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The Saharo-Arabian Gymnocarpos sclerocephalus (Caryophyllaceae) new to Europe in the semideserts of Almería, Spain

Abstract: The first European record of Gymnocarpos sclerocephalus (Paronychia sclerocephala, Sclerocephalus arabicus, Caryophyllaceae), from the semidesert of Tabernas (Almería, Andalusia, Spain), is presented. After a diagnostical description and ecological interpretation of the species, we provide arguments in favour of its native status in that Spanish region and explore the geographic and historical causes explaining the local occurrence of this and a number of other biogeographically analogous species.

Key words: Almería, Andalucía, Andalusia, Caryophyllaceae, dispersal, European flora, Gymnocarpos, Mediterranean flora, Saharo-Arabian flora, semideserts, Spain, Spanish flora

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Introduction

On 17 March 2018, during an amateur botanical trip in eastern Andalusia, Spain, organized by the Association Pulsatille, a peculiar member of the Caryophyllaceae was found in the semidesert of Tabernas in the province of Almería. The plant could eventually be identified as Gymnocarpos sclerocephalus (Decne.) Ahlgren & Thuill (Oxelman & al. 2002; = Paronychia sclerocephala Decne.), a strictly deserticolous Saharo-Arabian species not previously recorded in the region of Andalusia (Blanca & al. 2011; Cueto & al. 2018) or, more surprisingly, in any geographically European territory. In the present work, details of this finding and a brief discussion of its biogeographic context and relevance are presented.

The species

Diagnosis and systematic position

The genus Gymnocarpos Forssk. is diagnosable against all the other European Caryophyllaceae with stipulate leaves (Walters 1993) by its terete, fleshy leaves and, more specifically, by showing: (1) opposite leaves (unlike Corrigiola L. and Telephium L.); (2) fruit without inflated peduncle (unlike Pteranthus Forssk.); (3) gy-noecium trimerous, i.e. ovary tricarpellate and style tri-fid (unlike Herniaria L., Illecebrum L. and Paronychia Mill.); (4) sepals entire (unlike Loeflingia L.); (5) flow-ers apetalous (unlike Polycarpon L., Spergula L. and Spergularia (Pers.) J. Presl & C. Presl); and (6) stipules

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laminar, non-setaceous and fruits indehiscent, 1-seeded (unlike *Ortegia* L.).

Within its genus, *Gymnocarpos sclerocephalus* is unique for its annual habit and for the tightly clustered, partly connate inflorescences and infructescences (Fig. 1). It shares with the shrubby *G. decander* Forssk. the terete leaf-like bracts, so different from the large, scarious, *Paronychia*-like bracts of the rest of the genus.

Owing to its morphological distinctiveness, the species has often been classified in its own genus, *Sclerocephalus* Boiss., under the replacement name *S. arabicus* Boiss. (see, e.g., Chaudhri 1968; Petrusson & Thulin 1996), and as such it is still considered by Marhold (2011). However, molecular phylogenetics has been conclusive in showing that this species is deeply nested within *Gymnocarpos* (Oxelman & al. 2002; Jia & al. 2016).

According to the tribal system of Harbaugh & al. (2010), the most suitable suprageneric category for all these species is the tribe *Paronychieae* (the clade *Gymnocarpos* + *Herniaria* + *Paronychia*).

**Ecological interpretation of diagnostic features**

The above-mentioned generic and specific distinctive traits can be interpreted as the consequences of the ecological filtering imposed by an increasing aridity on more conventional *Paronychia*-like ancestors (Jia & al. 2016). The narrow, terete leaves and fleshy, green stems are easily cooled by wind to safe levels when stomata are closed under full sun and no transpiration takes place, their circular section also increasing the volume available to store rainwater and to diffuse the heat gained by radiation in the sun-exposed surface. In terms of water savings and survival, these two effects in combination more than compensate for the loss of specific leaf area. Similarly, the characteristic white hairs of the sepals (Fig. 1B, C) are likely to reflect sunlight and reduce thermal stress in the reproductive organs. Moreover, the mucronate apex of the leaves seems a way to facilitate morning dew to form falling droplets that the roots can absorb.

The tightly clustered infructescences and the apically spiny sepals suggest an efficient dispersal by epizoochory (Bittrich 1993: 214), explaining the particularly large geographical range of the species compared to other members of the genus and making still more plausible the full autochthony of the Spanish population. In can also be argued that seeds are protected within the spiny, dry heads and released only in response to rain...
(when the plant is more likely to complete its short cycle), in which case these unique inflorescences can be interpreted as a mechanism of serotiny.

The locality

A colony of two dozen individuals was found in the side slope of the “rambla” (local name for a wadi, or temporary riverbed) of Lanujar near its confluence with the rambla of Tabernas (Fig. 2A). The terrain is topographically even but composed of lithologically and volumetrically heterogeneous materials brought together by erosion and transport during storms (Fig. 2B). This geomorphological activity, combined with the slow growth of vegetation on which it partially depends, maintains a fine-grained mosaic of open, stony soils where annual plants like Gymnocarpos sclerocephalus may persist indefinitely without being eventually outcompeted by taller, perennial plants (Cabello & al. 2003: 494).

Within 10 m from the core of the population (Fig. 2B), the following accompanying species were recorded (the code after each species or subspecies summarizes its chorological type: [E] endemic to Spain; [ISA] Ibero-Saharo-Arabian; [IN] Ibero-North African): Diplotaxis harra (Forssk.) Boiss. [ISA+Sicily] subsp. lagascana (DC.) O. Bolós & Vigo [E], D. ilorcitana (Sennen) Aedo & al. [E], Filago clementei Willk. [IN], Forsskaolea tenacissima L. [ISA], Genista umbellata (L’Hér.) Poir. [IN] subsp. umbellata [IN], Lau­naea arborescens (Batt.) Murb. [IN], Limonium insigne (Coss.) Kuntze [E], Notoceras bicorne (Aiton) Amo & Mora [ISA], Pallenis hierichuntica (Michon) Greuter [ISA], Pteranthus dichotomus Forssk. [ISA], Salsola genistoides Poir. [IN] and Salsola oppositifolia Desf. [ISA+Italy].

Within 100 m, other biogeographically meaningful species like Cistanche lutea Desf. [IN], Cynomorium coccineum L. (see below) and Vella bourgaeana (Coss.) Warwick & Al-Shehbaz [E] were found.

As already stated, the interest of the plant was not fully realized during the first finding in March 2018, and no voucher was collected. A second visit one year later to the exact locality in order to fulfil this requirement was unsuccessful, but eventually the species could be collected in January 2020 in a nearby but different place, some 0.7 km to the southwest in the rambla of Tabernas, where it had already been observed by Julián Manuel Fuentes Carretero in May 2019 and December 2020. In the moment of this collection, two nuclei of 28 and 42 individuals were recorded, with 11 more scattered in between, totalling 81 individuals in an area of 2.4 ha. The full collection data of the voucher specimen are as follows:

SPAIN: comunidad autónoma de Andalucía, provincia de Almería, municipio de Rioja, Desierto de Tabernas, rambla de Tabernas, 37°00’00”N, 02°27’50”W, 230 m, therophytic grassland on marly, sand-rich soils, 5 Jan 2020, J. Fuentes & A. Ivorra s.n. [with F. Le Driant, honoris causa] (GDA 65550).

Biogeographic significance

Anything but an outlier

Gymnocarpos sclerocephalus was known to occur in a large area across the North African and Eastern Asian arid regions, from the Cape Verde archipelago to southern...
Iran (Fig. 3), and now must be added to the list of genera and species distributed mainly if not only in the Saharo-Arabian region and with their only European populations in the arid areas of southeastern Spain: *Ammochloa palaestina* Boiss., *Anabasis articulata* (Forssk.) Moq., *Commicarpus plumbagineus* (Cav.) Standl., *Enneapogon persicus* Boiss., *Forsskaolea tenacissima*, *Hammada articulata* (Moq.) O. Bòlòs & Vigo, *Ifloga spicata* (Forssk.) Sch. Bip., *Koelpinia linearis* Pallas, *Leysera leyseroides* (Desf.) Maire and *Notoceras bicorne*.

The list grows substantially if mostly Saharo-Arabian xerophytic genera or even species well represented in southeastern Spain but with a few colonies in other European regions, mainly on Mediterranean islands, are taken into account: *Androcymbium* Willd. (with *A. gramineum* (Cav.) J. F. Macbr. in Spain and northwestern Africa and *A. rechingeri* Greuter in Crete and Libya); *Apteranthes europaea* (Guss.) Plowes (SE Spain and Sicily and across North Africa and the Near East); *Cistanche Hoffmanns. & Link* (with *C. phelypaea* (L.) Cout. along western Spanish and Portuguese Atlantic coasts and *C. lutea* (Desf.) Hoffmanns. & Link in southeastern Spain and across Saharo-Arabian areas); *Cynomorium coccineum* (southern Portugal, Ibiza, southern Corsica, Sardinia, Sicily, Basilicata, Malta and across arid regions of North Africa and Asia); *Lasiopogon muscoideus* (Desf.) DC. (widespread in the deserts of southern Africa and across the whole arid belt of North Africa and southwestern Asia, from the Canary Islands to the Indus river, it reaches not only southeastern but also central Spain); *Launaea* Cass. (with up to 14 species across arid regions of Africa and the Near East, of which *L. arborescens*, *L. lanifera* Pau and *L. nudicaulis* (L.) Hook. f. occur also in southeastern Spain, *L. fragilis* (Asso) Pau and *L. pumila* (Cav.) Kunth are more widespread across eastern Spain, the former occurring also in Sicily, and a 15th species, *L. cervicorns* (Boiss.) Font Quer & Rothm., is endemic to the Balearic Islands); *Pteranthus dichotomus* (southeastern Spain, Cyprus, Malta and across North Africa and southwestern Asia); and *Volutaria Cass.* (with ten species: two endemic to Morocco, two endemic to the Canary Islands and six widespread across North Africa, three of which occur also in Europe: *V. crupinoides* (Desf.) Maire in central Portugal, *V. muricata* (L.) Maire in southern Spain and *V. tubuliflora* (Murb.) Sennen in southeastern Spain and Sicily).

There are still quite a few species which, despite belonging to genera widespread in Europe, also have a wide Saharo-Arabian range and their only European localities in southeastern Spain: *Achillea santolinoides* Lag., *Argyrolobium uniflorum* (Decne.) Jaub. & Spach, *Filago desertorum* Pomel, *Pallenis hierichuntica* (Michon) Greuter, *Plantago notata* Lag., *P. ovata* Forssk. and *Senecio flavus* (Decne.) Sch. Bip.

So what explains the existence of such a contingent of desert flora in this corner of Spain, surrounded by areas with physiognomically and to a great extent also taxonomically standard Mediterranean flora?

**Geology, climate and history collude to sculpt a unique landscape**

The idiosyncratic summer drought of the Mediterranean belt, imposed by the northward expansion of the Azores High, is enhanced in these areas by the strong rain shadow

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Fig. 3. Map created by combining the fragmentary or imprecise distributional information provided by the Global Biodiversity Information Facility (https://www.gbif.org/) and the Catalogue of Life (https://www.catalogueoflife.org/) with the general map in Jia & al. (2016). The red dot indicates the Spanish localities presented here.
of the Baetic mountains, whose highest massif, the Sierra Nevada (up to 3479 m a.s.l.), towers above the western edge of the Tabernas basin. The arrival of any substantial moisture from the Atlantic is hampered throughout the year, and total annual precipitation becomes very modest (around 200 mm on average, but below 100 mm in the drier years), evapotranspiration exceeding it by about fourfold. Precipitation is furthermore very irregular and unpredictable, much coming in short, heavy storms that physically erode the sparsely vegetated soils (Lázaro & al. 2004). Erosion disproportionally aggravates the water stress for plants and back-feeds the aridity of the region by reducing the capacity of soils to store water through the long sunny periods – this area receives the highest mean global daily radiation of continental Spain, above 5.3 kWh m⁻² day⁻¹ (Sancho & al. 2012).

A long history of aridity, dating back to the emersion of the Tabernas basin in the Pliocene (Alonso-Zarza & al. 2002), affects vegetation not only directly but also indirectly, insofar as it has contributed to generate and preserve unleased in the landscape large amounts of soluble evaporites with severe effects on plant development, both physical, as a result of superficial crusts and a too-strong adsorption of soil water, and chemical, because the abundance of certain ions hinders the absorption of essential nutrients and reduces the osmotic potential of soil water, further hampering its absorption by plants (Merlo & al. 2011; Moore & al. 2014; Escudero & al. 2015). In fact, Shmida (1985: 58–64) explored the strong links between desert and coastal flora as a consequence of the common effect of high ionic concentration in the edaphic solution.

However, it is possible that the striking desertic appearance nowadays predominant in this area is partly the result of human influence, and that a virtually continuous desert and coastal flora as a consequence of the common effect of high ionic concentration in the edaphic solution.

of the Canary Islands are not part of Europe? It is indeed, because even admitting that the traditional idea of a “Saharo-Arabian” desert region, one out of many biogeographical proposals to reunite the continuous arid belt of Africa and southwestern Asia. Other systems (Rivas-Martínez & al. 2017: 20) are less synthetic and distinguish, for instance, a Mediterranean Sub region for its floristic background, for the nature of its connections with bordering provinces and for the fact that the most strongly subarid sectors are local and depend on topographic rather than on macroclimatic causes (Rivas-Martínez & al. 2014).

Biogeography of the species: truly new to Europe?

Shmida (1985: 57) listed *Sclerocephalus* as one of the genera endemic to his “Sahara+Arabia” desert region, one out of many biogeographical proposals to reunite the continuous arid belt of Africa and southwestern Asia. Other systems (Rivas-Martínez & al. 2017: 20) are less synthetic and distinguish, for instance, a Mediterranean Sub region for its floristic background, for the nature of its connections with bordering provinces and for the fact that the most strongly subarid sectors are local and depend on topographic rather than on macroclimatic causes (Rivas-Martínez & al. 2014).

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Canary Islands considerably aside even from the otherwise marginally Mediterranean and by definition African adjacent Moroccan coasts. Therefore, Rivas Martínez & al. (2017), although including the Canary Islands in the Mediterranean Region, recognized them (with Madeira) as a separate subregion, the same rank assigned to the Maghreb Mediterranean, the Mediterranean Desertic Sahara and the West Mediterranean (significantly dubbed “Mediterranean Europe” and to which our population of *G. sclerocephalus*, as explained above, belongs).

As a more informal, pragmatic argument, the Canary Islands were excluded from the main initiatives to compile the floristic knowledge about the continent (*Flora europaea, Atlas florae europaeae*) and even about the whole Mediterranean Region (*Med-Checklist*). Only recently were they considered by the more comprehensive Euro+Med PlantBase (*Euro+Med 2006*+), as well as, most likely for purely normative convenience, by the *European Red List of vascular plants* (Bilz & al. 2011). More conclusively, Brummitt (2001: 37, 109) explicitly considered the Canary Islands as part of Africa.

Native status?

It seems very unlikely that *Gymnocarpos sclerocephalus*, an inconspicuous plant lacking any agricultural, medicinal, material or ornamental value, could have been deliberately introduced by humans. Its habitat is almost by definition unsuitable for human activities, so even an accidental transportation of seeds is hardly conceivable. Moreover, the population (Fig. 2A) lies more than 7 km away from the nearest inhabited, cultivated or in any other way exploited land (with the exception of the highway and a cluster of open-air cinematographic studios). A human introduction in this mostly unspoilt area therefore seems as unlikely as it is likely that the plant has remained unnoticed as a consequence of the opportunistic, ephemeral, unpredictable regeneration niche associated with rains, which as described above made it difficult even to collect a voucher in the very same spot where it was first found. It is true that, as Julián Fuentes Carretero (pers. comm.) tells us, giving voice to the understandable scepticism of some Andalusian botanists, the existence of a theme park with a zoo a few kilometres upstream and the comings and goings of cinematographic crews in this popular scenery make a human introduction plausible. But a second, perhaps stronger line of evidence comes from the accompanying species, all of which are well established as native and associated with natural vegetation (Decocq & al. 2004). No unquestionably alien species, e.g. of American or South African origin, of which there are plenty in the region and which would indicate the recent dumping of exogenous material or a long history of human disturbance, cohabit with *Gymnocarpos sclerocephalus*. On the contrary, as stated above, the accompanying species include many regional or even local endemics.

As suggested above, the best explanation for the local occurrence of *Gymnocarpos sclerocephalus* and all the other plants with a similarly intriguing distribution is the maintenance of larger or smaller patches of suitable habitat throughout the Quaternary climatic transitions, in agreement with the aforementioned abundance of uneroded outcrops of evaporite and with the Iberian endemic races of widespread Saharo-Arabian species (like *Diplotaxis harra* subsp. *lagascana*), whose existence can hardly be reconciled with a recent arrival of all this flora. But even if such arrival was relatively recent, it continues to make perfect sense that *G. sclerocephalus* reached this extreme Spanish outpost as part of the same natural process of range expansion from Asia across the Sahara documented by Jia & al. (2016). A detailed chorological map, given the shortage of sufficiently precise records, is unworkable; but on account of the approximate range presented in Fig. 3, the nearest African populations are at most a few hundred kilometres away, close enough to take a more or less ancient bird-borne dispersal event for granted. In fact, even if a recent colonization could be proven, the process might not only be analogous but also have a direct causal link via epizoochory to that recently documented for the trumpeter finch (*Bucanetes githagineus* Lichtenstein, 1823), a remarkable deserticolous bird having in Tabernas its main European stronghold (Barrientos & al. 2009). Recall that *G. sclerocephalus* occurs, without the least suspicion of being alien, in both the Canarian and the Cape Verde archipelagos, and in the latter case no less than 600 kilometres from continental Africa.

As a final thought on this issue, there is no more reason to question the native status of *Gymnocarpos sclerocephalus* than of its also epizoocorous Saharo-Arabian relative *Pteranthus dichotomus*, whose full autochthony in southeastern Spain has been unanimously admitted (Amich 1986; Díaz de la Guardia 2011). Along similar lines, the site of *G. sclerocephalus* is very close to those where *Filago desertorum* has finally been confirmed as a European plant, again without the least doubt about its native status (Gutiérrez Larruscain & al. 2017).

Conservation issues

Although more colonies are surely to be found in the same area, the species in continental Spain and Europe is so dependent on the above-described exceptional conditions that it must necessarily be very local. Hopefully, however, this single location is robust, well protected by its harsh environment from the two main agents of land transformation in southeastern Spain: greenhouse agriculture and tourism urbanization. Furthermore, it is expected to benefit rather than suffer from current climatic trends.

In the Canary Islands, the name *Gymnocarpos salsooides* Webb ex Christ was once used for a putative
endemic species different from the widespread *G. decander*, and therefore legally protected until 2010. But nowadays no species of the genus enjoys any protection. *Gymnocarpos decander* is listed as vulnerable in the current Spanish Red List (Bañares & al. 2010), whereas *G. sclerocephalus*, despite being much more local and rarer in the archipelago, is omitted.

We would advocate for a reassessment of such a decision. It could be argued that as long as *Gymnocarpos sclerocephalus* is found both in the Canary Islands and, as we now know, in continental Spain, its extinction risk at national level is reduced, and this could recommend against its addition to the Spanish Red List. But given that the concerns about the local conservation of *Forrskaoelea tenacissima* presented by Cabello & al. (2003) can be even more justly applied to *G. sclerocephalus*, this latter species should for the same reasons also be included at least in the Andalusian Red List (Cabezudo & al. 2005) and, hopefully, gain legal protection.

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