 51 ± 28% in pine-tree understorey ones, these differences being highly significant ($t = 5.97$, $P < 0.0005$, $df = 9$). Considering species life histories separately, pine-tree overstorey had a significant negative effect on the seeder ($t = 3.84$, $P < 0.005$, $df = 9$) and withering resprouter ($t = 4.01$, $P < 0.005$, $df = 9$) life histories, but not on the long-lived resprouter life history ($t = 2.23$, $P = 0.052$, $df = 9$; Figure 2).

The tree-like diagram resulting from the agglomerative cluster grouped nine out of 10 pine understorey subsamples in a single branch at the 50 level of linkage distance (Figure 3), which can be interpreted as a reflection of a high floristic similarity among heath patches under pines.

The number of narrow endemic taxa decreased significantly (almost twofold) in

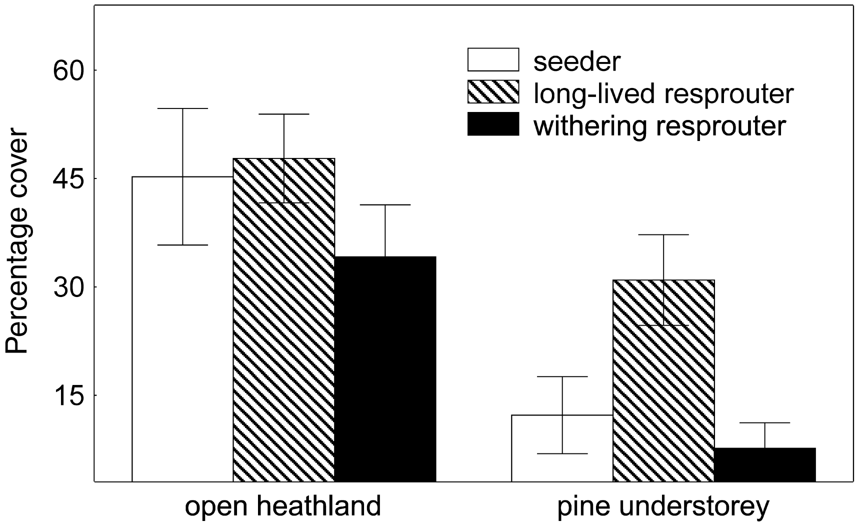

Figure 2. Relative abundance (percentage cover) of seeder, long-lived resprouter and withering resprouter life histories in open heathlands and neighbouring pine understoreys (mean ± 1 SE). Results of single paired Student's *t*-tests within each life-history category are indicated in the text.

subsamples under pine trees (3.4 ± 1.2 endemic species/0.1 ha) compared to open heathlands (6.3 ± 2.2 endemic species/0.1 ha; $t = 3.41$, $P < 0.01$, $df = 9$). By contrast, the number of nonendemic taxa in pine understorey subsamples (8.4 ± 2.1 species/0.1 ha) was slightly lower than that of their open heathland counterparts (9.8 ± 1.9 species/0.1 ha), differences being not significant ($t = 3.09$, $P = 0.012$, $df = 9$).

Discussion

The remarkable biodiversity value of mediterranean heathlands of the Strait of Gibraltar region has been traditionally overlooked by managers and policy makers. They have regarded these heathlands as tree-less, degraded vegetation stages susceptible to improvement, mainly by means of pine-tree afforestation (e.g. Ceballos and Martín-Bolaños 1930; Salas et al. 1989). However, this study shows the negative effects that planted pine woodlands have on the life-history and floristic diversity and endemism of the woody component of these mediterranean heathlands. Similar negative consequences on plant diversity have been reported for South African *fynbos* under pine plantations (Richardson and van Wilgen 1986). It should be noted that fynbos is a mediterranean, heathland-like vegetation analogous to these mediterranean open heathlands (Ojeda et al. 2001).

A surface soil acidity increase by needle litter (Barnes et al. 1998) has not been detected (see Results), as open heathland sandstone soils are fairly acid already (Arroyo and Marañón 1990; Ojeda et al. 1995). However, a physical negative effect of the needle litter layer on seedling recruitment might well be expected. We thus hypothesize that shade from pine-tree cover and the layer of needle litter, which can be rather thick in old pine stands, are the most likely factors accounting for the differences detected in this study.

Woody plant cover dropped heavily in pine-tree heath understoreys. Some species, abundant in open heathlands, showed a much lower cover or even disappeared in neighbouring pine-tree understoreys. This trend was not alike for all woody species, but it was significantly more noticeable in seeders and withering resprouters (Figure 2) and endemic taxa (see Results). This differential pattern could be explained by adult plant senescing in seeder species (e.g. *Calluna vulgaris*, *Satureja salzmanii*) and progressive above-ground die-back in some 'withering' resprouters, such as *Thymelaea villosa*, *Genista tridens* or *Stauracanthus boivinii* (Ojeda 2001), most of them being narrow endemics (Table 1). These two processes might be enhanced and more noticeable under pine-tree dense canopy. Recruitment of some of these seeder species and, especially, above-ground biomass resprouting of these 'withering' resprouters occur mainly after fire (Ojeda 2001). Moreover, dense layers of needle litter would hamper the recruitment success of most germinating seedlings. Long-lived resprouter species, such as *Erica scoparia*, *E. australis* or *Daphne gnidium* (Table 1) persist longer under pine-tree cover, being seemingly more resistant (Figure 2). This difference in resistance to local extinction between regeneration life histories has remarkable consequences in decreasing the

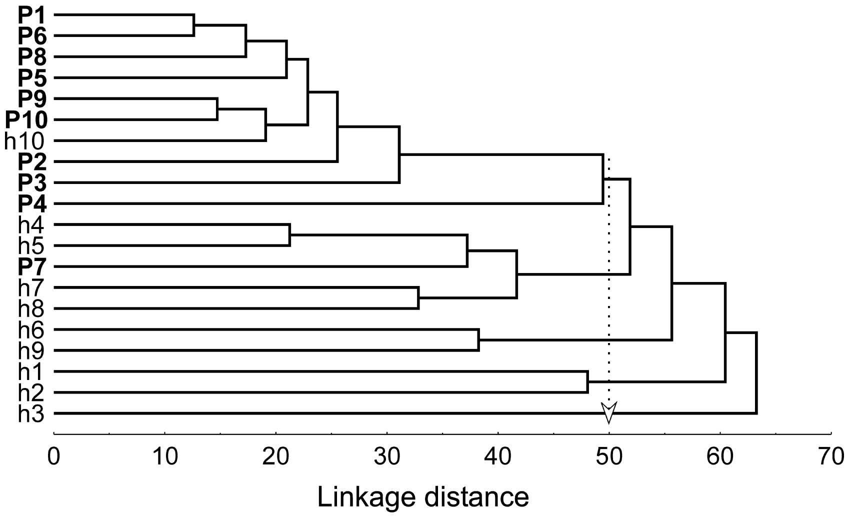

Figure 3. UPGMA tree diagram showing the clustering of the 20 subsamples. The horizontal axis denotes the Euclidean linkage distance between objects (subsamples). All pine-tree understorey subsamples but one (P7) were grouped together at the value 50 of linkage distance. h_i/P_i: pair of heathland/pine-tree understorey subsamples at the *i*th sampling site.

plant life-history diversity and, ultimately, in homogenizing the floristic composition of heath patches under pine trees (as reflected by Figure 3).

Nevertheless, we predict that long-lived resprouter species would finally undergo the same fate, and the heath vegetation under pine trees would subsequently collapse in old, dense pine stands, unless the pine-tree cover and needle litter are removed (e.g. by a wildfire or through habitat restoration). It is noteworthy that the only subsample under pine cover that was not clustered with the other ones was P7 (see Figure 3), a heath patch under 85% pine-tree cover which underwent a fast surface wildfire 10 years ago (in December 1991) that hardly scorched pine canopies. This fire also affected its neighbouring open heathland subsample.

Although it has not been within the scope of this study, we could anticipate three further negative effects of pine afforestation on mediterranean heathlands (see also Barbero et al. (1998) for a longer list of possible negative effects): (i) abandoned pine plantations, dense and having a thick layer of needle litter, represent a serious risk for uncontrolled, severe wildfires; (ii) the change of the structure of these afforested heathlands means the loss of this dense scrubland vegetation type for its associated fauna; and (iii) *E. scoparia* and, to a lesser extent, *E. australis* constitute part of the diet of game (red and roe deer) and free-range cattle (personal observations). They are among the more resistant woody species in pine-tree stands (see Table 1), but individuals lose foliage and are, subsequently, no longer valuable as food source for game and cattle. This not only means an actual loss of resources, but also implies an increase of browsing by these large herbivores on adjacent open heathland stands, which would have negative consequences if that increase exceeded the heathland's carrying capacity.

Mediterranean heathlands of the Strait of Gibraltar region are by no means valueless, degraded vegetation stages susceptible of being 'restored' (i.e. afforested). Instead, they are worth noting by their outstanding plant diversity and endemism levels (Ojeda et al. 2000a, 2001) and deserve to be considered in EU and IUCN conservation policies. We propose the implementation of further studies on the effects of pine-tree afforestation in other biodiversity aspects of these mediterranean heathlands, so as to be added up to the negative effects on woody plant diversity and endemism reported in this article. Should the negative effects on biodiversity surpass the potential economic benefits of pine afforestation, a policy of progressive elimination of these pine plantations and restoration of the mediterranean heathlands would be desirable.

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