Abies pinsapo forests in Spain and Morocco: threats and conservation

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Abstract The conifer forests of the Mediterranean Basin have been subjected to overuse by humans since ancient times. Some species have survived in inaccessible refuges but the ranges of other species have been greatly reduced by the effects of clearance for agriculture, livestock raising, illegal felling and, in some cases, fire. The firs are no exception and some now exist only as relict species. *Abies pinsapo* is an example, with the species surviving in only three enclaves in southern Spain and two in northern Morocco. Until the mid 20th century *A. pinsapo* forests were subject to major anthropogenic pressures, and in Spain they were under constant threat of overuse until they were acquired by the State. Conservation efforts have now, however, been undertaken in both Spain and Morocco, and the fact that all the *A. pinsapo* forests are covered by some form of protection preserves them from further inappropriate use or exploitation. These forests are now recovering after years of intensive grazing and use of their timber for construction, firewood and charcoal making. However, these relict forests face the new threats of climate change, arson and the appearance of pests. The limited area occupied by these forests makes them highly vulnerable to disturbance.

Keywords *Abies pinsapo*, conifer, forest, Mediterranean, Morocco, fir, Spain, threats

Introduction

The biodiverse mountainous areas of the Mediterranean region (Cowling et al., 1996) were a refuge for certain conifer taxa (species of *Abies*, *Cedrus*, *Cupressus*, *Juniperus* and *Pinus*) during glacial periods (Bennett et al., 1991). Some of these taxa have been widely used as sources of wood and food (Farjon et al., 1993) and, as a result, many of these mountain conifers have been overexploited and are now of considerable conservation concern.

In the Taurus Mountains of Turkey, particularly around the ancient city of Sagalassos, the forests have been subjected to human use for thousands of years (Vanhaverbeke & Waelkens, 2003, cited in Fontaine et al., 2007) and inappropriate silvicultural practices continue to threaten *Abies cilicica* (Fontaine et al., 2007). In Lebanon 10 conifer species are threatened to varying degrees by fragmentation and deterioration of their habitat (Talhouk et al., 2001). Elsewhere in the eastern Mediterranean *Abies nordmanniana* subsp. *equi-trojani, Abies borisii-regis* and some populations of *Pinus heldreichii* require management plans to guarantee their survival, as do the populations of *Cedrus brevifolia* in Cyprus (Quézel & Barbero, 1990). Most of the conifer forests in the southern Mediterranean are threatened as a result of deforestation and overgrazing (Barbero et al., 1990). In the Maghreb of Morocco there is particular concern for *Abies numidica, Abies pinsapo* var. *tazaotana, Pinus nigra* subsp. *mauritanica*, *Cupressus atlantica, Cedrus atlantica, Tetraclinis articulata* and *Juniperus thurifera* (Quézel & Barbero, 1990; Quézel, 1991).

In Spain human activity and climate change are affecting the regeneration of *Juniperus communis* in the south-east mountains (García et al., 1998). In northern Sicily *Abies nebrodensis* has been reduced to 29 individuals (Parducci et al., 2001) and the species is categorized as Critically Endangered on the IUCN Red List (Farjon et al., 2006). *A. numidica* in Algeria and *A. pinsapo* var. *tazaotana* in Morocco are categorized as Vulnerable (Conifer Specialist Group, 1998). Although the other Mediterranean firs are categorized as Lower Risk (i.e. they have been assessed and found not to be in danger of extinction), they still face the threats common to all Mediterranean mountain conifer forests, i.e. the combination of felling (often illegal), livestock raising, farming and repeated fires.

From the time *A. pinsapo* was described by Boissier in 1837 (Barbey, 1931) until forests containing the species were protected by a variety of measures in the 1970s the species was subject to intense human pressure that fragmented and reduced its area of extent in both Spain and Morocco. The descriptions of the two Moroccan varieties were made in the early 20th century. Var. *marocana* was described by Ceballos & Martín-Bolaños (1928) and var. *tazaotana* by Sánchez-Cózar (1946). It is likely that the isolation of these populations from human influence until the 19th century, due to difficulties of access, and the low mechanical properties of their wood in comparison with pine, are responsible for their survival.

However, the original area of *A. pinsapo* is now greatly reduced by timber harvesting, fire and overgrazing. Although felling for timber was not the principal cause of the reduction in extent of *A. pinsapo* forests, both single-species and mixed, there are records of timber occasionally being

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Received 11 September 2008. Revision requested 6 January 2009. Accepted 23 February 2009.

removed illegally, or without silvicultural criteria, and the natural structure of the forest has consequently been modified (Soto, 2006). Greater damage was caused by overgrazing, which prevented natural regeneration, particularly in sites with poor soil or in full sun (Ceballos & Vicioso, 1933). Fire has also destroyed *A. pinsapo* forests and caused a decline in their area of extent (Vega, 1999).

Although *A. pinsapo* forests are now protected they are still threatened, particularly by fire and climate change. Although *A. numidica* and *A. pinsapo* may be more resistant to climate change than the other circum-Mediterranean firs, because they adapt better to dry periods (Aussenac, 2002), the presence of pests associated with climate change could endanger their survival.

Here we review the current distribution of *A. pinsapo*, describe the effects of previous human influences on the species and the threats it now faces, and describe the conservation efforts so far undertaken and those still required.

Distribution and ecology

A. pinsapo has a very limited area of distribution. It is found in only five enclaves: three in the south of Spain and two in the north of Morocco.

Populations in Spain

A. pinsapo occurs in three areas in the high mountain ranges of the westernmost part of the Betic Cordillera, in Serranía de Ronda, spanning the provinces of Málaga and Cádiz (Fig. 1). The species occurs in shaded locations with a northerly or occasionally easterly or north-easterly exposure (Ceballos & Ruiz de la Torre, 1979).

In Málaga the species occurs at 1,000–1,800 m in the humid Mediterranean vegetation zone. The *A. pinsapo* forest in Los Reales de Sierra Bermeja (Fig. 1c), comprising 50 ha in 1933 (Ceballos & Vicioso, 1933), is in the municipalities of Genalguacil, Estepona and Casares, at altitudes of 1,300–1,400 m on peridotites. In 2008 this *A. pinsapo* forest occupied an area of only c. 35 ha and was in regression because of major fires in the area, which have divided it into three groves. Sierra de las Nieves is the most extensive area of *A. pinsapo* in the province of Málaga (Fig. 1b, Plate 1a). It extends over the municipalities of Ronda, Tolox and Yunquera at altitudes of 1,000–1,800 m on limestone soils. There are also isolated groves in the ranges of Alcor, Caparaín, Real, Istán, Río Verde and Gialda (Ceballos & Vicioso, 1933; Ceballos & Ruiz de la Torre, 1979). The *A. pinsapo* forest in Sierra de las Nieves expanded from 1,000 ha in 1933 to 2,871 ha in 2008.

In the province of Cádiz *A. pinsapo* is found only in Sierra del Pinar, in the municipality of Grazalema (Fig. 1a, Plate 1b), where it grows on limestone at altitudes of 1,000–1,650 m. This forest expanded from 200 ha in 1933 to 418 ha in 2008. Groves and isolated stands are also found in the western part of Monte Prieto, the sides of El Montón and on the northern slopes of Zafalgar and Los Pinos (Ceballos & Martín-Bolaños, 1930; Ceballos & Ruiz de la Torre, 1979).

A. pinsapo occurs in locations with average rainfall of $>1{,}000$ mm but nevertheless copes well with drought, although total rainfall is >100 mm during summer in all of its locations (Ceballos & Ruiz de la Torre, 1979). It grows in locations that have more hours of sunshine than areas where other Mediterranean firs grow and is capable of colonizing steep slopes, including eroded rocky ground. It occurs with drought tolerant oaks (*Quercus faginea, Quercus alpestris, Quercus ilex* and *Quercus suber*) and other conifers such as *Pinus pinaster*, and less commonly with *Pinus halepensis*, in this case in Sierra de la Yunquera (Ceballos & Ruiz de la Torre, 1979).

Populations in Morocco

A. pinsapo occurs in the western Rif in two enclaves (Fig. 1d). The northernmost is on Mount Tazaout (Plate 1d), also known as Yebel Tazaout, in the Beni Sey-yel region, where *A. pinsapo* var. *tazaotana* occupied an area of 493 ha at altitudes of 1,400–1,700 m in 2008. To the south *A. pinsapo* var. *marocana* spans the Chefchaouen mountains (Plate 1c), reaching as far as Ametráx, with a total area of 2,531 ha at altitudes of 1,400–2,100 m (Liu, 1971). The soil on which *A. pinsapo* grows is limestone. At high altitudes near mountain peaks the trees show signs of limited growth because of the constant winds and shallow soil. The rainfall in the species' area of occurrence averages $>1{,}000$ mm (Charco, 1999). Unlike the Spanish *A. pinsapo* forests, those in the Rif rarely form single-species forests but mix with Atlas cedars *Cedrus atlantica*. In some places the forests comprise firs, cedars and a conifer absent from the Andalusian *A. pinsapo* forests, *Pinus nigra* subsp. *mauritanica*, which is smaller than the *P. nigra* var. *salzmannii* found in the Betic Cordillera. In the lower, warmer and dryer areas *A. pinsapo* occurs with *Tetraclinis articulata*, *Olea marocana* and *Quercus coccifera*, and in the more humid, cooler areas it occurs with *Quercus ilex*. Of all the firs in the western Mediterranean, *A. pinsapo* var. *tazaotana* grows the tallest and has the greatest diameter.

Threats

Timber harvesting

Unlike other Mediterranean conifer species, such as *Cedrus libani*, which have been widely harvested throughout history (Speiser, 1955; Wilson, 1955), *A. pinsapo* has not been extensively felled for timber. This is probably because of the difficulty of access to the

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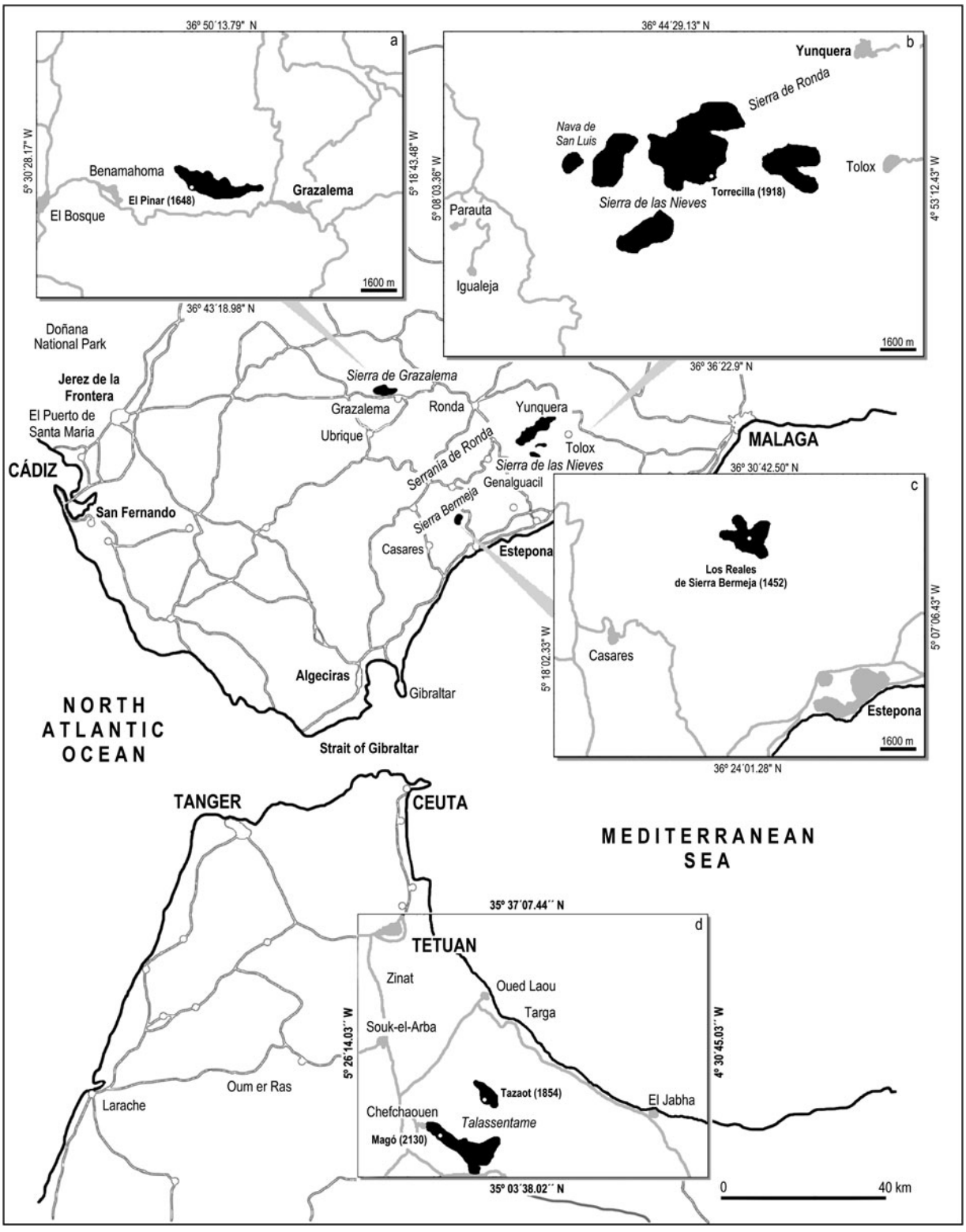

FIG. 1 Distribution of *Abies pinsapo* forests (black shaded areas), which are restricted to southern Spain and northern Morocco: (a) Sierra de Grazalema (Cádiz), (b) Sierra de las Nieves (Málaga), (c) Los Reales de Sierra Bermeja (Málaga), (d) Tazaout and Talassemtane (Morocco).

forests, the fact that the land occupied by the trees is unsuitable for farming because of the orography, and because *A. pinsapo* timber is no match in quality compared to pine or cedar.

Nevertheless, certain projects at various periods made use of *A. pinsapo* wood locally (Chapman & Buck, 1910). There are written records of *A. pinsapo* timber being used in the building of ships in the 16th century and for the

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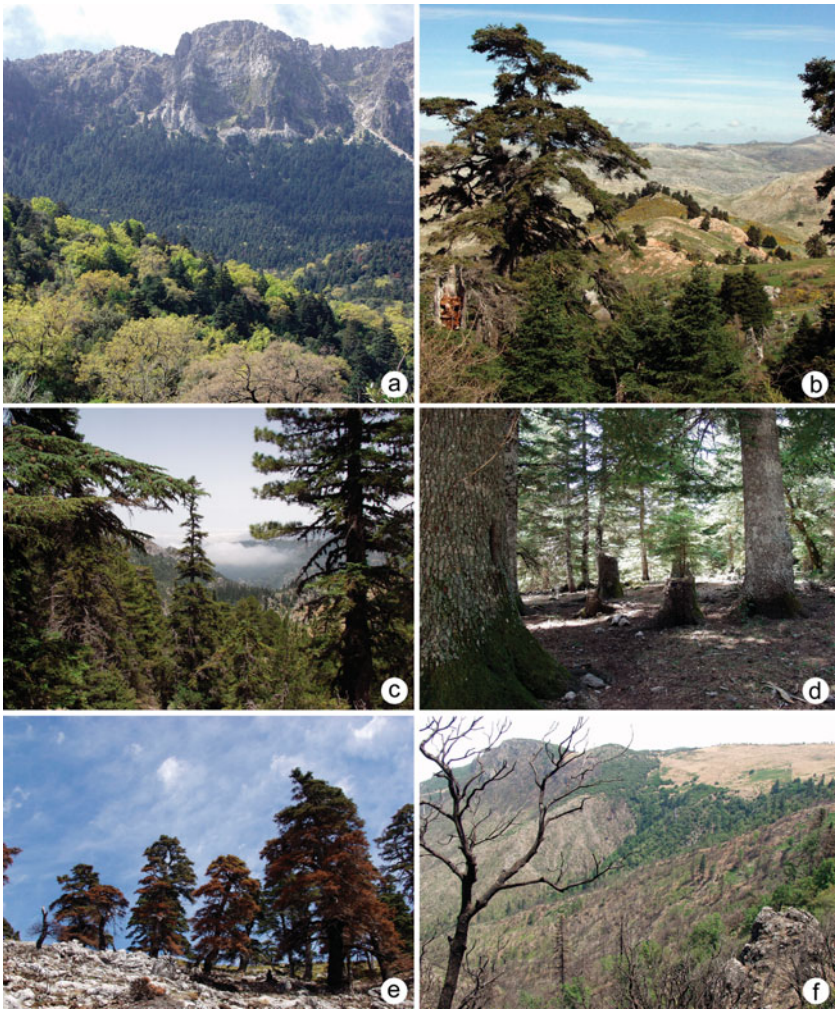

PLATE 1 *Abies pinsapo* forests. (a) Sierra de las Nieves (Spain). (b) Sierra de Grazalema (Spain). (c) Talassemtane National Park (Morocco). (d) Tazaout (Morocco): the stumps remained after the summer of 1946, from *A. pinsapo* felled for the building of a log hut as a base from which the Spanish Forest Service made an inventory of Mount Tazaout. (e) Sierra de las Nieves (Spain): a fire in 2004 affected trees in full sun that will not be able to regenerate. (f) Tazaout (Morocco): effects of the 2002 forest fire on the northern slope of Tazaout, in an area of 200 ha (photograph from 2004, showing almost no regeneration).

Algeciras-Ronda-Boadilla railway in the early 20th century. *A. pinsapo* was also used for the seating at the bull ring in Ronda (Peraza, 1964; Prioton, 1964), in mining, and in ice pits (in which snow was stored during the winter in alternate layers separated by *A. pinsapo* branches so that the ice that was formed could be used in the summer; Rodríguez, 1999). Much of the timber of *A. pinsapo* forests was used as paper pulp (Ceballos & Ruiz de la Torre, 1979). Although as fuelwood and charcoal it is of poor quality, *A. pinsapo* was sometimes used for these purposes locally (Barbey, 1931).

In 1904 and 1905, without following any silvicultural criteria, forest owners in Sierra del Pinar, Grazalema, felled c. 15,000 *A. pinsapo* for the construction of the first section of the railway line between Ronda and Algeciras. Difficulties encountered in hauling and transporting the logs resulted in most of them being discarded in the forest. In 1906 there was a change of ownership and the refusal of the new owner to let local workers make charcoal with the wood resulted in an intentionally-lit fire that affected 20 ha. In the 1930s *A. pinsapo* trees were taken from the Berranga and Las Tablas estates, in Sierra de Las Nieves, for the second section of the Ronda-Boadilla railway line. In Villaluenga del Rosario, in the province of Cádiz, a 1 ha stand was destroyed for making charcoal in 1931 (Soto, 2006).

Logging, in accordance with controlled logging plans, occurred in the *A. pinsapo* forests of the Rif in the first half of the 20th century, when Spain held the area as a Protectorate (Charco, 1999). The protective measures that apply to the *A. pinsapo* forests in Spain and Morocco now prohibit logging, and felling is only permitted for the purpose of creating fire-breaks.

Fire

The earliest recorded loss of *A. pinsapo* forests due to fire is from 1570 (Hurtado de Mendoza, 1842). In Sierra de Alcaparaín (municipality of Carratraca), Ceballos & Vicioso (1933) cite the disappearance in c. 1920 of the group of *A. pinsapo* trees listed by Laguna (1884), as a result of repeated fires. A stand of c. 1 ha on the bank of the Guadaiza River in Sierra Palmitera disappeared as a result of fire in 1975. In 1991 fire destroyed 1,000 ha of maritime

https://doi.org/10.1017/S0030605310000190 Published online by Cambridge University Press

pine *Pinus pinaster* and scrub in Sierra Blanca and Sierra Real, in addition to all the *A. pinsapo* trees in Sierra Real, some of which were 360 years old.

In Sierra Bermeja forest fires have fragmented and degraded the enclave of *A. pinsapo*, reducing the area of 50 ha in 1933 (Ceballos & Vicioso, 1933) to 35 ha in 2008. In the summer of 2004 fire destroyed an old stand with a south-east exposure in Sierra de las Nieves (Plate 1e) that cannot be restored because of the southerly exposure. A fire on the northern slope of Tazaout in 2002 affected an area of 200 ha. A visit to the area in 2004 confirmed that there was almost no regeneration because of the steep slope and competition from less demanding species (Plate 1f).

Although *A. pinsapo* lacks the resprouting ability characteristic of many Mediterranean plants (Keeley, 2006) it reacts to fire by adaptation. The species expands its cover and the diminished solar radiation hinders the build up of inflammable material (Vega, 1999). *A. pinsapo* is, however, not particularly inflammable (Rodríguez, 1999).

Until the second half of the 20th century grazing and charcoal making were the two main causes of fire in the *A. pinsapo* forests. Fires now normally only occur as a result of carelessness or arson. Although some groves of *A. pinsapo* have been lost as a result of fire (Soto, 2006) some, such as the Grazalema forest, have not been affected by fire for nearly 100 years (Arista, 1995).

From 1968 to 2007 the total loss of *A. pinsapo* forests was 564.7 ha, whereas during 2004-2008 only 1 ha was lost (López Quintanilla, pers. comm.). The intervals of time between the fires in Sierra Bermeja, which occurred in 1840 and 1865, and between those of 1932, 1966 and 1973, resulted in a forest with trees of different ages that, in conjunction with the mature trees, gave great stability to the *A. pinsapo* forest (Vega, 1999).

Fire destroys 700,000–1,000,000 ha of forest in the Mediterranean Basin every year (Vélez, 2000). Many of the areas recover through the adaptation mechanisms that many Mediterranean species have to fire (Pickett et al., 1987). However, fire-damaged *A. pinsapo* forests regenerate poorly in shady exposures and are incapable of regenerating in full sun.

Agriculture and livestock

Agriculture and farming techniques have also contributed to the decrease in the area of *A. pinsapo*, as in the case of the forests in Lajares and Caina, which were affected by several fires in the 19th century as a result of management of land occupied by vineyards. Fire was also used as a way to renew or increase grazing areas for livestock and this was the reason for the 1928 fire in the *A. pinsapo* forest in Barranco de los Mármoles, intentionally lit to increase pasture land for goats (Rodríguez, 1999). Pasturing continues under strict control in the three areas of Spanish *A. pinsapo* forests in Grazalema and Sierra Bermeja but it does not represent the same degree of threat as it did prior to the 1950s (Arista et al., 1997).

Pests

Drought affects the susceptibility of *A. pinsapo* to infestation by pests. The *A. pinsapo* in Sierra Bermeja have sometimes been infested with the basidiomycete *Armillaria mellea*, although the forest was never threatened and has fully recovered (Arista et al., 1997). Infestation by the lepidopteran *Dioryctria aulloi* has also been recorded; its life cycle is strongly influenced by climate, as seen in the incidence of this pest during the drought of 1991–1995 (Arista et al., 1997). However, the irregular annual seed production of *A. pinsapo* provides trees with a natural defence against establishment of this insect. During this drought a more serious attack by the coleopteran *Cryphalus numidicus* occurred, resulting in the death of some of the trees. In the Yunquera *A. pinsapo* forest this borer was accompanied by the appearance of the basidiomycete *Heterobasidion annosum* (Navarro et al., 2003). The *A. pinsapo* forests are also affected by the homopterans *Mindarus abietinus*, *Cinara pectinatae* and *Cinara confinis* (Cobos et al., 1998). The damage caused by *C. confinis* can lead to the death of twigs and branches.

Other threats

The fragmentation of the original *A. pinsapo* forests has led to isolation in small stands and in some cases isolated individuals. The average seed viability of *A. pinsapo* at low densities is only 21% whereas in dense forests it can be 82% (Arista & Talavera, 1996). The formation of biogeographical islands (MacArthur & Wilson, 1967) causes progressive deterioration in the genetic variability of *A. pinsapo*, leading to endogamy (Arista & Talavera, 1996). Lower rainfall and higher evapotranspiration because of climate change are a potential threat. In the early 1990s several *A. pinsapo* died from a combination of water stress and the appearance, propitiated by climate, of pests (Génova, 2007).

Discussion

The climate dynamics of the Strait of Gibraltar and the mountains on both sides of the Strait make the area a favourable enclave for *A. pinsapo*. The mist, high rainfall and altitudes up to 2,000 m give rise to unique bioclimatic conditions. Although the Spanish *A. pinsapo* are smaller than those of the Rif, in Sierra Bermeja they are more similar in shape to the firs of the Rif than to those of Grazalema or Sierra de las Nieves. The wood of the Moroccan varieties and the Sierra Bermeja *A. pinsapo* is also similar (Esteban et al., 2007). However, the trees in the

Table 1 International and national regulations for the conservation of *Abies pinsapo* in Spain and Morocco.

Organization	Regulation	Date	Scope	Details
International regulations				
UNESCO	Biosphere Reserve	1977	Sierra de Grazalema	Protection of 300 ha of *A. pinsapo*
European Union	Council Directive 92/43/CEE	21 May 1992	Forest ecosystems that include *A. pinsapo*	Inclusion of *A. pinsapo* forests whose preservation requires creation of special conservation zones
UNESCO	Biosphere Reserve	1995	Sierra de las Nieves	Relict *A. pinsapo* forest
European Union	Council Directive 92/43/CEE	19 July 2006	List of places of community interest in Mediterranean biogeographical region	Protection of Sierra de Grazalema (ES0000031), Sierra de las Nieves (ES6170006) & Los Reales de Sierra Bermeja (ES6170004)
National regulations				
Andalusian Parliament (Spain)	Creation of Sierra de Grazalema Natural Park	18 Dec. 1984	Sierra de Grazalema	Ecosystem is conserved & protected from previous abuse. Legal protection of Sierra de Grazalema
Andalusian Parliament (Spain)	Ratification of UMMP[1] for Sierra de Grazalema Natural Park	27 Dec. 1988	Sierra de Grazalema	Management & recovery of *A. pinsapo* forests
Andalusian Parliament (Spain)	Inventory of Protected Natural Areas in Andalusia; Creation of Sierra de las Nieves Natural Park & Los Reales de Sierra Bermeja Natural Site	18 July 1989	The three Spanish *A. pinsapo* forests	Conservation policies & economic development are brought into line
Andalusian Parliament (Spain)	Law on wild flora & fauna	28 Oct. 2003	The three Spanish *A. pinsapo* forests	*A. pinsapo* is listed as a threatened species
Andalusian Parliament (Spain)	Ratification of the NRMP[2] & UMMP[1] for Sierra de las Nieves Natural Park	9 Dec. 2003	Sierra de las Nieves	The largest Spanish *A. pinsapo* forest
Andalusian Parliament (Spain)	Ratification of the NRMP[2] & UMMP[1] for Sierra de Grazalema Natural Park	18 April 2006	Sierra de Grazalema	Warning on danger to Spanish *A. pinsapo* forests from *Heterobasidion annosum* & *Cryphalus numidicus*
Ministry of Agriculture (Morocco)	Creation of Botanical Reserve	1972	Chefchaouen mountains	*A. pinsapo* var. *marocana* comes under protection
High Commission for Water, Forests & Desertification Control (Morocco)	Creation of Talassemtane National Park	2004	Rif mountains (provinces of Chefchaouen & Tetuán)	Moroccan varieties are conserved & protected

[1]UMMP, Use and Management Master Plan
[2]NRMP, Natural Resources Management Plan

Sierra Bermeja *A. pinsapo* forest are the least tall, and have the smallest diameters and a twisted form. The Yunquera *A. pinsapo* forest has regenerated well, with a sufficiently high tree density that it requires silvicultural treatment. The Grazalema *A. pinsapo* forest was threatened by felling and excessive stock raising in the early 20th century. It now consists of mostly even-aged trees of homogeneous form with high diameters but there is little regeneration.

The Moroccan *A. pinsapo* forests are in better condition than those in Spain, not only because they have been better preserved because of their isolation from populated areas and the consequently lower anthropogenic impacts, but also because they occur in an area with higher rainfall and a wider altitudinal range. In the event of any climate change the Moroccan *A. pinsapo* would therefore have a greater chance of persistence. Of all the *A. pinsapo* forests, Tazaout has the largest trees, attaining heights of up to 50 m and base diameters of 1.30 m. The vitality of this forest is evident in the intense regeneration and, although *A. pinsapo* is mixed with maples, cedars and maritime pine *P. pinaster* and European black pine *Pinus nigra* , it is dominant.

The poorer condition of the Spanish *A. pinsapo* forests leads not only to smaller-sized trees but also to greater vulnerability to pests. The drought of 1991–1995 caused a loss of trees growing in the least favourable conditions and if such droughts recur there are likely to be further such losses. While the exposures in the Betic Cordillera are always northerly, *A. pinsapo* in Morocco prospers in northerly, westerly and occasion southerly exposures, influenced by the position of the mountains in relation to the incoming direction of the damp Atlantic winds.

Attempts to reforest with this species have not been satisfactory and natural regeneration depends on intense seed dissemination followed by at least 2 years of high rainfall and short, mild summers. In general, however, the *A. pinsapo* forests are stabilized and recovering after years of intensive goat pasturing, forest fires and use for fuelwood and charcoal making. However, the risk of fire is ever-present and that of climate change is looming. Although Aussenac (2002) suggested that *A. pinsapo* and *A. numidica* will be affected less by climate change than other Mediterranean firs because they have adapted to a less favourable environment, if the recent droughts recur the altitude range will progressively decrease and there will be an increased risk of infestation by pests.

Although at the end of the 19th century the forest guards in the municipal forests of Ronda were given responsibility for one of the first initiatives to protect the *A. pinsapo* forests, conservation measures did not actually begin until 1945, when the three areas of the Ronda *A. pinsapo* forests were purchased by the Spanish state. This was followed by the 1972 purchase of the Grazalema *A. pinsapo* forest, which became a Natural Park in 1984. Sierra de las Nieves became a Natural Park in 1989, and the area of Los Reales de Sierra Bermeja was given the special protection level of Natural Site (Table 1).

The Moroccan *A. pinsapo* forests are within Talassemtane National Park, where felling is prohibited. In addition, their remote location favours their conservation. The greatest threat besides fire comes from the crops of Indian hemp or hashish *Cannabis sativa* var. *indica*, which are increasingly being grown at mid-range altitudes.

All the *A. pinsapo* forests are now protected and safeguarded from the anthropogenic threats they have been subject to throughout history, with the exception of arson. Conservation efforts now focus on the development of fire prevention plans, including fire-break construction and constant surveillance, and pest control during severe drought. The possibility of undertaking silvicultural treatment is also being considered for some enclaves, to reduce competition among individual trees. In Spain, these initiatives are carried out through the Autonomous Community of Andalusia, Dirección General del Medio Natural, and in Morocco through the Haut Commissariat aux Eaux et Forêts et á La lutte contre la Désertification, Direction Régionale des Eaux et Forêts du Rif à Tetouan, Service Provincial des Eaux et Forêts du Chefchaouen.

Acknowledgements

We thank the Forestry Engineers Miguel A. Martín Casillas and José López Quintanilla for assistance during our visit to Sierra de las Nieves Natural Park and Sierra Bermeja Natural Site in the province of Málaga, and Sierra de Grazalema Natural Park in the province of Cádiz, Spain, and the Royaume du Maroc Haut Commissariat aux Eaux et Forêts et à la Lutte contre la Désertification, Direction Régionale des Eaux et Forêts du Rif à Tetouan, Service Provincial des Eaux et Forêts du Chefchaouen, in particular Amrani Mohamed, Ingénieur en Chef des Eaux et Forêts du Rif à Tetouan, and Assim El Houssain, Chef du District du Chefchaouen, who provided us with guided access to the forests in Talassemtane and Tazaout (Morocco).

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https://doi.org/10.1017/S0030605310000190 Published online by Cambridge University Press