

***Abies pinsapo* Boiss.: a protected species in a protected area**

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Abstract

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This paper presents the results of a study on the reproductive cycle of *Abies pinsapo*. The main reproductive aspects which affect the quantity and quality of the seeds, such as the low pollen dispersal capacity, the subdioecious condition and the combination growth form-tree architecture are discussed. The requirements for seed germination, seedling recruitment and some aspects of the species are analysed using all the available data.

Introduction

Abies pinsapo Boiss. is one of the 46 species of firs which are discontinuously distributed in the Northern hemisphere (Farjon 1990). *Abies pinsapo* was described for the first time by Clemente in the first decade of the 19th century. However, this description was lost and the species was later described by Edmund Boissier in 1938 (*Abies pinsapo* Boiss., Biblioth. Univ. Genève, sér. 2, 13: 402,406. 1839).

Abies pinsapo is a conifer endemic to the south of Spain and belongs to a circum-Mediterranean group of firs which is considered to be a relict species. The western Mediterranean species are separated into two sections: section *Abies* is represented by *A. alba* Miller (S. Europe) and *A. nebrodensis* (Lojac.) Mattei (Sicily), and section *Piceaster* (Fig. 1) by *A. pinsapo* Boiss. (S. Spain), *A. marocana* Trab. (N.W. Morocco), *A. tazaotana* Cózar ex Hug. Villar (N.W. Morocco), and *A. numidica* Carr. (N.W. Algeria). The species in section *Piceaster* are morphologically similar, having rigid leaves, and bracts smaller than the ovuliferous scales. Due to such similarities, many authors have grouped these taxa into three species: *A. pinsapo*, *A. tazaotana* and *A. numidica* (including *A. marocana* as subspecies of *A. pinsapo*; Maire 1952; Franco 1950) or into two species: *A. pinsapo* and *A. numidica* (Ceballos & Bolaños 1928; Farjon 1990), including *A. marocana* and *A. tazaotana* as varieties of *A. pinsapo* (Farjon 1990).

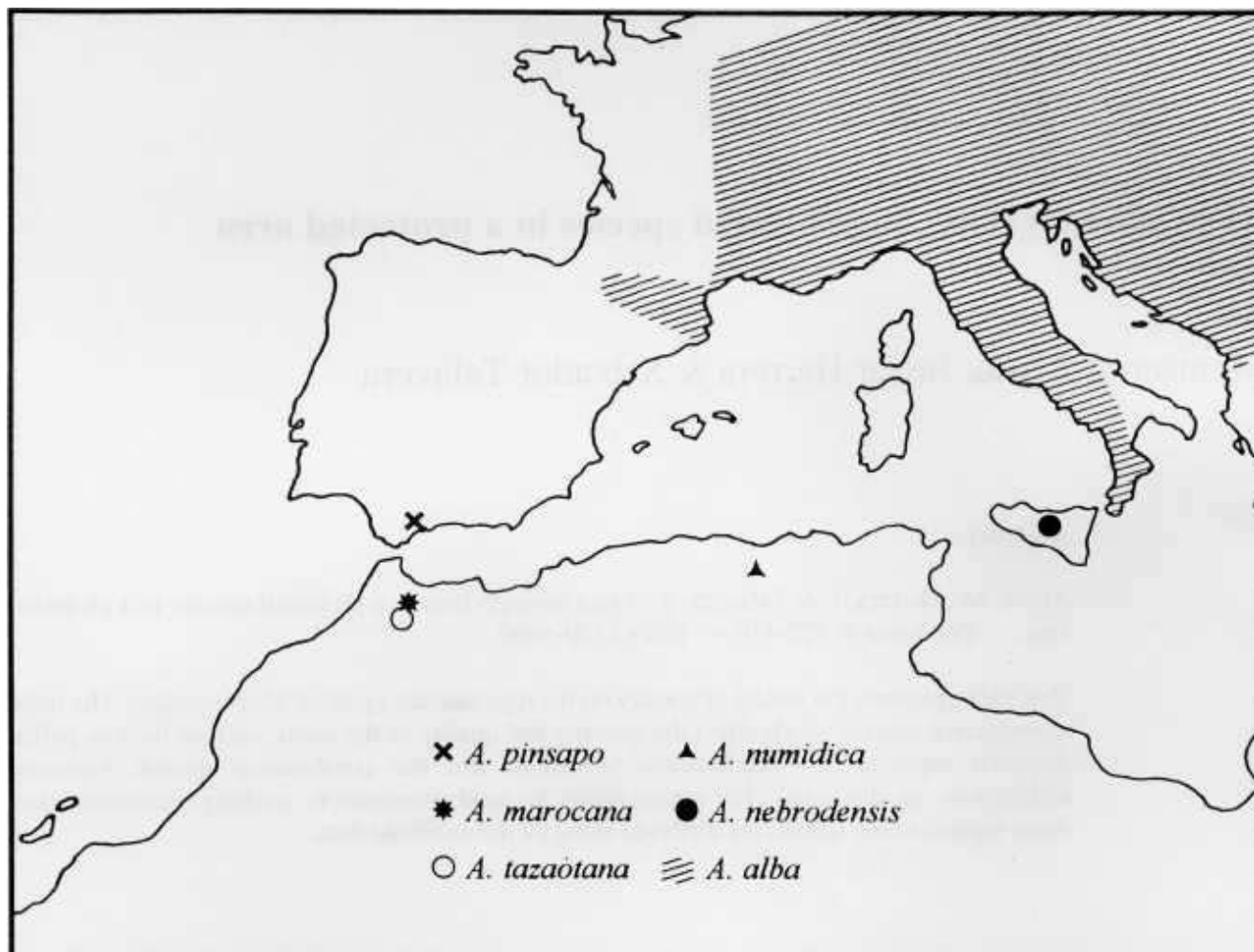


Fig. I. Distribution area of the section *Abies* according to Maire (1952) and Jalas & Suominen (1973).

Even though the specific limits of the genus *Abies* are not clear, the pinsapo populations of southern Spain have some different characters from those of N. Africa. For example, *A. pinsapo* has emarginate, mucronate bracts (subulate in *A. marocana* and *A. tazaotana*). The bracts of *A. pinsapo* are 1/3-1/4 shorter than the ovuliferous scales (c. 1/2 shorter in *A. marocana* and *A. tazaotana*; pers. observ. Fig. 2). Other characters such as number of leaf stomata or number and disposition of resin canals vary between trees and they cannot be used to distinguish these taxa (Martinez & Aisa 1995). Due to such morphological differences, we consider *A. pinsapo* Boiss. is an endemic species of the dolomitic and serpentine mountains of southern Spain. The information here presented come from the Doctoral thesis 'Biología del pinsapo (*Abies pinsapo* Boiss.)', University of Seville, Spain, 1993.

Distribution of *Abies pinsapo*

Currently, *Abies pinsapo* occurs at 900-1600 m in the Sub-Betic mountains, occupying a total of only 1200 ha. The most important forests are in Sierra de Grazalema (Cádiz Province), Sierra de las Nieves and Reales de Sierra Bermeja (Málaga province). However, isolated individuals or small populations of several individuals can be found at Ronda, Parauta, Istán, Monda, Ojén, Tolox, Yunquera, Estepona, Casarabonela and Cortes

de la Frontera (Málaga), and at Algodonales, Zahara de la Sierra, Grazalema and Benacoaz (Cádiz).

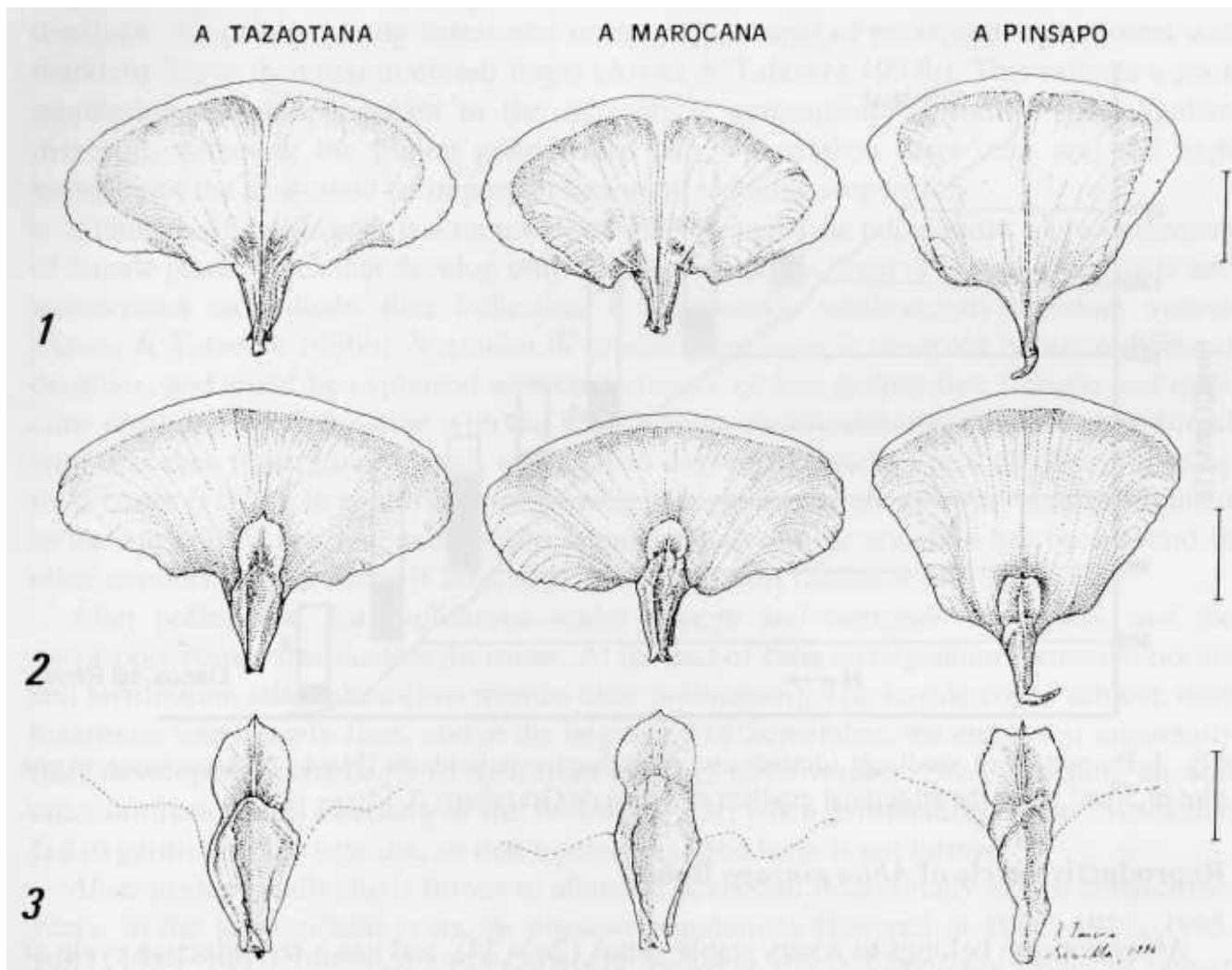


Fig. 2. Scales and Bracts of *Abies pinsapo* (Spain: Cadiz, Sierra de Grazalema, 1200 m, 12 Oct 1992, M. Arista, S. Talavera & J. Herrera 139392, SEV), *Abies marocana* (Morocco: Jbel Talamsentane, 1800 m, 8 Feb 1993, F. Ojeda 139393, SEV) and *Abies taaotana* (Morocco: bet Tassaor, 1700 m, 10 Feb 1993, F. Ojeda 139394, SEV). 1, ventral side of the ovuliferous scales; 2, dorsal side of the ovuliferous scales; 3, dorsal side of the bracts. 1 and 2 bar scales 10mm. 3 bar scale 8 mm.

Above 1100 m of elevation *Abies pinsapo* forms pure forests, but below 1100 m it forms mixed communities. In the tree layer of dolomitic soils *Abies pinsapo* forms a mixed oak-fir forest with species such as *Quercus rotundifolia* and *Quercus faginea*, their proportions varying with altitude (Fig. 3). The shrub layer, much more diverse, is composed of species such as *Daphne laureola* subsp. *latifolia*, *Hedera helix*, *Ruscus aculeatus*, *Iris foetidissima* and *Rubia peregrina* in the closed forest and of *Crataegus monogyna* subsp. *brevispina*, *Prunus spinosa*, *Ptilotrichum spinosum*, *Bupleurum spinosum*, *Thymus x arundanus*, *Ulex baeticus*, *Erinacea anthyllis*, *Bupleurum gibraltarium* and *Cistus albidus* in the gaps (Arista 1995). In the tree layer of serpentine soils and only occasionally on calcareous soils, *Abies pinsapo* occurs with *Quercus* and with other conifers such as *Pinus pinaster* and *Pinus halepensis*. The shrub layer in

serpentine soils is composed of *Erica terminalis*, *Genista lanuginosa*, *G. triacanthos*, *Cistus populifolius* subsp. *major*, *Bunium alpinum* subsp. *macuca*, *Cerastium gibraltarium* and *Alyssum serpyllifolium* subsp. *malacitanum*.

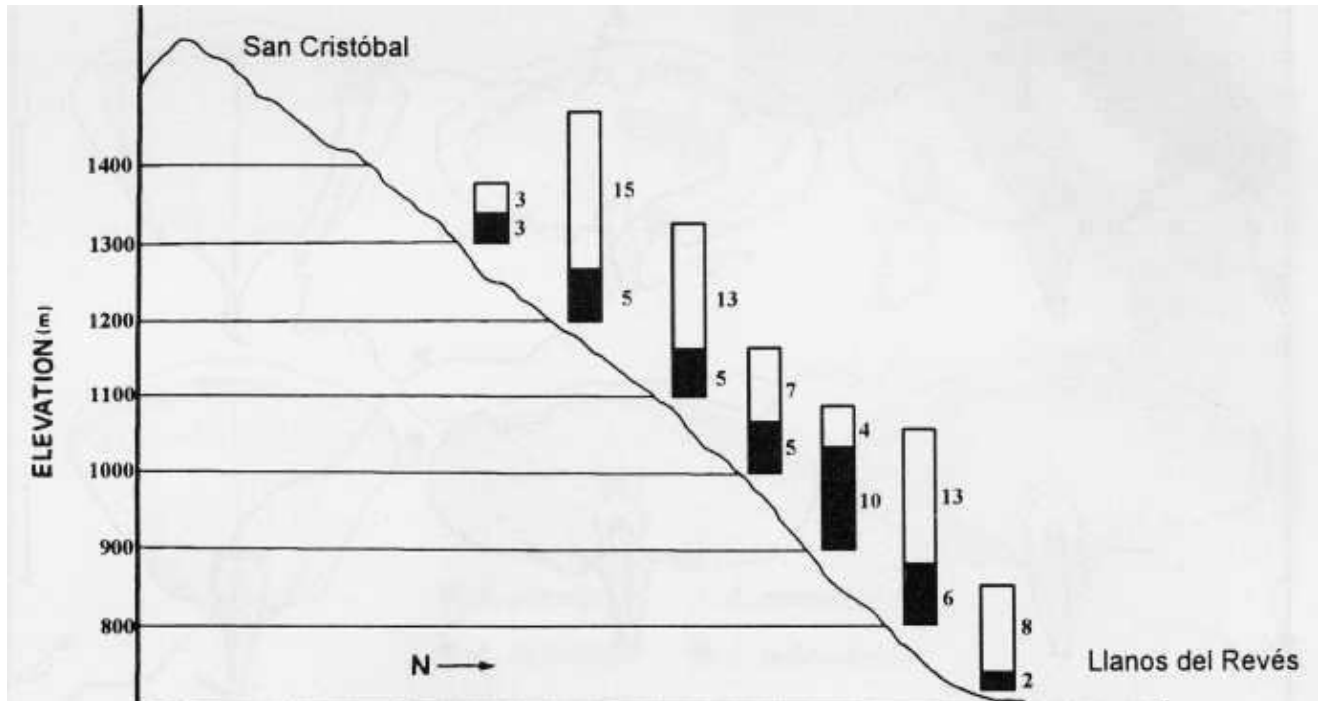


Fig. 3. Proportion of seedlings (dotted) and reproductive individuals (black) of *Abies pinsapo* per plot of 50 along the altitudinal gradient of Sierra de Grazalema (Cádiz).

Reproductive cycle of *Abies pinsapo* Boiss.

Abies pinsapo belongs to a very stable genus ($2n = 24$), and has a reproductive cycle of one year (Arista & Talavera 1994a) very similar to those described in other species of genus *Abies* (Miyake 1903, Hutchinson 1915, Eis 1970, Powell 1970, Owens & Molder 1977, Singh & Owens 1981, 1982). The differentiation of the reproductive buds occurs in late July; bracts or microsporophylls are initiated through August and into September, and the differentiation is completed at the end of the summer. Male buds are initiated on the abaxial surface of the elongating shoots of the lower branches, and at the end of the summer, these buds enter a resting phase. The dormancy is broken at the end of February and meiosis takes place. Mature pollen grains are shed in the five-celled stage between the end of April and mid-May. The female buds are also initiated in mid-July and are situated on the upper branches, on the adaxial surface of the elongating shoot. In mid-April bud burst takes place, and then meiosis occurs coinciding with pollination.

During pollen shedding, the scales of the female cones separate to provide a space through which airborne pollen grains enter. Therefore, seed cone receptivity is synchronised with pollen shedding within a tree. In an individual tree flowering lasted for six days (Arista & Talavera 1994b), but in the population the flowering period lasted one month. In recent years, flowering intensity and production of cones were similar in the three main forests of *Abies pinsapo*. The mean pollen cone production per tree ranged from 800 to 39 200 and the female production ranged from 62 cones per tree to 198.

Pollen fertility in *Abies pinsapo* is very high, nearly 100%, and *in vitro*, the pollen needs only distilled water and a temperature from 20 to 24°C for germination. Pollen dispersal capacity in *Abies pinsapo* was studied in Sierra de Grazalema at different stand densities. Air pollen density (measured using pollen traps) of pinsapo in open forest was markedly lower than that in closed forest (Arista & Talavera 1994b). This reflects a poor suspension of pinsapo pollen in the air, and in consequence a short-distance pollen dispersal. Although the pollen grains have two wings, their large size and the high humidity of the area could be important factors in reducing suspension.

Although *Abies pinsapo* is a monoecious species, in all the populations a predominance of female plants (trees that develop only female cones) was observed, with a few male and monoecious individuals, thus indicating a functionally subdioecious breeding system (Arista & Talavera 1996b). Variation in gender expression is observed between different densities, and could be explained as a consequence of tree architecture (female and male cone position) in combination with the growth form. At low density, trees are short-broad with branches from ground level, and tend to express themselves sexually by producing male cones (Fig. 4). In contrast, trees growing at high density are tall with branches limited to the top half of the tree, and tend to femaleness. A similar situation has been found in other conifers such as *Picea* (Caron & al. 1990) or *Pinus* (Smith & al. 1988).

After pollination, the ovuliferous scales enlarge and overgrow the bracts, and the megaspore begins free nuclear divisions. At the end of June archegonium formation occurs and fertilisation takes place (two months after pollination). The female cones achieve their maximum size in early June, and at the beginning of September, the embryo is apparently fully developed. Seeds begin to shed from October to November. Seeds reaching the soil enter dormancy until February of the following year, when germination begins. Seeds that fail to germinate this year die, so that a persistent seed bank is not formed.

Abies pinsapo individuals flower in alternate years and occasionally in two consecutive years. In the last fourteen years, *A. pinsapo* populations flowered in 1982, 1983, 1985, 1987, 1989, 1991, 1992 and 1994 (Arista & Talavera 1995). Cone crop cycles of two or three years are common in other fir species (Singh & Owens 1981, Shea 1989a, 1989b, Houle & Payette 1991). Synchronisation of the trees in flowering is probably due to an endogenous rhythm of the species controlled by intrinsic factors but that could be modified by extrinsic conditions (Powell 1977).

Cone production and fruit set from 1990 to 1993 in *Abies pinsapo* forests of Sierra de Grazalema, Sierra de las Nieves and Sierra Bermeja were very different. The fruit set was always higher among pinsapo trees of the Sierra de las Nieves and Sierra Bermeja relative to Sierra de Grazalema trees. This situation reflects the climate supported by the easternmost populations of *A. pinsapo*. In these populations rainfall during the flowering period is half that of the Sierra de Grazalema. This could involve a lower pollination index in Sierra de Grazalema trees, and thus a lower fruit set (Arista & Talavera 1995). Variation in fruit set was also found between different densities (Arista & Talavera 1996a). Low density *A. pinsapo* populations had markedly higher cone crop production and fruit-set per plant than those at high densities. Density even affected the cone size and the number of seeds per cone: cones from the high density zone were significantly larger and had a higher number of seeds than those from low density zone.

In the fully developed cone, all the ovules reach the full size although some of them have no embryo.

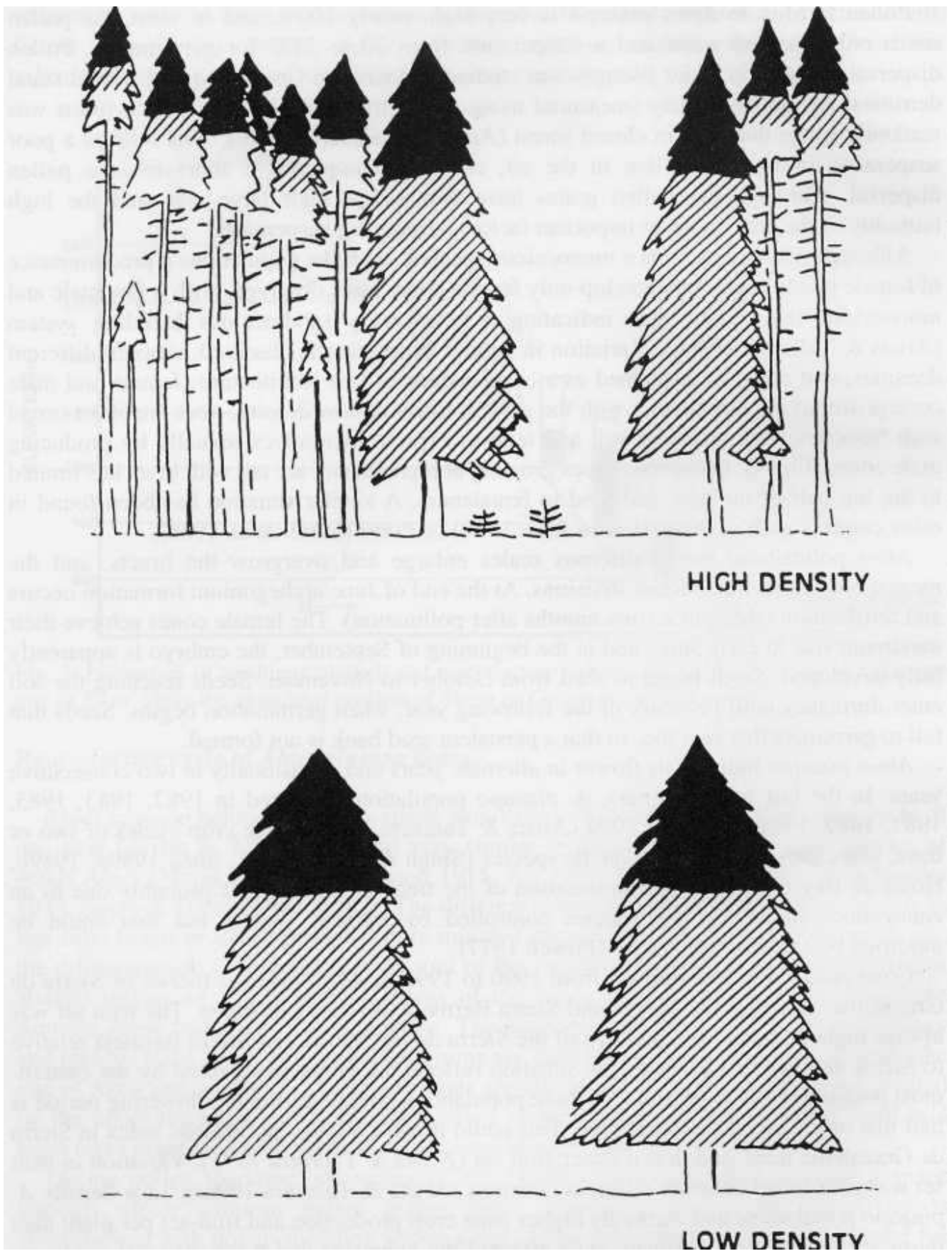


Fig. 4. Morphology of *Abies pinsapo* trees living in high and low density. The black zone indicates the female cone position and the striped the male cone position.

Seed crop viability between densities is markedly different, e.g. in 1992, average seed viability in the low-density zone was 21 %, but some trees had only 3 % of viable seeds. In the high density populations seed crop viability averaged 82 % with a range of 54 %-93.3 % (Arista & Talavera 1996). Differences in seed viability are also found in response to gender expression of the trees in low and high density populations. At high density, trees that produced only female cones during the flowering period had greater seed crop viability than those with male and female cones (averages of 80 % and 63.3 % respectively). In contrast, low density zone trees with only female cones at flowering had lower seed crop viability (average 8.3) than those with both male and female cones (average 31.8). This reflects differences in quantity and quality of the available pollen during the pollination period.

Germination of *Abies pinsapo* seeds takes place in February. In the laboratory, germination of seeds exceeding 60 mg (those that have an embryo, Arista & al. 1992) is near 100 %. In the field, seed germination depends on the place in which the seeds fall. Inside the forest, the gaps are the best places for germination, ranging from 26.6 % to 63.3 % (Arista 1993b). Under the forest canopy, germination is very low, near 0%. The highest mortality of seedlings occurs in the first year of life, after which mortality is practically zero. However, survival depends on the place in the forest at which germination occurs. In forest gaps, survival is very high even in the first year, with only 18 % of mortality. In contrast, in the interior forest mortality in the first year of seedling life is 52 %. Thus, mortality under the forest canopy is always higher than in gaps.

One-month-old seedlings from seeds collected from trees at low density have a greater vigour than those from the high density zone. This situation together with the different seed viability in trees of high and low density populations, could have important consequences. The lowered seed viability found in monoecious trees vs. female trees in high density stands suggests a possible inbreeding depression in the endogamous embryos of *A. pinsapo*, and consequently, the selective abortion of some of them. The theory that there is inbreeding depression in *A. pinsapo* is supported firstly by differences in seed crop viability and secondly by the higher vigour of seedlings from high density populations (Arista & Talavera 1996a). The results of this study are important because they have several implications for the collection and production of *A. pinsapo* seeds for reforestation plans. They provide additional evidence against the discredited practice of collecting cones from open-grown semi-isolated individuals. Although these trees often produce abundant, easily-collected cones, a significant proportion of seeds are not viable, due to high rates of self-fertilisation. Where the seeds are viable a subsequent lack of vigour in the seedlings results from selfing. The situation described here suggests that the natural regeneration of low density populations of *Abies pinsapo* is difficult.

Conservation

At present, most of the pinsapo forests are included in the so-called 'Network of Protected Areas in Andalusia': Sierra de Grazalema Natural Park (1984), Sierra de las Nieves Natural Park (1989) and Los Reales de Sierra Bermeja Nature Area (1989). Both Sierra de Grazalema and Sierra de las Nieves Natural Parks have been declared as Biosphere Reserves by UNESCO, in 1977 and 1995 respectively. At European level, the

pinsapo forests have been included in the Habitats Directive 92/43 and the species is protected by Decreto 104/94 in the 'Andalusian Catalogue of Threatened Wild Plants'.

In the pinsapo forest of Sierra de Grazalema, there seems to be no problem for natural regeneration. *Abies pinsapo* does not seem to be a long-lived species. The oldest pinsapo forest is at Cañada de los Cuervos, in the Sierra de las Nieves, Málaga province. In this forest, the oldest trees are under 200 years old. In Sierra de Grazalema there are no trees approaching this age (the oldest fir was about 123 years old), probably because it regenerated at the beginning of the century after an intense fire.

The *Abies pinsapo* forest of Sierra de Grazalema has a balanced multi-age condition in which recruitment and mortality rates tend to be constant. The proportion of seedlings in Sierra de Grazalema is very high (of 69%) and they have practically no signs of herbivore damage (less than 5% of the seedlings are consumed by herbivores). Size structure is very different in the other two important forests of *A. pinsapo*. In Sierra de las Nieves, the proportion of young individuals is very small (only 4%), indicating a low rate of recruitment. This situation reflects firstly, the strong herbivore damage caused by both wild and domestic livestock and secondly, the strong pruning on the lower branches of the trees which decreases the male cone crop production and in consequence, seed viability due to lack of pollination, and thirdly the markedly low level of heterozygosity of this population (Pascual & al. 1993), which probably affects seed vigour. In Sierra Bermeja, diameter distribution resembled a normal distribution, with trees of 40 cm DBH as the most frequent. This could reflect the selective choice to which the trees greater than 60 cm DBH had been submitted. In this population the seedlings also suffer herbivore damage, but at lower levels than in Sierra de las Nieves.

There is a significant negative correlation between tree density (a measurement of canopy cover) and number of pinsapo seedlings, indicating that *A. pinsapo* establishment rates are higher in the light gaps (Arista 1995). The small number of seedlings which survived under forest canopy suffers suppression. *Abies pinsapo* is a moderately shade-tolerant species, which can survive until it is 40 years old under forest canopy. During this time, it constitutes a seedling bank, which probably reoccupies the available space when a gap is formed.

The main pathogen agents of the pinsapo forest are the coleopteran *Cryphalus numidicus*, the lepidopteran *Dioryctria aulloi* and the fungi *Armillaria me/lea* (Vahl. Fr.) Kumm and *Heterobasidium annosum* Bres. (Cobos 1994). Little is known about the incidence of such forest pests; but there are some data on predation percentage of seed cones by *Dioryctria aulloi* (Arista & Talavera 1995) in Sierra de Grazalema, but it seems that the highest pathogen impact occurs in the Sierra de las Nieves population. This is being studied at present.

In conclusion, natural regeneration in the Sierra de Grazalema pinsapo forest is guaranteed due to both the good seed quality and the absence of herbivores (allowing seedling recruitment). Outside the closed forest, regeneration is more difficult and a potential genetic improvement would be possible with supplementary pollination management as has been suggested in other conifer forests (Franklin 1981, Askew 1992) or with artificial seed rain using vigorous seeds. Regeneration in Sierra de las Nieves and Sierra Bermeja forests requires mainly seedling protection from herbivores.

The situations described have been found in the absence of major events such as fire. *Abies pinsapo* is a moderately shade-tolerant species, which could dominate where there is

no exogenous disturbance, but less tolerant species (such as *Q. rotundifolia* and *Q. faginea*) are capable of persisting as minor component in the canopy of forest capturing space when major events occur (Barden 1979, 1981). In addition, *Abies pinsapo* seeds neither germinate after fire nor resprout but *Quercus* spp. do both. Therefore, fire, a recurrent disturbance in Mediterranean ecosystems, could be an important factor in determining species composition and dynamics, and is probably the most important danger in *A. pinsapo* forests.

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