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New insights into the distribution patterns of Mediterranean insular endemic plants: The Sicilian islands' group

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ABSTRACT

This study aimed to shed further light on the factors that play a significant role in the spatial distribution of Mediterranean endemic plants. A multiple linear regression was applied to identify which environmental variables influence significantly the range size of the strictly endemic plants from Sicily and its satellite islands, including the Maltese archipelago. The statistical analysis included 202 taxa and 27 environmental variables of which 19 were bioclimatic predictors and 8 were related to habitat, altitude, bedrock and land use. The regression analysis showed that the amount of explained variation in the range size was 57.6%. The environmental variables affecting endemic range size decreased in this order of significance: number of colonized habitats > species altitudinal range > mean temperature of the wettest three months > minimum temperature of the coldest month > bedrock-preference indifference > annual mean temperature. In particular, basophilous and acidophilous endemics showed similar range sizes; bioclimatic variables highlighted the phytogeographical role of geomorphology; land use, instead, did not prove a significant predictor of species range size. Another finding showed that there are no habitats more prone than others to favor a larger endemic range size. Results suggested also that the narrow distribution of mountain endemics should be mainly attributed to niche specialism rather than spatial constraints. Overall, a complex picture emerged from the analysis of the distribution patterns of the Sicilian endemic plants. On the one hand, this study showed how important species ecological adaptability and local geomorphology are to predict range size. On the other hand, endemic plant distribution should be also explained through the complex climatic and geological history of Sicily and its satellite islands.

1. Introduction

The Mediterranean basin is a world hotspot of plant biodiversity that hosts 10% of all known vascular plants, amounting to about 25,000 species of which 13,000 are endemic taxa (Quézel, 1985; Greuter, 1991; Myers et al., 2000; Cuttelod et al., 2008). Compared to the rest of the continent, the Mediterranean hosts 80% of all European endemic plants (Comes, 2004). The evolution of this great plant diversity is partly due to a highly heterogeneous landscape located in the transition zone of Europe, Africa and Asia, and to the result of important geological events (e.g. Messinian Salinity Crisis), climatic oscillations (e.g. glaciations), complex geography and topography (e.g. mountain ranges, volcanoes, peninsulas, islands, islets), and especially in the last 10,000 years, the impact of human civilizations (Blondel et al., 2010; Şekercioğlu et al., 2011). Endemic plants are of particular interest for a variety of reasons that include inherent geographic restriction, usually threatened conservation status, and important ecological roles such as specialist pollinators and/or dispersers (Meynecke, 2004). The Mediterranean region is thus a key area for the study of plant biodiversity, not only in terms of total species richness but also, and especially, for the high rates of overall and regional endemism.

A topic still not sufficiently investigated and understood of Mediterranean biodiversity concerns the factors that determine the spatial distribution of endemic plants. To date, most authors have focused on the drivers of speciation and endemic richness, and to a lesser extent on the drivers of endemic range size (Vilà and Muñoz, 1999; Georghiou and Delipetrou, 2010; Salvo et al., 2010; Kallimanis et al., 2011). Regarding endemic distribution, biogeographers have come to the general conclusion that narrow spatial range is the basic feature of Mediterranean plant endemism (Thompson, 2005). Plant narrow endemism is mainly associated with the geological and climatic history of the Mediterranean basin, which played a significant role in the evolution of biogeographic patterns that favored the genetic isolation of plant populations (Quézel, 1995). However, these conclusions

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do not provide exhaustive answers to the underlying processes of Mediterranean endemic phytogeography. Palaeogeological and palaeoclimatic investigations, indeed, do not consider adequately the role of many biogeographical drivers that act more locally such as habitat diversity, spatial arrangement of habitats (e.g. fragmentation), land use, orographic elevation, bedrock composition, and microclimate (Rosenzweig, 1995; Ohlemüller et al., 2008; Blondel and Médail, 2009). Moreover, environmental factors such as altitude, precipitation, temperature, and geology, as well as evolutionary history, have been mainly studied to find possible relationships with endemic plant richness rather than with endemic spatial distribution (Wohlgemuth, 1998; Lobo et al., 2001; Jansson, 2003; Casazza et al., 2008).

Island endemic plants are a significant aspect of Mediterranean endemism with over 800 single-island taxa distributed across the main islands, and amounting to c. 7% of the total Mediterranean endemic flora (Bonanno, 2013). Sicily, in particular, is the largest Mediterranean island (25,460 km^2), and is considered as one of the ten Mediterranean regional plant diversity hotspots (Médail and Diadema, 2009). Sicily existed as an island during most of the Miocene (23.0–5.3 Ma [million years]; Meulenkamp and Sissingh, 2003), and had close connections with Calabria (South Italy), Corsica, and Sardinia (Goes et al., 2004). A direct connection with Africa and Europe certainly existed during the Messinian salinity crisis (5.96–5.33 Ma), when the Mediterranean Sea dried up owing to the closure of the Strait of Gibraltar (Hsü, 1972), and the Straits of Sicily and Messina were probably above sea level. At the start of the Pliocene (5.33 Ma), the opening of the Strait of Gibraltar flooded the Mediterranean Basin, and Sicily became an island again (García-Castellanos et al., 2009). The eustatic sea level lowering during the climatic oscillations of the Pleistocene (e.g. glaciations; 2.58–0.01 Ma) allowed Sicily to connect to some of its satellite islands (e.g. Aegadian Islands, Malta) and probably also to Calabria, but not to the African mainland (Thake, 1985; Lambeck et al., 2004). Other satellite islands such as Aeolian Islands and Ustica, which originated from volcanic eruptions during the last one million years, despite the short distance, were never connected to Sicily (De Astis et al., 1997). Free from Quaternary glaciations, Sicily and its satellite islands have played a unique role as an interface between north-African and south-European biogeography, resulting in the evolution of a flora with a high rate of endemism. As a result of a long and complex geo-climatic history, as well as high habitat diversity, the Sicilian islands' group has always aroused high interest among botanists, which is why this region is floristically well known (e.g. Nimis, 1985; Brullo et al., 1995; Giardina et al., 2007; Bacchetta et al., 2010; Troìa et al., 2011).

The biogeographical patterns of the Sicilian endemic flora, however, have been poorly investigated, and in general, the factors influencing the range size of Mediterranean endemic plants are not fully understood given that current research mainly focused on origin and richness of endemic plants (Médail and Verlaque, 1997; Kallimanis et al., 2010; Panitsa et al., 2010; Kagiampaki et al., 2011). Although it is widely accepted that narrow range size is one of the fundamental distribution patterns of Mediterranean endemic plants, however, it is not sufficiently explained why range size is extremely variable among endemic plants themselves, even among congeners. An example can be seen in the Sicilian endemic *Anthemis ismelia* Lojac. distributed in less than 35 km^2, and *Anthemis cupaniana* Tod. ex Nyman found across an area of c. 2000 km^2. This study, in particular, aimed to shed further light on the environmental factors that determine the range size of Mediterranean endemic plants, by considering Sicily and its satellite islands (including Malta) as a study area. This study investigated specifically the distribution patterns of those endemic plants restricted to the Sicilian islands, namely those taxa neither shared with mainland nor with other Mediterranean islands.

2. Material and methods

2.1. Study area

The floristic peculiarities of Sicily and its satellite islands make these insular territories an independent phytogeographical entity of the Mediterranean floristic region (Tutin et al., 1964–1993). Fig. 1 shows the map of the Sicilian floristic territory that, apart from the island of Sicily, includes also the Maltese Archipelago (Malta, Gozo and Comino) and 15 Italian islands: the Aeolian Islands (Lipari, Vulcano, Salina, Stromboli, Filicudi, Alicudi, Panarea), Ustica, the Aegadian Islands (Favignana, Marettimo, Levanzo), Pantelleria, the Pelagie Islands (Lampedusa, Linosa, Lampione). Sicily is the largest and most populated island of the Mediterranean Sea (Table 1), characterized by a hilly landscape and by Mt. Etna, the highest active volcano of Europe (3340 m asl). The climatic conditions range from semi-arid to humid, and include annual rainfall values from 250 to 1400 mm, and an average temperature of 18 °C. The minor islands are also characterized by a significant environmental heterogeneity. The first distinction concerns the geological origin: volcanic (Aeolian archipelago, Ustica, Pantelleria, Linosa), and calcareous (Aegadian archipelago, Lampedusa, Lampione, Maltese archipelago). Another important aspect is the different morphology: hilly (Aeolian archipelago, Marettimo, Pantelleria), and flat (Ustica, Favignana, Levanzo, Pelagie and Maltese archipelagos).

2.2. Floristic inventory

We prepared a floristic database (see Appendix A) that relied both on published literature (e.g., Brullo et al., 2011a, 2013; Raimondo et al., 2012; Siljak-Yakovlev and Peruzzi, 2012; Troìa et al., 2012; Mazzola et al., 2013; Peruzzi et al., 2014), and on web-based sources (e.g., IPNI; Euro + Med PlantBase; The Plant List; International Legume Database & Information Service; TROPICOS Missouri Botanical Garden; World Checklist of Selected Plant Families; PAN-European Species directories Infrastructure). In this study, plant species strictly localized only within the Sicilian floristic territory were considered as Sicilian endemics. Species shared with nearby regions (e.g. mainland Italy, Sardinia, Tunisia, etc.) were excluded. The floristic data set included plants at species and sub-species level with a validated taxonomic status. Varieties, hybrids, and apomictic plants (e.g. *Limonium* Mill., *Hieracium* L., *Taraxacum* F.H.Wigg.) were excluded from the floristic database. The total number of analyzed taxa was 202, amounting to c. 7% of the whole native flora (c. 3000 taxa).

2.3. Habitat, land use, bedrock, distribution and climatic data

Ecological and geographical data were assigned to each species and arranged in an Excel spreadsheet. The ecological information included preferred habitats, land-use types, and pH level of substratum. Habitat and land-use types were attributed according to the Corine Biotopes and Land Cover classifications (European Environmental Agency, 2002; APAT, 2005; European Commission, 2007; ISPRA, 2009; Habitat Italia, 2010). The Corine classifications provide an inventory of habitats and land uses widely applied as a tool to develop and guide environmental policies within the European Community (van Oudheusden, 2005). In particular, we used the Corine standardized classifications to compare habitats and land uses located both in Sicily and in other European territories. Regarding bedrock, the preference of a species for a given substratum was classified in acidic, basic or indifferent according