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RESEARCH ARTICLE

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Contribution to the knowledge of the vascular flora of Miniera di Murlo area (southern Tuscany, Italy)

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Abstract

This work aims to increase the floristic knowledge of southern Tuscany by means of a floristic investigation which took place in the Miniera di Murlo (southern Tuscany, Italy). The study area, located in the province of Siena, has an extension of 2.26 km^2 and hosts a heterogeneity of habitats like rocky outcrops, woodlands, meadows and riparian formations. The prevalent geological type is an acidic sedimentary rock known as diaspri formation (jasper). The checklist of vascular flora consists of 501 taxa and includes six endemics and 13 alien species, among which *Vitis labrusca* is a newly-found species for the Province of Siena along with the native *Rosa balsamica* and *Rosa squarrosa*. The most interesting species, such as *Anthoxanthum aristatum*, *Gagea bohemica*, *Paragymnopteris marantae*, *Saxifraga granulata,* and *Teesdalia coronopifolia*,

are found on acidic rocks. Species of the Italian Red List, such as *Ruscus aculeatus*, and species of Regional conservation interest, such as *Centaurea aplolepa* subsp. *carueliana*, *Ervilia loiseleurii*, and *Vicia nigricans*, were recorded. The chorological spectrum reveals a dominance of Mediterranean species indicating warm climate conditions and mild winters whereas the life-form spectrum shows a slight dominance of hemicryptophytes followed by therophytes. However, a clear dominance of one life-form type over the other is lacking, since the acidic and dry rocky substrate partially compensates for the humidity provided by the stream. This study highlights the relevant floristic value of the Miniera di Murlo area and supports the possible creation of a protected area or its inclusion in the adjacent one.

Keywords
Central Italy, flora, floristic research, jasper, conservation, rare species, Italy, vascular plants

Introduction

Tuscany is a part of the Italian territory where discrepancies in floristic knowledge are recognized; it, therefore, represents a suitable area to carry out studies on plant diversity (D'Antraccoli et al. 2018). In recent years, Tuscan botanists have filled the gaps with regional (Arrigoni 2016, 2017, 2018) and local floristic inventories in the Siena province (Bonari et al. 2016, 2018), along with records of single plant species (Peruzzi et al. 2015a, 2016, 2017, 2018). The present research will contribute to increase the floristic knowledge across Tuscany.

This study involves an area in the surroundings of the Miniera di Murlo village in the Province of Siena (southern Tuscany, Italy). The bedrock consists of sedimentary rocks entirely made by silica, representing a sort of "geological island" occurring in an area with a completely different geological type. This edaphic condition primarily led us to the selection of Miniera di Murlo as an interesting area to investigate. According to preliminary floristic surveys, the Miniera di Murlo area could belong to those areas of high biodiversity value not included in any nature reserve. In Italy, unsuitable conservation of plant diversity hotspots may occur (Fois et al. 2018a, 2018b, Signorello et al. 2018) and the current nature reserves of Tuscany do not completely include all the areas of high naturalistic value.

Current floristic knowledge of Miniera di Murlo is based on previous research by Chiarucci (1993, 1994) and Centi (2001–2002), who investigated the vegetation of ophiolitic and jasper outcrops in the Murlo area. Beside these studies, some species of high botanical interest, such as *Asplenium septentrionale* subsp. *septentrionale*, *Ervilia loiseleurii*, *Gagea bohemica*, and *Vicia nigricans* were also found in this area (Angiolini and Centi 2001, Frignani et al. 2005, Peruzzi et al. 2010a, 2017). Despite this, the floristic information regarding the area is still incomplete and a comprehensive survey is needed.

Accordingly, the aim of this work was to compile a checklist of vascular plants of the Miniera di Murlo area and to analyse its ecological attributes.

Study area

The study was carried out in an area extending for 2.26 km^2 that includes the jasper outcrops near the Miniera di Murlo village (Siena) in southern Tuscany (43.140713N, 11.383862E; Fig. 1). The area develops into the basin of the river Ombrone among the reliefs of the Dorsal Monticiano-Roccastrada and a hilly area made up of Pliocene sediments called Crete Senesi (De Dominicis and Casini 1997, Anselmi 2001). The investigated area is crossed by the Crevole stream and presents a high degree of naturalness although it has been subjected to anthropogenic exploitation due to the presence of mines. It also includes the Monte Pertuso relief, which is the highest point of the study area (273 m a.s.l.). The Miniera di Murlo area is adjacent, but not included in, the Special Area of Conservation (SAC) Basso Merse (IT5190007) and the Basso Merse Nature Reserve established in 1995 and 1996, respectively.

Geology

The main geological outcrop in the investigated area is the diaspri formation (jasper), a sedimentary late-Jurassic formation belonging to the Ophiolitic Unit of the Ligurian Domain. The diaspri formation (Suppl. material 1: Fig. 1) is made up of thin layers of radiolarite, 4- to 10-cm thick, usually reddish-brown with green veins, sometimes also fully green in colour (Scaramucci et al. 2016), which are intercalated by centimetric layers of siltstone. This rock formation is known as radiolarite because of the presence of radiolari shells (microorganisms with a siliceous skeleton). It presents a red colour because of the presence of a hematic pigment with, sometimes, clay inclusions.

Jasper of the Ophiolitic Unit makes a basal contact with serpentine, basalt, and gabbro (igneous and metamorphic rocks from the oceanic crust) and an upper one with siliceous limestone, shale, and marl (Bucci et al. 2015). Moreover, the presence of microfossils shows that jasper belongs to Malm (Kimmeridgian-Tithonian stratigraphic stage of Upper Jurassic), while a low zone of carbonate dissolution, during the Upper Jurassic, explains the absence of carbon residues in jasper.

Climate

Climatic data were retrieved from the Hydrological Tuscan Service (SIR; http://www.sir.toscana.it) of Monteroni d'Arbia (43.229343N; 11.422277E, 165 m a.s.l.) located at 12.4 km from Miniera di Murlo. The climate is typical of Tuscan hill valleys, more continental compared to sites at higher altitudes in the same area. As evidenced by Pesaresi et al. (2014), the Miniera di Murlo area lies between the Mediterranean and temperate macroclimates. During anticyclonic weather conditions, the area is prone to strong nocturnal thermal inversions, especially during autumn and winter.

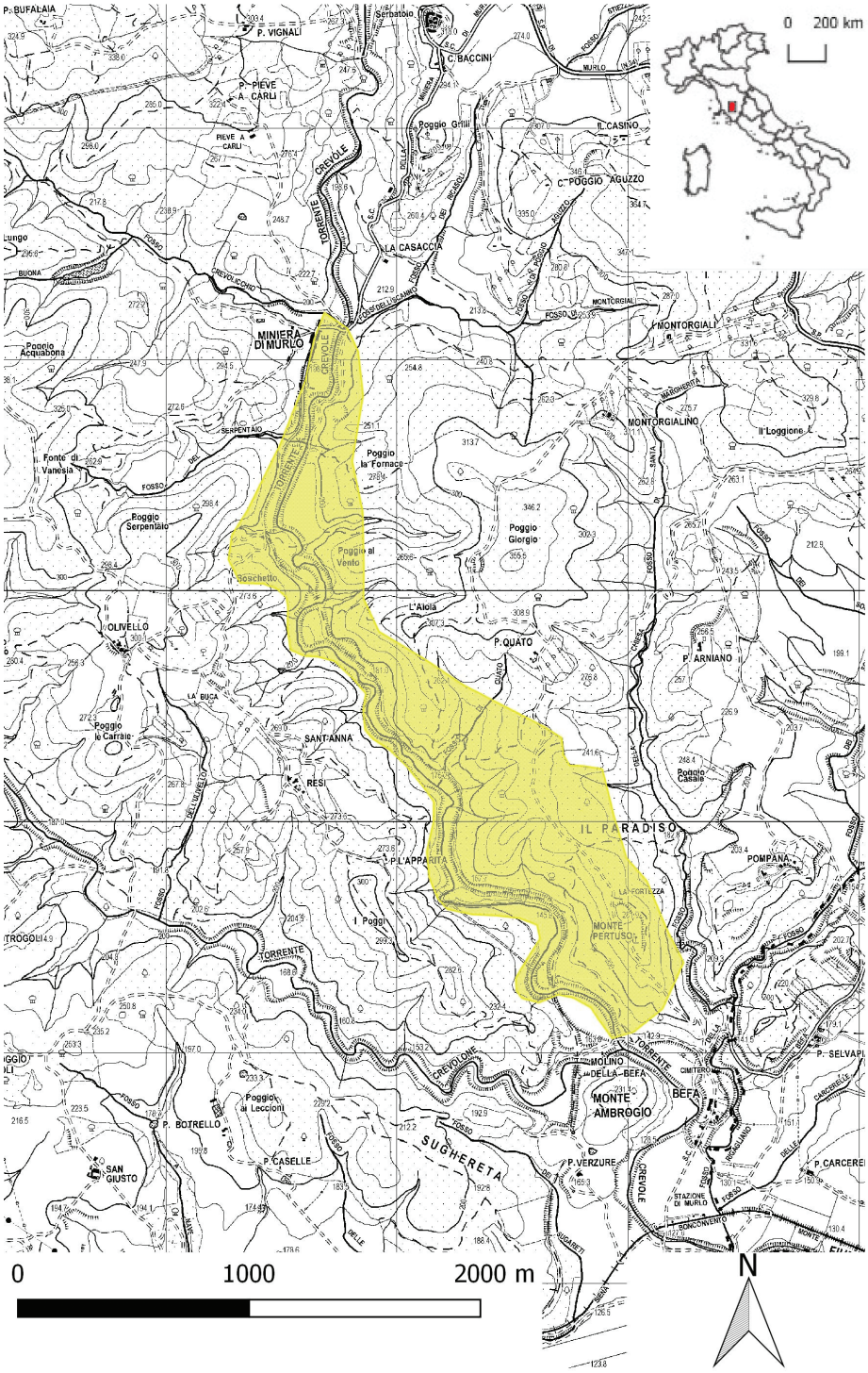

Figure 1. Boundaries of the study area (Miniera di Murlo, Siena).

Data for the period 2012–2017 showed an average annual temperature of 13.8 °C. The hottest months are July (average temperature 22.9 °C) and August (average temperature 23.2 °C), the coldest are January and February with an average temperature of 5.7 °C. The average annual rainfall is 871.3 mm with maximum values in October (138.8 mm) and November (125.6 mm), although in 2015 the month with maximum rainfall was August (278.4 mm). The thermopluviometric diagram (Suppl. material 1: Fig. 2) according to Bagnouls and Gaussen (1935), shows that the period of water deficit, derived from the ratio of precipitation to average temperature, concerns only June and July, but not August.

Vegetation types

The study area is characterised by different vegetation types typical of the Mediterranean area. Arid and acidic substrates with low fertility, such as jasper, promote the growth of Mediterranean evergreen sclerophyllous species, with a medium-high *Quercus ilex* cover and a relative abundance of shrubs, such as *Arbutus unedo*, *Erica arborea*, *E. scoparia*, and *Phillyrea latifolia*. The herb layer under this (semi-)closed canopy of evergreen woody species is strongly shaded and relatively poor in species. A less widespread forest type with different oak species (*Quercus cerris*, *Q. pubescens* and sparse *Q. suber*) also occurs. In addition, the study area presents scrublands with *Calluna vulgaris, Cytisus* spp., *Pyracantha coccinea*, and *Spartium junceum*, mostly located along wood edges, indicating the connection between the forest and a habitat with less developed soils.

Riparian vegetation along the stream is dominated by *Salix eleagnos, S. purpurea* subsp. *purpurea*, and *Populus nigra* subsp. *nigra.* Typical grassland vegetation with graminoids is also present. However, the most interesting vegetation type of the area is linked to the presence of jasper outcrops (Suppl. material 1: Fig. 3). This vegetation is dominated by vernal therophytes and succulent plants of the genera *Petrosedum* and *Sedum*. On the outcrops, patches of xerophilous and heliophilous Caryophyllaceae, such as *Scleranthus annuus* and *S. perennis* are dominant. The vegetation of the rocky slopes exposed to higher humidity (Suppl. material 1: Fig. 4) is dominated by hemicryptophytes, including several fern species.

Materials and methods

The floristic field surveys were carried out in 2017–2018. Plants collected in the field were dried in order to prepare herbarium specimens and were subsequently identified in the laboratory. The collected data were integrated with those from previous studies (Angiolini and Centi 2001, Centi 2001–2002, Frignani et al. 2005, Peruzzi et al. 2010a, 2017). The specimens collected during the field surveys are preserved at the herbaria of Siena (SIENA), Florence (FI) and Viterbo (UTV; acronyms according to Thiers 2015 onwards). For species identification, we mainly referred to Castroviejo et

al. (1984–2005), Fiori (1923–1929), Pignatti (1982, 2017a, 2017b, 2018) and Tutin et al. (1964–1980, 1993). For critical groups, specific monographs, books, and papers were consulted (Arrigoni 2003, 2016, 2017, 2018, Ciccarelli and Garbari 2004, Roma-Marzio et al. 2017). For native species, the nomenclature follows Bartolucci et al. (2018a) and further updates (Bartolucci et al. 2018b, 2018c), while for alien species Galasso et al. (2018a) and further updates (Galasso et al. 2018b, 2018c). The order of families is in accordance with Peruzzi (2010b), whereas genera and species are arranged in alphabetical order. Life forms and chorological types are in accordance with Pignatti (1982). Life-form and chorological type graphs are presented for both the general flora and for the species growing on jasper bedrock only. The distribution of endemic taxa follows Peruzzi et al. (2015b). To verify the conservation status of each taxon, the Red List of the Italian flora (Rossi et al. 2013), the List of plants of Regional conservation interest – Re.Na.To. Project (Sposimo and Castelli 2005, Viciani et al. 2014; http://www.regione.toscana.it/-/repertorio-naturalistico-toscano-re-na-to-http://www.regione.toscana.it/-/repertorio-naturalistico-toscano-re-na-to-) and the Italian Endemics Red List (Orsenigo et al. 2018) were checked. The checklist reports the following information for each taxon: scientific name, life form, chorological type, inclusion in the Italian Red List and in the List of plants of Regional conservation interest, species occurring on jasper, endemic/alien/cultivated species status, and the herbarium where the specimen is preserved. Graphs were plotted using R software (R Core Team 2018).

Results

The checklist consists of 501 taxa, distributed in 294 genera and 67 families (Suppl. material 1). The most represented families are Poaceae (67 taxa), Fabaceae (63 taxa) and Asteraceae (61 taxa). Among the 501 species, five occur in conservation lists: *Gagea bohemica* (EN; *Endangered*), *Vicia nigricans* (NT; *Near Threatened*), *Ruscus aculeatus*, *Centaurea aplolepa* subsp. *carueliana*, and *Ervilia loiseleurii* (all LC; *Least Concern*). Overall, the checklist includes 13 alien species (Table 1), mainly related to the Crevole stream riverbed.

The biological spectrum (Fig. 2A) of the entire flora shows a dominance of hemicryptophytes (H: 38.4%) and therophytes (Th: 36.6%), while less represented are the phanerophytes (Ph: 9%), geophytes (G: 8.5%), chamaephytes (Ch: 5.1%), and nanophanerophytes (NP: 2.4%); one helophytic species is also present. The H/Th ratio (bioclimatic index) is 1.01.

The jasper flora shows higher proportions of hemicryptophytes (H: 40.2%), chamaephytes (Ch: 7.2%), and nanophanerophytes (NP: 3.3%) versus a decrease of therophytes (Th: 32%) and geophytes (G: 8.3%); the percentage of phanerophytes does not change (Ph: 9%) (Fig. 2B).

Regarding chorological types (Fig. 3A), the checklist contains 25% of Steno-Mediterranean, 22% of Euro-Mediterranean, 17% of wide distribution species, 15% of

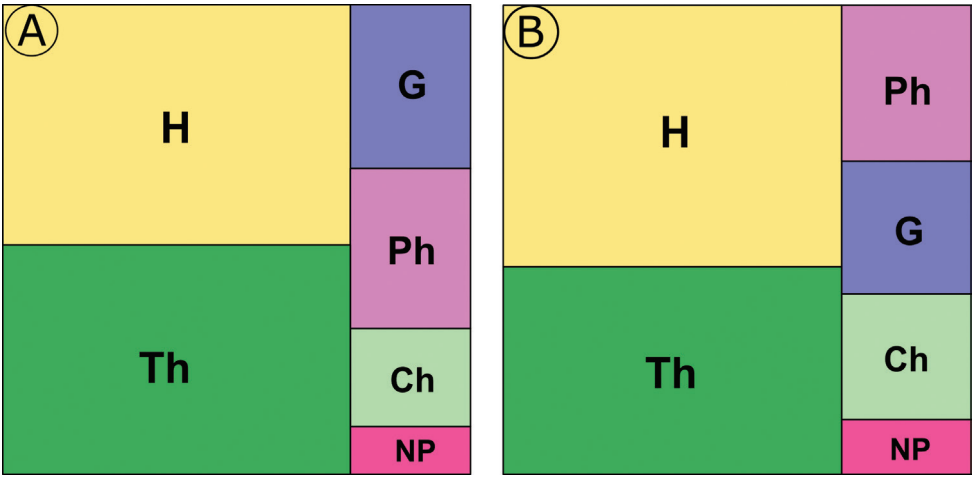

Figure 2. Life-form spectrum of species found at Miniera di Murlo (Siena). The spectrum shows the categories that appear more than five times in the checklist. **A** Life forms of all species found in the study area **B** Life forms of species occurring on jasper bedrock only. Categories are according to Pignatti (1982): hemicryptophytes (H); therophytes (Th); phanerophytes (Ph); nanophanerophytes (NP); geophytes (G); chamaephytes (Ch).

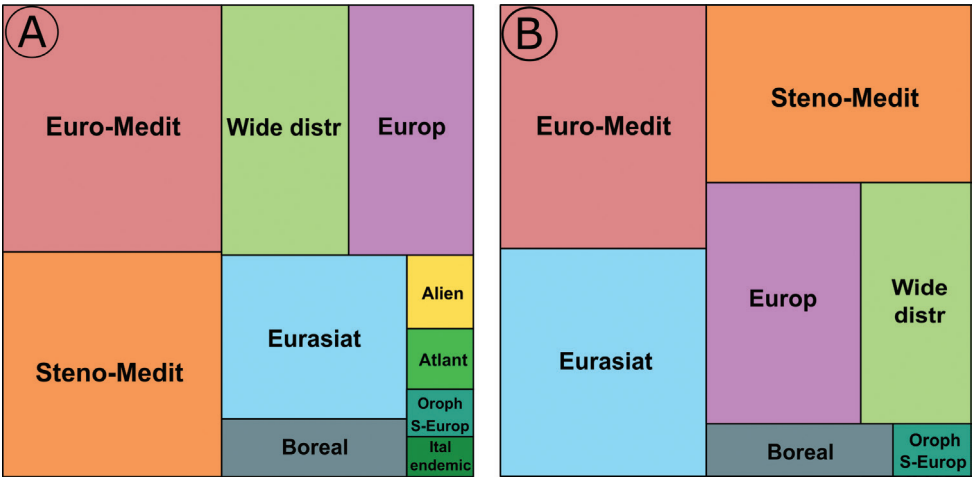

Figure 3. Chorological spectrum of species found at Miniera di Murlo (Siena). The spectrum shows the categories that appear more than five times in the checklist **A** Life forms of all species found in the study area **B** Life forms of species occurring on jasper bedrock only. Categories are according to Pignatti (1982): Alien= Alien species, Atlant= Atlantic species, Boreal= Boreal species, Eurasiat= Eurasiatic species, Euro-Medit= Euro-Mediterranean species, Europ= European species, Ital endemic= Italian endemics, Oroph S-Europ= South-European orophilous species, Steno-Medit= Steno-Mediterranean species, Wide distr= wide distribution species.

Table 1. Alien species found at Miniera di Murlo (Siena). The status and associated code in the study area, in Tuscany and in Italy for alien species follow Galasso et al. (2018a). A (archaeophyte), N (neophyte), T (taxonomically doubtful), FER (feral: wild plant originated from a culton escaped from domestication), NAT (naturalized alien) and INV (invasive alien).

Alien species	Status in the study area	Status in Tuscany	Status in Italy
Bidens frondosa	INV	P A NAT	N INV
Erigeron bonariensis	NAT	P A INV	N INV
Erigeron sumatrensis	NAT	P A INV	N INV
Euphorbia humifusa	NAT	P A NAT	N NAT
Helianthus tuberosus	CAS	P A INV	N INV
Malus domestica	CAS	P A CAS	A NAT FER
Opuntia engelmannii	INV	P A NAT	N NAT
Robinia pseudoacacia	NAT	P A INV	N INV
Setaria italica subsp. *pycnocoma*	NAT	P A NAT	N NAT FER
Setaria italica subsp. *viridis*	NAT	P A NAT	N NAT FER
Vitis labrusca	CAS	P A CAS	N NAT FER
Veronica persica	NAT	P A INV	N INV
Xanthium italicum	INV	P A NAT	T N INV

Table 2. Distribution of Italian endemic *taxa* according to Bartolucci et al. (2018a) found at Miniera di Murlo (Siena) and their status according to Orsenigo et al. (2018). Species are sorted in increasing order of regional occurrence and acronyms (from north to south Italy): EMR= Emilia Romagna, TOS= Tuscany, MAR= Marche, UMB= Umbria, LAZ= Lazio, ABR= Abruzzo, MOL= Molise, CAM= Campania, PUG= Puglia, BAS= Basilicata, CAL= Calabria, SIC= Sicily. Status acronyms: LC= Least Concern, DD: Data Deficient, (DD*): not reported in Orsenigo et al. (2018).

Italian endemics	Status	Distribution
Centaurea aplolepa subsp. *carueliana*	LC	PIE; LIG; TOS
Vicia ochroleuca subsp. *ochroleuca*	LC	TOS; CAM; BAS; CAL; SIC
Polygala flavescens subsp. *flavescens*	DD	EMR; TOS; MAR; UMB; LAZ; ABR; MOL; CAM; PUG; BAS
Helleborus viridis subsp. *bocconei*	LC	EMR; TOS; MAR; UMB; LAZ; ABR; MOL; CAM; BAS; CAL; SIC
Digitalis micrantha	(DD*)	EMR; TOS; MAR; UMB; LAZ; ABR; MOL; CAM; PUG; BAS; CAL
Linaria purpurea	LC	EMR; TOS; MAR; UMB; LAZ; ABR; MOL; CAM; PUG; BAS; CAL; SIC

European, 13.5% of Eurasiatic, and 5% of Boreal species, while alien, Atlantic, south-European orophilous, and Italian endemic species (Table 2) are less than 5%.

The jasper chorological spectrum (Fig. 3B) reveals the dominance of Steno-Mediterranean, Euro-Mediterranean, and Eurasiatic species (all > 20%). Both European (16.3%) and wide distribution (11.7%) species are well represented, while few are Boreal species (4.2%), south-European orophilous species (1.7%) and Italian endemics (1.4%). Moreover, the jasper checklist comprises two Atlantic and one alien species.

Discussion

Diversity, distribution, and conservation aspects

The checklist includes many species related to the physical and chemical features of the substrate. Low levels of nutrients, especially nitrates, are highlighted by numerous Fabaceae (Christenhusz et al. 2017). In addition, jasper outcrops host perennial and annual succulents (particularly Crassulaceae). Moreover, the acidity of jasper favours the development of typical species of siliceous rocky habitats, like *Gagea bohemica*, *Paragymnopteris marantae*, *Scleranthus perennis*, and *Teesdalia coronopifolia* (Biondi et al. 2009). This peculiar flora has its phenological optimum in the spring when low evaporation allows higher moisture. It is linked to very shallow and skeletal soils, with a low amount of nutrients and acidic reaction and it largely corresponds to *Habitat* 8230 of Annex I of the EU Habitats Directive 92/43/EEC (Selvaggi and Giusso del Galdo 2016). In these conditions, calcifuge and/or acidophilous species, such as *Centaurea aplolepa* subsp. *carueliana*, *Festuca lachenalii* and *Iberis umbellata*, also occur, while many ferns (mainly of the genera *Asplenium* and *Polypodium*; *Habitat* 8220 of Annex I of the EU Habitats Directive 92/43/EEC) grow on the siliceous cliffs. Some of the recorded species have a narrow distribution range: in Tuscany, *Saxifraga granulata* is present only in the northern Apennines and on the Island of Elba (Foggi et al. 2006, Mannocci et al. 2016, Carta et al. 2018, Coppi et al. 2018), while *Gagea bohemica* occurs in the continental part of Tuscany only in Miniera di Murlo (Peruzzi et al. 2017). In addition, *Ruscus aculeatus* is included in the Italian Red List (Rossi et al. 2013) with LC status, while *Vicia nigricans* and *Gagea bohemica* are both included in the Regional conservation list as NT and EN, respectively (Sposimo and Castelli 2005, Viciani et al. 2014). Moreover, *Centaurea aplolepa* subsp. *carueliana* and *Ervilia loiseleurii* are also listed there as LC. Only one cultivated species occurs (*Malus pumila*).

Among the alien species, *Bidens frondosa* and *Opuntia engelmannii* are those with the most worrying alien status (*sensu* Galasso et al. 2018a). They show a higher alien status in the study area compared to the one assigned at the Regional and national level (see Galasso et al. 2018a). *Opuntia engelmannii* is the most aggressive, growing on the jasper outcrop of Monte Pertuso where it is invasive (Suppl. material 1: Fig. 5; Selvaggi and Giusso del Galdo 2016). *Vitis labrusca* is a newly-found alien species for the province of Siena along with the native *Rosa balsamica* and *Rosa squarrosa* (Roma-Marzio et al. 2016, https://goo.gl/QUkDjT).

Life-form spectrum

The life-form spectrum shows the clear predominance of hemicryptophytes and therophytes. The H/Th ratio, indicator of the Mediterranean (values <1) or continental (values >1) nature of the flora (Sabato and Valenzano 1975), shows a value close to 1, underlying no prevalence of hemicryptophytes over therophytes (and *vice versa*) and

no clear bioclimatic character of the flora. The acidic and dry substrate might influence the life-form spectrum, by contrasting the humidity provided by the Crevole stream. Despite a similar acidic substrate, a different H/Th ratio was found in the floras of Monte Leoni (H/Th: 1.2; Selvi 1998) or in the Merse river valley (H/Th: 2.02; Landi et al. 2009) since these areas are situated in a more humid bioclimatic context compared to Miniera di Murlo. The percentage of geophytes is lower than in other floras due to the abundance of poorly evolved soils, being probably harsh environments for the growth of these species (e.g. Landi et al. 2009, Bonari et al. 2018). The significant proportion of phanerophytes, along with the nanophanerophytes, highlights the large surface area covered by forests. Due to the low water regime of the Crevole stream, no hydrophytes are present, while only one helophyte occurs (*Lythrum salicaria*).

In comparison with the life-form spectrum of the general flora, the one relating to plant species growing on jasper bedrock reveals a prevalence of hemicryptophytes followed by a lower percentage of therophytes. The decrease in therophytes, short-cycle plants favoured by open and disturbed environments (Kalusová et al. 2017), is likely due to the reduced presence of these habitats on jasper.

The flora of the jasper substrate shows an increase of chamaephytes compared to the percentage of the general flora. This shows that soils derived from jasper bedrock promote the growth of drought-tolerant species. Rocky substrates, although with different chemistry, lead to the development of selective vegetation types and associated plants. This is evident when the life-form spectrum of Miniera di Murlo is compared with that of Tuscan serpentine floras, showing only small differences (Chiarucci 2004).

Chorological spectrum

The analysis of the chorological spectrum reveals a prevalence of Mediterranean species that indicate warm conditions and mild winters (Pignatti 1994). Euro-Mediterranean and Steno-Mediterranean species represent almost the 50% of the chorological spectrum. Moreover, the percentages of European, Eurasiatic, and Boreal species indicate that the flora of Miniera di Murlo is mainly composed by Mediterranean species, although a substantial influence from typical species of the Euro-Siberian region occurs. The species with wide distribution indicate the presence of areas with anthropogenic disturbance (i.e., abandoned or grazed areas, and trails) or with azonal vegetation (i.e., rocky outcrops and riverbed). Atlantic species are scarcely present, as in the Italian territory in general, except for western regions, such as Tuscany and Sardinia (Pignatti 1994). The very low percentage of south-European orophilous species follows the geomorphology of the area, dominated by a hilly territory. Italian endemics are linked to the bedrock, as found on serpentine by Chiarucci (2004). Among them, *Centaurea aplolepa* subsp. *carueliana* is the only endemic with a restricted range that is limited to the Regions of Piedmont, Tuscany, and Liguria (Bartolucci et al. 2018a).

The chorological spectrum of plant species growing on jasper reveals a prevalence of Mediterranean species and an increase of Eurasiatic ones. This suggests that soils on jasper bedrock keep promoting the growth of Mediterranean species while improving the growth of species typical of the Euro-Siberian region, showing an equilibrium between Mediterranean and Euro-Siberian species.

Conclusions

This work contributes to the knowledge of the vascular flora of a poorly researched area of southern Tuscany. Our results showed that the Miniera di Murlo area represents a hotspot for vascular plants, mainly due to the presence of a peculiar bedrock: the jasper. Despite the past presence of mines and its exploitation, the area hosts some rare species that support its inclusion in a new Special Area of Conservation, or within the current Basso Merse SAC or Nature Reserve. Active management projects or the inclusion of the Miniera di Murlo area inside a nature reserve would help to limit the spread of alien species and to better preserve the native ones.

This work has highlighted how gaps in floristic knowledge can lead to incorrect delimitation of protected areas, causing the exclusion of relevant sites with particular habitats, such as jasper outcrops. It is important to promote awareness in public administrations regarding the potential of floristic investigations as a fundamental and decisive tool to support the establishment of protected areas.

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Supplementary material 1

Checklist of the vascular flora of the Miniere di Murlo area (Siena, Italy)

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