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Composition, ecology and conservation of the south-Iberian serpentine flora in the context of the Mediterranean basin

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Abstract

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Peridotite outcrops have special lithological (serpentine) and soil characteristics; they also support an unique flora and vegetation "that clearly differ from that of other soil types. One of the most important peridotite outcrops in the Western Mediterranean Basin is located in Sierra Bermeja (Andalusia, Spain). The establishment of a complete ecological-floristic checklist of serpentinophytes in this area, and a comparison with other serpentine-endemic floras in the Mediterranean Basin, is essential for the assessment, management and conservation of these special areas. The recognition of serpentinophytes was made following six criteria used for floras inhabiting special substrata,. The list of species exclusively or partially found on peridotite comprises 27 taxa with a variable degree of serpentinophily: obligate serpentinophytes (obligate endemics), preferential serpentinophytes (populations located mainly on serpentine) and subserpentinophytes (with some populations located on magnesium-rich substrata). As observed in other Mediterranean outcrops, the number of obligate serpentinophytes increases with the area of the outcrop, and the genera *Alyssum*, *Arenaria*, *Armeria*, *Centaurea* and *Silene* were the most frequent. Most of the studied serpentinophytes, except for a few xerothermophilous taxa, present a wide bioclimatic (altitudinal) range and grow in shrublands and pastures in rocky places with shallow soils. As many as 56% of the serpentinophytes are threatened and, among obligate serpentinophytes, 45% are categorized as critically endangered or endangered, emphasizing the need for urgent conservation measures on the species and their habitats Based on this checklist, more detailed studies may focus on serpentinophytes for their particular physiology, adaptive traits, functional types, phenology and applications.

Keywords: serpentinophytes, peridotite rocks, conservation, ecology, Mediterranean flora, management.

Resumen

Pérez-Latorre, A.V., Hidalgo-Triana, N. & Cabezudo, B. 2013. Composición, ecología y conservación de la flora serpentínica suribérica en el contexto de la cuenca mediterránea. *Anales Jard. Bot. Madrid* 70(1): 62-71 (en inglés).

Las peridotitas muestran especiales características litológicas (serpentinas) y edáficas; lo que condiciona una flora y vegetación original y distinta de los alrededores. Uno de los afloramientos más importantes de la cuenca mediterránea occidental está representado por Sierra Bermeja (Andalucía, España). Es esencial establecer un catálogo florístico-ecológico completo de serpentinófitos y compararlo con otros catálogos de endemismos serpentinícolas en el Mediterráneo, para la ordenación, gestión y conservación en estas áreas particulares. La selección de serpentinófitos se realizó siguiendo seis de los criterios utilizados para floras que habitan sustratos especiales. La lista de especies ligadas total o parcialmente a las peridotitas incluye 27 taxones, con un grado variable de serpentinofilia: serpentinófitos estrictos (endemismos obligados), serpentinófitos preferentes (con poblaciones mayoritariamente sobre peridotitas) y subserpentinófitos (con algunas poblaciones localizadas en substratos ricos en magnesio). Como se observa en otros afloramientos del Mediterráneo, el número de serpentinófitos estrictos aumenta con el área del afloramiento y los géneros *Alyssum*, *Arenaria*, *Armeria*, *Centaurea* y *Silene* son los más comunes. La mayoría de serpentinófitos presentan un amplio rango bioclimático altitudinal, excepto algunos xerotermófilos, y casi todos crecen en matorrales y pastizales en lugares rocosos con litosuelos. Un 56% de los serpentinófitos están amenazados y, entre los serpentinófitos estrictos, un 45% están catalogados en peligro crítico o en peligro, subrayando la urgente aplicación de medidas sobre las especies y sus hábitats. Tomando este listado de serpentinófitos como base, debe profundizarse en estudios sobre su fisología especial, síndromes, tipos funcionales, fenología y aplicaciones.

Palabras clave: serpentinófitos, peridotitas, conservación, ecología, flora mediterránea, manejo.

INTRODUCTION

Peridotites are recognized as one of the most peculiar rock types on Earth, both for their plutonic igneous origin and chemical composition (Roberts & Proctor, 1992). Serpentine soils originate from this type of rock, and are well known for their physical and chemical anomalies that present a hostile environment for plants (Brooks, 1987). Anomalies such as high Fe and Mg contents, a low Ca content, a deficiency of nutrients (N, P, K), infertility, toxic concentrations of heavy metals (Cr, Ni, Co, Va), very slow soil development and high xerothermicity characterize these soils (Whittaker, 1954; López González, 1975; Brooks, 1987). Such characteristics make serpentine habitats highly selective for plants and relatively few species, called serpentinophytes or serpentinophilous, are adapted to grow on such a substrate (Rune, 1953; Jeffrey, 1987; Selvi, 2007). Following Kruckeberg (2002), serpentinophytes can be divided into three categories: a) endemic taxa, linked exclusively to peridotites, b) preferential taxa, whose distribution is mainly associated with peridotite but occasionally found on other substrata and c) taxa living on a variety of substrata but also on peridotite (bodenvag taxa).

Obligate serpentinophytes may have a particular metabolism for avoiding the toxic effect of heavy metals (Roberts & Proctor, 1992; Brady & al., 2005). Moreover, some facultative species show a serpentine-morph syndrome, e.g. a complex of morpho-functional adaptations that distinguish the serpentine populations from those living on other substrates (stenophyllous, glabrous, glaucous, macro-rooted plants, plagiotropism and nanism) (Pichi-Sermolli, 1948). The high concentrations of magnesium in serpentine soils allow the presence of a magnesicolous flora that develops equally on serpentine and dolomite rocks (Rivas Goday, 1974; Mota & al., 2008). Studies on species adapted to this type of serpentine

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ecosystem are considered of great interest for the restoration of contaminated soils, the mining of heavy metals, the study of the evolution in extreme habitats, and in conservation biology surveys (Brady & al., 2005).

The most important area for obligate serpentinophytes in Europe (with 123 taxa) is situated in the Balkans (Stevanovic & al., 2003). The westernmost peridotite outcrops in the Mediterranean Basin are situated in the south of the Iberian Peninsula (Andalusia) where they cover a total area of 430 km^2 (IGME, 1970 and 1981), with an altitudinal range from 100 to 1500 m occupying three bioclimatic belts (Pérez Latorre & al., 1998). South-Iberian peridotites have frequently been converted into serpentines by hydrolysis (Yusta & al., 1985).

The flora and plant communities of Andalusian peridotites have been studied by several authors, including Rivas Goday (1974), López González (1975) and Rivas Goday & López González (1979). Some species are hyper-accumulators of Ni (Rufo & al., 2004; Díez-Garretas & al., 2009) and others show the serpentine-morph syndrome characters described above (López González, 1975; Alados & al., 1999). Climax forest vegetation in these habitats is characterized by pine (*Pinus pinaster* Aiton) and fir forest (*Abies pinsapo* Clemente ex Boiss.) but they are frequently substituted by shrublands because of frequent fires (Cabezudo & al., 1989; López González, 1975; Pérez Latorre & al., 1998). Most south-Iberian serpentinophytes and the plant communities where they live are included in the 92/43EU "Habitats" Directive; some of them are also threatened and/or protected. Some of the peridotite outcrops are listed as LIC (Important Areas for European Conservation) and/or regional protected areas (Natural Park, Natural Site) and they are considered as Mediterranean phylogeographic refuges and "hot-spots" for Mediterranean plant diversity (e.g. part of the Serrania de Ronda refugia; Médail & Diadema, 2009). They are also considered important areas (exceptional category) for threatened Spanish flora (Bañares & al., 2003). Moreover, peridotite outcrops have a great importance in the phytogeographical scheme of the Iberian Peninsula as they are given the category of sector (Bermejense sector) within the Betica province (Western Mediterranean region) (Nieto & al., 1991). In an attempt to broaden our knowledge of peridotite plant biology and distribution, the main aims of this work were to: 1, provide a checklist of the serpentinophytes of the southern Iberian Peninsula; 2, study serpentinophytes as a group in terms of life form, systematic spectrum (families), ecology, phytosociology and threat level; and 3, compare the group of south-Iberian serpentinophytes with other Mediterranean serpentine floras and the flora living on other closely related rocks such as dolomites.

MATERIAL AND METHODS

Study area

The main peridotite outcrops in the south of the Iberian Peninsula (Fig. 1) are located in the province of Malaga (Ronda Mountain Range; Fig. 2). The mineralogical composition is characterized by harzburgite, lherzolite, piroxenite and serpentinite. They can be grouped them into four geographical units (Fig. 2): 1, Sierra Bermeja: the most important outcrop, covering 319 km^2 with an altitude range of between 50 and 1500 m. 2, Sierra Alpujata: 71 km^2 with an altitude range of between 140 and 1050 m. 3, Sierra de Aguas: 36 km^2 and lying between 200 and 950 m. 4, Sierras del Guadalhorce: small and isolated outcrops with a total area of 6 km^2 and altitude range between 100 and 400 m.

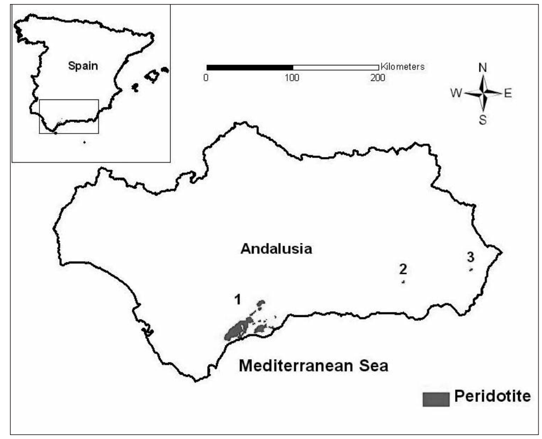

Fig. 1. Peridotite outcrops in Southern Iberian Peninsula (Andalusia, Spain): **1,** Ronda Mountain ranges (Malaga); **2,** Sierra Nevada (Almeria); **3,** Lubrín (Almeria). Serpentinophytes are restricted to the outcrops of Malaga.

Serpentinophytes checklist

The list of species to be included as serpentinophytes has been created based in several sources. We follow the criteria used by Mota & al. (2008, 2011) to select taxa associated with special substrata, among them, six were applied to establish the serpentinophyte checklist. These criteria were as follows. 1, inductive: species observed on serpentine by our group since 1989 (Cabezudo & al., 1989). 2, expertise: data taken from authors in the specialized literature and our own data that link taxa to serpentine. 3, bibliographical: individual taxa classified as serpentinophytes in the literature. 4, syntaxonomic: presence or absence of serpentinophytes in relevés and in syntaxa detected by others, such as *Staehelino-Ulicion baetici*, which are linked exclusively to serpentine. In addition, the 5

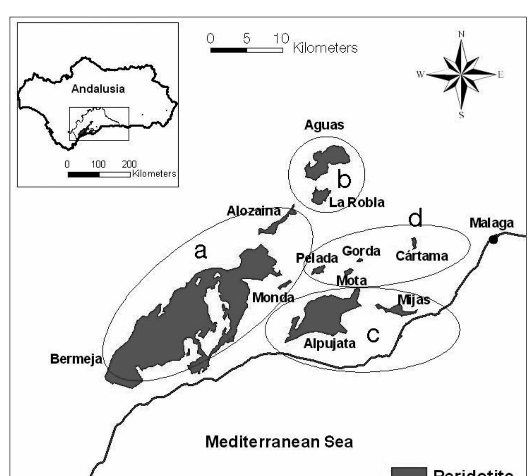

Fig. 2. Location and area of the peridotite outcrops in Malaga: **a,** Bermeja, 319 km^2; **b,** Aguas, 35 km^2; **c,** Alpujata, 71 km^2; **d,** Guadalhorce, 6 km^2.

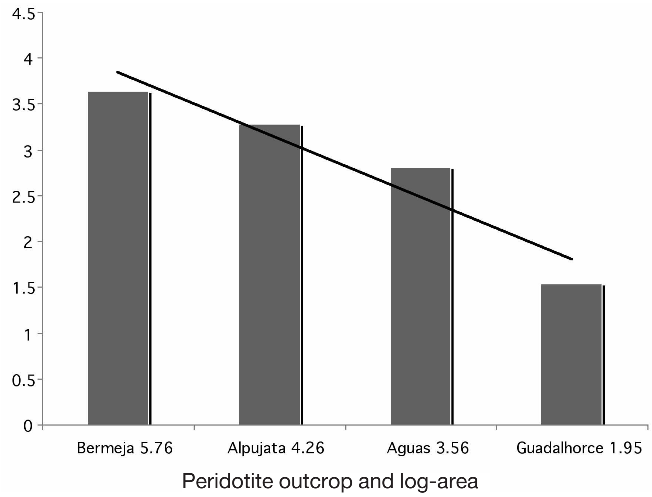

Fig. 3. Serpentinophyte richness correlated with the log-adjusted area of each peridotite outcrop (lineal adjust $R^2 = 0.9087$).

and 6 criteria (bio-indicator and edaphic) were used to propose three types of serpentinophytes depending whether some populations of the species may grow on other substrates.

First, a bibliographical search for species cited as possible serpentinophytes was made (Rivas Goday, 1974; López González, 1975; Rivas Goday & López González, 1979; Castroviejo & al., 1986-2011; Blanca & al., 2011) and completed with chorological data obtained from GBIF (Global Biodiversity Information Facility in Spain) in 2011. To complete the data, a series of surveys in the peridotites of Malaga and Almeria (Fig. 1) were made (years 2009 to 2011), recording floristic (plant collecting), phenological, phytosociological (vegetation relevés), chorological (patterns of local distribution of populations) and ecological (habitat, altitude range, bioclimatic belt and rainfall range -ombrotype- Rivas Martínez, 2011) data. All the collected specimens were deposited in the University of Malaga Herbarium (MGC). Taking into account all the distributional data collected, the percentage of populations for each serpentinophyte known to grow on peridotites was estimated. This estimation was based on the number of geographically and/or ecologically separate localities for each population. Three categories of serpentinophily were described that were adapted from other categories used for plants living on soils such as dolomite and gypsum (Jeffrey, 1987; Mota & al., 2008, 2011) and depended on the ecological and chorological affinity for peridotite and serpentine substrata. 1, obligate serpentinophytes: taxa linked exclusively to peridotite. 2, preferential serpentinophytes: at least 90% of populations linked to peridotites. 3, subserpentinophytes: at least 66% of populations linked to peridotites. We also considered some other species with a number of populations growing on peridotite, which may be regarded as subserpentinophytes following more exhaustive studies.

Data provided about serpentinophytes

The following data are provided for each taxon: scientific name, growth-form (Orshan, 1986), habitat, bioclimatic belt, altitude range, ombrotype, phytosociology, global and local distribution in the four geographic units described above, flowering/sporulation season (Roman numbers) and threat category (IUCN). Ecological data were mostly taken from Bañares & al. (2003) and Blanca & al. (1999-2000, 2011), with some data collected *in situ* as stated above. For the phytosociological nomenclature and syntaxonomy Pérez Latorre & al. (1998), Rivas Martínez & al. (2002) and Rivas Martínez (2011) were consulted and some vegetation inventories were made. Threat categories were taken from Andalusian (Blanca & al., 1999, 2000; Cabezudo & al., 2005), Spanish (Moreno, 2008) and European (Bilz & al., 2011) red lists and conservation legislation. Serpentinophyte richness per outcrop (Fig. 3) was calculated as a function of a logarithm-adjusted area (Whittaker & Fernández-Palacios, 2007; Pérez-García & al., 2012). The botanical nomenclature follows Flora de Andalucia Oriental (Blanca & al., 2011) unless otherwise indicated.

RESULTS

Obligate serpentinophytes (Table1)

Allium rouyi Gaut.

Geophyte with bulb. Lithosols. Thermomediterranean (150-700 m). Subhumid-humid. Open shrublands, pastures and rocks (*Staehelino-Ulicion baetici*, *Andryalo-Crambion filiformis* and *Phlomido-Brachypodietum retusi*). Local endemism. Bermeja and Alpujata. VI-VII. CR (Spanish and Andalusian red lists), EN (Andalusian legislation) and LC (European red list). The taxonomic status and restricted distribution follow Cabezudo & al. (1992) and Pastor & al. (1995).

Alyssum serpyllifolium Desf. subsp. **malacitanum** Rivas Goday.

Chamaephyte / Hemicryptophyte multi-shooted. Slopes and rocky places. Thermo-meso-supramediterranean (50-1300 m). Dry-subhumid-humid. Scrublands and perennial pastures (*Staehelino-Ulicion baetici, Andryalo-Crambion filiformis*). Local endemism. Bermeja, Alpujata, Aguas and Guadalhorce. II-VI (VII). LC (Blanca & al., 2011). This taxon should be considered as an amphiphyte (Orshan, 1986) as it presents two types of renewal buds. It has been reported as a nickel hyperaccumulator (Rufo & al., 2004; Díez-Garretas & al., 2009). Individuals with intermediate characters to those of subsp. *serpyllifolium* may be found in the proximity of serpentines on limestone and dolomitic sandstones (Blanca & al., 2011).

Arenaria capillipes Boiss.

Therophyte. Lithosols. Meso-supramediterranean (800-1500 m). Subhumid-humid-hyperhumid. Ephemeral pastures (*Arenario capillipedis-Iberidetum fontqueri*). Local endemism. Bermeja. IV-VI. NT (Spanish and Andalusian red lists), VU (Andalusian legislation).

Armeria colorata Pau (Fig. 4d)

Chamaephyte with rosettes. Screes, crevices and rocky

Table 1. Presence and percentage above the total of obligate serpentinophytes in each peridotite outcrop in the south of the Iberian Peninsula. The relative frequency of obligate serpentinophytes in each outcrop follows the categories in Blanca & al. (2011) adapted to the study area (rr, very rare; ra, rare; oc, occasional; fr, frequent).

Taxon / Outcrop	Bermeja	Alpujata	Aguas	Guadalhorce
Allium rouyi	rr	rr	–	–
Alyssum serpyllifolium subsp. *malacitanum*	fr	fr	fr	oc
Arenaria capillipes	ra	–	–	–
Armeria colorata	rr	rr	–	–
Armeria villosa subsp. *carratracensis*	rr	rr	ra	–
Asplenium adiantum-nigrum var. *corunnense*	ra	–	–	–
Bupleurum acutifolium	ra	–	–	ra
Centaurea carratracensis	–	–	oc	–
Centaurea haenseleri	ra	–	–	–
Centaurea lainzii	rr	–	–	–
Cephalaria baetica	oc	ra	–	–
Euphorbia flavicoma subsp. *giselae*	rr	–	–	–
Iberis fontqueri	oc	oc	ra	–
Klasea baetica	rr	ra	rr	–
Linum suffruticosum var. *carratracensis*	oc	oc	oc	–
Notholaena marantae subsp. *marantae*	ra	ra	ra	–
Peucedanum officinale subsp. *brachyradium*	rr	–	–	–
Saxifraga gemmulosa	ra	rr	rr	–
Silene fernandezii	ra	rr	–	–
Silene inaperta subsp. *serpentinicola*	rr	rr	–	rr
Staehelina baetica	fr	fr	oc	–
Teucrium reverchonii	oc	oc	oc	–
Obligate serpentinophytes per outcrop	21	14	10	3
Obligate serpentinophytes per outcrop (%)	95	64	46	14
Outcrop area (km^2)	319	71	36	6

places on lithosols. Meso-supramediterranean (650-1500 m). Humid-hyperhumid. Perennial pastures and open scrublands (*Andryalo-Crambion filiformis*, *Staehelino-Ulicion baetici*). Local endemism. Bermeja and Alpujata. V-VII. EN (Spanish red list and Andalusian red list and legislation).

Armeria villosa Girard subsp. **carratracensis** (Bernis) Nieto Fel.

Chamaephyte with rosettes. Crevices, cliffs and slopes. Thermo-mesomediterranean (650-1300 m). Subhumid-humid. Perennial pastures and open scrublands (*Andryalo-Crambion filiformis*, Staehelino-*Ulicion baetici*). Local endemism. Bermeja, Alpujata and Aguas. V-VII. EN (Spanish red list and Andalusian red list and legislation). A molecular, morphometric and experimental study established that this subspecies is hybrid taxon produced by the hybridization between the previous species and *A. villosa* subsp. *longiaristata* (Nieto Feliner & al., 2002).

Asplenium adiantum-nigrum L . var. **corunnense** H. Christ

Hemicryptophyte with rosettes. Shaded and wet rock fissures. Meso-supramediterranean (1060-1410 m). Humid-hyperhumid. Umbrophilic rupicolous vegetation. (*Asplenio corunnensis-Saxifragetum gemmulosae*). Pen. Ibérica e Italia. Bermeja. (IV) V-X (XI). LC (Blanca & al., 2011). The taxonomicl status given by Nogueira and Ormonde (1986) is adopted for this fern. In other floras, e.g. N Italy, this fern is considered as a preferential serpentinophyte (Selvi, 2007).

Bupleurum acutifolium Boiss.

Herbaceous chamaephyte. Rocky slopes and lithosols. Thermo-mesomediterranean (150-1200 m). Subhumid-humid. Shrublands (*Staehelino-Ulicion baetici*). Local endemism. Bermeja and Guadalhorce. VI-IX. VU (Spanish and Andalusian red lists).

Centaurea carratracensis Lange (Fig. 4c)

Erect hemicryptophyte. Lithosols and slopes. Thermo-mesomediterranean (300-950 m). Dry-subhumid. Shrublands, scrublands and slopes vegetation. (*Staehelino-Ulicion baetici*, *Andryalo-Crambion filiformis*). Local endemism. Aguas. (IV) V-VII. EN (Spanish and Andalusian red lists).

Centaurea haenseleri Boiss. & Reut.

Hemicryptophyte with rosettes. Lithosols and rock fissures. Meso-supramediterranean (700-1500 m). Subhumid-humid-hyperhumid. Rupicolous vegetation (*Andryalo-Crambion filiformis*). Local endemism. Bermeja. V-VII. EN (Spanish and Andalusian red lists).

Centaurea lainzii Fern. Casas

Scapiform hemicryptophyte. Slopes and stony areas. Thermo-mesomediterranean (300-1100 m). Humid. Perennial pastures and shrublands (*Andryalo-Crambion filiformis*, *Staehelino-Ulicion baetici*). Local endemism. Bermeja. V-VII. CR (Spanish and Andalusian red lists).

Cephalaria baetica Boiss.

Chamaephyte (scrub). Slopes and stony areas. Thermo-mesomediterranean (400-1100 m). Subhumid-humid-hyperhumid. Shrublands. (*Andryalo-Crambion filiformis*). Local endemism. Bermeja. VII-VIII (XI). NT (Spanish red list), EN (Andalusian red list).

Euphorbia flavicoma DC. subsp. **giselae** Simon Pall.

Chamaephyte. Lithosols. Thermo-mesomediterranean (500-1200 m). Humid-hyperhumid. Open forests (*Pino pinastri-Quercetum cocciferae*, *Bunio macucae-Abietetum pinsapo*). Local endemism. Bermeja. IV-VII. NT (Blanca & al., 2011). The scarce populations in the Sierra Bermeja should be considered as an independent endemic taxon as they show some differences from the French populations (hair density and length; Simon Pallisé, 1997). Other differential characters that we observed are related to leaf size and margin.

Iberis fontqueri Pau

Fasciculate therophyte. Slopes, stony places and lithosols. Thermo-mesomediterranean (200-1100 m). Subhumid-humid. Ephemeral pastures. (*Arenario-capillipedis-Iberidetum fontqueri*). Local endemism. Bermeja, Alpujata and Aguas. III-VI. VU (Spanish and Andalusian red lists).

Klasea baetica (Boiss.) Holub

Scapiform hemicryptophyte. Stony soils. Thermo-meso-supramediterranean (300-1400 m). Subhumid-humid-hyperhumid. Shrublands (*Staehelino-Ulicion baetici*). Local endemism. Bermeja and Aguas. IV-VI. EN (Spanish and Andalusian red lists). Blanca & al. (2011) mention this taxon as a Betic-Rifean species. However, we were unable to find any record for the Rif mountains (Morocco) and it is absent from the "Checklist of Vascular Plants of Northern Morocco" (Valdés & al., 2002).

Linum suffruticosum L. var. **carratracensis** (Rivas Goday & Rivas Mart.) G. López

Chamaephyte (scrub). Stony slopes. Thermo-meso-mediterranean (340-1200 m). Subhumid-humid. Shrublands and perennial pastures. (*Staehelino-Ulicion baetici*, *Andryalo-Crambion filiformis*). Local endemism. Bermeja, Alpujata and Aguas. V-VII. LC (Blanca & al., 2011).

Notholaena marantae (L.) Desv. subsp. **marantae** (Fig. 4a)

Hemicryptophyte with rosettes. Rock fissures and stony slopes. Thermomediterranean (350-700 m). Subhumid-humid. Rupicolous perennial pastures. (*Notholaeno marantae-Cheilanthetum guanchicae*). Circum-Mediterranean, East Africa and Himalaya. Bermeja, Alpujata and Aguas. (II-VI). LC (Blanca & al., 2011). In the north Italian flora it is considered as a preferential serpentinophyte (Selvi, 2007).

Peucedanum officinale L. subsp. **brachyradium** García Martín & Silvestre

Erect hemicryptophyte. Slopes. Thermomediterranean (800-900 m). Humid. Pine woods and kerm-oak shrublands (*Pino pinastri-Quercetum cocciferae*). Local endemism. Bermeja. IX-X. CR (Spanish and Andalusian red lists).

Saxifraga gemmulosa Boiss.

Cushion hemicryptophyte. Fissures of rocky shaded places and slopes. Thermo-meso-supramediterranean (560-1410 m). Subhumid-humid-hyperhumid. Umbrophilic rupicolous vegetation (*Asplenio corunnensis-Saxifragetum gemmulosae*, *Selaginello denticulatae-Saxifragetum gemmulosae*). Local endemism. Bermeja, Alpujata and Aguas. IV-VI. VU (Spanish and Andalusian red lists). It has been described as a nickel hyper-accumulator (Rufo & al., 2004; Díez-Garretas & al., 2009).

Silene inaperta L. subsp. **serpentinicola** Talavera

Erect therophyte. Stony slopes and lithosols. Thermo-mesomediterranean (200-1000 m). Dry-subhumid-humid. Ephemeral pastures. (*Omphalodion commutatae*). Local endemism. Bermeja, Alpujata and Guadalhorce. V-VII. EN (Spanish and Andalusian red lists).

Silene fernandezii Jeanmonod

Herbaceous chamaephyte. Slopes, rock fissures and stony ground. Thermo-meso-supramediterranean (600-1500 m). Subhumid-humid-hyperhumid. Rupicolous vegetation. (*Andryalo-Crambion filiformis*). Local endemism. Bermeja and Alpujata. V-VI (VII). EN (Spanish and Andalusian red lists; Andalusian legislation).

Staehelina baetica DC. (Fig. 4b)

Chamaephyte (scrub-like to cushioned). Stony slopes and lithosols. Thermo-meso-supramediterranean (300-1400 m). Subhumid-humid-hyperhumid. Shrublands. (*Staehelino-Ulicion baetici*). Local endemism. Bermeja, Alpujata and Aguas. V-VII. LC (Blanca & al., 2011).

Teucrium reverchonii Willk.

Chamaephyte. Stony slopes and lithosols. Thermo-mesomediterranean (300-1200 m). Dry-subhumid. Shrublands. (*Staehelino-Ulicion baetici*). Local endemism. Bermeja, Alpujata and Aguas. V-VI (VII). NT (Blanca & al., 2011).

Preferential serpentinophytes

Galium boissieranum (Steud.) Ehrend. & Krendl

Herbaceous chamaephyte. Stony slopes. Thermo-meso-supramediterranean (300-1500 m). Subhumid-humid. Shrublands (*Staehelino-Ulicion baetici*). Local endemism. Bermeja, Alpujata and Aguas. (IV) V-VII (IX). VU (Spanish and Andalusian red lists). About 90% of its populations grow on peridotites and the rest on dolomites, as occurs in Sierra Blanca de Ojen (Malaga) and Sierra de Grazalema (Cadiz).

Galium viridiflorum Boiss. & Reut. (Fig. 4e)

Scandent chamaephyte. Streams and wet soils. Thermo-mesomediterranean (100-1200 m). Subhumid-humid. Wet

Fig. 4. Some selected South-Iberian serpentinophytes. Obligate serpentinophytes: **a,** *Notholaena marantae* (Sinopteridaceae); **b,** *Staehelina baetica* (Asteraceae); **c,** *Centaurea carratracensis* (Asteraceae); **d,** *Armeria colorata* (Plumbaginaceae). Preferential serpentinophytes: **e,** *Galium viridiflorum* (Rubiaceae). Subserpentinophytes: **f,** *Genista hirsuta* subsp. *lanuginosa* (Fabaceae). (Photographs: a, d, f, A.V. Pérez-Latorre; b, c, M. Becerra; e, F. Casimiro-Soriguer).

grasslands, hydrophilic vegetation and riverine forests. (*Galio viridiflori-Schoenetum nigricantis*, *Molinio-Ericetum erigenae*, *Erico-Nerietum oleandri*, *Erico-Salicetum pedicellatae*). Local endemism. Bermeja, Alpujata and Aguas. V-VII (VIII). VU (Spanish and Andalusian red lists and Andalusian legislation), special protection status (Spanish legislation), EN (European red list). It is the only serpentinophyte of our list included in Annex II of the "Habitats" Directive 92/43EU. There are scarce populations in Tejeda-Almijara ranges (Malaga-Granada) on dolomitic soils.

Subserpentinophytes

Arenaria retusa Boiss.

Erect therophyte. Stony slopes and lithosols. Thermo-mesomediterranean (150-1000 m). Subhumid-humid. Ephemeral pastures. (*Omphalodion commutatae*). Local endemism. Bermeja, Alpujata and Aguas. III-VI. LC (Blanca & al., 2011). Some populations inhabit dolomites in the north of Ronda and Grazalema mountain ranges (Malaga and Cadiz provinces) and calcareous sandstones in the north of Malaga province.

Genista hirsuta Vahl subsp. **lanuginosa** (Spach) Nyman (Fig. 4f)

Cushion chamaephyte / nanophanerophyte (shrub). Slopes and lithosols. Thermo-mesomediterranean (50-1300 m). Subhumid, humid, hyperhumid. Shrublands (*Staehelino-Ulicion baetici*). Bermeja, Alpujata and Aguas. III-VI (VII). LC (Blanca & al., 2011). Some populations inhabit micaschists and gneiss in Ronda mountain range (Malaga province), Chipiona (Cadiz province) and Xauen (Rif, north Morocco). We agree with Talavera (1999) with regard to the differential characters of the serpentinicolous populations, to which we add a reduced number of leaves and distance between thorns, and denser pubescence. These populations should be included in the obligate serpentinophyte group if assigned a taxonomic status.

Senecio eriopus Willk. subsp. **eriopus**

Hemicryptophyte with rosettes. Stony slopes. Thermo-mesomediterranean (500-1300 m). Subhumid-humid-hyperhumid. Shrublands (*Staehelino-Ulicion baetici*). Local endemism. Bermeja and Alpujata. V-VI. NT (Blanca & al., 2011). It also grows on dolomites, sandstones and marbles in Ronda and Grazalema mountain ranges (Malaga and Cadiz provinces) and in the Alpujarras region (Granada province).

Other important species

Digitalis obscura L. subsp. *laciniata* (Lindl.) Maire grows mainly on peridotites and secondarily on dolomites and sandstones in Andalusia and Morocco. *Elaeoselinum asclepium* (L.) Bertol. subsp. *millefolium* (Boiss.) García Martín and Silvestre is endemic to the south of the Iberian Peninsula, where it mainly inhabits peridotites, although it can also be found on sandstones and dolomites. Both taxa nearly reach the limit percentage for serpentine populations to be considered as subserpentinophytes. *Avenula gervaisii* Holub subsp. *gervaisii* and *Scorzonera baetica* (Boiss.) Boiss. have approximately 50% of the populations growing on serpentines.

Bupleurum foliosum Salzm. ex DC., *Polygala baetica* Willk., *Rubia agostinhoi* Dans. & P. Silva, *Festuca lasto* Boiss. and *Silene scabriflora* Brot. subsp. *tuberculata* (Ball) Talavera are very restricted species that only inhabit the Strait of Gibraltar phytogeographical area (south-western Andalusia and northern Morocco) on sandstones and siliceous soils. Some populations reach Sierra Bermeja peridotites and so a biogeographical connection may be supposed.

Halimium atriplicifolium (Lam.) Spach. subsp. *serpentinicola* Rivas Goday and Rivas-Martínez does not show any differences from *H. atriplicifolium* subsp. *atriplicifolium* (Nogueira & al., 1993; Morales Torres, 2009). Most of its populations could be considered as magnesicolous (peridotites and dolomites).

DISCUSSION

Except for *Asplenium adiantum-nigrum* var. *corunnense* and *Notholaena marantae*, the south Iberian serpentinophytes are considered as Mediterranean floristic elements (Blanca & al., 2011), showing eco-morphological and functional adaptations to the characteristic dry period of the Mediterranean climate (Orshan, 1986). Xeromorphic adaptations and a predominantly spring flowering season (Pérez Latorre & Cabezudo, 2002) are regarded as relevant factors for colonizing Mediterranean peridotites (Chiarucci, 2003). One exception worthy of note is *Peucedanum officinale* subsp. *brachyradium* with its autumn-flowering.

The chorological spectrum of south Iberian serpentinophytes reflects their affinity for the peridotite outcrops of Malaga province, grouped in the Bermejense phytogeograhical sector (Nieto & al., 1991). Most of the obligate serpentinophytes (20) are local endemisms except for *Asplenium adiantum-nigrum* var. *corunnense* and *Notholaena maranthae,* which have a wider distribution. The endemicity rate for obligate serpentinophytes is 91%. The two preferential serpentinophytes (*Galium boissieranum* and *G. viridiflorum*) are also restricted endemisms from Malaga, Cádiz and Granada provinces. Two of the subserpentinophytes (*Arenaria retusa* and *Senecio eriopus*) are restricted endemisms of Malaga and Cádiz (*Senecio* is also present in Granada), as is *Genista hirsuta* subsp. *lanuginosa* but this taxon reaches Morocco. 74% of the serpentinophytes are local endemisms and this percentage reaches 89% if an area centered in Malaga province and surroundings is considered.

As was found with Italian peridotite outcrops (Selvi, 2007), the number of obligate serpentinophytes in Andalusia increases with the outcrop area (Table 1). Serpentinophyte richness (Fig. 3) increases with that of the log-correlated area of the outcrops (lineal adjust $R^2 = 0.9087$). Sierra Bermeja shows the highest richness (3.64) and is the only outcrop where all the serpentinophytes, except *Centaurea carratracensis*, are found. This mountain range enjoys a high protection status at both regional (Natural Site) and European (LIC) levels. Guadalhorce is the smallest outcrop and shows the lowest richness (1.54).

Serpentinophytes and dolomitophytes in Andalusia (Mota & al., 2008) show a very similar spectrum of biological types (Table 2). Hemicryptophytes (33.3%) and chamaephytes (44.4%) dominate on peridotites, while geophytes and phanaerophytes are nearly absent. This result coincides with findings for peridotites in northern Italy (Selvi, 2007).

In contrast, the taxonomic spectrum for obligate serpentinophytes (Table 3) and dolomitophytes (Mota & al., 2008) show several differences. Fabaceae and Scrophulariaceae, both absent from the group of obligate serpentinophytes, are the best represented families amongst dolomitophytes, whereas members of Brassicaceae, Caryophyllaceae

Table 2. Comparison of the percentage of growth-forms between serpentinophytes and dolomitophytes *sensu* Mota & al. (2008). Growth-forms follow Orshan's classification (amphiphyte: two growth forms in the plant).

Growth form	Serpentinophytes	Dolomitophytes
Therophyte	14.8	13.9
Geophyte	3.7	rare
Hemicryptophyte	33.3	48.6
Chamaephyte	44.4	36.1
Amphiphyte	3.7	–

and Lamiaceae are frequent in both edaphic types. The family Asteraceae has the highest number of serpentinophyte species. Worthy of note is the lack of serpentinophytes among the family Poaceae, as also occurs in eastern Greek peridotites (Trigas & Iatrou, 2006) but not in north Italian outcrops (Selvi, 2007).

The most representative genera in the serpentine flora of Andalusia and Portugal (Menezes & Pinto da Silva, 1992) are *Alyssum*, *Arenaria*, *Armeria*, *Asplenium*, *Centaurea* and *Silene.* Genera common to Italian (Selvi, 2007) and Andalusian peridotite flora are *Alyssum*, *Armeria*, *Centaurea* and *Euphorbia*. *Alyssum*, *Centaurea* and *Silene* are common among Greek (Trigas & Iatrou, 2006) and Andalusian peridotites, while only *Alyssum* and *Silene* are common among Turkish (Reeves & Adigüzel, 2004) and Andalusian peridotites. *Notholaena marantae* and *Digitalis obscura* subsp. *laciniata* are the only serpentinicolous taxa common to Moroccan (Ater & al., 2000) and Andalusian peridotites.

When comparing Iberian serpentine endemics with other ultramafic Mediterranean areas in the world such as California (Kruckeberg, 1992; Safford & al., 2005), of particular note are the dominance of Brassicaceae and Liliaceae in California (Asteraceae in the Iberian Peninsula), the presence of *Galium* and *Allium* as common serpentinophyte genera, the very few endemics among the Poaceae (none in the Iberian Peninsula), and the coincidence of bodenvag forest genera (*Pinus jeffrey* and *Quercus vaccinifolia* in California and *Pinus pinaster* and *Quercus coccifera* in the Iberian Peninsula).

Centaurea prolongi Boiss., *Hormathophylla longicaulis* (Boiss.) Cullen & T.R. Dudley, *Linaria saturejoides* Boiss., *Omphalodes commutata* G. López and *Ulex baeticus* Boiss. *s.l.* are considered as dolomitophytes by Mota & al. (2008) but they can also be found growing on peridotite, so we prefer to consider them as magnesicolous species. While *Alyssum serpyllifolium s.l.* (subsp. *malacitanum* for this work), *Armeria villosa* subsp. *carratracensis* and *Iberis fontqueri* appear as dolomitophytes in Mota & al. (2008), the data obtained in the present study indicate that they should be considered as obligate serpentinophytes.

Most serpentinophytes present a wide bioclimatic range, as they may inhabit two or more bioclimatic belts (24 taxa, 89%) or two or more ombrotypes (25 taxa, 93%). *Alyssum malacitanum*, *Genista lanuginosa* (1250 m) and *Galium boissieranum* (1200 m) show the widest altitudinal interval, while *Peucedanum brachyradium* (100 m) and *Notholaena marantae* and *Asplenium corunnense* (350 m) show the narrowest interval. Only 10 taxa (37%) reach the supramediterranean bioclimatic belt (the least extensive), while the thermo and mesomediterranean belts are equally rich in serpentinophytes., although *Allium rouyi, Notholaena marantae* and *Peucedanum brachyradium* are restricted to the thermomediterranean bioclimatic belt. *Alyssum malacitanum, Centaurea carratracensis, Teucrium reverchonii* and *Silene serpentinicola* should be considered as the most xero-thermophilous taxa since they are the only ones that inhabit the thermomediterranean belt with its dry ombrotype.

The habitats and plant communities preferred by the serpentinophytes are shrublands on poorly developed soils (*Staehelino-Ulicion baetici* alliance in *Cisto-Lavanduletea* class) and the communities living on slopes, lithosols and rock fissures (alliance *Andryalo-Crambion filiformis*, class *Phagnalo-Rumicetea indurati*) (Table 4). These types of communities are the ones with the highest endemicity rate among Mediterranean habitats (Snoguerup, 1971; Gómez-Campo, 1985; Médail & Verlaque, 1997). However, one species, *Galium viridiflorum* stands out because it is the only serpentinophyte associated with wet ecosystems. This pattern is also found in serpentinicolous vegetation of northern Portugal and south Iberia, which shows similar trends, both being abundant in shrublands and rupicolous plant communities (Menezes & Pinto da Silva, 1992).

According to the Spanish Red List of endangered species (Moreno, 2008), the percentage of obligate serpentinophytes threatened is 59% (13 taxa), of which 45% (10 taxa) are included in the two high risk categories (CR and EN) and 15% (3 taxa) are classified as VU. If we consider all the serpentinophytes (27 taxa), 56% are threatened (15 taxa). A study carried out in northern Italian peridotites revealed that among 11 obligate serpentinophytes only one is considered as EN at a regional level (Selvi, 2007).

It is clear that adaptation to serpentine substrate is one of

Table 3. Number and percentage of serpentinophytes indexed by families.

Family	Species (%)
Obligate serpentinophytes	
Asteraceae	5 (23)
Caryophyllaceae	3 (14)
Apiaceae	2 (9)
Brassicaceae	2 (9)
Plumbaginaceae	2 (9)
Alliaceae	1 (5)
Aspleniaceae	1 (5)
Dipsacaceae	1 (5)
Euphorbiaceae	1 (5)
Lamiaceae	1 (5)
Linaceae	1 (5)
Saxifragaceae	1 (5)
Sinopteridaceae	1 (5)
Preferential serpentinophytes	
Rubiaceae	2 (100)
Subserpentinophytes	
Caryophyllaceae	1 (33)
Fabaceae	1 (33)
Asteraceae	1 (33)

Table 4. Number of serpentinophytes appearing in each syntaxon and its habitat. O, obligate; P, preferential; S, subserpentinophyte. (*): *Galio viridiflori-Schoenetum nigricantis*, *Molinio arundinaceae-Ericetum erigenae*, *Erico terminalis-Nerietum oleandri*, *Erico erigenae-Salicetum pedicellatae*.

Syntaxon	Habitat/vegetation	Serpentinophytes		
		O	P	S
Staehelino-Ulicion baetici	xerophytic shrublands	11	1	2
Andryalo-Crambion filiformis	stony slopes	10	–	–
Asplenio corunnensis-Saxifragetum gemmulosae	fissures of shaded rocks	2	–	–
Arenario capillipedis-Iberidetum fontqueri	lithosols	2	–	–
Pino pinastri-Quercetum cocciferae	tall shrublands with pines	2	–	–
Omphalodion commutatae	sandy lithosols	1	–	1
Bunio macucae-Abietetum pinsapo	fir forests	1	–	–
Notholaeno marantae-Cheilanthetum guanchicae	fissures in sunny rocks	1	–	–
Phlomido lychnitidis-Brachypodion retusi	xerophytic pastures	1	–	–
Selaginello denticulatae-Saxifragetum gemmulosae	shaded, slight slopes with clay	1	–	–
Higrophilous communities (*)	springs and streams	–	1	–

the main sources od endemicity, and therefore of plant diversity. Due to the exceptional nature of the vegetation and flora that are found therein, which is underlined by the results of this work, the biggest of the Andalusian peridotite outcrops (Sierra Bermeja) has been proposed as National Park, the maximum protection category for natural spaces in Spain. These areas are the same as those proposed by Médail & Diadema (2009) as a phylogeographical refuge and a "hot-spot" in the context of the Mediterranean Basin (5. Serrania de Ronda), and overlap an important area for threatened Spanish flora (Bañares & al., 2003).

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