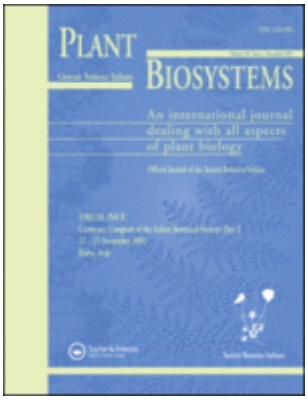
Towards a Red List of the terricolous lichens of Italy



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Towards a Red List of the terricolous lichens of Italy

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Abstract

Terricolous lichens, threatened in many areas of Europe, have been greatly overlooked in conservation policies. This work provides a provisional Red List of the terricolous lichens of Italy, to favour their inclusion in conservation policies. The taxa were assigned to IUCN categories according to a simplified assessment procedure based on their rarity and past/current distribution in the administrative regions and ecoregions of Italy. We evaluated 162 species: 30 were listed as regionally extinct, 22 critically endangered, 16 endangered, 49 vulnerable, 27 near-threatened, 7 least-concern, and 11 data deficient. A quarter of the terricolous lichens of Italy is likely to be threatened, but a rigorous assessment is hindered by the scarcity of data. Further field work is needed for more precise assessments of their conservation status.

Keywords

Biodiversity, conservation, floristics, historical collections, lichen biota, Natura 2000 Network.

Introduction

Lichens are considered as optimal indicators of environmental quality (ANPA 2002). Terricolous lichens, being particularly sensitive to anthropogenic impact, are therefore threatened in many areas of Europe, mainly due to habitat loss and fragmentation, air pollution and global change (Scheidegger and Clerc 2002). Unfortunately, these organisms have been greatly overlooked in conservation polizie, and only in the last decade they have gained the attention of Italian lichenologists, who focused on the effects of habitat loss and global change (Gheza et al. 2018, 2020, 2021a; Di Nuzzo et al. 2021; Vallese et al. 2021).

In biological conservation, Red Lists play an important role, addressing the attention towards the most threatened species. Red Lists including terricolous lichens are available for several European

countries, but not for Italy. The first Red List of Italian lichens (Nimis 1992) included several terricolous species, but it was based on still fragmentary data and old criteria, which hindered its integration in official conservation policies. Another Red List, that follows more modern IUCN criteria, albeit simplified for fungal species (Dahlberg and Mueller, 2011), included epiphytic lichens only (Nascimbene et al. 2013). A strict application of IUCN assessment procedures was used only for a few terricolous species of conservation concern (*Cladonia* subgenus *Cladina*: Ravera et al. 2016).

Red-listing is a complex procedure that requires accurate data which are not always available for understudied organisms, as lichens. Mainly for this reason, a strict application of the IUCN criteria is not always possible for fungal species, so that for lichens the assessment of the conservation status was often based on a simplified approach (Nascimbene et al. 2013).

This work aims at providing a provisional Red List of the terricolous lichens of Italy which could be useful to enhance their inclusion in conservation policies, but also to highlight gaps in current knowledge.

Materials and methods

A preliminary selection was carried out, leading to a list of 162 infrageneric taxa to assess for the Red List, out of the 452 terricolous lichens occurring in Italy (36%). The assessment was performed following Dahlberg and Mueller (2011) and the framework by Nascimbene et al. (2013), mainly evaluating data on rarity and past/current distribution of the taxa in the 20 administrative regions and the 9 ecoregions of Italy (Nimis 2016), to obtain an estimate of their trends and extinction risk. A detailed account of the assessment procedure is reported in Supplementary File 1.

Results

Overall, 162 infrageneric taxa were assessed for the attribution to IUCN categories (Supplementary File 2), and 117 of them (72% of assessed taxa and 26% of terricolous lichens of Italy) were

attributed to a threatened or extinction category. Among them, 30 taxa were not reported in the last 50 years, 85 showed a declining trend, and 41 are known from a single locality. Many taxa have not been reported from at least one of the 20 administrative regions of Italy in the last 50 years.

The 30 taxa (19%) not reported from any Italian region in the last 50 years have been assessed as "regionally extinct" (RE). The 22 taxa (14%) known from a single locality in Italy in the last 50 years have been assessed as "critically endangered" (CR). Sixteen taxa (10%) have been assessed as "endangered" (EN), 49 (30%) "vulnerable" (VU), and 27 (17%) "near threatened" (NT). Most of them showed a decline in the last decades, i.e. were reported from fewer regions in the last 50 years. Only 7 taxa were assessed as "least concern" (LC). The remaining 11 taxa, with insufficient information, were classified as "data deficient" (DD); they are mainly species reported as new to Italy in the last 10 years.

Discussion

The data gathered for this assessment paint a troubling picture for the terricolous lichens of Italy. Similarly to epiphytic species (Nascimbene et al. 2013), about a quarter of the terricolous lichens were assessed as threatened or already virtually extinct, but this may be due to a real extinction or just to scarce knowledge; more intense field-studies, especially in previously overlooked habitats and for recently-described taxa, may lead to the rediscovery of taxa assessed as RE or CR.

Scarce data hinder rigorous assessment procedures. A simplified procedure can lead to an overestimation of the species assessed as extinct, but also to an underestimation of the assigned categories. A comparison between a strict assessment with IUCN criteria vs our simplified assessment is possible only for three species assessed as EN by Ravera et al. (2016), i.e. *Cladonia ciliata*, *C. mediterranea* and *C. portentosa*, which were assessed by us as NT, LC and NT, respectively.

The first "Golden Age of Italian lichenology" in the mid 19th century was followed by almost a century of inactivity (Nimis 1993), until the late 20th century, when there was a first phase of new

explorations that soon led to a phase of synthesis of historical and newly collected data, culminating with the publication of two national checklists (Nimis 1993, 2016) and an online database updated in real time and supplemented with identification keys (Nimis and Martellos 2021). Recent developments have provided a priceless working basis, but have also highlighted the still insufficient knowledge, and should be considered as a starting point for a new analytical phase, made possible thanks to the recent tools for species identification and concerning not only mere floristics but also other urgent topics (Supplementary File 3).

Acknowledgements

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References

ANPA. 2002. I.B.L. Indice di Biodiversità Lichenica. Roma: Agenzia Nazionale per la Protezione dell'Ambiente.

Dahlberg A, Mueller GM. 2011. Applying IUCN red-listing criteria for assessing and reporting on the conservation status of fungal species. Fungal Ecol. 4:147-162.

Di Nuzzo L, Vallese C, Benesperi R, Giordani P, Chiarucci A, Di Cecco V, Di Martino L, Di Musciano M, Gheza G, Lelli C, Spitale D, Nascimbene J. 2021. Contrasting multitaxon responses to climate change in Mediterranean mountains. Sci. Rep. 11: 4438.

Gheza G, Assini S, Lelli C, Marini L, Mayrhofer H, Nascimbene J. 2020. Biodiversity and conservation of terricolous lichens and bryophytes in continental lowlands of northern Italy: the role of different dry habitat types. Biodiv. Conserv. 29(13): 3533-3550.

Gheza G, Assini S, Marini L, Nascimbene J. 2018. Impact of an invasive herbivore and human trampling on lichen-rich dry grasslands: soil-dependent response of multiple taxa. Sci. Total

Environ. 639: 633-639.

Gheza G, Di Nuzzo L, Vallese C, Barcella M, Benesperi R, Giordani P, Nascimbene J, Assini S. 2021a. Morphological and chemical traits of *Cladonia* respond to multiple environmental factors in acidic dry grasslands. Microorganisms 9(2): 453.

Nascimbene J, Nimis PL, Ravera S. 2013. Evaluating the conservation status of epiphytic lichens of Italy: a red list. Plant Biosyst. 147(4):898-904.

Nimis PL. 1992. Lista rossa dei Licheni d'Italia. In: Conti F, Manzi A, Pedrotti F, editors. Libro rosso delle piante d'Italia. Roma: Associazione Italiana per il World Wildlife Fund. p 503-555.

Nimis PL. 1993. The lichens of Italy. An annotated catalogue. Torino: Museo Regionale di Scienze Naturali. p. 897.

Nimis PL. 2016. The lichens of Italy. A second annotated catalogue. Trieste: EUT. p. 740.

Nimis PL, Martellos S. 2021 (continuously updated). ITALIC – The Information System on Italian Lichens. Version 6.0. University of Trieste, Dept. of Biology. http://dryades.units.it/italic

Ravera S, Isocrono D, Benesperi R, Giordani P, Nascimbene J, Tretiach M, Montagnani C. 2016. Assessment of the conservation status of the mat-forming lichens *Cladonia* subgenus *Cladina* in Italy. Plant Biosyst. 150(5):1010-1022.

Scheidegger C, Clerc P. 2002. Rote Liste der gefährdeten Arten der Schweiz: baum- und erdbewohnende Flechten. Bern, Birmensdorf, Geneve: BUWAL-Reihe Vollzug Umwelt.

Vallese C, Nascimbene J, Giordani P, Benesperi R, Casazza G. 2021. Modelling range dynamics of terricolous lichens of the genus *Peltigera* in the Alps under a climate change scenario. Fungal Ecol. 49: 101014.

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Supplementary File 1
Assessment procedure.

Preliminary selection of the species
The term "terricolous" is in itself an intrinsically fuzzy concept: here we follow Nimis and Martellos (2001) in flagging as "terricolous" all lichens mainly found on the ground, irrespectively of whether they occur on mineral or humus soil, strongly weathered rocks, dead bryophytes or plant debris.
In Italy, 452 infrageneric taxa of mainly terricolous lichens have been reported so far (Nimis and Martellos 2021). Similarly to the Red List of epiphytic lichens (Nascimbene et al. 2013), a preliminary selection was carried out to consider for assessment only those taxa reported as "extremely rare" or "very rare" in all administrative regions and ecoregions of Italy. These data were taken from ITALIC (Nimis and Martellos 2021), where the attribution to a commonness-rarity class, mainly deriving from Nimis (2016), was calculated separately for each of the nine ecoregions of Italy on the basis of three main criteria: (1) the number of specimens in the TSB lichen herbarium (% on the total for each ecoregion); (2) the number of citations in the literature; (3) an expert judgement, used only in particular cases.

Criteria for assessment
All available literature records of the selected taxa were retrieved, to extract information useful for their assessment. In addition, the main lichen herbarium archives available online were also consulted (GB, LD, S, TSB, UPS), and the specimens from the "Erbario Crittogamico Italiano" were checked in FI. On this basis, the following parameters were established, which were then used for assessment.
(1) Whether a taxon was reported at least from one Italian administrative region in the last 50 years; this information was used as a proxy of extinction probability, when there is no recent report.
(2) Whether a taxon is known from a single locality in Italy in the last 50 years; this information was used as a proxy of the threatened status.
(3) Total number of Italian administrative regions from which a taxon was reported at least once (both old and recent records included).
(4) Number of Italian administrative regions from which a taxon was reported at least once in the last 50 years; a difference between (3) and (4) was used as a proxy of a declining trend, more accurate data to estimate trends being not available.
(5) Sensitiveness of each taxon to human disturbance according to the value of the poleotolerance index assigned by Nimis (2016) and Nimis and Martellos (2021). The poleotolerance index is an indicator of the tendency of a lichen to occur in areas with different degrees of human disturbance. Since the value 0 ("species which exclusively occur on old trees in ancient, undisturbed forests") is assigned to epiphytic species only, we considered value 1, assigned to "species mostly occurring in natural or semi-natural habitats".

Attribution to IUCN categories
The conservation status according to IUCN categories was assessed by adapting the criteria proposed by Dahlberg and Mueller (2011) to the information available for the selected taxa, following the same procedure applied by Nascimbene et al. (2013) for epiphytic lichens.
Our data do not allow estimations of population size, fluctuations or viability of the assessed taxa. For these reasons, we mainly used parameters related to criteria B and D. Criterion B is related to geographic range, which was expressed on the basis of occurrences in the 20 administrative regions

of Italy, and to decline, which was inferred by comparisons between the number of administrative regions in which a taxon was reported at least once and the number of regions in which it was not reported in the last 50 years. Criterion D is related to rarity in the 9 ecoregions of Italy.

"Regionally extinct" (RE) was assigned to taxa not reported from any Italian region in the last 50 years. However, the lack of recent findings could be due to poor field investigations, and the extinction status remains hypothetical. For the same reason, we refrained to attribute the category "Extinct" (EX) to species known only from type collections older than 50 years (e.g. *Involucropyrenium sbarbaronis*, *Staurothele terricola*), including them under RE.

"Critically endangered" (CR) was assigned to taxa known from a single locality in the last 50 years (Criterion D).

"Endangered" (EN) was assigned to taxa known from one to two Italian regions in more than one locality (Criterion D) and (1) likely to have a declining trend [Criteria B1ab(i), B1ab(ii), B2ab(i), B2ab(ii)] and/or (2) extremely/very sensitive to human disturbance (according to their poleotolerance, Criterion A4e).

"Vulnerable" (VU) was assigned to taxa known from 3 to 5 Italian regions in more than one locality (Criterion D) and (1) likely to have a declining trend [Criteria B1ab(i), B1ab(ii), B2ab(i), B2ab(ii)] and/or (2) extremely/very sensitive to human disturbance (according to their poleotolerance, Criterion A4e).

"Near threatened" (NT) was assigned to taxa reported from more than 5 Italian regions in more than one locality (Criterion D) and (1) likely to have a declining trend [Criteria B1ab(i), B1ab(ii), B2ab(i), B2ab(ii)] and/or (2) extremely/very sensitive to human disturbance (according to their poleotolerance, Criterion A4e).

"Least concern" (LC) was assigned to taxa known from more than 5 Italian regions in more than one locality, which are likely to have no declining trend.

"Data deficient" (DD) was assigned to taxa (1) which are taxonomically poorly known and/or belong to critical taxonomic groups, and/or (2) whose distribution in Italy is poorly known, including those which have been reported from Italy for the first time within the last 10 years.

The few species assessed in detail based on a strict application of the IUCN criteria, i.e. those of *Cladonia* subgenus *Cladina* (Ravera et al. 2016), have been assessed again, in order to allow a comparison between the two assessment methods.

References

Dahlberg A, Mueller GM. 2011. Applying IUCN red-listing criteria for assessing and reporting on the conservation status of fungal species. Fungal Ecol. 4:147-162.

Nascimbene J, Nimis PL, Ravera S. 2013. Evaluating the conservation status of epiphytic lichens of Italy: a red list. Plant Biosyst. 147(4):898-904.

Nimis PL. 2016. The lichens of Italy. A second annotated catalogue. Trieste: EUT. p. 740.

Nimis PL, Martellos S 2001. Keys to the lichens of Italy I. Terricolous species, Ed. Goliardiche, Trieste, 341 pp.

Nimis PL, Martellos S. 2021 (continuously updated). ITALIC – The Information System on Italian Lichens. Version 6.0. University of Trieste, Dept. of Biology. http://dryades.units.it/italic

Ravera S, Isocrono D, Benesperi R, Giordani P, Nascimbene J, Tretiach M, Montagnani C. 2016. Assessment of the conservation status of the mat-forming lichens *Cladonia* subgenus *Cladina* in Italy. Plant Biosyst. 150(5):1010-1022.

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Supplementary File 2
Red List of the terricolous lichens of Italy.

For each taxon, the following information is reported: (1) IUCN category; (2) if information is missing from more than 50 years at the national level; (3) if the taxon is likely to experience a declining trend, according to (4) the number of administrative regions from which the taxon has been reported in the last 50 years and (5) the total number of administrative regions from which the taxon has been reported; (6) if the taxon is known from a single locality; (7) if the taxon is extremely/very sensitive to human disturbance according to the poleotolerance value assigned by Nimis (2016) and Nimis and Martellos (2021).
Nomenclature follows Nimis and Martellos (2021).

References

Nimis PL. 2016. The lichens of Italy. A second annotated catalogue. Trieste: EUT. p. 740.
Nimis PL, Martellos S. 2021 (continuously updated). ITALIC – The Information System on Italian Lichens. Version 6.0. University of Trieste, Dept. of Biology. http://dryades.units.it/italic

Taxon	1	2	3	4	5	6	7
Acarospora nodulosa (Dufour) Hue var. *nodulosa*	**EN**			1	1		x
Acarospora nodulosa var. *reagens* (Zahlbr.) Clauzade & Cl. Roux	**EN**			2	2		x
Acarospora placodiiformis H. Magn.	**CR**			1	1	x	x
Acarospora schleicheri (Ach.) A. Massal.	**VU**		x	2	3		x
Agonimia gelatinosa (Ach.) M. Brand & Diederich	**VU**			4	4		x
Agonimia globulifera M. Brand & Diederich	**VU**			3	3		x
Agonimia opuntiella (Buschardt & Poelt) Vězda	**LC**			10	10		x
Agonimia vouauxii (B. de Lesd.) M. Brand & P. Diederich	**DD**			1	1	x	
Alyxoria culmigena (Lib.) Ertz	**NT**		x	5	6		x
Anaptychia bryorum Poelt	**NT**		x	5	6		x
Aphanopsis coenosa (Ach.) Coppins & P. James	**RE**	x	x	0	1		x
Bacidia killiasii (Hepp) D. Hawksw.	**RE**	x	x	0	1	x	x
Bacidia viridescens (A. Massal.) Th. Fr.	**RE**	x	x	0	1	x	x
Baeomyces carneus (Retz.) Flörke	**CR**		x	1	2		x
Bellicidia incompta (Borrer) Kistenich, Timdal, Bendiksby & S.Ekman	**NT**		x	5	10		
Biatorella fossarum (Fr.) Th. Fr.	**NT**		x	1	7		
Bibbya lutosa (Ach.) Kistenich, Timdal, Bendiksby & S.Ekman	**NT**		x	4	6		x
Buellia asterella Poelt & Sulzer	**RE**	x	x	0	1	x	x
Buellia elegans Poelt	**VU**		x	2	3		x
Caloplaca congrediens (Nyl.) Zahlbr.	**VU**			3	3		x
Caloplaca fulvolutea (Arnold) Jatta	**VU**			3	3		x
Caloplaca livida (Hepp) Jatta	**RE**	x	x	0	3		x
Caloplaca nivalis (Körb.) Th. Fr.	**RE**	x	x	0	4		x
Caloplaca raesaenenii Bredkina	**CR**			1	1	x	x
Catillaria contristans (Nyl.) Zahlbr.	**RE**	x	x	0	1	x	x
Cetraria juniperina (L.) Ach.	**LC**			6	6		x
Cetraria obtusata (Schaer.) van den Boom & Sipman	**VU**			4	4		x
Circinaria crespiana (V.J. Rico) Sohrabi & V.J. Rico	**CR**			1	1	x	x
Circinaria hispida (Mereschk.) A. Nordin, Savić & Tibell	**EN**			2	2		x
Cladonia acuminata (Ach.) Norrl.	**LC**			6	6		x
Cladonia caespiticia (Pers.) Flörke	**NT**		x	11	15		x
Cladonia ciliata Stirt.	**NT**		x	6	8		x
Cladonia conista (Ach.) Robbins	**DD**			4	4		x
Cladonia corsicana (Rondon & Vězda) Pino-Bodas, Burgaz & M.P. Martín	**DD**			1	1	x	x
Cladonia cryptochlorophaea Asahina	**NT**		x	5	8		x
Cladonia cyanipes (Sommerf.) Nyl.	**VU**		x	2	3		x

Taxon	1	2	3	4	5	6	7
Cladonia cyathomorpha Walt. Watson	**VU**			3	3		x
Cladonia decorticata (Flörke) Spreng.	**VU**		x	2	4		x
Cladonia dimorpha S. Hammer	**VU**			3	3		x
Cladonia ecmocyna Leight.	**NT**		x	6	7		x
Cladonia glauca Flörke	**VU**		x	1	5		
Cladonia incrassata Flörke	**VU**		x	4	5		x
Cladonia mediterranea P.A. Duvign. & Abbayes	**LC**			7	7		x
Cladonia peziziformis (With.) J.R. Laundon	**NT**		x	5	6		x
Cladonia portentosa (Dufour) Coëm.	**NT**		x	8	9		x
Cladonia pulvinata (Sandst.) Herk & Aptroot	**DD**			2	2		x
Cladonia scabriuscula (Delise) Nyl.	**VU**		x	2	4		x
Cladonia stellaris (Opiz) Pouzar & Vězda	**VU**		x	3	5		x
Cladonia straminea (Sommerf.) Flörke	**DD**			1	1	x	x
Cladonia strepsilis (Ach.) Grognot	**VU**		x	3	5		x
Cladonia stygia (Fr.) Ruoss	**DD**			1	1		
Cladonia subturgida Samp.	**DD**			3	3		x
Cladonia subulata (L.) F.H. Wigg.	**NT**		x	8	10		x
Cladonia trassii Ahti	**VU**		x	1	3		x
Cladonia turgida Hoffm.	**NT**		x	2	7		x
Cladonia zopfii Vain.	**DD**			1	1	x	x
Clavascidium umbrinum (Breuss) Breuss	**CR**			1	1	x	x
Dactylina ramulosa (Hook. f.) Tuck.	**VU**		x	3	4		x
Diploschistella athalloides (Nyl.) Lücking, Knudsen & Fryday	**EN**			1	1		x
Diploschistes diacapsis (Ach.) Lumbsch	**NT**		x	9	10		x
Enchylium bachmanianum (Fink) Otálora, P.M. Jørg. & Wedin	**RE**	x	x	0	1	x	x
Enchylium coccophorum (Tuck.) Otálora, P.M. Jørg. & Wedin	**EN**			2	2		x
Enchylium limosum (Ach.) Otálora, P.M. Jørg. & Wedin	**NT**		x	3	11		
Endocarpon adsurgens Vain.	**CR**			1	1	x	
Epigloea grummannii Döbbeler	**CR**			1	1	x	x
Epigloea medioincrassata (Grummann) Döbbeler	**EN**			1	1		x
Epigloea soleiformis Döbbeler	**VU**			3	3		x
Farnoldia muscigena (Vězda) Hafellner & Tretiach	**EN**			2	2		x
Gyalecta friesii Körb.	**RE**	x	x	0	1	x	x
Gyalecta peziza (Mont.) Anzi	**RE**	x	x	0	3		x
Gyalecta russula (Nyl.) Baloch, Lumbsch & Wedin	**VU**		x	3	4		x
Gyalecta ulmi (Sw.) Zahlbr.	**NT**		x	8	14		x
Gyalidea asteriscus (Anzi) Aptroot & Lücking	**VU**		x	3	4		x
Gyalidea scutellaris (Bagl. & Carestia) Lettau	**RE**	x	x	0	3		x
Gyalolechia canariensis (Follmann & Poelt) Søchting, Frödén & Arup	**CR**			1	1	x	x
Gyalolechia desertorum (Tomin) Søchting, Frödén & Arup	**VU**		x	3	4		x
Halecania lecanorina (Anzi) M. Mayrhofer & Poelt	**CR**		x	1	4	x	x
Heppia adglutinata (Kremp.) A. Massal.	**VU**		x	4	6		x
Involucropyrenium sbarbaronis (Servít) Breuss	**RE**	x	x	0	1		x
Involucropyrenium waltheri (Kremp.) Breuss	**RE**	x	x	0	3		x
Lecania pusilla Tretiach	**EN**			1	1		x
Lecania subfuscula (Nyl.) S. Ekman	**EN**			1	1		x
Lecanora leptacina Sommerf.	**RE**	x	x	0	1	x	x
Lecidea miscella Ach.	**CR**			1	1	x	x
Lempholemma polyanthes (Bernh.) Malme	**NT**		x	6	10		x
Lepraria caesioalba (B. de Lesd.) J.R. Laundon	**LC**			10	10		x
Lepraria crassissima (Hue) Lettau	**VU**			4	4		x
Lepraria umbricola Tønsberg	**EN**			2	2		x
Leptochidium albociliatum (Desm.) M. Choisy	**NT**		x	6	8		x
Leptogium byssinum (Hoffm.) Nyl.	**RE**	x	x	0	1		x
Leptogium terrenum Nyl.	**RE**	x	x	0	1		x
Lichenomphalia alpina (Britzelm.) Redhead, Lutzoni, Moncalvo & Vilgalys	**CR**			1	1	x	x
Lichenomphalia hudsoniana (H.S. Jenn.) Redhead, Lutzoni, Moncalvo & Vilgalys	**VU**		x	4	5		x
Lichenomphalia meridionalis (Contu & La Rocca) P.-A. Moreau & Courtec	**CR**			1	1	x	x
Lichenomphalia umbellifera (L.) Redhead, Lutzoni, Moncalvo & Vilgalys	**NT**		x	8	10		x
Lichenomphalia velutina (Quél.) Redhead, Lutzoni, Moncalvo & Vilgalys	**NT**		x	6	7		x
Lobaria linita (Ach.) Rabenh.	**NT**			6	6		x
Massalongia carnosa (Dicks.) Körb.	**NT**		x	7	10		x
Micarea melaenida (Nyl.) Coppins	**VU**			3	3		x
Micarea ternaria (Nyl.) Vězda	**RE**	x	x	0	1	x	x
Micarea viridileprosa Coppins & van den Boom	**CR**			1	1	x	x
Multiclavula vernalis (Schwein.) R.H. Petersen	**CR**			1	1	x	x
Myochroidea rufofusca (Anzi) Printzen, T. Sprib. & Tønsberg	**RE**	x	x	0	2		x
Neocatapyrenium radicescens (Nyl.) Breuss	**CR**			1	1	x	x

Taxon	1	2	3	4	5	6	7
Nephroma expallidum (Nyl.) Nyl.	**VU**			3	3		x
Ochrolechia frigida (Sw.) Lynge	**RE**	x	x	0	4		x
Ochrolechia xanthostoma (Sommerf.) K. Schmitz & Lumbsch	**RE**	x	x	0	3		x
Opegrapha pulvinata Rehm	**VU**			3	3		x
Parvoplaca chelyae (Pérez-Vargas) Vondrák, Halici & Arup	**VU**			3	3		x
P*eltigera extenuata* (Vain.) Lojka	**DD**			3	3		x
Peltigera lepidophora (Vain.) Bitter	**LC**			9	9		x
Peltigera scabrosa Th. Fr.	**RE**	x	x	0	1	x	x
Peltula patellata (Bagl.) Swinscow & Krog	**EN**		x	1	2		x
Phaeophyscia constipata (Norrl. & Nyl.) Moberg	**VU**		x	3	4		x
Phaeophyscia hispidula (Ach.) Essl.	**VU**		x	2	3		x
Phaeorrhiza sareptana (Tomin) H. Mayrhofer & Poelt var. *sphaerocarpa* (Th. Fr.) H. Mayrhofer & Poelt	**EN**			2	2		x
Physconia muscigena var. *bayeri* (Nádv.) Poelt	**RE**	x	x	0	1	x	x
Placidiopsis tiroliensis Breuss	**CR**			1	1	x	
Placidium adami-borosi Szatala	**VU**			3	3		x
Placidium imbecillum (Breuss) Breuss	**CR**			1	1	x	x
Polyblastia philaea Zschacke	**CR**			1	1	x	x
Polyblastia rouxiana Vězda & Vivant	**VU**			4	4		x
Polychidium muscicola (Sw.) Gray	**NT**		x	7	10		x
Pseudopannaria marcii (B. de Lesd.) Zahlbr.	**CR**			1	1	x	x
Psilolechia clavulifera (Nyl.) Coppins	**EN**			2	2		x
Psora gresinonis B. de Lesd.	**VU**			3	3		x
Psora rubiformis (Ach.) Hook.	**VU**		x	3	4		x
Psora saviczii (Tomin) Follmann & A. Crespo	**EN**			1	1		x
Psoroglaena biatorella (Arnold) Lücking & Sérus.	**EN**			1	1		x
Rinodina candidogrisea Hafellner, Muggia & Obermayer	**VU**			3	3		x
Rinodina conradii Körb.	**NT**		x	4	7		x
Rinodina intermedia Bagl.	**RE**	x	x	0	2		x
Rostania ceranisca (Nyl.) Otálora, P.M. Jørg. & Wedin	**VU**		x	2	3		x
Schadonia alpina Körb.	**RE**	x	x	0	1	x	x
Schadonia fecunda (Th. Fr.) Vězda & Poelt	**RE**	x	x	0	3		x
Scytinium biatorinum (Nyl.) Otálora, P.M. Jørg. & Wedin	**CR**		x	1	4	x	x
Scytinium intermedium (Arnold) Otálora, P.M. Jørg. & Wedin	**VU**		x	4	10		x
Scytinium palmatum (Huds.) Gray	**NT**		x	10	12		x
Solorina bispora Nyl. var. *subspongiosa* (Zschacke) Frey	**DD**			1	1	x	x
Sphaerophorus fragilis (L.) Pers.	**NT**		x	3	7		x
Sporodictyon terrestre (Th. Fr.) Savić & Tibell	**VU**		x	3	5		x
Staurothele geoica Zschacke	**VU**			4	4		x
Staurothele terricola (Bagl.) Poelt & Nimis	**RE**	x	x	0	1	x	x
Tetramelas papillatus (Sommerf.) Kalb	**VU**		x	2	4		x
Tetramelas thiopolizus (Nyl.) Giralt & P. Clerc	**VU**			3	3		x
Thalloidima massatum (Tuck.) Kistenich, Timdal, Bendiksby & S.Ekman	**VU**		x	2	3		x
Thalloidima toepfferi Stein	**VU**			3	3		x
Thelenella muscorum var. *octospora* (Nyl.) Coppins & Fryday	**CR**			1	1	x	x
Thelidium bubulcae (A. Massal.) Arnold	**RE**	x		0	1	x	x
Thelocarpon citrum (Wallr.) Rossman	**RE**	x		0	1	x	x
Thelocarpon macchiae Nimis, Poelt & Puntillo	**VU**			3	3		x
Thelocarpon sphaerosporum H. Magn.	**RE**	x	x	0	1	x	x
Thelopsis isiaca Stizenb.	**LC**			7	7		
Toninia squalescens (Nyl.) Th. Fr.	**RE**	x	x	0	1	x	x
Toninia tristis subsp. *pseudotabacina* Timdal	**VU**		x	4	5		x
Topelia rosea (Servít) P.M. Jørg. & Vězda	**VU**		x	3	4		x
Trapeliopsis pseudogranulosa Coppins & P. James	**VU**			4	4		x
Trapeliopsis wallrothii (Spreng.) Hertel & Gotth. Schneid.	**NT**		x	4	7		x
Vahliella atlantica (P.M. Jørg. & P. James) P.M. Jørg.	**DD**	x	x	0	1	x	x
Verrucaria geophila Zahlbr.	**VU**			4	4		x
Vezdaea aestivalis (Ohlert) Tscherm.-Woess & Poelt	**EN**			2	2		x
Xanthoparmelia pokornyi (Körb.) O. Blanco, A. Crespo, Elix, D. Hawksw. & Lumbsch	**CR**			1	1	x	x

Towards a Red List of the terricolous lichens of Italy

Gabriele Gheza, Luca Di Nuzzo, Pier Luigi Nimis, Renato Benesperi, Paolo Giordani, Chiara Vallese, Juri Nascimbene

Supplementary File 3
Main research topics that should be addressed about terricolous lichens of Italy.

Improving floristic knowledge
As pointed out in the main text, poor data hinder rigorous assessment procedures, and future, more intense field-studies on the terricolous lichens of Italy may lead to the rediscovery of taxa assessed here as extinct or threatened, consequently allowing an update of their status.
Another issue concerns the originality of data. Out of the 1968 records considered in our dataset, only 1354 were original, which means that the remaining 614 (31%) were just repetitions of original records cited, often uncritically, in the subsequent literature. It should be noticed that also for many other terricolous lichens which are not considered as extremely/very rare by Nimis and Martellos (2021), and therefore were not assessed here (see Supplementary File 1), many literature records refer to old collections cited in subsequent literature. Considering the species assessed in the present work, most of the records not confirmed in the last 50 years are from the Northern regions, which have the older historical tradition thanks to the classical floristic explorations of the 19th century, like those by Anzi (1860), Baglietto and Carestia (1880), and Arnold (Dalla Torre and Sarnthein 1902). In contrast, the Southern regions benefitted from more recent explorations (e.g. Nimis and Poelt 1987; Puntillo 1996), which led to a higher rate of new taxa reported in the last 50 years.
The overall situation suggests that new floristic explorations are needed not only in previously overlooked areas or in areas explored a long time ago, but also in areas explored more recently. Such explorations should focus mainly on (1) previously overlooked habitats and (2) critical taxa, i.e. recently-described taxa or problematic taxonomical groups (Nimis 2016b).

Relationships between terricolous lichens and their habitats
One might wonder what is the real use of "lists of threatened lichens", knowing that such lists are often not formalized in national legislation concerning environment protection, and that the policies guiding conservation efforts – and, therefore, the funds allocated to conservation – are mainly driven by a few so-called "charismatic" taxa (Mammola et al. 2020). Conservation based only on "charismatic" taxa has been proved to be ineffective towards overlooked taxa like lichens (Rubio-Salcedo et al. 2013), whereas a strong protection of whole habitats would give greater benefits to lichens, and also to all other taxa involved (Nimis 1992; Scheidegger and Werth 2009; Smith 2014).
The red list of epiphytic lichens (Nascimbene et al. 2013) was able to also consider the association of assessed species with habitats of conservation concern according to the Habitats Directive and the Natura 2000 Network. Unfortunately, knowledge about the relationships between terricolous lichens and Natura 2000 Habitats is still too scanty in Italy, being available only for few habitat types in a narrow geographic extent (Gheza et al. 2020).
One of the main challenges of future research on terricolous lichens is the elucidation of such relationships, also in order to achieve the recognition of these organisms in the policies establishing management and protection of habitats of conservation concern, and to cope with the threats impending on them.

Main threats to terricolous lichens
Habitat loss, fragmentation and degradation are the main threats for terricolous lichens (Scheidegger and Clerc 2002), followed by air pollution and nitrogen deposition (Scheidegger and Clerc 2002; Stevens et al. 2012; Sparrius et al. 2013). The latter fosters vegetation succession and vascular plant encroachment, which are as well threatening factors (Löbel et al. 2006; Rai et al. 2011; Sparrius et al. 2013; Gheza et al. 2020), including negative effects of invasive species

(Cogoni et al. 2011; Sparrius et al. 2013). Furthermore, climate change is an increasing threat (Aptroot et al. 2021; Di Nuzzo et al. 2021), also because in some cases it exacerbates local pressures. All of these factors impact terricolous lichens globally, but further threats act at a more local scale.

In high-altitude habitats, e.g. subalpine and alpine pastures and grasslands, human activities impact terricolous lichens mainly due to trampling and grazing (Rai et al. 2011; Heggenes et al. 2017). Trampling is mostly related to recreational activities (Grabherr 1982; Jägerbrand and Alatalo 2015). Pasturing can affect terricolous lichens by both grazing and trampling by cattle (Ardelean et al. 2015; Heggenes et al. 2017). In inland lowlands, habitat loss and pollution are exacerbated by the higher level of anthropization, Italy being amongst the European countries with the highest land consumption (ISPRA 2021), and this is likely to impact terricolous lichens especially in the Po Plain (Gheza et al. 2016, 2019, 2020). Also in coastal habitats, e.g. Mediterranean garrigues and shrubs, human disturbance related to tourism is a major threat for lichens (Benesperi et al. 2013). Finally, frequent burning is also likely to threaten terricolous lichens (Cogoni et al. 2011; Calabria et al. 2016), which have a long recovery time after the passage of fire.

Future research should consider all of these threats, in order to investigate their effects at a broad and a local scale and develop effective conservation strategies for terricolous lichens impacted by them.

References

Anzi M. 1860. Catalogus lichenum quos in Provincia Sondriensi et circa Novum-Comum collegit et in ordinem systematicum digessit presbyter Martinus Anzi. Como: Tipografia C. Franchi. 126 pp.

Aptroot A, Stapper NJ, Košuthová A, Herk K v. 2021. Lichens as an indicator of climate and global change. In: Letcher TM (ed.). Climate change – observed impacts on Planet Earth (third edition). p 483-497.

Ardelean IV, Keller C, Scheidegger C. 2015. Effects of management on lichen species richness, ecological traits and community structure in the Rodnei Mountains National Park (Romania). PLoS ONE 10(12): e0145808.

Baglietto F, Carestia A. 1880. Anacrisi dei licheni della Valsesia. Atti Soc. Critt. Ital. 2(2/3):143-356.

Benesperi R, Lastrucci L, Nascimbene J. 2013. Human disturbance threats the red-listed macrolichen Seirophora villosa (Ach.) Frödén in coastal Juniperus habitats: evidence from western peninsular Italy. Environ. Manage. 52(4):939-945.

Calabria LM, Petersen K, Hamman ST, Smith RJ. 2016. Prescribed fire decreases lichen and bryophyte biomass and alters functional group composition in Pacific Northwest prairies. Northwest Science 90(4):470-483.

Cogoni A, Brundu G, Zedda L. 2011. Diversity and ecology of terricolous bryophyte and lichen communities in coastal areas of Sardinia (Italy). Nova Hedwigia 92(1/2):159-175.

Dalla Torre KW, Sarnthein L. 1902. Die Flechten (Lichenes) von Tirol, Vorarlberg und Liechtenstein. Innsbruck: Wagner.

Di Nuzzo L, Vallese C, Benesperi R, Giordani P, Chiarucci A, Di Cecco V, Di Martino L, Di Musciano M, Gheza G, Lelli C, Spitale D, Nascimbene J. 2021. Contrasting multitaxon responses to climate change in Mediterranean mountains. Sci. Rep. 11: 4438.

Gheza G, Assini S, Lelli C, Marini L, Mayrhofer H, Nascimbene J. 2020. Biodiversity and conservation of terricolous lichens and bryophytes in continental lowlands of northern Italy: the role of different dry habitat types. Biodiv. Conserv. 29(13): 3533-3550.

Gheza G, Assini S, Valcuvia Passadore M. 2016. Terricolous lichen communities of *Corynephorus canescens* grasslands of Northern Italy. Tuexenia 36: 121-142.

Gheza G, Barcella M, Assini S. 2019. Terricolous lichen communities in *Thero-Airion* grasslands of the Po Plain (Northern Italy): syntaxonomy, ecology and conservation value. Tuexenia 39: 377-400.

Grabherr G. 1982. The impact of trampling by tourists on a high altitudinal grassland in the Tyrolean Alps, Austria. Vegetatio 48:209-217.

Heggenes J, Odland A, Chevalier T, Ahlberg J, Berg A, Larsson H, Bjerketvedt DK. 2017. Herbivore grazing—or trampling? Trampling effects by a large ungulate in cold high-latitude ecosystems. Ecology and Evolution 7:6423-6431.

ISPRA 2021. Consumo di suolo, dinamiche territoriali e servizi ecosistemici – edizione 2021. Roma: Sistema Nazionale per le Aree Protette, Report di Sistema n. 22. Available at: www.consumosuolo.isprambiente.it.

Jägerbrand AK, Alatalo JM. 2015. Effects of human trampling on abundance and diversity of vascular plants, bryophytes and lichens in alpine heath vegetation, Northern Sweden. SpringerPlus 4:95.

Löbel S, Dengler J, Hobohm C. 2006. Species richness of vascular plants, bryophytes and lichens in dry grasslands: the effects of environment, landscape structure and competition. Folia Geobot. 41:377-393

Mammola S, Riccardi N, Prié V, Correia R, Cardoso P, Lopes-Lima M, Sousa R. 2020. Towards a taxonomically unbiased European Union biodiversity strategy for 2030. Proc. R. Soc. B 287:20202166.

Nascimbene J, Nimis PL, Ravera S. 2013. Evaluating the conservation status of epiphytic lichens of Italy: a red list. Plant Biosyst. 147(4):898-904.

Nimis PL. 1992. Lista rossa dei Licheni d'Italia. In: Conti F, Manzi A, Pedrotti F, editors. Libro rosso delle piante d'Italia. Roma: Associazione Italiana per il World Wildlife Fund. p 503-555.

Nimis PL. 2016b. Spunti di ricerca dal nuovo catalogo dei licheni d'Italia. Not. Soc. Lich. Ital. 29:31-32.

Nimis PL, Martellos S. 2021 (continuously updated). ITALIC – The Information System on Italian Lichens. Version 6.0. University of Trieste, Dept. of Biology. http://dryades.units.it/italic

Nimis PL, Poelt J. 1987. The lichens and lichenicolous fungi of Sardinia (Italy). Studia Geobot. 7(suppl. 1):1-269.

Puntillo D. 1996. I licheni di Calabria. Torino: Museo Regionale di Scienze Naturali. p. 296.

Rai H, Khare R, Gupta RK, Upreti DK. 2011. Terricolous lichens as indicator of anthropogenic disturbances in a high altitude grassland in Garhwal (Western Himalaya), India. Botanica Orientalis – Journal of Plant Science 8:16-23.

Rubio-Salcedo M, Martinez I, Carreno F, Escudero A. 2013. Poor effectiveness of the Natura 2000 Network protecting Mediterranean lichen species. J. Nat. Conserv. 21:1-9.

Scheidegger C, Clerc P. 2002. Rote Liste der gefährdeten Arten der Schweiz: baum- und erdbewohnende Flechten. Bern, Birmensdorf, Geneve: BUWAL-Reihe Vollzug Umwelt.

Scheidegger C, Werth S. 2009. Conservation strategies for lichens: insights from population biology. Fungal Biol. Rev. 23(3):55-66.

Smith PL. 2014. Lichen translocation with reference to species conservation and habitat restoration. Symbiosis 62:17-28.

Sparrius LB, Kooijman AM, Sevink J. 2013. Response of inland dune vegetation to increased nitrogen and phosphorus levels. Appl. Veg. Sci. 16:40-50.

Stevens CJ, Smart SM, Henrys PA, Maskell LC, Crowe A, Simkin J, Cheffings CM, Whitfield C, Gowing DJG, Rowe EC, Dore AJ, Emmett BA. 2012. Terricolous lichens as indicators of nitrogen deposition: evidence from national records. Ecol. Indic. 20:196-203.