Threatened plants of arid ecosystems in the Mediterranean Basin: a case study of the south-eastern Iberian Peninsula

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Abstract Networks of protected areas are one of the main strategies used to address the biodiversity crisis. These should encompass as many species and ecosystems as possible, particularly in territories with high biological diversity, such as the Spanish arid zones. We produce a priority ranking of the arid zones of south-east Spain according to the rarity and richness of their characteristic flora and the level of endangerment. The resulting hierarchy shows that optimal zones for the preservation of the flora are located outside the network of protected areas. In particular, it is important to extend the network and encourage the creation of microreserves in the depression of the River Guadiana Menor (Granada), where there is least protection. This river valley is a particularly important arid site because of its unique flora and fauna, and palaeontological and archaeological findings.

Keywords Arid ecosystems, flora, Mediterranean Basin, preservation, priority algorithm, threatened plants

This paper contains supplementary material that can be found online at http://journals.cambridge.org

Introduction

The Mediterranean Basin is a biodiversity hotspot (Mittermeier et al., 1998) and a biogeographical nexus for the European, Saharan and Irano-Turanian regions. Within this region southern Spain has one of the highest levels of plant diversity in the Mediterranean area (Médail & Quézel, 1997), with many rare and endemic species (Domínguez et al., 2000; Moreno Saiz et al., 2013).

Despite the early interest of botanists and naturalists in the Spanish arid zones (Suárez et al., 1991) these territories have been little appreciated because of their harsh, monotonous landscape. However, they constitute one of the most unique landscapes in Western Europe (Blanca, 1993). Historical processes such as glaciation, the desiccation of the Mediterranean Sea during the Messinian period and the subsequent connections with Africa and the Middle East have resulted in high diversity and endemism in the flora (Miller & Hobbs, 2002).

Plant diversity in arid regions is decreasing, however, as a result of overgrazing, agriculture, habitat fragmentation, pollution and other anthropogenic effects (Pimm et al., 1995; Carrión et al., 2003; Fernández-González et al., 2005). Studies have shown that in many cases networks of protected areas neither represent nor protect the biodiversity of a country or a region (Margules & Pressey, 2000). However, both the exploitation of ecosystem services (Costanza et al., 1997) and socioeconomic and tourism development rely on the quality of the resources in protected areas.

Addressing the ongoing loss of wild plants not only requires strategies for in situ protection and the restoration of affected ecosystems but also an ex situ preservation policy (Farnsworth et al., 2006; Cogoni et al., 2013). Such strategies require complex planning and development but are often implemented with limited knowledge (Castro et al., 1996). Sites have generally been selected for preservation on the basis of threatened flora, particularly where there is a high number of rare or endemic species (Pärtel et al., 2005; Fenu et al., 2012) or where there is urgent need for a preservation strategy (Holsinguer & Gottlieb, 1991; Jae Choi et al., 2012).

Our main aim in the work reported here is to identify gaps in the network of natural protected areas of Andalusia (Red de Espacios Naturales Protegidos de Andalucía; RENPA), particularly in the arid zones of south-east Spain, based on the level of threat to the flora. We compare the optimal network of conservation areas, obtained from algorithms for reserve selection, with the current design. Finally, we compare the degree of protection granted to natural sites in mountain areas with that granted to arid zones, according to their inclusion or not in the protected area network, to investigate if there has been any preference or bias towards more humid mountain areas at the expense of arid zones. Inequality in the protection of arid and humid areas is evident in other parts of the world; e.g. in

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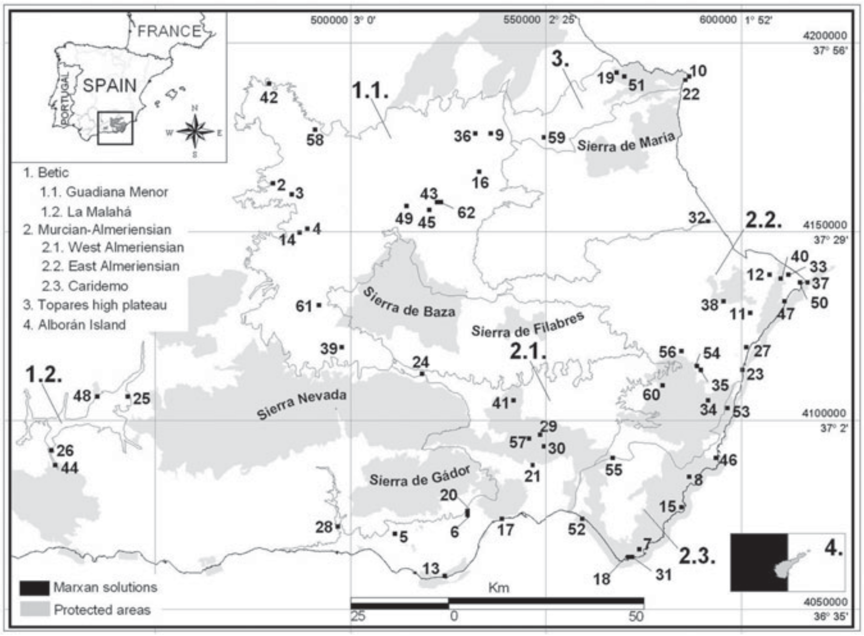

FIG. 1 Arid zones of the south-eastern Iberian Peninsula, with solutions proposed by *Marxan* shown in the context of the network of protected areas in Andalusia. The rectangle on the inset shows the location of the main map in south-east Spain.

Chile there are more conservation gaps in the north (the most arid territories) than in the southern humid regions (Arroyo et al., 2006).

Study area

Our study covered the arid zones of Andalusia, in the south-east of the Iberian Peninsula (Fig. 1). This area encompasses the driest territories in Western Europe (Mota et al., 2004). The climate is Mediterranean, with a pronounced summer season and frequent winter drought. The low annual rainfall (200–463 mm; Peinado et al., 1987) is a consequence of the Foehn effect induced by the surrounding mountains (Picard, 1958). As a result, the climate in the inner depressions is continental, with wide summer–winter thermal amplitude (Cano et al., 1994). On the other hand, coastal zones are exposed to the action of the dry, warm winds from the Sahara, which considerably increase aridity (Peinado et al., 1987). The geological profile of the area is heterogeneous, dominated by carbonated materials (limestones and dolomites). There are siliceous outcrops peculiar to the Alpujarride Complex, volcanic materials and diverse Quaternary substrates, mostly marls, gypsums, mud and muddy sand (Gibert et al., 2007). These soft and erodible substrates increase xericity (Valle et al., 1987). The occurrence of such a variety of substrates has not only provided a refuge for palaeoendemic taxa but has also encouraged speciation processes. The causes may be intrinsic or a result of the pronounced environmental gradients (Stebbins & Major, 1965).

The study area is divided into the following zones, according to biogeographical criteria (Rivas-Martínez, 2007): Betic arid zones, Murcian–Almeriensian arid zones, the Topares Manchean plateau, and Muluyano–Kabiliensean Alborán Island.

Methods

Data sources

We combined the criteria of Pearson & Cassola (1992), Lawler et al. (2003) and Andelman & Fagan (2000), compiling a list of the threatened flora in the arid zones of Andalusia (Supplementary Table S1). The list included species categorized as Critically Endangered, Endangered, Vulnerable, Near Threatened or Data Deficient on the IUCN Red List (IUCN, 2001). We believe conservation initiatives should focus not only on threatened species but also on preventing other species from being added to the Red List. Conservation tends to be more successful and efficient when the species concerned are relatively abundant (Keller & Bollmann, 2004). Our initial data sources were red data books and regional and national lists of vascular flora (Cabezudo et al., 2005; Moreno Saiz, 2008), supplemented by more recent information such as Flora de Andalucía Oriental (Blanca et al., 2009) and other works (Mota et al., 2011).

We gathered information on the distribution of taxa from various sources, including field surveys. The herbarium specimens we collected were included in the HUAL herbarium, which provided us with scientific data on the state of flora conservation (Mota et al., 2010). We also consulted other herbarium collections (GDA, GDAC and MUB) and online databases (*Anthos*, 2012; *GBIF.ES*, 2013), which we checked using *ArcGIS v. 10* (ESRI, Redlands, USA) to ensure that only reliable data were included. We followed the indications of *Flora de Andalucía Oriental* (Blanca et al., 2009) to resolve nomenclatural conflicts. We plotted distribution data in a grid of 1 × 1 km, in the Universal Transverse Mercator (UTM) projection with reference system ED50.

Selection of natural areas

We used *Marxan v. 2.1.1* (McDonnell et al., 2002) to identify the main natural areas where threatened flora requires protection. *Marxan* identifies the representation of species and ecosystems in biodiversity conservation at the lowest possible cost. It uses the simulated annealing algorithm (Kirkpatrick, 1983), which optimizes the solution progressively by iteration.

We used a weighting procedure to ascertain the level of threat (Mendoza-Fernández et al., 2010), which allowed us to convert a qualitative assessment into a quantitative one. We entered relative weights of 1,000 for Critically Endangered species, 200 for Endangered species, 50 for Vulnerable species, 10 for Near Threatened species, and 1 for Data Deficient species.

The procedure was iterated 1,000 times. The best solution determined which sites were included in the final selection. The summed solution gave an indication of the irreplaceability of the solutions yielded by *Marxan* (Pressey & Taffs, 2001). We found that 160 species occurred in at least one site in the final solution.

We compared the sites selected by *Marxan* (interpreted here as the optimal sites for conservation of the flora of these arid zones) with the current distribution of the protected area network in Andalusia (i.e. the current conservation strategy) and thereby estimated the proportion of sites that have already been granted protected status and those that are devoid of protection.

Richness, and continuous and discontinuous rarity

The fundamentals of our method are similar to those used by Martínez-Hernández et al. (2011) and are based on richness (α diversity), and continuous and discontinuous rarity. Richness is the number of catalogued taxa present in each 1 × 1 km cell. It is often used as an expression of diversity (Usher, 1985). Continuous rarity is an estimation of the rarity level of each cell according to the endemicity level of each taxon. The continuous rarity value of each cell is the sum of the rarity of each taxon occurring in it. The rarity of each taxon is the inverse of the number of cells in which that taxon occurs.

Discontinuous rarity is estimated in a similar way to richness but takes into account only taxa occurring in a small number of grids. Following Gaston (1997) the discontinuous rarity threshold is the number of grids that include only 25% of the less distributed species defined by the rarity quartile.

Conservation of arid zones vs Betic mountain areas

To compare the conservation focus in mountain areas versus that in the arid zones we compared our proposed selection of reserves for threatened flora in arid zones with the priority ranking of natural sites from Mendoza-Fernández et al. (2010; Supplementary Table S2). Mendoza-Fernández et al. (2010) examined Sites of Community Importance for threatened flora and analysed the distribution of priority habitats (Directive 92/43/EEC) in eastern Andalusia, including the Betic mountains.

We considered the distribution of the cells selected by *Marxan* to be the optimal or reference solution for natural sites with the highest values of rare, endemic or threatened flora. We also took into account the distribution of the Natura 2000 Network (Sites of Community Importance) by overlaying the spatial information and cartography in a geographical information system. We estimated the ratio of the number of sites located in the Betic mountains designated as Sites of Community Importance to the total number of sites obtained from the *Marxan* analysis for the same territory. In this way we obtained the percentages of selected sites that are inside and outside protected areas. We also estimated this ratio for arid zones.

Results

There are 160 threatened plant species in the arid zones in the study area, in 1,823 UTM grid cells (Fig. 1).

Network of natural areas

Based on 3,505 presence records *Marxan* selected a total of 62 1 × 1 km UTM grid cells, drawing up a network of sites compliant with the objective that every threatened species occurs in at least one site in the final solution. Of the 62 grids 12 were selected as irreplaceable sites in the optimal solution (Stoms et al., 1998). These grids, numbers 1–12 in Fig. 1 and Supplementary Table S3, correspond to sites on Alborán Island, south of Sierra de Gádor, in Cabo de Gata-Níjar Natural Park, along the coastline and in the highlands of eastern Almería, in the Guadiana Menor valley and on the high plateau of Topares. This means that *Marxan*, using the criteria of species richness, rarity, complementarity (Sarkar et al., 2002) and level of endangerment (IUCN, 2001), considers these sites irreplaceable for an optimal conservation network, at the lowest possible cost, for the flora of the Andalusian arid zones.

Richness, and continuous and discontinuous rarity

Punta Entinas Natural Reserve (site 13) and Alto de los Alamicos (site 38) have the highest number of threatened plants (12). These two areas are particularly rich in species that are characteristic of arid landscapes. Rambla de Genaro (site 29) in Tabernas, one of the most desert-like areas in Europe (Mota et al., 2004), has 11 threatened taxa. The highlands in the east of Almería province are also rich in threatened species. Sierra del Aguilón (site 40) has nine threatened taxa and La Sierrecica (site 11) has seven. Like the Desierto de Tabernas Natural Reserve, the Cabo de Gata-Níjar Natural Park is an emblematic territory for plant species characteristic of arid zones but in this case associated with the coast. We also found seven threatened taxa in La Hoya de Baza, in the Guadiana Menor Sector, which is characterized by pronounced continentality. Barranco del Agua (site 9) and Arroyo del Margen (site 16) have the greatest richness of threatened plant species in the Guadiana Menor Sector.

The hierarchy of sites selected according to the values of continuous rarity and discontinuous rarity was coincidental with the irreplaceable character of these sites. Except for one site, Punta Entinas (site 13), which was not considered irreplaceable, the other 12 sites with the highest values of continuous rarity were also sites selected as irreplaceable solutions by *Marxan*. A similar result was obtained for discontinuous rarity. The highest values of continuous and discontinuous rarity ($\geqslant 1$) were found on Alborán Island (site 1), in the Punta Entinas Natural Reserve (site 13), at Rambla de Galera-Barranco del Agua (site 9), Alicún de Ortega (site 4), Peñón de Alamedilla (site 14) and Pedro Martínez (site 2), in the Guadiana Menor valley, at La Sierrecica (site 11), in the municipal area of Cuevas de Almanzora, on the southern slopes of the Sierra de Gádor (site 6), at la Pinosa, on the high plateau of Topares (site 10) and at Rellana de San Pedro (site 7) and El Romeral (site 8) in the Cabo de Gata-Níjar Natural Park (Supplementary Table S3).

Distribution of protected areas

A comparison of the optimal sites for protection, as determined by *Marxan*, with the current network of protected areas revealed that 30 of the selected grid cells are already included in the network of Sites of Community Importance. However, 32 sites (52% of all grid cells selected), do not have any designated protection. The discontinuous rarity values revealed that 24 of the sites without protection have taxa with restricted distributions (stenochorous plants). Eight of the sites excluded from the network of Sites of Community Importance were selected in all of the summed solutions provided by *Marxan*. Forty-nine of the 160 plant species (31%) occur at sites with no designated protection. These included 14 Critically Endangered, 10 Endangered, 10 Vulnerable, 12 Near Threatened and three Data Deficient species.

We grouped the unprotected sites of threatened flora in the Andalusian arid zones into six zones, which can in turn be categorized as coastal arid areas, such as the southern slopes of Sierra de Gádor and the coast of the east of Almería, or continental areas, such as La Malaha, west of the Guadiana Menor, Hoya de Baza and Hoya de Guadix.

The River Guadiana Menor valley is the most significant omission in the current protection for threatened wild flora (Fig. 1). The flora at the 18 sites selected there, four of which are irreplaceable, have no protection status.

Conservation of arid zones vs Betic mountain areas

The estimation of the ratio of the modelled solutions for the Betic mountains in east Andalusia to the distribution of protected areas revealed that 94% of the solutions proposed by *Marxan* for optimal conservation of the threatened flora in these mountain areas are already included in the network of protected areas. In contrast, only 49% of the proposed solutions for arid zones are already protected.

Discussion

The arid zones of the south-east Iberian Peninsula are of considerable botanical interest, with a high rate of occurrence of endemic and Iberian–North African species. Much of this biodiversity is threatened to some degree. One hundred and sixty of the plant taxa that occur in the Andalusian arid zones are included in red lists (Cabezudo et al., 2005; Moreno Saiz, 2008; Blanca et al., 2009).

Despite this and the high degree of endemism, our analysis indicates that the protection afforded to this flora is less than in the surrounding montane areas. Although there have been requests (Melic & Blasco-Zumeta, 1999; Mota et al., 2004) no National Parks have been declared in the arid zones of the Iberian Peninsula. This is probably because of the poor aesthetic image of xerophytic communities. However, in moderately rainy years these communities can exhibit unusually high biomass (Esteve, 1973), with ephemeral species formations (Sánchez-Gómez et al., 2009) in which endemic therophytes, such as *Linaria nigricans* L. and *Chaenorhinum grandiflorum* (Coss.) Willk., are particularly striking. These formations only thrive during wet periods but their demographic explosion is spectacular, accompanied by abundant flowering (Mota et al., 1998).

As a result of the imbalance in conservation efforts almost all the sites proposed in this article for conservation of the threatened flora of the Betic mountains are already protected in some way, whereas the protected areas in arid zones account for $< 50\%$ of the areas proposed by our analysis. The extension of the protected area network or the creation of a network of flora microreserves in accordance with the Important Plant Area programme of Plantlife International (2004) could be efficient strategies for the in situ protection of plant diversity in these arid zones. Although the Andalusian legislation for protected sites does not cover flora microreserves, this type of protected area was intended to create a representative network of plant biodiversity (Hernández & Gómez-Hinostrosa, 2011). Microreserves must be established in areas with high biodiversity and they should include plant communities or habitats listed in the Directive 92/43/EEC (Laguna et al., 2004). Although the geographical spread of such a network of reserves could pose a problem, with isolated patches of habitat, it would improve the protection of a large number of species (Higgs & Usher, 1980). In addition, it would complement the protected area network in enhancing ecological awareness and promoting the natural values of these arid zones, which support flexible and stress-tolerant taxa, particularly of endemic plants that have undergone dramatic environmental changes and population bottlenecks in the past (Allen et al., 1999). This flora could be less vulnerable than other types to the effects of climate change and consequently there are implicit benefits from its preservation, as suggested by ecophysiological studies of *Gypsophila struthium* L., whose photosynthetic activity is hardly affected under conditions that severely affect other species (Merlo Calvente et al., 2009).

The creation of flora microreserves would be particularly useful in the Guadiana Menor valley, the section of our study area where there are the most serious gaps in protection. This area is not only of botanical interest; its natural value has been confirmed by studies of its fauna (Palomo et al., 2007), specifically invertebrates (Verdú & Galante, 2009) and steppe birds (Madroño et al., 2004). Furthermore, the Guadiana Menor river basin, particularly the region of Guadix-Baza, contains archaeological sites of the Copper and Bronze Ages and remains of Roman and Arab settlements (De la Cruz et al., 2010). Some of the most famous palaeontological discoveries in the Iberian Peninsula, including the Man of Orce (Gibert et al., 1992), have been made here and numerous sites are still being investigated. These archaeological studies not only contribute to the knowledge of prehistory but also relate human activities in the past with the former vegetation (Salazar et al., 2002). The basin comprises three areas that are of particular floristic value. The first area, to the west of the Guadiana Menor valley, is the only site where *Astragalus guttatus* Banks & Solander has been recorded in the Iberian Peninsula. It also hosts *Arenaria arcuatociliata* G. López & Nieto Fel. (Mota et al., 2010) and *Haplophyllum bastetanum* F.B. Navarro, V.N. Suárez-Santiago & Blanca, which are endemic to the Guadix-Baza depression. To the east, the Hoya de Baza is characterized by flora associated with gypsum outcrops, such as *Gypsophila tomentosa* L. and *Senecio auricula* Coss. subsp. *auricula*. These rare taxa also occur on gypsum outcrops in the centre of the Peninsula (Blanca et al., 2009). The second area is characterized by the flora of continental saltmarshes, including the halophilous endemic plants *Limonium majus* (Boiss.) Erben and *Limonium minus* (Boiss.) Erben. The third area, the Hoya de Guadix in the south, is a natural corridor to the Murcian–Almeriensian territory and hosts *Krascheninnikovia ceratoides* (L.) Gueldenst, which was previously thought to be extinct.

Although the Guadiana Menor valley is surrounded by the National and Natural Parks of Baza, Sierra Nevada and Cazorla-Segura-Las Villas, there is an obvious protection gap in this continental depression, which merits conservation on account of its natural, anthropological and historical value (Mota, 2011). The protection of this area would address the disproportionate conservation focus on mountain areas compared to arid depressions. The cultural and natural assets of the area make it a potential focus for the development of environmental educational campaigns. There is also a need for further research of this zone, where new species (e.g. *Teucrium moleromesae*; Sánchez-Gómez et al., 2013), have recently been discovered.

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