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Siliceous Outcrops Host New Records of Biodiversity Interest for Arctic–Alpine Lichens in the Southern Apennines: An Assessment Based on Field Surveys and Herbarium Data

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Abstract

The Calabrian–Lucanian Apennines are a lichenologically insufficiently explored area. The purpose of the study was to improve the knowledge of its lichen flora in the wider context of ecology and biogeography and with regard to conservation perspectives. Our study is primarily based on recent collections but also includes comparative analyses of previous herbarium samples to verify identity; in particular a direct comparison with the CLU Herbarium (Calabria University) HLUC (Basilicata University) together with data from national collections (ORO, TO, Gheza Private Collection, TSB) and international collections (Consortium of Lichen Herbaria) has provided a solid taxonomic framework. A total of 102 species have been identified. The area yields a remarkable diversity of the genus *Umbilicaria* with 17 taxa recorded. *Placidium subrufescens* is recorded for the first time in Italy; seven species are new records in southern Italy, and 13 in the Basilicata Region. The majority of rare and infrequent lichen species appear to be glacial relics at the southern limit of their range. These southern populations are highly fragmented and localized. They are vulnerable to environmental changes and likely to suffer from climate change. The habitats that were surveyed—mainly siliceous outcrops embedded within carbonatic sequences—supported the same arctic–alpine lichen biota. The study emphasizes the high degree of the region's biodiversity and the necessity for conservation efforts.

Keywords: biodiversity; glacial relics; herbarium data; Italy; lichen biota; rarity

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1. Introduction

The southern Apennine chain is a NW–SE-oriented segment of the Italian Apennines consisting of an Adriatic-verging accretionary wedge derived from the Neogene compressional deformation of the Africa–Apulian passive margin. The southern Apennine refers to

a mountain range in southern Italy characterized by its geological formations biodiversity and climatic variations. It extends from the Campania Region to the Calabria Region playing a significant role in the ecology hydrology and human geography of the area.

The southern sector of the Italian Apennines is characterized by complex geological formations including siliceous outcrops. These substrates originated from a broad spectrum of geological processes [1]. Beyond their geological significance these outcrops represent key sites of ecological and phytogeographical interest. In the southern Apennines siliceous substrates support more diverse lichen vegetation along an altitudinal gradient with a greater presence of rare and arctic–alpine species at relatively high altitudes. Whilst the study on alpine terrestrial lichens illustrates how climate-related changes threaten specialized microhabitats along steep altitudinal gradients the siliceous schist outcrops of the southern Apennines represent an equally vulnerable yet significantly understudied refuge for unique biodiversity [2].

The vegetation associated with these habitats comprises frequently discontinuous communities composed of lichens bryophytes and stonecrop species (*Sedum* spp.) frequently occurring in small patches with grazed grasslands. Despite their ecological relevance these habitats remain insufficiently studied particularly with regard to lichen diversity and community composition. Existing data are insufficient for a proper assessment of their conservation status [3].

Within the framework of the European Habitats Directive the conservation status of habitats is assessed every six years across biogeographical regions in relation to their favourable conservation status. According to the European Environment Agency [4] habitat 8230 ("Siliceous rock with pioneer vegetation of the Sedo-Scleranthion or of the Sedo albi-Veronicion dillenii") shows favourable conservation status in northern and central European regions such as Finland Poland Slovakia the western Alps the Pyrenees and central–southern Portugal. In contrast in Mediterranean areas particularly Spain Portugal France most of Italy and Bulgaria the conservation status has been assessed as "Unfavourable–Inadequate" indicating that changes in management or conservation policies are required to restore favourable conditions although no immediate risk of disappearance has been identified. Similarly habitat 8220 ("Siliceous rocky slopes with chasmophytic vegetation") is currently considered to require improved management measures in the Mediterranean biogeographical region [4]. The principal threats affecting these habitats include human disturbance associated with recreational activities such as rock climbing cycling and skiing.

Mediterranean alpine ecosystems of the southern Apennines served as crucial refugia during the Pleistocene glaciations [5]. Having remained isolated for long periods and only partially glaciated during the ice age of Pleistocene they host several cryophilic endemic plant species [6] and arctic–alpine lichen taxa [7].

For many plant and lichen species the Calabrian–Lucanian Apennines represent the southernmost distribution limit in Europe. Arctic–alpine lichens are recognized as sensitive indicators of the effects of global warming especially at the southern limit of their range [8]. From a global change perspective this cold-adapted disjunct component of the lichen biota is strongly exposed to the impact of warming conditions [2]. In the Mediterranean basin including the Italian Apennines the ongoing increase in temperatures since the second half of the 20th century has been accompanied by a reduction in winter precipitation. These climatic trends pose a significant threat to glacial relicts that are exceptionally vulnerable to ongoing global warming [8–11].

Our study integrates field surveys with rigorous comparative analyses of herbarium specimens. The CLU Herbarium (University of Calabria) along with records from national (ORO, TO, Gheza Private Collection, TSB) and international collections (Consortium of Lichen Herbaria) provided a robust taxonomic framework. By focusing almost exclu-

sively on macrolichen communities colonizing medium- to high-altitude siliceous outcrops (450–1700 m a.s.l.) this research aims to highlight the conservation priority of these sensitive glacial relicts within the Mediterranean biogeographical region.

The core vision of this study is to provide a comprehensive taxonomic and conservation assessment of the lichen flora associated with siliceous rock substrates in central–southern Italy. By integrating recent field surveys in Basilicata with a rigorous comparative analysis of historical and recent herbarium data from both Calabria and Basilicata this work aims to characterize a vulnerable point-source (fragmented) habitat. The ultimate goal is to establish a bioclimatic and lithological baseline to guide future monitoring and preservation strategies for these rare lichen communities.

2. Materials and Methods

2.1. The Study Area and Geological Setting

The study area is characterized by a complex geological evolution that provides a wide variety of lithological substrates for lichen colonization. The southern Apennines form an east-verging duplex system dominated by two primary rock types: (i) carbonate substrates represented by the Meso-Cenozoic shallow-water marine deposits of the Apenninic Platform; and (ii) acidic or mixed-siliciclastic substrates derived from the basinal-to-slope deposits of the Lagonegro Molise and Sannio nappes as well as the deep-marine sediments of the Ligurian and Sicilidi units [1]. Conversely the Calabrian Arc—laterally juxtaposed against the southern Apennines since the Pleistocene—presents a distinct contrast in substrate chemistry. It is predominantly composed of an orogenic pile of Hercynian metamorphic and crystalline basement rocks (e.g., granites gneisses and schists) locally associated with alpine ophiolitic metamorphic complexes. This geological configuration creates a sharp contrast between the extensive calcareous basic environments of the Apenninic domain and the predominantly acidic crystalline and siliceous environments of the Calabrian sector heavily influencing local lichen biota distribution and functional traits [11,12].

2.2. Sampling Strategy and Study Sites

Lichenological surveys were carried out at 22 purposively selected sites characterized by high cryptogamic richness (8 in the Basilicata Region and 14 in the Calabria Region; Table 1 and Figure 1). The sampling stations are distributed across 11 municipalities encompass an altitudinal gradient ranging from 450 m to 1700 m a.s.l. (Mt. Nardello) and are restricted to siliciclastic outcrops. To maximize species detection and account for seasonal or environmental variations field surveys were performed across an extensive temporal and geographical scale. Each site was sampled following a time-constrained random walk approach with at least three replicate visits per site (sites 1–8) and a standardized sampling effort of 5 to 6 h per session. The surveyed area at each station was adjusted proportionally to the extent of the lichen-bearing rock substrate; no permanent plots were established.

In the Basilicata Region surveys were carried out from spring 2011 to spring 2025 and the collected material was deposited in the HLUC Herbarium (Herbarium Lucanum). The herbarium has c. 20,000 samples (c. 1000 of which are lichens) mainly collected in Basilicata.

In the Calabria Region data were obtained from dedicated field campaigns and the extensive database of the CLU Herbarium (University of Calabria) which has served as the primary taxonomic and historical reference for the area since 1984, and presently includes c. 18,000 samples collected mainly by D. Puntillo in various parts of Italy especially in Calabria.

Historical and relatively recent specimens collected in the study areas and held respectively in the ORO, TO, TSB, CLU and HLUC herbaria were compared in order to verify erroneous or unidentified species-level records.

In particular with regard to herbarium specimens from neighbouring Calabria the region geographically and lithologically closest to Basilicata the comparison was thorough and repeated across all taxa. Furthermore data were also derived from unpublished surveys. Consequently the field data herbarium data and unpublished survey data were reorganized.

The mineralogical composition and geological features of the studied sites were extracted from official geological maps [1] and the relevant literature [5,6].

This study focuses primarily on macrolichens while also including selected microlichens of particular ecological or taxonomic interest.

Accurate field identification of many lichen taxa is often challenging due to their small size and the need to study microscopic features and secondary metabolites through chemical analyses. The limitations of field-based identification were extensively discussed by Roux [13] and Nimis [14] who demonstrated that laboratory-based identification can increase the number of recorded taxa by over 100% compared to field observations alone. Although integral sampling of all specimens is the most accurate method for biodiversity assessment its large-scale implementation is constrained by conservation concerns. Therefore this study integrates field records with a targeted collection of specimens for detailed laboratory analysis to ensure taxonomic accuracy while minimizing disturbance to these sensitive habitats.

Table 1. Description of localities referenced in the present work listed from north (Basilicata) to south (Calabria). For each locality the following information is provided: geology municipality locality name coordinates (decimal degrees WGS84 system) altitude collection year and field or herbarium data. These locality numbers are cited accordingly in the subsequent species list.

Site ID	Geology	Municipality	Locality	Latitude (N) (LAT)	Longitude (E) (LON)	Altitude (m a.s.l.)	Collection Year	Field Visits/ Herbarium
1	schists	Calvello	Serra di Calvello	40.463289	15.779016	1200	2017	3 field visits
2	schists	Marsicovetere	Monte Volturino	40.401308	15.818906	1575	2011; 2025	4 field visits
3	schists	Abriola	Il Ciglio	40.559300	15.814320	1380	2019	4 field visits
4	schists	Bella	Monte Santa Croce	40.778290	15.587290	1390	2024	3 field visits
5	schists	San Fele	Monte Castello	40.821060	15.540030	900	2024	3 field visits
6	schists	Oliveto Lucano	Gallipoli Cognato	40.525022	16.113721	900	2011	3 field visits
7	schists	Marsico Nuovo	Monte Lama	40.455292	15.780228	1400	2023	3 field visits
8	ophiolites	Terranova di Pollino	Timpa di Pietrasasso	39.995517	16.266318	1300	2023	3 field visits
9	biotite gneiss	San Luca	Pietra Impiccata	38.159734	15.931542	1650	1989	Herbarium
10	biotite gneiss	Roghudi	Valle del Fiume Menta	38.131823	15.893180	1650	1984	Herbarium
11	schists	Casali del Manco	C. Ceraso	39.290994	16.368603	1017	1994	Herbarium
12	biotite gneiss	San Luca	Serra Priolo	38.158054	15.933187	1670	1987	Herbarium
13	biotite gneiss	San Luca	Puntone Gramolara	38.141221	15.986891	1370	1987	Herbarium
14	granites	San Giovanni in Fiore	Colle Donato	39.305565	16.640331	1470	1987	Herbarium
15	quartzite	Spezzano della Sila	Pietra Bianca	39.357720	16.556024	1420	1988	Herbarium
16	quartzite	Casali del Manco	Serra Ripollata	39.364084	16.591788	1650	1998	Herbarium
17	ophiolites	Campana	Rupi di Campana	39.419377	16.816973	560	1985	Herbarium
18	gneiss	Celico	Monte Scuro	39.340125	16.399115	1600	1985; 1991	Herbarium
19	schists	Rose	Vallone Giancorella	39.397313	16.305572	610	2015	Herbarium
20	granites	Casali del Manco	San Nicola Silano	39.312351	16.299601	1420	1985	Herbarium
21	biotite gneiss	Savelli	Valle Torrente Senapite	39.308558	16.808687	450	1984	Herbarium
22	biotite gneiss	Scilla	Monte Nardello	38.161157	15.869407	1700	2015	Herbarium

Site ID: Site Identification Number; LAT: Latitude in decimal degrees; LON: Longitude in decimal degrees; m a.s.l.: metres above sea level; collection year; field/herbarium.

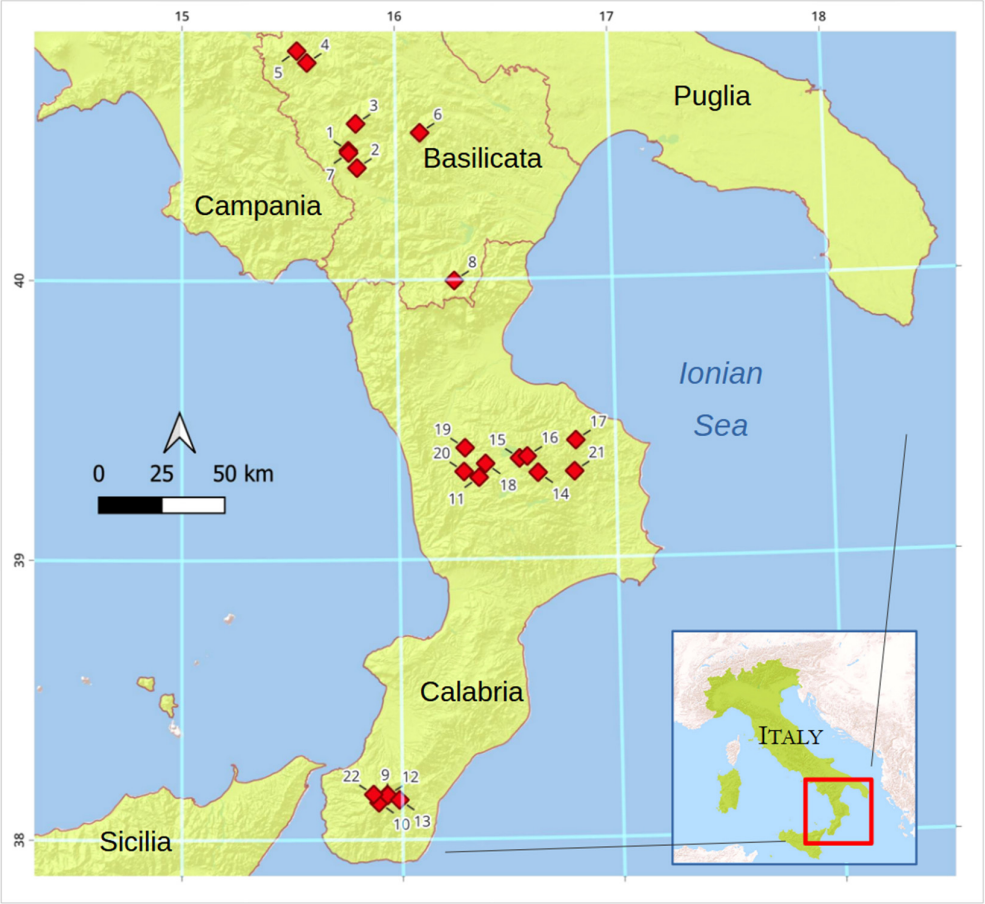


Figure 1. Geographic distribution of the 22 study sites across the southern Apennines (Basilicata and Calabria Regions, southern Italy). Numbers of localities correspond to the site IDs listed in Table 1.

Specimen observations and macrophotography were performed using a Zeiss Axioskop microscope (Manufacture Zeiss, Oberkochen, Germany) and a Nikon SMZ 660 stereomicroscope (Manufacture Nikon, Tokyo, Japan). Thallus anatomy was investigated through hand-cut sections mounted in water. Routine chemical spot tests were performed for all critical specimens following standard lichenological procedures.

The lichen nomenclature synonymy of historical records and ecological and geographic distribution data follow the updated standards [15]. Historical distribution data from several Italian herbaria were efficiently retrieved and consulted through ITALIC 8.0 The Information System on Italian Lichens. This platform significantly accelerated the comparative analysis of modern field records against historical national collections. Dot-maps are now visible in the taxon pages of ITALIC where the data in Darwin Core format can also be downloaded. The included herbaria are also searchable through the "Herbaria" query interface.

All collected specimens were deposited in the Herbarium Lucanum (HLUC) of the University of Basilicata the CLU Herbarium (Museo di Storia Naturale della Calabria ed Orto Botanico University of Calabria) and TSB Herbarium (Università di Trieste).

3. Results

The following list (Table 2) includes primarily macrolichens and selected crustose microlichens identified in the study area. For each taxon the accepted name is followed by its regional/national significance substrate site IDs (referring to Table 1 and Figure 1) exsiccata and notes. Chorological and ecological notes are provided for species of particular

phytogeographical interest with emphasis on the arctic–alpine component. Table 3 provides an updated sites summary with rare taxa and ecological traits.

Table 2. Checklist of lichen taxa surveyed in the siliceous outcrops of the southern Apennines (Basilicata and Calabria Italy). Taxa are listed in alphabetical order. For each taxon the substrate site IDs (referring to Table 1) and herbarium voucher numbers are reported alongside notes taken from the Nimis ITALIC 8.0 catalogue https://italic.units.it (accessed on 25 May 2026).

N	Taxon	Substrate	Site ID	Herbarium and Voucher No.	Notes
1	*Adelolecia pilati* (Hepp) Hertel & Hafellner	Siliceous rock	9 10	CLU [No. 6533 8110 8201 9662 10528; 6991 10793]	Arctic–alpine
2	*Agonimia tristicula* (Nyl.) Zahlbr.	Terricolous mosses	2	CLU [No. 17799] TSB [No. 22115]	A widespread probably holarctic species
3	*Anaptychia crinalis* (Schaer.) J. Nowak	Siliceous soil	2 3 4	HLUC [No. 623; 676; 746; 792]	Historical record confirmed Threatened taxa
4	*Brodoa intestiniformis* (Vill.) Goward	Siliceous rock	9	CLU [No. 878 2801 5177] TSB [No. 6699 11376]	Arctic–alpine
5	*Bryoria fuscescens* (Gyeln.) Brodo & D. Hawksw.	Terricolous mosses	3 9	CLU [No. 773 2226]	A circumpolar temperate-to-boreal–montane species
6	*Bryoria smithii* (Du Rietz) Brodo & D. Hawksw.	Siliceous rock	2	HLUC [No. 663]	A temperate species
7	*Calogaya schistidii* (Anzi) Arup Frödén & Søchting	Terricolous mosses	1 2 3 4	CLU [No. 16567 17780; 16507] TSB [No. 22160] HLUC [No. 662; 680]	Most common in upland areas
8	*Caloplaca stillicidiorum (Vahl) Lynge* var. *muscorum (A. Massal.)*	Mosses	2 8	CLU [No. 13455]	Mostly found in dry-continental areas on basic siliceous substrata
9	*Candelariella coralliza* (Nyl.) H. Magn.	Siliceous rock	1 2 3 4 8	CLU [No. 1100; 638; 1103]	A mainly boreal–montane to arctic–alpine circumpolar species
10	*Catapyrenium cinereum* (Pers.) Körb.	Siliceous soil	9	CLU [No. 2877]	A boreal–montane-to-arctic–alpine circumpolar species
11	*Catapyrenium daedaleum* (Kremp.) Stein	Siliceous soil	4	HLUC [No. 1101]	A boreal–montane-to-arctic–alpine species recently reported in the Basilicata Region [16]
12	*Cetraria aculeata* (Schreb.) Fr.	Siliceous soil	1 2 3 4 6	CLU [No. 16870] HLUC [No. 796a; 767] TSB [No. 22154; 10730]	Widespread mainly temperate
13	*Cetraria islandica* (L.) Ach.	Siliciferous soil	2 9	CLU [No. 6966 10856] HLUC [No. 57]	An arctic–alpine-to-boreal–montane circumpolar lichen
14	*Cetraria muricata* (Ach.) Eckfeldt	Siliceous soil	2 3 9 10	HLUC [No. 56; 796b] CLU [No. 855 2315; 40]	Optimum on siliceous soil in wind-exposed siliceous ridges above treeline but also found on decalcified soils over calcareous substrata
15	*Cladonia cariosa* (Ach.) Spreng	Siliceous soil	4 15	CLU [No. 5411]	A cool-temperate-to-subarctic–subalpine circumpolar lichen
16	*Cladonia cervicornis* (Ach.) Flot.	Siliceous soil	4	HLUC [No. 228]	A temperate-to-southern boreal–montane lichen

Table 2. *Cont.*

N	Taxon	Substrate	Site ID	Herbarium and Voucher No.	Notes
17	*Cladonia coccifera* (L.) Willd.	Siliceous soil	5	HLUC [No. 1102; 677]	A cool-temperate-to-arctic–alpine species recently reported in Basilicata [17]
18	*Cladonia coniocraea* (Flörke) Spreng.	Siliceous soil	1 3 15	HLUC [No. 785] CLU [No. 5368 5392]	A widespread holarctic species
19	*Cladonia foliacea* (Huds.) Willd.	Siliceous soil	1 3 6 10 13 16	CLU [No. 4075 10323]	A mild-temperate lichen found on both calcareous and siliceous soil
20	*Cladonia furcata* (Huds.) Schrad. subsp. *furcata*	Siliceous soil	1 3 6 22	HLUC [No. 784; 789b] TSB [No. 6805] CLU [No. 46]	A holarctic temperate-to-boreal–montane lichen
21	*Cladonia furcata* subsp. *subrangiformis* auct. non (Sandst.) Abbayes	Siliceous soil	4	HLUC [No. 790]	A mild-temperate lichen
22	*Cladonia pyxidata* (L.) Hoffm. f. *pyxidata*	Siliceous soil	3 4 5	HLUC [No. 493; 498]	A widespread very polymorphic holarctic species
23	*Cladonia ramulosa* (With.) J.R. Laundon	Siliceous soil	4 9	HLUC [No. 1104] CLU [No. 2791]	Recently reported in Basilicata [16]
24	*Cladonia rangiformis* Hoffm.	Siliceous soil	1 2 3 4 5 6 7 8 9 10 13	CLU [No. 759] TSB [No. 22102; 775; 814]	A mainly temperate lichen in open habitats
25	*Cornicularia normoerica* (Gunnerus) Du Rietz	Siliceous rocks	2 9 10	CLU [No. 10677 757 760 880; 763] HLUC [No. 777]	A circumpolar arctic–alpine lichen with optimum above treeline
26	*Cystocoleus ebeneus* (Dillwyn) Thwaites	Siliceous rocks	1 2 9 10	HLUC [No. 758] CLU [No. 1981 2759 2812; 4733]	A cool-temperate-to-boreal–montane probably holarctic lichen
27	*Dermatocarpon intestiniforme* (Körb.) Hasse	Siliceous rocks	2 9 10	HLUC [No. 665] TSB [No. 7016]	A mainly boreal–montane-to-arctic–alpine circumpolar lichen
28	*Dermatocarpon luridum* (With.) J.R. Laundon	Siliceous rocks	2 5	HLUC [No. 640 748]	A cool-temperate-to-subarctic–subalpine probably circumpolar species
29	*Diploschistes scruposus* (Schreb.) Norman	Siliceous rocks	1 2 3 4 11	HLUC [No. 634 751 793]	A widespread holarctic lichen found on siliceous rocks
30	*Enterographa zonata* (Körb.) Torrente & Egea	Siliceous rocks	1	CLU [No. 13214]	A temperate to southern-boreal-montane perhaps circumpolar
31	*Fuscidea cyathoides* (Ach.) V. Wirth & Vězda	Siliceous rocks	2	HLUC [No. 723]	A cold-temperate to southern boreal-montane, perhaps circumpolar lichen
32	*Glaucomaria rupicola* (L.) P.F. Cannon subsp. *rupicola* var. *rupicola*	Siliceous	1 2 3 4 6 18	CLU [No. 16566; 363] TSB [No. 11780]	A widespread holarctic silicicolous lichen
33	*Hypogymnia bitteri* (Lynge) Ahti	Siliceous rocks	3	HLUC [No. 772]	A cool-temperate-to-boreal–montane circumpolar lichen
34	*Hypogymnia physodes* (L.) Nyl.	Siliceous rocks	2 3 4	HLUC [No. 740]	A widespread holarctic lichen on bark or lignum
35	*Hypogymnia tubulosa* (Schaer.) Hav.	Siliceous rocks	2 3 4 10	HLUC [No. 771]	A widespread holarctic lichen on bark or lignum

Table 2. *Cont.*

N	Taxon	Substrate	Site ID	Herbarium and Voucher No.	Notes
36	*Lecidea sarcogynoides* Körb.	Siliceous rocks	9 18	CLU [No. 5369 7968; 9797 9866]	A temperate species of siliceous mineral-rich rocks
37	*Leptochidium albociliatum* (Desm.) M. Choisy	Mosses	2 3 6 10 16	HLUC [No. 234; 682; 769; 791; 799] CLU [No. 5416 7641] TSB [No. 6827]	A cool-temperate-to-arctic–alpine lichen
38	*Leprocaulon quisquiliare* (Leers) M. Choisy	Siliceous rock	3 4	HLUC [No. 766]	A mainly mild-temperate-to-Mediterranean lichen
39	*Leptogium furfuraceum* (Harm.) Sierk	Siliceous soil	4	HLUC [No. 726]	A mild-temperate-to-humid subtropical species; epiphytic lichens are classified as Endangered [18]
40	*Lethariella intricata* (Moris) Krog	Siliceous rock	3	Not collected due to conservation concerns	Probably an old relict Mediterranean species Near-threatened [18]
41	*Melanelia stygia* (L.) Essl.	Siliceous rock	2 9 12	HLUC [No. 805] TSB [No. 11240; 10092]	A circumpolar arctic–alpine lichen Recently reported in Basilicata [17]
42	*Myriospora smaragdula* (Ach.) Uloth	Siliceous rock	1 2 8 15	CLU [No. 12261; 5389]	A cool-temperate-to-boreal–montane perhaps circumpolar lichen
43	*Nephroma parile* (Ach.) Ach.	Mosses	4	Not collected	A cool-temperate-to-circumboreal–montane lichen
44	*Ophioparma ventosa* (L.) Norman	Siliceous rock	9	CLU [No. 6637]	An arctic–alpine circumpolar lichen
45	*Parmelia omphalodes* (L.) Ach.	Siliceous rock	2 3 4 6 9 10 13 22	HLUC [No. 626; 743; 795; 804] CLU [No. 776; 1247; 109]	An arctic–alpine circumpolar lichen
46	*Parmelia saxatilis* (L.) Ach.	Siliceous rock	3 4 6 9 10 13	HLUC [No. 721] CLU [No. 11336; 4787; 1243]	Very common saxicolous species
47	*Parmelina pastillifera* (Harm.) Hale	Siliceous rock	2 3 4	HLUC [No. 749; 724; 761; 775]	A temperate lichen in humid regions
48	*Parmelina tiliacea* (Hoffm.) Hale	Siliceous rock	2 3 4 21		A mainly mild-temperate lichen
49	*Peltigera horizontalis* (Huds.) Baumg.	Siliceous soil	3 4 6 18	HLUC [No. 750] CLU [No. 1910]	Lichen with a wide altitudinal range but with optimum in the montane belt.
50	*Peltigera rufescens* (Weiss) Humb.	Siliceoussoil	4	HLUC [No. 725]	A widespread holarctic lichen but also in Mediterranean belt
51	*Physconia muscigena* (Ach.) Poelt var. *muscigena*	Siliceous soil	4	HLUC [No. 736]	A circumpolar arctic–alpine lichen in open situation
52	*Pisutiella grimmiae* (Nyl.) S. Y. Kondr. L. Lőkös & E. Farkas	On *Candelariella* sp.	2 6 8	CLU [No. 16554; 18078]	A holarctic temperate to boreal–montane lichen
53	*Placidium adami-borosi* Szatala	Siliceous soil	2 4 9 10	CLU [No. 2794 6242] TSB [No. 13947] HLUC [No. 810]	A mainly Mediterranean (-montane) lichen found on soil derived from metamorphic base-rich rocks

Table 2. *Cont.*

N	Taxon	Substrate	Site ID	Herbarium and Voucher No.	Notes
54	*Placidium subrufescens* (Breuss) Breuss	Siliceous soil	2 4	HLUC [No. 811]	A mainly Mediterranean-to-Mediterranean–montane lichen, this species is generally calcicolous but in this case was found on different siliceous substrata
55	*Placocarpus schaereri* (Fr.) Breuss	Siliceous rock	1 2 5 9	HLUC [No. 611] CLU [No. 764 10121]	A Mediterranean-to-mild-temperate lichen; this species is generally calcicolous but in this case was found on different siliceous substrata
56	*Platismatia glauca* (L.) W.L. Culb. & C.F. Culb.	Siliceous rock	2 3 4 9 10 16	HLUC [No. 734 741 744 790] CLU [No. 2167; 1127; 310 449]	A cool-temperate-to-boreal holarctic species
57	*Pleopsidium chlorophanum* (Wahlenb.) Zopf	Siliceous rock	2 10	HLUC [No. 621 774 807] CLU [No. 2767 2817 2822]	An arctic–alpine bipolar lichen
58	*Protoparmelia badia* (Hoffm.) Hafellner var. *badia*	Siliceous rock	1 2 9	CLU [No. 16685; 16504 16540 16600] TSB [No. 10731]	Has a wide altitudinal range reaching the nival belt of the Alps
59	*Protoparmeliopsis laatokkensis* (Räsänen) Moberg & R. Sant.	Siliceous rock	9	CLU [No. 5173 10887] TSB [No. 11254]	Found on schist serpentine and amphibolite mostly on horizontal faces near the ground
60	*Protoparmeliopsis bolcana* (Pollini) Lumbsch	Siliceous rock	2 14	TSB [No. 22199]	Ecologically similar to *P. muralis* but more restricted to natural habitats
61	*Pseudephebe minuscula* (Arnold) Brodo & D. Hawksw.	Mosses	2 3 9 10	HLUC [No. 736] TSB [No. 11254]	An arctic–alpine circumpolar species
62	*Pseudephebe pubescens* (L.) M. Choisy	Siliceous rock	2 9 10	HLUC [No. 798; 732] CLU [No. 16511 16542 16558; 879] TSB [No. 10903; 6812]	A lichen that is arctic–alpine to (more rarely) boreal–montane
63	*Pseudevernia furfuracea* (L.) Zopf	Siliceous rock	1 2 3 4	HLUC [No. 585 620 720; 683; 770; 745 762]	A cool-temperate-to-boreal–montane lichen
64	*Psilolechia lucida* (Ach.) M. Choisy	Siliceous rock	1	CLU [No. 18220]	Restricted to natural habitats. In Italy most frequent in the Alps and in the most humid parts of the Mediterranean belt
65	*Psorinia conglomerata* (Ach.) Gotth. Schneid.	Siliceous rock	2 4	HLUC [No. 794; 1105]	A mainly arctic–alpine circumpolar species
66	*Ramalina capitata* var. *digitellata* (Nyl.) Nimis	Siliceous rock	19	CLU [No. 17410]	Found on top of exposed siliceous boulders frequently visited by birds in Mediterranean Italy
67	*Ramalina polymorpha* (Lilj.) Ach.	Siliceous rock	2 8 18 20	HLUC [No. 778 779] CLU [No. 1218; 18050]	Found on top of isolated siliceous boulders manured by birds
68	*Rhizocarpon geminatum* Körb.	Siliceous rock	2 9	TSB [No. 22200] CLU [No. 6496 6974]	A widespread lichen of dry-continental areas
69	*Rhizocarpon geographicum* (L.) DC. subsp. *geographicum*	Siliceous rock	1–22	HLUC [No. 105] CLU [No. 105; 16540 16561]	Widespread

Table 2. *Cont.*

N	Taxon	Substrate	Site ID	Herbarium and Voucher No.	Notes
70	*Schaereria fuscocinerea* (Nyl.) Clauzade & Cl. Roux	Siliceous rock	2 9	HLUC [No. 759] TSB [No. 10727] CLU [No. 6141 9436]	An arctic–alpine-to-boreal–montane circumpolar species.
71	*Scytinium palmatum* (Huds.) Gray	Mosses	2 3 4 9	HLUC [No. 587; 681]	A mild-temperate lichen
72	*Thalloidima opuntioides* (Vill.) Kistenich Timdal Bendiksby & S.Ekman	soil	4	CLU [No. 10258] HLUC [No. 727]	Widespread circumpolar arctic to temperate
73	*Thalloidima tauricum* Szatala	Siliceoussoil	2	HLUC [No. 800]	A mainly southern species with a Eurasian distribution but generally rare in the Mediterranean belt
74	*Toninia squalida* (Ach.) A. Massal.	Siiceoussoil	9	CLU [No. 2882 5371]	An incompletely holarctic lichen
75	*Umbilicaria cylindrica* (L.) Delise var. *cylindrica*	Siliceous rock	2 3 9 13 15	CLU [No. 16849; 16514 16518 16519 16540 16559; 5646] TSB [No. 10818] HLUC [No. 718 722]	An ecologically wide-ranging cool-temperate-to-arctic–alpine circumpolar lichen
76	*Umbilicaria cylindrica* var. *tornata* (Ach.) Nyl.	Siliceous rock	2 9	HLUC [No. 669]	An arctic–alpine lichen on exposed siliceous rocks
77	*Umbilicaria crustulosa* subsp. *punctata* A. Crespo & Sancho	Siliceous rock	3	HLUC [No. 678]	A rare Mediterranean–montane lichen
78	*Umbilicaria decussata* (Vill.) Zahlbr.	Siliceous rock	2	HLUC [No. 709 808]	An arctic–alpine-to-boreal–montane circumpolar lichen
79	*Umbilicaria deusta* (L.) Baumg.	Siliceous rock	2 4 9 10 14 16 22	HLUC [No. 182 716] CLU [No. 16515 16517 16521; 5645; 9125; 783 794 805 2866 2867 9138]	An arctic–alpine-to-boreal–montane circumpolar lichen
80	*Umbilicaria freyi* Codogno Poelt & Puntillo	Siliceous rock	11 13 19	TSB [No. 11045] CLU [No. 3129]	Ranging from the Alps to the mountains of Calabria
81	*Umbilicaria grisea* Hoffm.	Siliceous rock	2 4 5 6 11 13 17 19	HLUC [No. 488] CLU [No. 9098; 3131]	Usually below the alpine belt
82	*Umbilicaria hirsuta* (Westr.) Hoffm.	Siliceous rock	1 9 10 11 12 13 18 19	HLUC [No. 668] CLU [No. 16665; 1216 1217; 1048 10900; 822 2868 2869] TSB [No. 4048 10900]	A widespread arctic–alpine-to-boreal–montane circumpolar lichen
83	*Umbilicaria hispanica* (Frey) Davydov Peršoh & Rambold	Siliceous rock	2 9 10 13 14	HLUC [No. 688] CLU [No. 786 797 801 819 2856 9137; 35 802]	Mostly in upland areas of the Mediterranean Region
84	*Umbilicaria hyperborea* (Ach.) Hoffm.	Siliceous rock	2	HLUC [No. 641]	An arctic–alpine probably circumpolar lichen
85	*Umbilicaria nylanderiana* (Zahlbr.) H. Magn.	Siliceous rock	2 9 12 19	CLU [No. 803 808 818 2853 28549099 9376] TSB [No. 44864 44865] HLUC [No. 642 708]	An arctic–alpine probably circumpolar lichen

Table 2. *Cont.*

N	Taxon	Substrate	Site ID	Herbarium and Voucher No.	Notes
86	*Umbilicaria polyphylla* (L.) Baumg.	Siliceous rock	1 2 3 8 9 10 13 14 16 18 20	HLUC [No. 666] CLU [No. 12597; 16576; 794 799 2855 2870 9136 9138; 761] TSB [No. 30846]	Present both in the Alps and in the high Mediterranean mountains
87	*Umbilicaria proboscidea* (L.) Schrad.	Siliceous rock	2	HLUC [No. 714]	A mainly arctic–alpine circumpolar lichen
88	*Umbilicaria pustulata* (L.) Hoffm.	Siliceous rock	1–8 10 14 15 18 20 21	HLUC [No. 39; 679; 719; 754; 815] CLU [No. 712; 352 353]	A temperate-to-boreal–montane circumpolar species
89	*Umbilicaria subpolyphylla* Oxner	Siliceous rock	2	HLUC [No. 627]	A southern European species
90	*Umbilicaria torrefacta* (Lightf.) Schrad.	Siliceous rock	2 9 10 14	HLUC [No. 717] CLU [No. 787 807 820 2871 2872 5644 9099; 9365]	An arctic–alpine circumpolar lichen
91	*Umbilicaria vellea* (L.) Ach.	Siliceous rock	1 2 9 11 12 19	HLUC [No. 801; 711] CLU [No. 784] TSB [No. 11268; 11053]	An arctic–alpine probably circumpolar lichen
92	*Xanthoparmelia angustiphylla* (Gyeln.) Hale	Siliceous rock	2 9	HLUC [No. 733]	More widespread in Mediterranean Italy
93	*Xanthoparmelia conspersa* (Ach.) Hale	Siliceous rock	1–9 21	HLUC [No. 731; 766; 812] TSB [No. 6625]	Restricted to upland areas in southern Italy less frequent than the vicariant X. tinctina in the Mediterranean belt
94	*Xanthoparmelia loxodes* (Nyl.) O. Blanco et al.	Siliceous rock	1 3 4 5 6	Not collected	A mainly temperate common species of basic siliceous rocks
95	*Xanthoparmelia perrugata* (Nyl.) O. Blanco et al.	Siliceous rock	2 4	HLUC [No. 624 742]	A species that is boreal to (mainly) Mediterranean
96	*Xanthoparmelia protomatrae* (Gyeln.) Hale	Siliceous rock	4	HLUC [No. 753]	A mainly temperate-to-Mediterranean species
97	*Xanthoparmelia pulla* (Ach.) O. Blanco et al.	Siliceous rock	1 2 3 4 7 10 18	HLUC [No. 735; 747] CLU [No. 1228; 42 9128] TSB [No. 10729]	Has a very wide altitudinal range
98	*Xanthoparmelia stenophylla* (Ach.) Ahti & D. Hawksw.	Siliceous rock	1 3 4 5	HLUC [No. 619; 675; 730] TSB [No. 22203]	A Eurasian species with a very wide altitudinal range
99	*Xanthoparmelia sublaevis* (Cout.) Hale	Siliceous rock	4 5	HLUC [No. 820]	Common in the Mediterranean belt but also occurs in dry–warm alpine valleys
100	*Xanthoparmelia tinctina* (Maheu & A. Gillet) Hale	Siliceous rock	1 3 4 5	HLUC [No. 137] CLU [No. 3487]	A mainly mediterranean species found on siliceous rocks
101	*Xanthoparmelia verruculifera* (Nyl.) O. Blanco et al.	Siliceous rock	2	HLUC [No. 821]	Widespread on siliceous rocks in North America Europe and northern Africa
102	*Zeora sulphurea* (Hoffm.) Flot.	Siliceous rock	2	CLU [No. 16533] HLUC [No. 613] TSB [No. 22094]	

Some voucher numbers are missing because the specimen was not present in the herbarium but was recorded in the field survey.

Table 3. Updated site summary (with rare taxa and ecological traits).

Site ID	Species Richness (Total Taxa)	Arctic–Alpine Taxa	Rare/Threatened Taxa Present (Notes)	Ecological Zone/Altitudinal Proxy
1	26	2	0	Lowland to mid-montane
2	62	17	1 (*Anaptychia crinalis Bryoria smithii Placidium subrufescens Psorinia conglomerate Umbilicaria proboscidea*)	Broad transitional altitudinal belt
3	38	4	2 (*Anaptychia crinalis Lethariella intricata*)	Montane/old-growth forest edge
4	43	4	2 (*Anaptychia crinalis Leptogium furfuraceum Placidium subrufescens Psorinia conglomerata*)	Montane open habitats
5	13	1	0	Transitional montane
6	16	2	0	Mid-montane
7	4	0	0	Restricted local sampling
8	9	1	0	Dry-continental xeric rock
9	35	15	0	High alpine (above treeline/ridge)
10	24	10	0	High alpine (above treeline)
11	5	2	0	Transitional montane
12	5	3	0	High alpine (above treeline/ridge)
13	11	2	0	High alpine/open heath
14	5	2	0	Transitional montane
15	6	0	0	Lower montane soil
16	6	1	0	Restricted cold-temperate spot
17	2	0	0	Montane open habitats
18	8	1	0	Montane open habitats
19	5	3	0	Montane open habitats
20	3	0	0	Montane open habitats
21	2	0	0	Montane open habitats
22	4	2	0	Montane open habitats

A summary of the most significant floristic findings including new records at national macro-regional and regional levels is provided in Table 4 and Figure 2.

Table 4. Summary of new lichen records and their phytogeographical and ecological interest.

Taxon	Floristic Novelty Category	Phytogeographical and Ecological Interest
Bryoria smithii	New to southern Italy	Boreal–montane; highly disjunct and rare in the South.
Cladonia cariosa	New to Basilicata	Associated with early-successional pioneer soil communities.
Dermatocarpon intestiniforme	New to southern Italy	Boreal–montane-to-arctic–alpine circumpolar lichen.
Dermatocarpon luridum	New to Basilicata	Amphibious species; restricted to periodically inundated rocks.
Fuscidea cyathoides	New to Basilicata	Mostly in humid upland areas.
Leptogium furfuraceum	New to Basilicata	In warm–humid areas near wood.
Nephroma parile	New to Basilicata	Sensitive cyanolichen; indicator of pristine air quality.
Placidium adami-borosi	New to Basilicata	On soil derived from metamorphic base-rich rocks.
Placidium subrufescens	New to Italy	Mediterranean–montane; rare on siliceous soils.
Pseudephebe minuscula	New to Basilicata	Arctic–alpine element at its extreme southern distribution limit.
Psorinia conglomerata	New to southern Italy	Arctic–alpine relict; indicator of stable glacial niches.
Schaereria fuscocinerea	New to Basilicata	In exposed situations on hard siliceous rocks.
Thalloidima tauricum	New to Basilicata	specialist in dry–xeric grasslands.
Umbilicaria crustulosa subsp. *punctata*	New to southern Italy	Mediterranean-montane; on siliceous rocks
Umbilicaria proboscidea	New to southern Italy	Arctic–alpine relict; high conservation priority.
Umbilicaria subpolyphylla	New to southern Italy	Often overlooked due to morphological similarities.
Xanthoparmelia angustiphylla	New to Basilicata	Typical of exposed Mediterranean–montane outcrops.
Xanthoparmelia perrugata	New to Basilicata	Silicicolous species showing competitive traits on bare rock.
Xanthoparmelia protomatrae	New to Basilicata	Rare sub-Mediterranean element on sunny metal-rich rocks.
Xanthoparmelia sublaevis	New to southern Italy	Specialized on thermophytic siliceous rocky outcrops.
Xanthoparmelia verruculifera	New to Basilicata	Common elsewhere but officially missing from past regional lists.

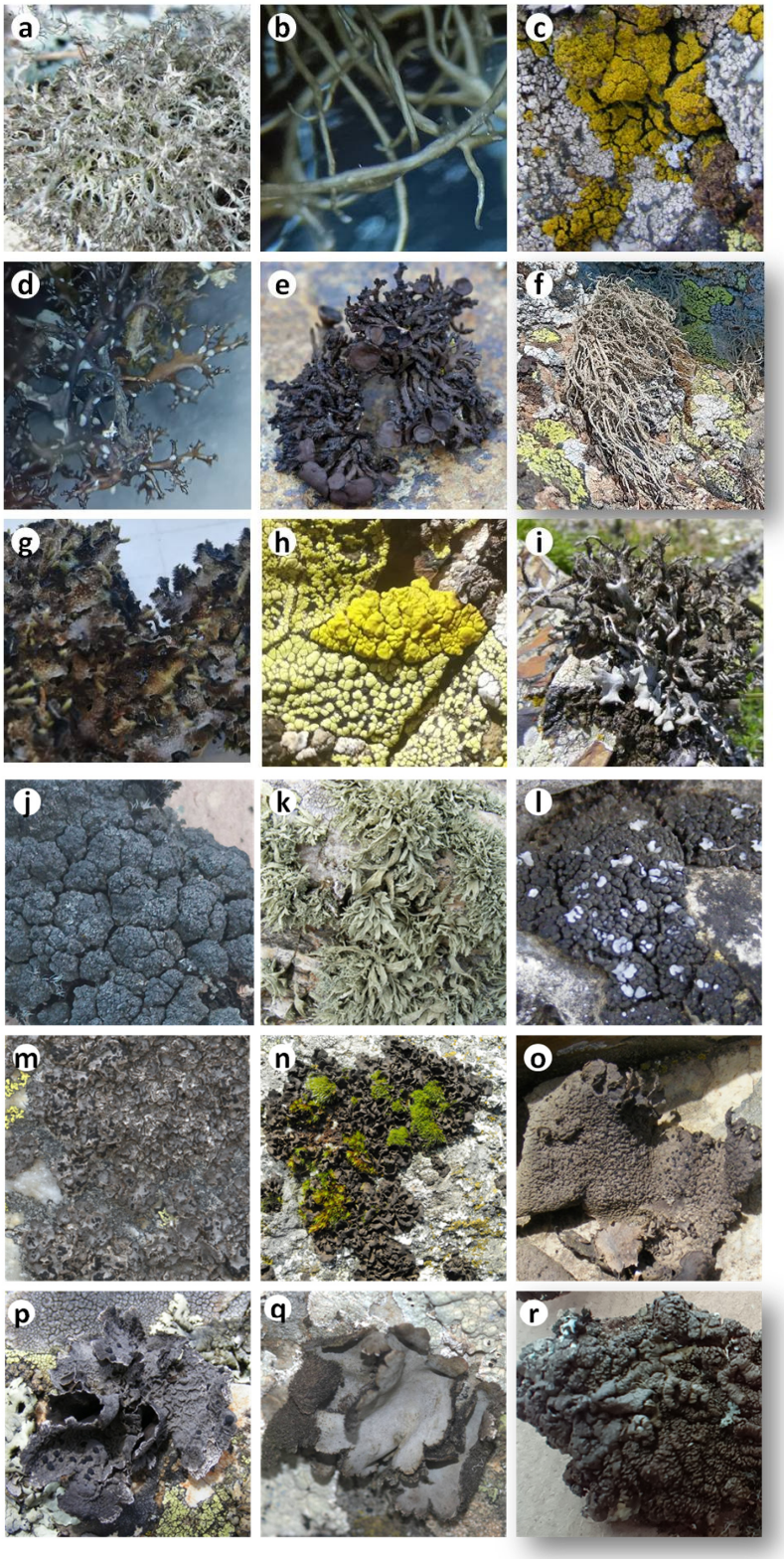


Figure 2. Most significant floristic findings: (**a**) *Anaptychia crinalis* (Schaer.) J. Nowak; (**b**) *Bryoria smithii* (Du Rietz) Brodo & D. Hawksw.; (**c**) *Candelariella coralliza* (Nyl.) H. Magn.; (**d**) *Cetraria aculeata* (Schreb.) Fr.; (**e**) *Cornicularia normoerica* (Gunnerus) Du Rietz; (**f**) *Lethariella intricata* (Moris) Krog; (**g**) *Parmelia omphalodes* (L.) Ach.; (**h**) *Pleopsidium chlorophanum* (Wahlenb.) Zopf; (**i**) *Pseudevernia furfuracea* (L.) Zopf; (**j**) *Psorinia conglomerata* (Ach.) Gotth. Schneid.; (**k**) *Ramalina polymorpha* (Lilj.) Ach.; (**l**) *Thalloidima tauricum* Szatala; (**m**) *Umbilicaria cylindrica* var. *tornata* (Ach.) Nyl.; (**n**) *Umbilicaria deusta* (L.) Baumg.; (**o**) *Umbilicaria nylanderiana* (Zahlbr.) H. Magn.; (**p**) *Umbilicaria proboscidea* (L.) Schrad.; (**q**) *Umbilicaria vellea* (L.) Ach.; (**r**) *Xanthoparmelia perrugata* (Nyl.) O. Blanco et al.

4. Discussion

The floristic check list of this study (Table 2) substantially improves upon the current knowledge of the lichen biota across the Italian Peninsula. The flora survey reveals important biogeographical discoveries including the presence of *Placidium subrufescens* recorded for the first time in Italy this species is generally calcicolous but in this case was found on different siliceous substrata from two sites in the Basilicata Region. *Placidium subrufescens* belongs to a group of species that is characterized by a prosoplectenchymatous medulla a well delimited paraplectenchymatous lower cortex, marginal pycnidia, and cylindrical to bacilliform conidia. It is similar to *P. imbecillum* from which it differs mainly in having thicker squamules with a thicker medulla, and smaller ascospores [7, key no. 15]. Furthermore 7 taxa are recorded as new to southern Italy and 13 taxa representing new regional records for Basilicata (Table 4), extending their known geographical range within the Italian Peninsula. The strong presence of species with a range extending from boreal–mountainous to arctic–alpine zones in the southern Apennines may suggest that these sites act as a southern refuge for certain elements of the arctic–boreal biota. Overall these findings underscore the high conservation value of these montane and alpine ecosystems for preserving disjunct and rare lichen biota. In these extreme environments harsh climatic conditions act as an environmental filter excluding generalist temperate taxa while favouring stress-tolerant glacial lichens. Across the 22 sites listed in Tables 1 and 3 the overall species richness varied considerably ranging from 2 to 62 taxa; Site 2 recorded the greatest diversity (62 taxa) and the highest concentration of species specialized to the arctic–alpine environment (17 taxa). The study area shows a remarkable floristic link with the high-altitude environments of the central and western siliceous Alps (e.g., the Gran Paradiso and Ortles-Cevedale massifs). In particular sites such as Monte Volturino (Site 2) and Monte Nardello (Site 22) host cold and foggy microhabitats that likely facilitate the persistence of cold-adapted species close to their southernmost distribution limits in Europe. Although the Alps host the core populations of many recorded taxa (e.g. *Umbilicaria* spp., *Pseudephebe* spp., *Xanthoparmelia* spp., *Cornicularia* sp.) the same genera occur in the southern Apennines even if their occurrence here is highly fragmented and localized. Nevertheless these southern populations are biogeographically significant.

Comparative research and taxonomic revisions in Italy are made possible primarily by herbarium collections containing nomenclatural types of the particular genera presented in this research e.g., *Umbilicaria*, *Cladonia* [19], *Xanthoparmelia* [20] and catapyrenioid species [21–23]. The integration of historical herbarium records with field survey data proved essential for reconstructing the actual diversity and distribution of lichens in Italy e.g., [24–26]. This integrative approach is particularly important for poorly investigated groups such as lichens for which historical data often represent the only available evidence of past distributions.

The Calabrian–Lucanian Apennines can now be considered an area of exceptional lichenological interest. These records have important biogeographical implications. For example *Umbilicaria proboscidea* is particularly noteworthy: Italian records were previously known only from the Alps [24,27,28] and its discovery on Site 2 represents the first record for Peninsular Italy. Likewise, the records of *Psorinia conglomerata* and *Melanelia stygia* show that the southern Apennines functioned as refugia and dispersal corridors for cold-adapted lichens. Our floristic knowledge of southern Italy remains incomplete but this study lays the foundation for future research aimed at identifying and evaluating microclimatic potential refugia for sensitive arctic–alpine lichens and a baseline for prioritizing specific siliciclastic sites as interesting biodiversity areas. These findings further emphasize the importance of siliceous outcrops as biodiversity areas comparable in importance if not in extent to northern Italian alpine sites suggesting that these Mediterranean micro-habitats

may play a similarly critical role in preserving specialized flora under changing climatic conditions [24,29]. A major outcome of this research is the remarkable diversity of the genus *Umbilicaria* with 17 taxa recorded out of the 32 taxa known in Italy. These species are highly specialized saxicolous lichens typically restricted to stable weather-resistant acidic rocks [28,30–36]. The identification of *U. subpolyphylla*—a taxon often overlooked or confused with *U. polyphylla*—suggests that the Mediterranean–montane distribution of this genus is more complex than previously thought [32]. The abundance of *Umbilicaria* species observed at sites like Monte Volturino reflects a high degree of environmental stability. These sites which have already been recognized for their geological importance and included in geoconservation initiatives [37–39] could represent refuge habitats of exceptional lichenological value. Despite their ecological importance populations of cold-adapted lichens in southern Italy are extremely fragmented and highly vulnerable to ongoing climate change. Many of these species occur near the warm edge of their distribution range and may therefore be particularly sensitive to even slight increases in temperature or reductions in atmospheric humidity and fog frequency according to [35,37,40–42].

The habitats hosting such a relevant lichen biota namely the EU Habitats 8230 and 8220 require urgent and targeted conservation measures as they represent unique evolutionary legacies within the Mediterranean basin that are currently under-represented in national conservation policies. The occurrence of lichen species of high biogeographical and ecological relevance adds further weight to their conservation claims.

In the end we believe this study fills an important gap in our knowledge regarding the diversity of lichens in the Mediterranean area. The species discoveries made on these siliceous outcrops in southern Italy are of immense value to the scientific community interested in lichen diversity but they also provide valuable information regarding biogeography and conservation.

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