Article

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The vascular flora of Mount Limbara (northern Sardinia): from a troubled past towards an uncertain future

Abstract

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Mount Limbara is located in the north-eastern part of Sardinia (Italy). It is the third highest peak of the island and covers an area of 262.47 km². In the past, the studies concerning the flora of this mountain interested only restricted sectors or specific taxa, but a comprehensive floristic study of the whole territory was lacking. An annotated flora of the vascular flora growing in this area is here presented, based on field surveys carried out from 1993 to 2020, on the analysis of literature and on a review of specimens from five herbaria. The flora of Mount Limbara amounts to 1,147 taxa grouped in 46 orders, 120 families and 486 genera. The endemic and sub-endemic taxa are 86, while the alien flora consists of 137 taxa. The number of alien taxa is mostly related to human introduction. Among the taxa recorded in the past, 69 are here excluded and considered doubtful while 41 taxa are not confirmed. We compared the flora of Mount Limbara with that of other Sardinian mountains, highlighting the importance of this area, which appears to have the richest mountain flora of Sardinia, but also of the non-native flora. Finally, 132 taxa included in the Italian lists of threatened plants grow in the massif, thus adding conservation value to the study area.

Key words: checklist, endemism, native taxa, alien taxa.

Introduction

Plant checklists supply key information for biodiversity and ecological studies by providing a comprehensive summary of the floristic composition of a specific study area (Walker 2003). The literature is rich in local floras referring to small areas such as mountains, protected areas, islands and National parks. However, the completion of checklists requires a large amount of time in the field, species identification and conservation of samples, as well as bibliographic and herbarium research (Martellos & Nimis 2015).

For what concerns the island of Sardinia (Italy), there is a vast literature related to local floristic checklists, mostly carried out on coastal areas, smaller islands and islets, but also mountains (Arrigoni 2006). Nevertheless, among the highest mountains of Sardinia, only the Gennargentu massif, with two different recent works published (Bacchetta & al. 2013, Arrigoni & Camarda 2014), can be currently considered a well-studied area.

Sardinia is the second largest island in the Mediterranean basin, with an area of 24,090 km². Its position in the centre of the Tyrrhenian area, together with the neighbouring island of Corsica, is due to slow movement from the Gulf of Lions/Provence, occurring between the late Oligocene and the early-middle Miocene (Bache & al. 2010). This implies an isolation of about 20 Ma (Carminati & Doglioni 2005), which is responsible for many environmental peculiarities of the two islands, though Sardinian flora is poorer than in other insular regions. It consists of 2,441 native taxa (Bartolucci & al. 2018a), while in Corsica 2,724 taxa are known (Jeanmonod & Gamisans 2013) and in Sicily as many as 2,787 taxa (Bartolucci & al. 2018a). This paucity could be partly related to the lower height reached by Sardinian mountains (Gennargentu, 1834 m; M. Corrasi, 1437 m; M. Limbara, 1359 m), if compared with Corsican (M. Cintu, 2706 m; M. Ritondu, 2622 m; Paglia Orba, 2525 m) and Sicilian ones (Etna, 3343 m; Madonie, 1979 m; Nebrodi, 1847 m).

Biogeographically, Sardinia and Corsica were considered part of a separated biogeographic province from Italo-Tyrrhenian, which includes the western coastal regions of Italy from Liguria to Calabria (Ladero Alvarez & al. 1987; Bacchetta & Pontecorvo 2005). More recently, the province including Sardinia, Corsica and the Tuscan Archipelago was considered the Sardo-Corsican super-province (Bacchetta & al. 2012). The whole territory of Sardinia has been divided into 6 biogeographical sectors and 22 sub-sectors: Mount Limbara is included in the Goceano-Logudorese sector and Gallurese sub-sector (Fenu & al. 2014).

The present study began in 1993. Our interest is justified by the considerable ecological importance of the site, due to the characteristic microclimate resulting from its location and altitude range but is also closely linked to its historical vicissitudes. This work goes to complete the knowledge of a mountain flora that, despite the presence of a previous floristic work (Veri & Bruno 1974), was still not sufficiently studied, given its importance in the Mediterranean context. Our aim was to provide a detailed checklist of the vascular flora of Mount Limbara, to enable future characterisation of its biotic environments, help in identifying target species, understanding ecological changes, as well as in the fulfilment of the management plan for the Special Area of Conservation ITB011109 “Monte Limbara”.

Materials and method

Study area

Geography of the mountain

The Limbara massif is located in north-eastern Sardinia, delimiting the historical regions of Gallura and Monte Acuto, and covers the municipalities of Berchidda, Calangianus, Oschiri and Tempio Pausania, in the administrative province of Sassari (Fig. 1). The total area studied in this work covers 262.47 km², of which 166.24 km² are included in the SAC ITB011109 “Monte Limbara”, designated by the Habitat Directive 92/43/EEC (Natura 2000 2017).

Mount Limbara has a limited elevation. The highest peaks reach about 1300-1350 m a.s.l. (P. Balistreri, 1359 m; P. Sa Berritta, 1352 m; P. Bandera, 1345 m; P. Giugantinu, 1333 m), but the SAC also includes the lowlands as low as 160 m a.s.l. along the northern shores of Lake Coghinas, making a total altitudinal difference of around 1200 m (Calvia 2016).

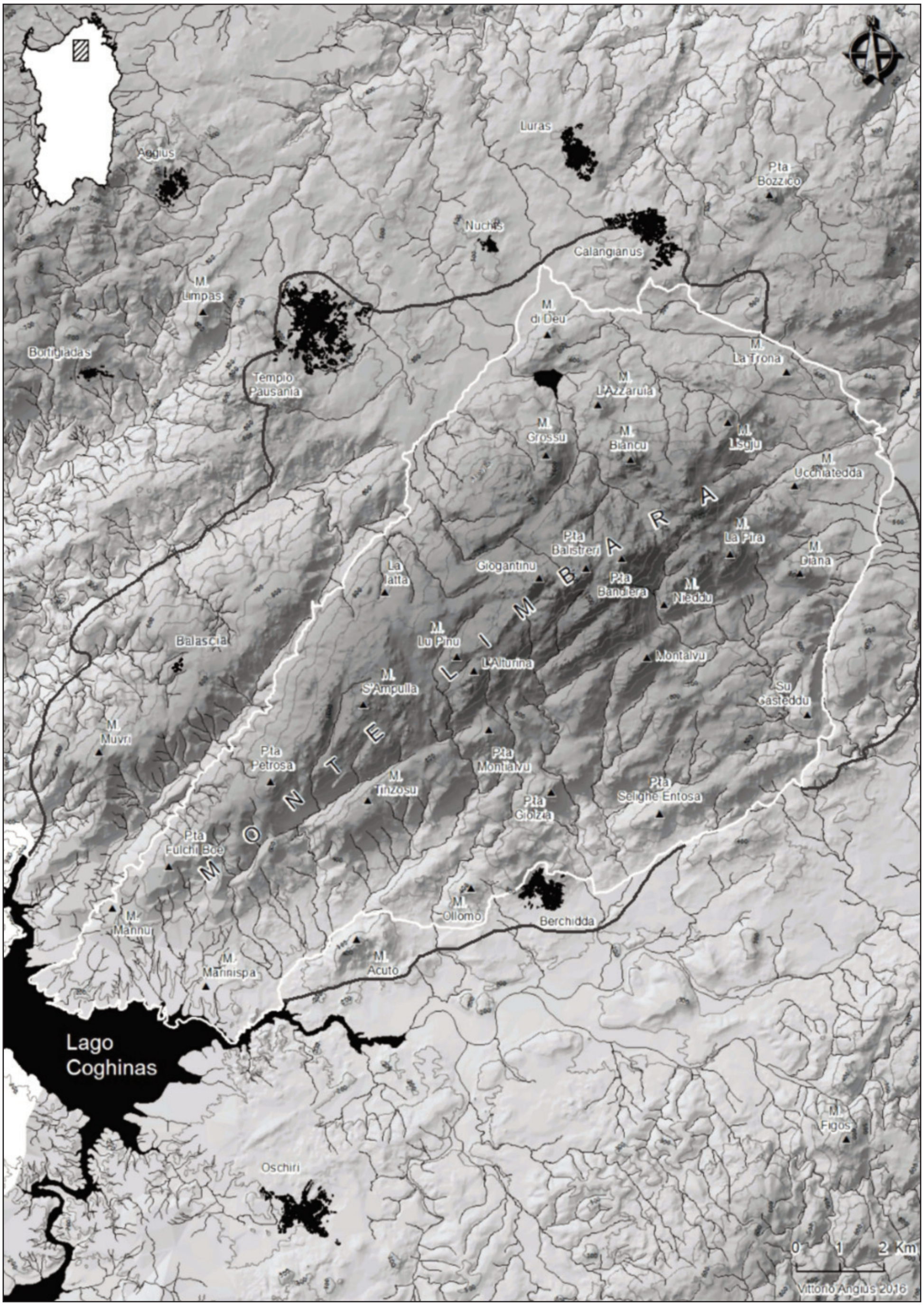

Fig. 1. Map of the study area. Black lines correspond to the borders of our study area; white line corresponds to the borders of the SIC ITB011109 "Monte Limbara".

This research was carried out primarily within the boundaries of the SAC, also including four connected zones defining the best characterization of the area (Calvia 2016).

Bioclimate of Mount Limbara

The Limbara massif is characterised by the interaction between the Mediterranean climate (dominant in the lowlands) and the temperate climate (prevalent in the topmost zone). The presence of a non-Mediterranean bioclimate was firstly hypothesised by Arrigoni (1968a). Later, analysis of the thermo-pluviometric data from the station of Vallicciola (1050 m a.s.l.), for the years 1965-87, showed a sub-Mediterranean variant of the temperate bioclimate, with a lower supra-temperate thermotype, an upper humid ombrotype, and an eu-oceanic continental type (Farris & al. 2007). This is confirmed by the Bioclimate Map of Sardinia (Canu & al. 2015). Furthermore, three bioclimates were identified: Oceanic Pluviseasonal Mediterranean (lowlands); sub-Mediterranean temperate (transition areas) and Oceanic temperate (summit areas).

As regards the iso-bioclimates present in the study area, cartographic analysis enabled the identification of eight types (Canu & al. 2015): five types are included in the Oceanic Pluviseasonal Mediterranean bioclimate; two iso-bioclimates are included in the sub-Mediterranean temperate bioclimate; only one iso-bioclimate is attributable to the Oceanic temperate bioclimate.

Geological and hydrographical features

The mountain has a granitoid lithology dating back to the Hercynian orogeny of the Carboniferous (Carmignani & al. 2001). There are two main intrusive types with different facies: the inequigranular monzogranites on the north-eastern side of the area, and the equigranular leucogranites in the rest of the mountain (Carmignani & al. 2001). The only exception is found on the south-western sides of the massif, as far as the shores of Lake Coghinas, where the predominant lithoid types are metatexites and amphibolites with shorter intrusions, mainly granodiorite and vein rocks of different compositions (Carmignani & al. 2001).

The hydrogeological structure is defined by the hydrographic basins of the main rivers of northern Sardinia: all the streams flowing down the eastern and southern slopes of the mountain (Berchidda, Oschiri) flow into Lake Coghinas. The majority of the streams flowing down the north-western slopes of the mountain (Calangianus, Tempio Pausania) drain into Lake Liscia, with some exception, flowing into the Coghinas river. Finally, on the northern side (Calangianus), a single stream becomes part of the Rio Padrongianus and flows into the Gulf of Olbia (Calvia 2016).

In some areas, small water reservoirs have been created for fire protection use. Finally, another water reservoir was recently created on the northern slope of the mountain for water withdrawal use (Calvia 2016).

Vegetation

Historical writings depict a past landscape quite different from now: wide holm oak forests, vast cork oak woodlands in the basal areas and downy oak in the cooler ones. In the most mesophilous parts, yew and holly were widespread (Moris 1837-1859; Casalis 1851; Cavara 1908; Spano 1958; Desole 1966).

The current situation is greatly modified: cuts, charcoal-burning, wildfires and grazing have almost completely degraded the mountain vegetation, which consisted primarily of garrigue and scrub vegetation until the second half of the last century (Ruggero 1999). Then, a slow recovery of the native tree cover occurred but on the other hand, many non-native species, mostly conifers, have been introduced (Pavari 1935; Pavari & De Philippis 1941; Veri & Bruno 1974), accompanied by the implementation of significant hydraulic and forestry measures (Ruggero 1999).

Today the vegetation of the mountain is largely a mosaic characterised by different types of vegetation. Scrub and oak woodlands predominate, with the former tending often to evolve towards the latter. The holm oak woodlands extend over wide areas, but usually consist of coppices, rarely converted into high forests (Ruggero 1999). This kind of woodland is included in the vegetational associations *Galio scabri-Quercetum ilicis*, more thermophilous, and *Saniculo europeae-Quercetum ilicis*, more mesophilous (Bacchetta & al. 2009). Natural high forests are today very rare and generally localized in the steepest and wildest areas of the mountain. In the basal areas, the most represented type of woodland is the Sardinian calcifuge meso-Mediterranean cork oak association *Violo dehnhardtii-Quercetum suberis* (R.A.S.-P.F.A.R. 2007). There are other minor types of woodland such as the relict quaking aspen stands, or the maritime pine woodlands of the north-eastern sides (Calvia 2016). The less evolved soils are covered by mountain garrigue with Salzmann's broom and caraway thyme, an association known as *Violo limbarae-Genistetum salzmannii* (Valsecchi 1994), interspersed with patches of grassland with therophytes and hemicryptophytes. An important chasmophyte flora thrives among the granite outcrops, belonging to the *Potentillion crassinerviae* alliance (Bacchetta & al. 2009) and *Arenarion balearicae* in the shadier ones (Biondi & al. 2014). The vegetation of temporary ponds and wet places falls within different associations of the *Isöeto-Nanojuncetea*, *Isöeto-littorelletea*, *Phragmito-Magnocaricetea* classes (Bagella & al. 2009). Finally, more than 1,800 ha are today covered by reforestations and many areas are now affected by naturalised or invasive trees (Ruggero 1999), especially conifers: e.g. *Abies cephalonica* Loudon, *Cedrus atlantica* (Endl.) Carrière, *Pinus nigra* subsp. *laricio* Maire, *P. pinea* L.

History of the studies

The early botanists who visited some parts of the Limbara massif were Moris (1837-1859), Reverchon (often cited by Barbey 1884) and Nicotra (1895, 1896). Herbarium specimens and publications by Cavara (1908) and Terracciano (1909, 1910a, 1910b, 1914) are available and are related to field excursions on limited areas of the mountain. Other findings are reported by Fiori (1913), Negodi (1931), Schmid (1933). During the second half of the 20th century, other scholars searched for specific taxa or studied vegetation and climate: Desole (1960, 1966), Joncheere (1963), Arrigoni & Vannelli (1967), Arrigoni (1968b, 1970), Arrigoni & al. (1976-1991), Valsecchi (1977a, 1979, 1993, 1994). In the last two decades the mountain has been cited in various floristic works (Fridlender 1999, 2000; Foggi & al. 2007; Desfayes 2008; Peruzzi & al. 2011; Sáez & al. 2011, and Farris & al. 2012).

The first checklist of the vascular flora of Mount Limbara amounted to 506 taxa (Veri & Bruno 1974). Though important from many points of view, it was incomplete, since the cited authors surveyed only a few points scattered through the central zone of the mountain, while omitting the rest of the area, as well as all zones under 500 m a.s.l.

Data collection and analysis

We studied the flora of Mount Limbara mostly through research in the field, from 1993 to 2020. For each taxon found (excepted many orchids), we prepared one or more herbarium specimens that are now preserved in our herbaria (Roma-Marzio & al. 2017), or sometimes in CAG, FI, PAV, RO, and ROV (acronyms follow Thiers 2018).

In addition to research in the field, we carried out a bibliographic study, completed by observation of herbarium specimens from CAG, FI, RO, SS, and SASSA.

For each taxon we reported scientific name, biological and chorological type, abundance code, habitats, altitudinal range, first report on the area, herbarium specimen/s seen and notes (potential). For the alien taxa we add abbreviations, following Galasso & al. (2018a): A = adventitious; P = planted; CAS = Casual; INV = invasive; NAT = naturalised; OP = only planted (our addition).

For the systematics and nomenclature, we followed Bartolucci & al. (2018a) and Galasso & al. (2018a), except where the opinions of the authors differed, as specified in the notes. The plants were determined using Italian floras and floras of other countries (Fiori 1923-29; Tutin & al. 1964-80, 1993; Zangheri 1976; Pignatti 1982, 2017-2019; Bolòs & Vigo 1984-2001; Castroviejo & al. 1986-2015; Arrigoni 2006-2015; Jeanmonod & Gamisans 2013; Tison & de Foucault 2014), and through literature (Arrigoni & al. 1976-1991; Valsecchi 1977a, 1979; Jeanmonod & Gamisans 1992; Valsecchi 1993; Bacchetta & al. 2003; Domina & Arrigoni 2007; Garbari & al. 2007; Habashi & Jeanmonod 2008; Portal 2009; Frignani & Iiriti 2011; Peruzzi & al. 2011).

The biological forms follow Raunkiaer's classification (Raunkiaer 1934). The names of orders and families follow PPG I (2016) for pteridophytes, Farjon (2017) for gymnosperms, APG IV (2016) for angiosperms; genera are reported according to Peruzzi (2010). All the taxa within each family are listed in alphabetical order. All the scientific names are reported in bold and italic, but those considered alien are reported in italic only. The OP taxa have an additional asterisk (*).

Geographical abbreviations are reported following Pignatti (2017-2019).

We considered as endemics all taxa limited to the Sardo-Corsican biogeographic province (Bacchetta & al. 2012), as well as those included in other Italian regions (Peruzzi & al. 2014). Those present in limited areas of other countries are reported as sub-endemics. For (sub-)endemic taxa, geographic abbreviations follow Euro+Med Plantbase (2020).

Abundance is expressed as follows: EX = extinct; RRR = extremely rare, taxa found only once and not confirmed later; RR = very rare, taxa found in one or more localities, but with a number of individuals lower than 50; R = rare, taxa found in one or more localities but having a more consistent number of plants than the previous category; S = sporadic, taxa scattered in the area but not abundant; C = common, taxa found in a wide range of localities and locally abundant; CC = very common, taxa widespread in the whole study area and often dominant.

Results

The floristic list consists of 1,147 taxa (see appendix 1), which are divided as follows: 1,010 taxa native (88%), and 119 (10.4%) alien. An additional 18 taxa are OP (1.6%).

The flora includes 46 orders, 120 families (15 of which are alien/OP taxa only) and 486 genera (61 of which are alien/OP taxa only).

The taxa at the species level are 1,025, while 109 are the subspecies, 9 are hybrids and 4 are varieties. Pteridophytes consist of 13 families, 18 genera, 33 species. Gymnosperms are represented by 3 families, 11 genera and 22 species (18 of them introduced). Angiosperms are 104 families, 461 genera and 1,090 taxa, divided as follows: 17 families, 113 genera and 276 taxa are Monocots (20 of them non-native); 87 families, 350 genera and 814 taxa are Dicots (99 non-native).

The most represented families are *Asteraceae* (138 taxa), *Poaceae* (125), *Fabaceae* (110), *Caryophyllaceae* (38), *Apiaceae* and *Lamiaceae* (36). The richest genera are *Trifolium* (27 taxa), *Carex, Ranunculus* (18), *Juncus*, *Vicia* (17), *Euphorbia (15)*, *Galium* and *Medicago* (14).

Among the biological life forms, a predominance of therophytes is observed (see Fig. 2).

From a chorological point of view, all strictly Mediterranean (35.8%) and Euro-Mediterranean (16.4%) elements dominate (see Fig. 3).

The endemic contingent of Mount Limbara amounts to 86 taxa, belonging to 67 genera and 35 families. All the vascular endemics found are Angiosperms, with 64 Dicots and 22 Monocots. The most represented families are *Asteraceae* (12 taxa), *Lamiaceae* (8), *Asparagaceae*, *Iridaceae*, *Orchidaceae* and *Poaceae* (4).

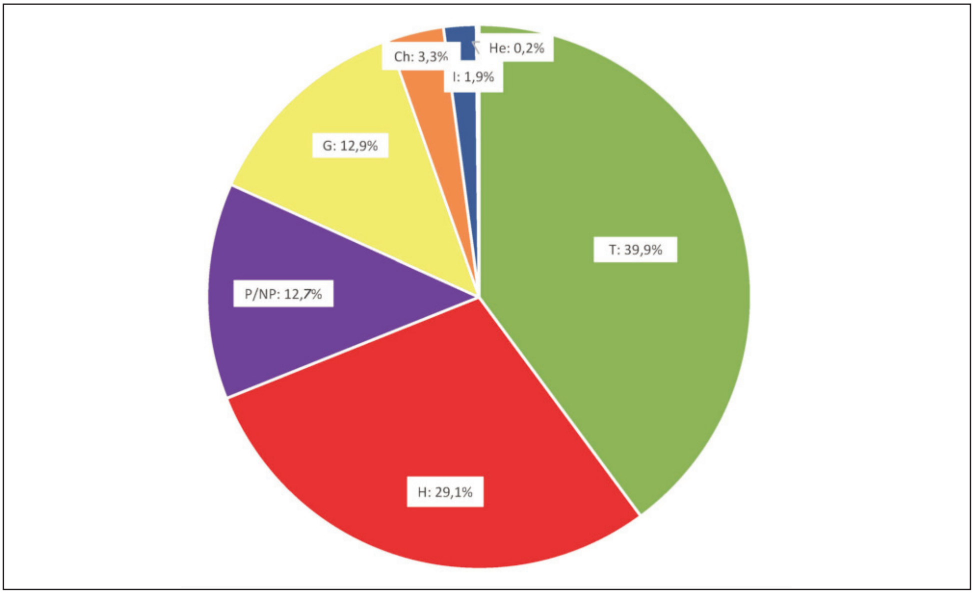

Fig. 2. Biological spectrum of the vascular flora of Mount Limbara.

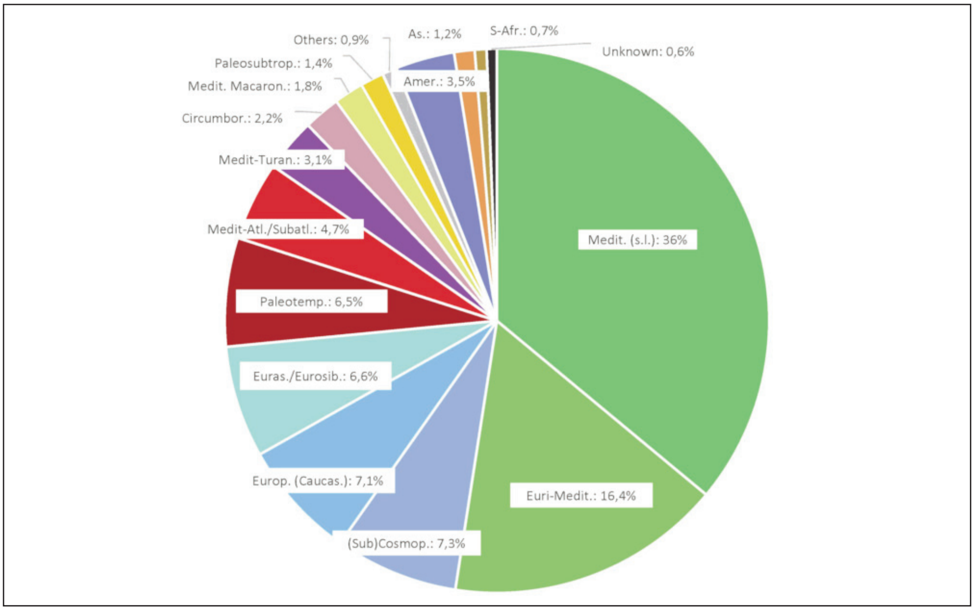

Fig. 3. Chorological spectrum of the vascular flora of Mount Limbara.

The chorology of the endemics shows a predominance of Sardo-Corsican taxa (see Fig. 4). Three taxa are exclusive to Limbara (*Hieracium mattirolianum* subsp. *martellianum* (Zahn) Greuter, *H. racemosum* subsp. *limbarae* (Arrigoni) Greuter, *Rubus limbarae* Camarda), representing 3.5% of the entire endemic flora. Furthermore, 8 endemic taxa (9.3% of the total) have their *locus classicus* in the area: *Barbarea rupicola* Moris, *Festuca sardoa* (Hack.) K.Richt., *Hieracium bernardii* subsp. gallurense (Arrigoni) Greuter, *H. mattiroloanum* subsp. *martellianum*, *H. racemosum* subsp. *limbarae*, *Romulea ×limbarae* Bég., *Rubus limbarae*, *Viola limbarae* (Merxm. & W. Lippert) Arrigoni (see Béguinot 1908; Arrigoni 1985; Camarda 2003; Peruzzi & al. 2015).

The alien plants on Limbara are attested in 137 taxa, 47 of them are CAS, 67 NAT, 5 INV, while 18 are OP. From a chorological point of view, American taxa dominate, being 40 (6 of which are OP), followed by Asian (14, 3 OP) and Mediterranean (14, 2 OP).

The biological spectrum of the alien taxa shows the richness of phanerophytes, being 61 (nano-phanerophytes included), 18 of which are only planted. Therophytes follow, with 31 taxa, then there are 19 hemicryptophytes, 14 geophytes, 10 chamaephytes, and 2 hydrophytes.

We excluded 69 taxa reported by mistake and doubtful (see ESF 1). We separated 41 taxa reported before in the area, but not confirmed later nor found during this research (see ESF 1).

The taxa enlisted in the threatened lists amount to 132, corresponding to 13% of the native floristic contingent: 13 were classified as DD (Data Deficient), 73 LC (Least Concern), 27 NT (Near Threatened), 3 VU (Vulnerable), and 16 EN (Endangered).

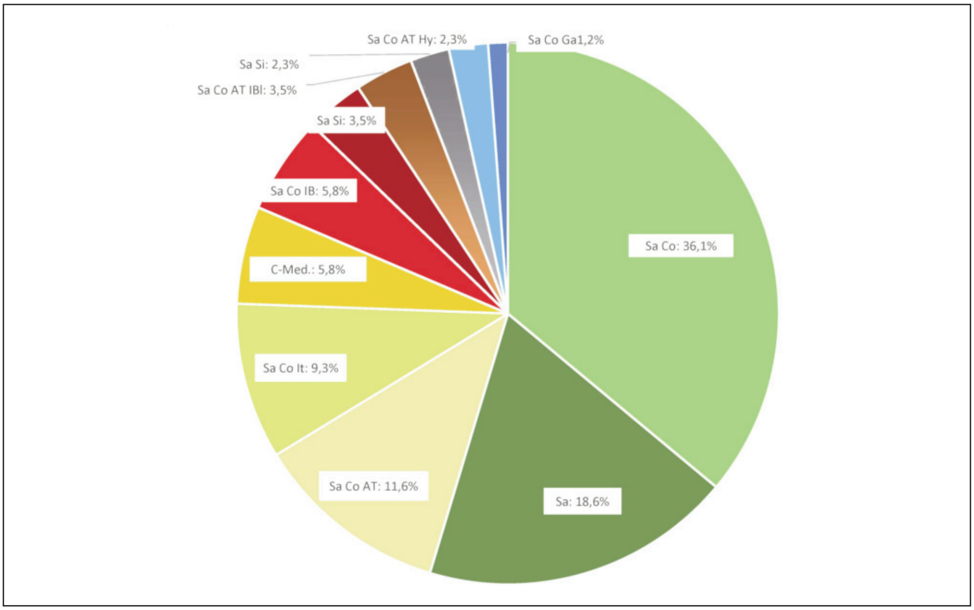

Fig. 4: Chorological spectrum of the endemic and sub-endemic taxa of the vascular flora of Mount Limbara.

Discussion

Biogeographic features and anthropogenic factors

The updated vascular flora of the Limbara massif consists of 1,147 taxa. This area, roughly corresponding to 1% of the entire Sardinia, hosts about 38.5% of its vascular flora (Galasso & al. 2018a). The 1,009 native taxa correspond approximately to 41% of the native flora of the island (Bartolucci & al. 2018a). However, the most imposing number is that of alien taxa, 119 (OP excluded), corresponding to 22.8% of the alien flora present in Sardinia (Galasso & al. 2018a).

The H/T ratio, indicator of the Mediterranean (H/T= <1) or continental (H/T= >1) nature of the flora (Cannucci & al. 2017), shows a general value lower than 1 in all the areas of the mountain lower than 1200 m a.s.l. The lowest value is on the basal zones (0.6) then increases with the altitude, reaching 0.76 between 500 and 800 m a.s.l., and 0.81 in the mountain area from 800 to 1200 m. Finally, the highest peaks have a value of 1.04. This data highlights the weak continentality of the tops of the mountain and a certain similarity with the 1.03 value provided from Foresta Anela, on the Goceano mountain chain (Farris & al. 2018).

One interesting fact emerging from this study concerns the chorological analysis, particularly about the endemic contingent. As the Limbara massif is located at an intermediate position between the southernmost mountain of Corsica (Montagne di Cagna, with similar elevation and geology) and the mountains of central Sardinia (Supramontes and

Gennargentu), the high number of Sardo-Corsican endemics is not surprising, corresponding to 36.1% of the entire endemic vascular flora. Considering in particular the Sardo-Corsican province (sensu Bacchetta & al. 2012), i.e. including the Tuscan Archipelago, it rises to 47.7%. The percentage of endemic taxa shared by Mount Limbara and Corsica increases to 76.8% when widely distributed taxa are considered. On the other hand, the endemics exclusive to Sardinia amount to 18.6%.

A further factor emphasising the affinity between Mount Limbara and Corsica emerges from the presence of several taxa that, despite having often a wider distribution elsewhere, in Sardinia grow only in Gallurese sub-sector (sensu Fenu & al. 2014) and on the Limbara massif in particular: e.g. *Cyclamen hederifolium* Aiton, *Daphne laureola* L., *Festuca sardoa* (Hack.) K. Richt., *Genista salzmannii* DC., *Knautia integrifolia* (L.) Bertol., *Ornithopus perpusillus* L., *Pinus pinaster* Aiton.

On the Limbara massif, the interaction between the Mediterranean climate of the lowlands and the temperate climate of the topmost zone can be observed (see Fig. 5). In this context, the slopes of the mountain (influenced by the Oceanic Pluviseasonal Mediterranean bioclimate) up to an altitude of approximately 500 m, show the highest presence of taxa, 927, corresponding to 80.9% of the whole flora, widespread in 102.11 km² (38.9% of the entire study area). Quite the opposite, the oceanic temperate zone, comprised from 1200 m to the peaks of the massif, hosts 440 taxa, corresponding to 38.4% of the total vascular flora of Mount Limbara, but concentrated in 2.6 km² (1% of the entire study area). This richness is partially due to the impact of human activities and the intense anthropisation of the area (roads, military bases, radio-television communicatory centres, parking areas), which degraded the surrounding zones, allowing the occurrence of a more synanthropic flora.

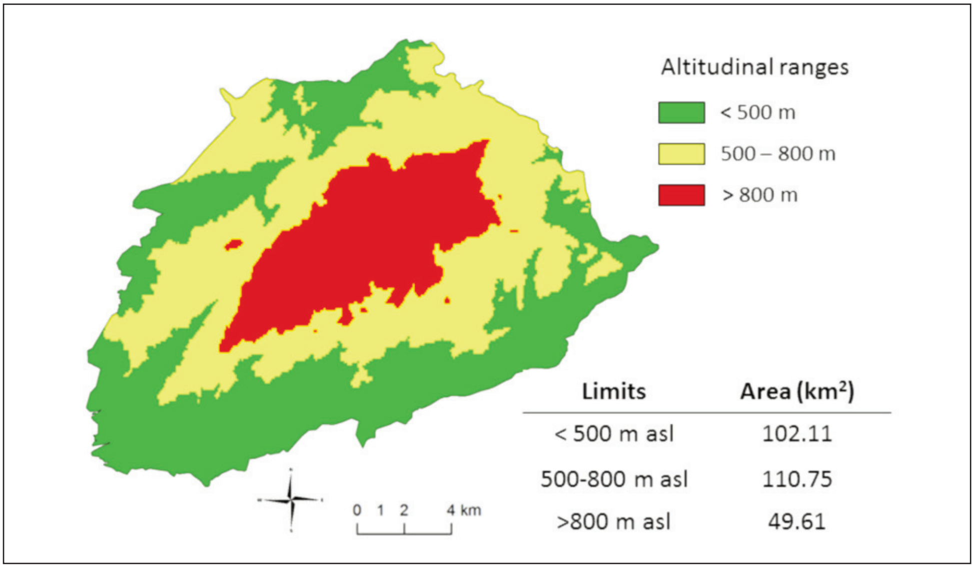

Fig. 5. Map of the elevation subdivision of the study area.

The strong anthropisation explains also the high percentage of alien taxa, probably the highest for what concerns the mountain areas of Sardinia. Comparing the flora of Mount Limbara and other floras, these differences are underlined: e.g. Montalbo had an alien contingent of 12 taxa only (Camarda 1984a); Marganai, 14 (Angius & al. 2011); Gennargentu, 38 (Bacchetta & al. 2013) (see Table 1). By comparing our data with those collected by Veri & Bruno (1974), further differences are observable (see Table 2). In particular, the amount of phanerophytes represents the most impacting data, being today 146 taxa. In the last forty-five years their number has drastically increased since the mentioned authors counted 81 taxa only (30 of which had been planted then or shortly before). This confirms the increasing number of alien taxa in the last decades. The 137 alien taxa currently known, corresponding to 11.9% of the entire mountain flora, are the result of a wide variety of actions, especially reforestations (76 taxa were directly introduced by cultivation), which have modified many aspects of the original landscape and are already affecting the stability of many mountain environments (Bartolucci & al. 2018b; Galasso & al. 2018b, 2019). However, the number of non-native and endemic taxa is inversely proportional from the lowlands to the tops. The higher number of alien taxa is found on the lower parts of the study area (91, 9.8% of the entire basal flora) while the endemics are 47 (5% only). These percentages are reversed at the tops of the mountain, where non-native taxa are 20 (4.7%) while endemics are 55 (12.5%). Hence, despite the large presence of human settlements and disturb, the natural value of the mountain tops is still significant, confirming the hypothesis of a nano-hotspot in this area, as proposed by Fois & al. (2018).

Conservation value of the mountain

We highlight the relatively high number of threatened taxa growing in the study area (Conti & al. 1997; Hugot 2010; Fenu & al. 2011; Cañadas & al. 2013; Caria & al. 2013; Marengo & al. 2015; Porceddu & al. 2015; Rossi & al. 2015; Fenu & al. 2016; Orsenigo & al. 2020; Rossi & al. 2020). The 132 taxa included in the red lists of the vascular plants of Italy, equal to 13% of the native flora of the mountain, suggest the conservation value of the massif. Despite 13 taxa are classified as Data Deficient, and other 73 as Least Concern, the presence of 27 Near Threatened, 3 Vulnerable and 16 Endangered taxa is valuable.

Of the taxa classified as Vulnerable, *Odontites corsicus* (Loisel.) G. Don and *Ranunculus ophioglossifolius* Vill. are common throughout the study area. *Marsilea strigosa* Willd. is common along the shores of Lake Coghinas. This population represents one of the richest communities of Italy in terms of number of individuals (Caria & al. 2013). Finally, among the endangered taxa, *Carex panormitana* Guss. and *Spiranthes aestivalis* (Poir.) Rich. have among the richest populations known worldwide, counting thousands of plants (Manca & Calvia 2012; Pisanu & al. 2013).

Interestingly, 41 taxa included in the red lists of the vascular plants of Italy are closely linked to wet environments, underlining the importance of these vulnerable habitats due to climate change and related consequences, as well as human induced disturbance (Filipe & al. 2013, Bagella & al. 2016, Angiolini & al. 2019). Some typical taxa of wet environments, previously collected on the area, are now locally extinct (*Ludwigia palustris* (L.) Elliott, *Ranunculus repens* L., *Spirodela polyrhiza* (L.) Schleid.) or are facing a reduction of their extent (e.g. *Anacamptis laxiflora* (Lam.) R.M. Bateman,

Table 1. Comparative analysis of the present flora and that described by Veri & Bruno (1974).

Typology	Native	Alien	Only planted	Total	%	% OP not included	% only native
Therophytes	427	30	0	457	39.9	40.5	42.3
Hemicriptophytes	314	19	0	333	29.1	29.5	31.1
Geophytes	134	14	0	148	12.9	13.0	13.2
Phanerophytes	85	44	18	147	12.7	11.4	8.4
Chamaephytes	28	10	0	38	3.3	3.4	2.8
Hydrophytes	20	2	0	22	1.9	2.0	2.0
Helophytes	2	0	0	2	0.2	0.2	0.2
Total	1010	119	18	1147	100.0	100.0	100.0
Present study							
Therophytes	157	0	0	157	29.4	31.0	31.1
Hemicriptophytes	185	0	0	185	34.6	36.6	36.6
Geophytes	85	0	0	85	15.9	16.8	16.8
Phanerophytes	51	1	29	81	15.1	10.3	10.1
Chamaephytes	25	0	0	25	4.7	4.9	5.0
Hydrophytes	0	0	0	0	0.0	0.0	0.0
Helophytes	2	0	0	2	0.4	0.4	0.4
Total	505	1	29	535	100.0	100.0	100.0
Veri & Bruno (1974)							

Pridgeon & M.W. Chase, *Epilobium montanum* L., *Mentha requieni* Benth., *Oenanthe lisae* Moris).

Though not mentioned in any list, several other taxa growing on Mount Limbara, that are rare at a regional level and are facing a decrease within their ranges, deserve protection (e.g. *Cyperus flavescens* L., *Lysimachia minima* (L.) U. Manns & Anderb., *Nymphaea alba* L.).

Paradoxically, not only rare plant species are contracting their habitats on the Limbara massif, but we speculate that also several synanthropic and nitrophilous taxa. Since the second half of the 20th century, many areas of the mountain started to be abandoned, then colonised again by pioneer taxa, as a consequence of land use change. Traditional pastoralism often required the usage of setting wildfires for obtaining new pastures for the flocks (Desole 1960). The abandonment of such activities freed vast areas of the mountain from the human pressure, thus allowing the slow recovery of high scrublands and woodlands (Calvia 2016). During the last decades, in protected areas of the mountain, as well as those where the ovine stocks have disappeared, the vegetation recovery is fast, as observed also in other Mediterranean areas (Lasanta-Martínez & al. 2005; Rocchini & al. 2006). Consequently, we have observed that a number of taxa connected with livestock, frequent in a recent past, are facing a rapid reduction from the central areas of the mountain (e.g.

Table 2. Comparative analysis between the vascular flora of Mount Limbara and those of other mountain areas of Sardinia.

Site	Elevation (m a.s.l.)	Area (km²)	No. of taxa	No. of natives	No. of endemics	% endemics	No. of non native	% non native	Source
M. Limbara	160-1359	262.5	1147	1010	86	7.5	137	11.9	This work
M. Limbara	160-500	102,1	927	836	48	5.2	91	9.8	This work
M. Limbara	500-800	110.8	891	817	57	6.4	74	8.2	This work
M. Limbara	800-1200	47	763	709	76	10	54	7.1	This work
M. Limbara	1200-1359	2.6	440	420	55	12.5	20	4.5	This work
M. Limbara	ca. 500-1359	n.r.	506	505	55	10.9	1	0.2	Veri & Bruno 1974
Gennargentu	1500-1834	16.8	214	n.d.	66	30.8	n.d.	n.d.	Arrigoni & Camarda 2014
Gennargentu	900-1834	240	675	n.d.	105	15.6	n.d.	n.d.	Arrigoni & Camarda 2014
Gennargentu	ca. 1000-1834	500	948	910	141	14.9	38	4	Bacchetta & al. 2013
Supramontes	0-1463	335	n.d.	n.d.	138	n.d.	n.d.	n.d.	Fenu & al. 2010
Anela forest	600-1158	12.8	391	391	45	11.5	n.d.	n.d.	Farris & al. 2018
Monte Albo	150-1127	68	659	647	49	7.5	12	1.8	Camarda 1984a
Monte Gonare	538-1083	10	520	513	23	4.4	7	1.3	Camarda 1984b
Sarrabus-Gerrei	0-1067	1597	1447	1327	112	7.7	120	8.3	Iiriti 2006
Marganai	200-939	36.1	648	634	73	11.3	14	2.2	Angius & al. 2011
Sardinia	0-1834	24090	2400	n.d.	ca. 215	ca. 9	n.d.	n.d.	Arrigoni 2006-2015
Sardinia	0-1834	24090	2408	n.d.	258	10.7	200	8.3	Conti & al. 2005
Sardinia	0-1834	24090	2441	2441	331	13.6	n.d.	n.d.	Bartolucci & al 2018a
Sardinia	0-1834	24090	2922	n.d.	n.d.	n.d.	481	16.5	Galasso & al. 2018a

Arum italicum Mill., *Carduus* sp. pl., *Chenopodium album* L., *Ferula communis* L., *Thapsia garganica* L., *Urtica* sp. pl.), though remaining frequent where agro-pastoral activities still occur. On the other hand, as woodland surfaces are increasing, some taxa which faced a dramatic collapse during the last centuries, e.g. *Ilex aquifolium* L., *Pinus pinaster*, *Taxus baccata* L. (Desole 1960, 1966), are now spreading again. This woodland recovery confirms the trend previously observed in other Italian contexts (Falcucci 2007; Puddu 2012; Barbati & al. 2013; Smiraglia & al. 2015; Farris & al. 2018).

Conclusions

After 27-year long research, the vascular flora of Mount Limbara is here presented, showing a plant richness that is the highest between the mountain areas studied this far in Sardinia. Despite the deep modifications occurred during the last centuries and the degradation due to human activities as well, the Limbara massif preserves a relevant flora. However, the checklist here reported includes also a high number of alien taxa (137). Consequently, the management problems, mostly connected to the introduction of alien taxa and soil modifications, such as drainage of wet sites, pose an intriguing question about the future variations of these threatened environments and their flora. With this study, we highlight the massive invasion that is taking place on many parts of the mountain, due to the rapid naturalisation of pioneer species, e.g. *Cytisus scoparius* (L.) Link and *Pinus nigra* subsp. *laricio*. From this point of view, it is important also the comparison of our data with those reported by past authors, to understand how impacting are today the actions borne through the massive plantations of the recent past. Thus, the vascular flora of Mount Limbara, can represent a starting point for the further studies of the changes involving plant invasions in wild mountain areas, specifically in the Mediterranean area.

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