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# Dynamics and ecological functions of cryptogam soil crusts (CSC) in planitial landscapes of continental-temperate regions

Gabriele Gheza

Supervisor:
Silvia Assini
University of Pavia

Co-supervisor:
Juri Nascimbene
University of Bologna

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# Table of contents

# Summary

Dry grasslands and heathlands are important habitats for biodiversity conservation, hosting several rare species and species-rich communities. Furthermore, they host terricolous cryptogams, mostly lichens and bryophytes that greatly contribute to ecosystem functioning in arid environments. In Europe, dry grasslands on both siliceous and calcareous substrates and *Calluna* heathlands are listed among habitats of conservation concern according to the Habitat Directive, being threatened by multiple impacts.

Large-scale impacts include habitat loss and fragmentation, atmospheric nitrogen deposition and climate change, whereas small-scale impacts are mainly related to invasive plant species, overgrazing and heavy mechanical disturbance. The impact of these factors can vary according with soil pH. However, these interactive effects could differ among the different taxa which compose the vegetation of these habitats.

The simultaneous assessment of the response of multiple taxa to disturbance could therefore provide more robust information on biodiversity patterns and support more effective conservation compared to focusing on a single taxon. Despite the fact that in dry grasslands and heathlands, beside vascular plants, both lichens and bryophytes may significantly contribute to ecosystem diversity and functioning, these organisms are still largely overlooked in biodiversity surveys and conservation policies.

This thesis aims at exploring:

(1) the terricolous lichen diversity hosted in dry habitats in a human-impacted lowland (the Po Plain, N Italy);

(2) the compositional patterns of lichens and bryophytes across dry grasslands and heathlands, also accounting for the dynamic stage of the vegetation (i.e. pioneer vs mature);

(3) the effects of small-scale disturbances on the three main taxa found in cryptogam-rich dry grasslands (i.e. vascular plants, lichens, bryophytes) on both acidic and calcareous soils;

(4) the potential of cryptogam soil crusts in delivering the ecosystem service of storing seeds of vascular plants, in the perspective of its exploitation in habitat restoration.

(1) Extensive floristic surveys in all the considered dry grassland and heathland patches of the central-western Po Plain were carried out to investigate the overall terricolous lichen biota of the study area.

(2, 3) Diversity and dynamics were studied by means of vegetation surveys in circular plots (radius = 3 m). The plots were located at regular spans along transects placed along the longest diagonal of the polygon drawn around each habitat patch. The number of plots per patch was area-dependent according to this scale: 100-1000 $m^2$ = 1; 1001-3000 $m^2$ = 2; 3001-5000 $m^2$ = 3; 5001-20000 $m^2$ = 5; > 20000 $m^2$ = 7. Overall, the surveyed plots were 185 in 60 grasslands and 114 in 22 heathlands. The percent cover of each plant, bryophyte and lichen species was recorded, as well as environmental (soil pH and texture, vegetation structure, altitude, bare soil percent) and disturbance-related variables (human trampling, cattle and lagomorphs fecal pellets, disturbance by wild boars). Climate variables (mean annual temperature and precipitation) were retrieved from ARPA websites.

(2) The composition in lichens and bryophytes was compared among the 3 habitat types (3 groups) and between their dynamic stages (pioneer vs mature, 6 groups) to understand whether it is habitat- and stage-specific. These data were analyzed by Non-Metric Multidimensional Scaling, PERMANOVA and Indicator Species Analysis. Environmental variables and species richness were compared by means of the Kruskal-Wallis test.

(3) Drivers of cover and species richness of the 3 taxa were analyzed only for dry grasslands by means of generalized linear models with a backward deletion procedure to eliminate non-significant variables.

(4) The seed storing function of fruticose lichen mats was studied taking 5 samples of lichen crusts (30 x 30 $cm^2$) in 4 acidic grassland patches (= 20 samples) in winter, with each sample taken at the centre of one plot surveyed in the previous spring. The samples were dryed, crumbled on sterile gardening soil and covered with a tissue to avoid external contamination in a controlled situation. The seedlings which germinated were reared until the identification at species level was possible. All the germinated individuals were counted.

Data were analyzed in comparison to data from the donor plots where lichen samples were taken by means of Kruskal-Wallis test and linear regression, considering all the species and then native and non-native species separately .

(1) Overall, 33 terricolous lichen species were recorded, of which: 2 new to Italy

(*Cladonia conista*, *C. pulvinata*), 2 new to Piemonte (*Cladonia peziziformis*, *C. polycarpoides*), 3 new to Lombardia (*Cladonia peziziformis*, *Cladonia subrangiformis*, *Scytinium schraderi*), 7 of conservation and biogeographical interest (*Cladonia coccifera*, *Cladonia portentosa*, *Cladonia strepsilis*, *Cladonia uncialis*, *Cladonia verticillata*, *Dibaeis baeomyces*, *Pycnothelia papillaria*). The knowledge of genus *Cladonia* in the Po Plain has been greatly improved.

(2) In spite of the widespread presence of few common species and the generally low species richness, composition differs significantly between the 3 habitat types and between pioneer vs mature heathlands, less markedly between dynamic stages within each grassland type. Three well-characterized assemblages which include many species of conservation concern were found for both lichens and bryophytes; the most peculiar one is that of calcareous grasslands. Cryptogam assemblages are influences also by rainfall, soil features and vegetation structure.

(3) Increase of soil pH and disturbance by lagomorph fecal pellets have a negative effect on lichens, as well as their interaction (the negative effect of pellets is more evident at the increase of soil pH). Soil pH, fecal pellets and precipitation have instead a positive effect on bryophytes. Human trampling and fecal pellets have a negative effect on vascular plants, whereas increase of soil pH has a positive effect; the interaction of soil pH and pellets has an effect opposite than on lichens (the negative effect of pellets is more evident at the decrease of soil pH).

(4) Terricolous lichen mats are able to store and release vascular plant seeds which are viable and can germinate when placed in proper conditions. The number of species and individuals of vascular plants germinated from lichen mats is comparable to what recorded in nature in the donor plots. Native species richness was higher, whereas native species germinated with less individuals than non-native species.

These results are useful in addressing conservation towards the management and protection of all the lowland dry habitats, due to the differentiation among the cryptogam assemblages they host and to the presence of several interesting species; also, all the dynamics stages within each habitat should be preserved. Furthermore, it is advised that conservation management should consider also cryptogams, which often have needs and responses to disturbance factors which are different from those of vascular plants. Finally, the use terricolous lichen mats for habitat restoration as vectors not only for lichens but also for vascular plants is suggested, although the occurrence of non-native species needs to be carefully taken in account and further investigated.

# Introduction

## Cryptogam Soil Crusts (CSC)

Cryptogam Soil Crusts (CSC), also known as Biological Soil Crusts (BSC), are communities of organisms which grow on the soil surface in dry and semidry ecosystems of the Earth (Belnap & Lange 2003; Maestre *et al.* 2011; Weber *et al.* 2016). CSCs include bacteria, algae, fungi, lichens and bryophytes that greatly contribute to ecosystem functioning (Weber *et al.* 2016).

Although CSCs are currently recognized as a fundamental component of dry ecosystems, their scientific recognition and functional analysis are a relatively young field of research. Terricolous lichen- and bryophyte-dominated communities represent an important macroscopic component of biological soil crusts in many dry ecosystems, strongly influencing their structure and function (Belnap & Lange 2003; Weber *et al.* 2016). This thesis focuses on lichen- and bryophyte-dominated CSCs.

## Terricolous cryptogams in human-impacted lowlands

Terricolous cryptogams are often the most impacted component of biodiversity in lowlands: in fact, they are exposed to a strong competition with vascular plants, and generally they are not able to overcome them due to their smaller size, slower growth rate and lesser competitiveness (Scheidegger & Clerc 2002); therefore, they are very often more vulnerable and less represented than epiphytic and saxicolous cryptogams in human-impacted landscapes. Furthermore, sensitive or rare species – especially lichens – are unable to recover after their disappearance due to disturbance, even when the causes of disappearance are ceased (Sparrius 2011; Leppik *et al.* 2013). On the other hand, their physiological characteristics, which make them more stress-tolerant than vascular plants, and their independence from the substrate for their sustenance, allow them to colonize habitats which are prohibitive for vascular plants, making them important pioneer organisms. These habitats are characterized by oligotrophic soils, severe edaphic conditions and/or extreme climates (Scheidegger & Clerc 2002). The terricolous cryptogam diversity still found in these habitats could be used to infer information about the whole diversity they host, their stability and the anthropogenic influence acting on them (Scheidegger & Clerc 2002; Rosentreter & Eldridge 2002; Bültmann 2005).

The Po Plain is an emblematic example of heavily human-impacted lowland area, being severely anthropized and also one of the most polluted areas of Europe (European

Environment Agency 2004). It is not a favourable area for lichens and bryophytes: especially the lichen biota of the Po Plain is extremely poor, mainly due to air pollution and almost total deforestation (Nimis 1993; Nimis & Martellos 2004). Habitats with the aforementioned features are increasingly rarer in this area, due to anthropization and agricultural exploitation, which lead to loss of natural habitats, pollution and eutrophication (Assini 2008). Since terricolous lichen biota of the Po Plain has been poorly studied before (Gheza 2015; Gheza *et al*. 2015, 2016), the first aim of this thesis was to improve the floristic knowledge in this area (**Chapters 1-2**; **Appendix I**).

## Cryptogam-rich habitats in temperate lowlands

Cryptogam-rich dry habitats still occur in several parts of Central Europe, and have a high conservation value, hosting species-rich assemblages and contributing to ecosystem functioning (Jentsch & Beyschlag 2003; Janišova *et al*. 2011). For example, this is the case of acidic inland sand dunes in Germany and the Netherlands (Jentsch & Beyschlag 2003; Sparrius 2011), or that of alvars in Baltic countries (Leppik *et al*. 2013).

In Italy, terricolous cryptogam-rich habitats are still found mainly in alpine and coastal areas, while in the Po Plain they are scattered and fragmented (Gheza 2015). These habitats are worthy of conservation according to the Natura 2000 policies (Directive 1992/43/EEC). In particular, acidophilous dry grasslands are attributed to the Natura 2000 habitats 2330 (*Corynephorion* grasslands on inland sand dunes and fluvial sediments) and 6210 (*Thero-Airion* grasslands on fluvial sediments), acidophilous *Calluna vulgaris* heathlands to the habitat 4030, while calciphilous dry grasslands to 6110* and 6210*. The conservation status of all these habitats has been assessed as unfavourable in continental Italy (Genovesi *et al*. 2014), with a decreasing trend (Genovesi *et al*. 2014).

Another goal of this thesis was therefore to explore the role of lowland dry habitats located in an unfavourable situation for the conservation of cryptogam diversity (**Chapter 3**).

## Threats for cryptogam-rich dry habitats

Cryptogam-rich dry grasslands and heathlands are threatened by several factors (Jentsch & Beyschlag 2003; Janišova *et al*. 2011) which can also act as major drivers of biodiversity.

Habitat loss and fragmentation is currently the main threat impending on dry habitats in continental Europe at a broad scale (Jentsch & Beyschlag 2003; Janišova *et al*. 2011), together with atmospheric nitrogen deposition (Sparrius 2011) and climate change effects (Jones 1997). Small-scale threats are mainly related to invasive plant species (Assini 2008), overgrazing (Kohyani *et al.* 2008) and mechanical disturbance (i.e. trampling). Furthermore, it has been shown that the effect of some factors can vary according to the variation of environmental conditions, e.g. soil pH (Kohyani *et al.* 2008).

In this context, my research was focused on the role played by small-scale disturbance factors occurring in dry habitats in the Po Plain – human trampling and eutrophication due to fecal pellets deposition by the alien invasive lagomorph *Sylvilagus floridanus* – and their interactions with the main environmental factors, i.e. soil pH, rainfall and temperature (**Chapter 4**). In particular, disturbance by *S. floridanus* was expected to impact dry grasslands (Assini, 2008). Also human disturbance was expected to impact mainly dry grasslands, since heathlands in the Po Plain are often located in military or ill-famed areas. Therefore, the analysis of these drivers focused only on dry grasslands (**Chapter 4**).

### Ecosystem services provided by CSCs

The main ecosystem functions and services provided by CSCs include Carbon and Nitrogen fixation, control of water fluxes, soil erosion prevention and formation of organic soil (Maestre *et al.* 2011; Pietrasiak *et al.* 2013; Zedda & Rambold 2015; Weber *et al.* 2016). They also act as important biodiversity reservoirs, not only for the intrinsic cryptogam diversity they host (often including rare species), but also because they provide microhabitats for invertebrates and, in some cases, they can foster the development of vascular plants (Maestre *et al.* 2011; Zedda & Rambold 2015; Weber *et al.* 2016; Zhang *et al.* 2016).

Although most of these functions have already been studied (Maestre *et al.* 2011; Pietrasiak *et al.* 2013; Weber *et al.* 2016), a surprisingly neglected issue is the potential role of CSC in trapping plant seeds. In particular, the viability of seeds trapped in CSCs dominated by fruticose lichens and mosses has been poorly studied (Zhang *et al.* 2016).

Following a recent field experiment (Gheza & Assini 2018), I analyzed the role that fruticose lichen-dominated CSCs play in trapping and storing seeds of vascular plants and whether these seeds are able to germinate. This information could be useful in a perspective of habitat restoration (**Chapter 5**).

## A focus on *Cladonia*

Terricolous lichen communities, especially on acidic substrates, are often dominated by taxa belonging to *Cladonia* (Bültmann 2005; Rola *et al.* 2014). This genus has a worldwide distribution and includes about 500 taxa (Burgaz & Ahti 2009; Nimis 2016). Species delimitation is often difficult, due to the very high morphological and chemical variability (Burgaz & Ahti 2009).

*Cladonia* species have been quite well-studied in Central Europe, but in the Mediterranean countries they are rather overlooked (Burgaz *et al.* 2017). Also in Italy, only very few studies focused on this genus (Coassini Lokar *et al.* 1986; Rivellini & Valcuvia Passadore 1996; Ravera *et al.* 2016).

Most of the species recorded during my research belong to *Cladonia*. Therefore, I had the opportunity to deepen the knowledge of floristics (**Chapter 1**; **Appendix I**) and ecology (**Chapter 2**) of these lichens. The analysis of a great number of specimens was necessary to accomplish the identification of all the material collected in the field, and these efforts took me to examine a huge amount of literature and specimens from the Herbaria of Pavia (PAV), Graz (GZU) and my personal herbarium. This allowed me to produce an updated key to all the species hiterto known in Italy (**Appendix II**) and to cooperate to the writing of an illustrated monograph of the Italian *Cladonia* species (**Appendix III**) and to the compilation of the ISPRA monitoring protocol for *Cladonia* subgenus *Cladina* – which is the only lichen taxon protected by the Habitats Directive – in Italy (Ravera & Gheza 2016).

## Aim of this thesis

The aim of this thesis is to improve the knowledge of CSCs diversity (**Chapters 1-3**, **Appendix I**), dynamics (**Chapters 3-4**) and ecological role (**Chapter 5**) in dry and semidry habitats in the lowlands of continental-temperate regions of Southern Europe.

In particular, this thesis aims at exploring:

(1) the terricolous lichen diversity hosted in dry habitats in a human-impacted lowland (the central-western Po Plain, N Italy), through extensive floristic surveys useful to investigate the overall terricolous lichen biota of the study area (**Chapters 1-3**, **Appendix I**);

(2) the compositional patterns of lichens and bryophytes across dry grasslands and heathlands, also accounting for the dynamic stage of the vegetation (i.e. pioneer vs mature), by means of vegetation surveys in standardized plots (**Chapter 3**);

(3) the effects of small-scale disturbances on the three main taxa found in cryptogam-rich dry grasslands (i.e. vascular plants, lichens, bryophytes) on both acidic and calcareous soils, by means of vegetation surveys in standardized plots integrated with the collection and analysis of data about disturbance (**Chapter 4**);

(4) the potential of cryptogam soil crusts in delivering the ecosystem service of storing seeds of vascular plants, in the perspective of its exploitation in habitat restoration (**Chapter 5**).

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# Chapter 1

# Addenda to the lichen flora of the Ticino river valley (western Po Plain)

Gabriele Gheza

## Abstract

The Ticino river valley is a focal area for biodiversity in the western Po Plain (Northern Italy). Lichens have been collected by the author from 91 sites in the period 2011-2017. These collections and the few literature data published in the last decade have been summarized. Twenty-eight species (15 terricolous, 5 epiphytic, 3 lignicolous, 3 saxicolous, 1 epiphytic and lignicolous, 1 terricolous and epiphytic), mostly belonging to genus *Cladonia*, are reported here as addenda to the floristic list published 15 years ago by the Lombardy Ticino Park, which included 123 species. Many of the newly recorded species are interesting under a conservation or biogeographical standpoint.

## Keywords

*Calluna* heathlands, *Cladonia*, dry grasslands, floristics, lichen diversity, macrolichens, planitial woods.

Natural History Sciences 5 (2): 33-40.

## Introduction

The Ticino river is one of the most important rivers of Northern Italy, its valley being one of the most well-preserved and biodiverse areas of the Po Plain (Furlanetto, 2002), the most anthropized and polluted area of Italy (World Health Organization, 2016).

The study of the lichen flora of the Ticino river valley began with Biroli (1808), who studied the western side in the surroundings of Novara. The first contribution for the eastern side is due to Cozzi (1917), who studied lichens in a rather wide area between Gallarate and Lonate Pozzolo, which at that time was covered with *Calluna* heathlands and mixed broadleaved woods. After that, only few terricolous lichens found in the "Gallarate heathland" were cited by Giacomini (1958) in a phytosociological paper.

Studies focused on epiphytic lichens took place in the late 1990s for biomonitoring projects. From the first study, carried out in 1994 (Casarini *et al.*, 1995), derived a first checklist of epiphytic lichens of the Lombardy Ticino Natural Park (Roella, 1999). A second study took place in 1999 (Furlanetto *et al.*, 2000). Furthermore, some epiphytic and saxicolous lichens were recorded in the city of Pavia, which is located within both the river valley and the Park, respectively by Casarini *et al.*, (1994) and Rigamonti *et al.* (2007).

With the checklists by Valcuvia Passadore *et al.* (2002 a, b), which included lichens from all substrates, the knowledge rose to a higher level. However, this fundamental work did not take into account some older literature (i.e. Cozzi, 1917; Giacomini, 1958) and the sampling effort for the new surveys was rather scarce if compared to the extent of the Park and of the river valley.

The most recent studies focused on terricolous lichens, which have been rather well surveyed under the floristic standpoint (Gheza, 2015; Ravera *et al.*, 2016, 2017 a, b; Gheza *et al.*, 2018) and, partly, under a phytosociological perspective (Gheza *et al.*, 2016). Terricolous lichens were rather neglected in the Po Plain (Gheza, 2015), but these studies showed that several areas with habitats of conservation value host lichen species of conservation and biogeographical interest, and even two species never found before in Italy (Gheza *et al.*, 2018).

The aim of this paper is to update the lichen flora of the Ticino river valley reporting all the species found for the first time or rediscovered in the area after the study by Valcuvia Passadore *et al.* (2002 a, b), summarizing literature records and unpublished personal collections of the author carried out in the period 2011-2017. Particularly, the records of the 28 species which are new to the area are given in detail.

# Material and methods

## *Study area*

The Ticino river valley lies at the boundary between Lombardy and Piedmont, between the southern end of the Lake Maggiore (Sesto Calende, 198 m) and the confluence of the Ticino with the Po river (Ponte della Becca near Pavia, 53 m), for a length of about 110 km.

The whole rivercourse south of Lake Maggiore is included within two very important protected areas. The Lombardy Park (Parco Naturale Lombardo della Valle del Ticino) includes the eastern part, from Lake Maggiore to Cassolnovo and both sides downrun there to the confluence with the Po river, south of Pavia. The Lombardy Park includes 8 Sites of Community Importance (IT2010010 Brughiera del Vigano; IT2010012 Brughiera del Dosso; IT2030013 Ansa di Castelnovate; IT2010014 Turbigaccio, Boschi di Castelletto e Lanca di Bernate; IT2050005 Boschi della Fagiana; IT2080014 Boschi Siro Negri e Moriano; IT2080015 San Massimo; IT2080016 Boschi del Vignolo) and extends through 3 Provinces (Varese, Milano, Pavia). The Piedmont Park (Parco Naturale della Valle del Ticino Piemontese) includes all the western part from Lake Maggiore to the boundary with Lombardy beetween Cerano (Novara) and Cassolnovo (Pavia). The whole Park is a Site of Community Importance (IT1150001 Valle del Ticino) included in the province of Novara.

The bioclimate of the Ticino river valley is temperate-continental in the central-southern part and temperate-oceanic in the northern part (Rivas-Martìnez *et al.*, 2004).

Geological substrates are composed of mainly acidic sediments of the Holocene (pebbles, gravels and sands) dated to the recent Alluvium, while the surrounding substrates are referable to the "fundamental level of the plain" of the Pleistocene (D'Alessio & Comolli, 1996).

The natural and seminatural areas are mostly covered by woodlands, which include xero- or mesophilous woods dominated by *Quercus robur* L. (Natura 2000 Habitats 9160, 9190) and more hygrophilous mixed woods with *Alnus glutinosa* (L.) Gaertn., *Fraxinus excelsior* L., *Ulmus minor* Mill. and *Salix alba* L. (Habitats 91E0, 91F0). Residuals of *Castanea sativa* Mill. groves (Habitat 9260) are found in the northwestern part. In several localities, allochthonous pine groves are found as residuals of artificial plantations. Fragments of *Calluna vulgaris* (L.) Hull heathlands (Habitat 4030) are still found in the northern part of the river valley. Among herbaceous vegetation, the most valuable habitats are hygrophilous tall herb fringes (Habitat 6430), lowland hay meadows (Habitat 6510) and pioneer dry grasslands attributable to the *Corynephorion* Klika 1931 (Habitat 2330) and the *Thero-Airion* Tüxen ex Oberdorfer 1957 (Habitat 6210). Humid habitats are widespread, including oligotrophic (Habitat 3130) and eutrophic (Habitat 3150) backwater plant communities, running water communities of the *Ranunculion fluitantis* Neuhäusl 1959 (Habitat 3260) and vegetation of muddy river banks (Habitat 3270). Agricultural areas include fields cultivated with corn, wheat (in the northern part) and rice (in the central-southern part) and poplar plantations. Widespread in many habitats are some invasive woody species, i.e. *Ailanthus altissima* (Mill.) Swingle, *Prunus serotina* Ehrh. and *Robinia pseudoacacia* L., which often form monospecific groves in areas with high human impact.

### ***Sampling sites***

Overall, 91 sites (65 in the Lombardy Park and 26 in the Piedmont Park) have been considered for single or repeated lichen surveys by the author in the period 2011-2017, not only in the proper river valley but also on the fluvial terraces at its edges. Only the 27 sampling sites in which the new species were collected by the author (21 in the Lombardy Park and 6 in the Piedmont Park) are listed below, from north to south, with the name of the collection locality, the municipality, the province and region, the coordinates (in the UTM WGS84 system), the altitude above the sea level and the habitat type in which the specimens were collected.

All the available residuals of those habitats hosting terricolous lichens – dry grasslands and *Calluna* heathlands – have been surveyed thoroughly, increasing the number of sites in respect to those surveyed by Gheza (2015). Also several sites in well-preserved woods, more or less homogeneously distributed along the river valley, have been surveyed, and some agricultural areas have been considered too, in order to collect also epiphytic species from various trees. Several records have however an occasional character, because a systematic and exhaustive survey of the entire area has not yet been realized at present.

1. Brughiera del Vigano, Golasecca (Varese, Lombardy), 32T 473550.5060659, 270-275 m, mixed wood dominated by allochtonous *Pinus sp*. and *Quercus robur*.

2. Surroundings of Cascina Casone, Pombia (Novara, Piedmont), 32T 475605.5054239, 170-175 m, dry grasslands (*Thero-Airion* and *Corynephorion*).

3. Baraggia di Pombia, Pombia (Novara, Piedmont), 32T 473786.5055073, 180-183 m,

mature dry *Calluna* heathland.

4. Ansa di Castelnovate, Vizzola Ticino (Varese, Lombardy), 32T 473965.5052551, 160-165 m, dry grasslands (*Thero-Airion* and *Corynephorion*).

5. Barbelera, Oleggio (Novara, Piedmont), 32T 474883.5051775, 161-163 m, dry grasslands (*Thero-Airion* and *Corynephorion*).

6. Marcetto, Oleggio (Novara, Piedmont), 32T 475076.5051299, 160-162 m, dry grasslands (*Thero-Airion* and *Corynephorion*).

7. Bosco di Tornavento (northern sector), Lonate Pozzolo (Varese, Lombardy), 32T 478431.5050149, 218-222 m, mixed broadleaf wood dominated by *Quercus robur*.

8. Brughiera di Tornavento, Lonate Pozzolo (Varese, Lombardy), 32T 478268.5049320, 200-202 m, open dry *Calluna* heathland.

9. Bosco di Tornavento (southern sector), Lonate Pozzolo (Varese, Lombardy), 32T 478617.5048757, 198-200 m, mixed wood with *Quercus robur*, *Pinus sp*. and *Robinia pseudoacacia*.

10. Abandoned airfield "La Promessa" (northern sector), Lonate Pozzolo (Varese, Lombardy), 32T 479079.5046631, 189 m, patch of open dry *Calluna* heathland.

11. Abandoned airfield "La Promessa" (western sector), Lonate Pozzolo (Varese, Lombardy), 32T 478613.5046423, 187-188 m, small patch of open dry *Calluna* heathland.

12. Abandoned airfield "La Promessa", Lonate Pozzolo (Varese, Lombardy), 32T 479289.5046158, 185-187 m, dry grasslands (*Thero-Airion*).

13. Turbigaccio, Lonate Pozzolo (Varese, Lombardy), 32T 476213.5047261, 145 m, dry grasslands (*Thero-Airion* and *Corynephorion*).

14. Tenuta Bornago, Cameri (Novara, Piedmont), 32T 476709.5044341, 140-145 m, dry grasslands (*Thero-Airion* and *Corynephorion*).

15. Surroundings of Cascina Rossa, Bernate Ticino (Milano, Lombardy), 32T 484074.5035048, 117 m, dry grassland (*Thero-Airion*).

16. Tenuta La Fagiana, Pontevecchio di Magenta (Milano, Lombardy), 32T 486444.5030677, 105-110 m, open *Quercus robur* wood.

17. Tenuta La Fagiana, Pontevecchio di Magenta (Milano, Lombardy), 32T 486316.5030625, 107-109 m, dry grasslands (*Thero-Airion*).

18. Surroundings of Villa Giulia, Cerano (Novara, Piedmont), 32T 487041.5027334, 99-103 m, dry grasslands (*Thero-Airion*).

19. Bosco del Modrone, Sforzesca, Vigevano (Pavia, Lombardy), 32T 494909.5015667, 76 m, dry grassland (*Thero-Airion*) with oak trees, logs and stumps.

20. Bosco della Ghisolfa, Sforzesca, Vigevano (Pavia, Lombardy), 32T 494163.5014115, 87-89 m, mixed broadleaf wood dominated by *Quercus robur*.

21. Bosco Ronchi, Sforzesca, Vigevano (Pavia, Lombardy), 32T 495844.5013587, 72-76 m, dry grasslands (*Thero-Airion*).

22. Bosco Ronchi, Sforzesca, Vigevano (Pavia, Lombardy), 32T 496308.5013294, 72-76 m, mixed broadleaf wood dominated by *Quercus robur*.

23. Butterfly Trail of Molino d'Isella, Gambolò (Pavia, Lombardy), 32T 496122.5012667, 73 m, ruderal dry grassland.

24. Torre d'Isola (Pavia, Lombardy), 32T 508504.5005975, 84 m, poplar plantation.

25. Centro Ippico di Pavia (Pavia, Lombardy), 32T 510212.5003452, 71 m, poplar and walnut plantation.

26. San Martino Siccomario (Pavia, Lombardy), 32T 513524.5001696, 70 m, poplar plantation.

27. San Martino Siccomario (Pavia, Lombardy), 32T 511365.5000769, 77 m, tree-lined avenue in the inhabited center.

### *Lichen sampling and other data sources*

Specimens were collected in the field during 243 field inspections which included all the 91 sites at least once for each site. Furthermore, all the literature records published after Valcuvia Passadore *et al*. (2002 b) have been considered. Not all the species in the floristic list reported below are actually new for the study area: some of them were reported in older papers (Biroli 1808; Nocca & Balbis 1823; Cozzi 1917; Giacomini 1958) but were overlooked since the early 20th century, and, together with other two recorded in the previous floristic list by Roella (1999) (*Cladonia caespiticia*, *Normandina pulchella*), were not reported by Valcuvia Passadore *et al*. (2002 b).

Overall, 102 records (45 unpublished and 57 from literature) are reported in the floristic list below. For each species, every single record includes: the number referred to the sampling site, the substrate on which the specimen was collected, and the sources of the record. Each species is shortly discussed in regard to historical records and current distribution.

Abbreviations used for herbaria and literature in the floristic list and in Appendix 2: B08: Biroli (1808); C17: Cozzi (1917); GG: herbarium Gheza; GG15: Gheza (2015); GA18: Gheza *et al.* (2018); G58: Giacomini (1958); RA16: Ravera *et al.* (2016); RA17a: Ravera *et al.* (2017 a); RA17b: Ravera *et al.* (2017 b); RI07: Rigamonti *et al.* (2007).

## Results and Discussion

Overall, about 500 specimens belonging to 64 lichen species (Appendix 1) were collected directly by the author. Most of them belong to common and widespread species, and are not listed here. Only an account of the 28 species not reported for the study area in the floristic list by Valcuvia Passadore *et al.* (2002b) is given in detail.

Among these 28 species, 15 (54%) are terricolous, 5 (18%) epiphytic, 3 (10,5%) lignicolous, 3 (10,5%) saxicolous, 1 (3,5%) epiphytic and lignicolous, 1 (3,5%) terricolous and epiphytic. Among the epiphytic species, 3 were collected on *Quercus robur*, 2 on *Pinus sp.*, 1 on *Populus sp.*, 1 on *Robinia pseudoacacia*, 1 on *Tilia sp.*

***Athallia pyracea*** **(Ach.) Arup, Frödén & Søchting**

24: on bark of *Populus sp.* (GG). 25: on bark of *Populus sp.* (GG). 26: on bark of *Populus sp.* (GG). 27: on bark of *Tilia sp.* (GG).

The species occurs mainly on bark of *Populus sp.* in agricultural areas and of *Tilia sp.* in urbanized areas. It tolerates well eutrophication, and is rather frequent in mature poplar stands, in both the river valley and the main level of the plain in the surroundings (e.g. in the whole province of Pavia, pers. obs.).

***Cladonia caespiticia*** **(Pers.) Flörke**

1: on organic soil at the base of *Pinus sp.* (GG). 5: on soil (GG). 7: on bark of *Q. robur* (GG). 8: on soil at the base of *Calluna* shrubs (GG). 12: on soil (GG).

The species can be terricolous on acidic organic soil and epiphytic on acidic bark, especially at the base of trunks, in dry grasslands, *Calluna* heathlands and mixed woods. It was not reported by Valcuvia Passadore *et al.* (2002b), even if it was listed in the checklist of the epiphytic lichens by Roella (1999). Uncommon, but probably also overlooked, especially in the northern part of the study area.

***Cladonia cariosa*** **(Ach.) Spreng.**

8: on acidic sandy-gravelly soil (GG; RA16). 12: on acidic soil (GG). 15: on acidic sandy-pebbly soil (GG; RA16).

Terricolous on sandy-gravelly and sandy-pebbly soil in pioneer or disturbed situations, in dry grasslands or at the edge of *Calluna* heathlands. Very rare, maybe also overlooked, it was probably more widespread in the past (cf. the record by Nocca & Balbis (1823) for the countryside near Pavia).

***Cladonia cervicornis*** **(Ach.) Flot.**

4: on soil (GG; GG15). 5: on soil (GG; GG15). 11: on soil (GG). 14: on soil (GG; GG15).

Terricolous on sandy-pebbly soil, in dry grasslands and *Calluna* heathlands. Very rare.

***Cladonia chlorophaea*** **(Sommerf.) Spreng.**

4: on acidic sandy-pebbly soil (GG; GG15). 23: on acidic sandy-pebbly soil (GG; GG15).

Terricolous on sandy-pebbly soil in pioneer or disturbed situations, in dry grasslands and at the edge of trails. An overlooked species, probably more widespread. Without chemical analysis it can be easily confused with the morphologically similar *Cladonia conista* (which contains fumarprotocetraric and bourgeanic acid).

***Cladonia coccifera*** **(L.) Willd.**

2: on acidic sandy-pebbly soil (GG). 3: on soil (GG; GG15). 4: on soil (GG; GG15). 5: on soil (GG; GG15). 6: on soil (GG; GG15). 8: on soil (GG; GG15). 10: on soil (GG; GG15). 11: on soil (GG; GG15). 12: on soil (GG; GG15). 14: on soil (GG; GG15). 17: on soil (GG; GG15). 18: on acidic sandy-pebbly soil (GG). 19: on acidic sandy-pebbly soil (GG).

Terricolous on sandy-pebbly and slightly humified soil. Rather widespread in dry habitats, mainly in the central and northern parts of the river valley.

***Cladonia conista*** **(Nyl.) Robbins**

8: on sandy-pebbly soil (GG; GA18). 12: on sandy-pebbly soil (GG; GA18). 15: on sandy-pebbly soil (GG; GA18). 19: on sandy-pebbly soil (GG; GA18).

Terricolous on sandy-pebbly soil in pioneer or disturbed situations, in dry grasslands and open *Calluna* heathlands. An overlooked species, maybe more widespread, reported as new to Italy from 4 sites in the Ticino river valley by Gheza *et al.* (2018). Without chemical analysis it can be easily confused with the morphologically similar *Cladonia chlorophaea* (which contains only fumarprotocetraric acid).

***Cladonia digitata* (L.) Hoffm.**

16: on several logs of *Quercus robur* (GG).

An epiphytic and lignicolous species found in only one site in the river valley. *C. digitata* is tipically found in higher altitudinal belts in Italy (Nimis, 2016) and is extremely rare in the Po Plain, where the only other record comes from an oak wood on the inland sand dunes of Cergnago, in the Eastern Lomellina (Gheza *et al.*, 2015). It was found together with other lignicolous species: *Cladonia coniocraea* (Flörke) Spreng., *Cladonia fimbriata* (L.) Fr. and, in one case only, *C. floerkeana* (see below). Extremely rare.

***Cladonia floerkeana* (Fr.) Flörke**

16: on a single log of *Quercus robur* (GG).

As the previous species, *C. floerkeana* is an epiphytic and lignicolous species found in only one site in the river valley, on a single decorticated oak log in an open oak wood. Ecology and distribution in Italy are similar to those of *C. digitata* (Nimis, 2016), which was found on the same log as well. Extremely rare.

***Cladonia macilenta* Hoffm.**

16: on several logs and stumps of *Q. robur* (GG). 19: on several logs and stumps of *Q. robur* (GG).

A mainly lignicolous species tipically found in higher altitudinal belts in Italy, as well as the two previous species. Extremely rare, but probably also overlooked, especially when sterile.

***Cladonia parasitica* (Hoffm.) Hoffm.**

3: on organic soil on a stump (GG15). 16: on dead wood of *Q. robur* (GG). 22: on dead wood of *Q. robur* (GG). 23: on bark of *Q. robur* (GG15).

A mainly lignicolous species, found in deciduous oak woods on logs and snags. Extremely rare, but maybe also overlooked.

***Cladonia peziziformis* (With.) J.R.Laundon**

8: on acidic sandy-pebbly soil (GG). 12: on acidic sandy-pebbly and slightly humified soil (GG; RA16).

Terricolous on sandy-pebbly or little humified soil in pioneer or disturbed situations, this species is easily outcompeted by mosses and vascular plants (Tønsberg & Øvstedal, 1995) and therefore needs availability of open soil to persist. It was firstly reported by Gheza in Ravera *et al*. (2016) for one locality and then found, a little more widespread, in another locality. Extremely rare.

***Cladonia polycarpoides* Nyl.**

2: on sandy-pebbly soil (GG; RA17a). 3: on sandy-pebbly soil (GG; RA17a). 4: on sandy-pebbly soil (GG; RA17a). 5: on sandy-pebbly soil (GG; RA17a). 6: on sandy-pebbly soil (GG; RA17a). 14: on sandy-pebbly soil (GG; RA17a). 15: on sandy-pebbly soil (GG). 17: on sandy-pebbly soil (GG; RA17a). 18: on sandy-pebbly soil (GG; RA17a). 19: on sandy-pebbly soil (GG; RA17a). 21: on sandy-pebbly soil (GG; RA17a).

Terricolous, generally found on sandy-pebbly soil in dry grasslands or even at the edge of *Calluna* heathlands. A thorough review of herbarium and newly collected specimens showed that the records of *Cladonia subcervicornis* (Vain.) Kernst. by Valcuvia Passadore *et al*. (2002 a, b) and those of *Cladonia symphycarpa* (Flörke) Fr. by Gheza (2015) must be referred instead to this species. Rather common in dry grasslands.

***Cladonia portentosa* (Dufour) Coem.**

5: on humified soil (GG). 6: on sandy-pebbly and humified soil (GG; GG15). 11: on sandy-pebbly and humified soil (GG). 14: on sandy-pebbly and humified soil (GG; GG15). 18: on sandy-pebbly and humified soil (GG; RA16). 19: on sandy-pebbly and humified soil (GG).

Terricolous, mostly found on evolved soils in thick lichen mats. The species was not reported for site 5 by Gheza (2015), but a deeper study of the area allowed to find several thalli in an undisturbed clearing in the wood near the dry grassland surveyed for that paper, together with two thalli of *C. uncialis* (see below). Sites 5 and 19 are the fourth and fifth occurrence sites of the species on the western side of the river valley (see Gheza & Assini in Ravera *et al*. (2016) for an overview). The record from site 11 is the only one for the eastern side. Very rare.

***Cladonia pulvinata* (Sandst.) Herk & Aptroot**

8: on sandy-pebbly soil (GG; GA18). 11: on sandy-pebbly soil (GG; GA18). 12: on sandy-pebbly soil (GG; GA18).

Terricolous on sandy-pebbly or little humified soil in pioneer situations associated with open *Calluna* heathlands. It was reported as new to Italy from 5 sites in the Po Plain – 3 of which are those cited here, located in the Ticino river valley and surrounding area – by Gheza *et al*. (2018). Extremely rare, perhaps more widespread in the past.

***Cladonia ramulosa*** **(With.) J.R.Laundon**

23: on sandy-pebbly soil (GG; GG15).

Known only from one site, it was reported under "*Cladonia sp*." by Gheza (2015). Extremely rare.

***Cladonia rei*** **Schaer.**

2: on soil (GG; GG15). 3: on soil (GG). 4: on soil (GG; GG15). 5: on soil (GG; GG15). 6: on soil (GG; GG15). 8: on soil (GG; GG15). 10: on soil (GG). 11: on soil (GG). 12: on soil (GG; GG15). 13: on soil (GG; GG15). 14: on soil (GG; GG15). 15: on soil (GG). 17: on soil (GG). 18: on soil (GG). 20: on soil (GG). 21: on soil (GG). 23: on soil (GG; GG15).

A terricolous species able to colonize different soil types. It is often found in disturbed situations, e.g. at the edge of footpaths and in dry grasslands, but it is also able to colonize wide areas under *Calluna* shrubs in mature dry heathlands. Rather common and widespread in dry habitats, probably overlooked in the past.

***Cladonia strepsilis*** **(Ach.) Grognot**

4: on sandy-pebbly soil (GG; RA17b). 11: on soil (GG; RA17b). 14: on soil (GG; RA17b).

A terricolous species found in pioneer situations, typical of high altitude habitats in Italy (Nimis, 2016), exceptionally found in the Ticino river valley in recent years. Extremely rare, probably overlooked in the past.

***Cladonia uncialis*** **(L.) F.H.Wigg.**

5: on organic soil (GG). 6: on organic soil (GG; GG15). 11: on sandy-pebbly soil (GG). 14: on organic soil (GG; GG15).

The species was not reported for site 5 by Gheza (2015), but a deeper study of the area allowed to find two thalli in an undisturbed clearing in the wood near the dry grassland surveyed for that paper. This is the third record of the species on the western side of the river valley. The record from site 11 is the only one from the eastern side, and comes after a long time since the last record of the species in that area by Giacomini (1958). Extremely rare.

***Cladonia verticillata* (Hoffm.) Schaer.**

11: on sandy-pebbly soil (GG).

A terricolous species which appears with very well-developed podetia in undisturbed but still open *Calluna* heathlands. The last known record of the species was that by Cozzi (1917) for the "Boscaccio di San Macario". Extremely rare.

***Coenogonium pineti* (Ach.) Lücking & Lumbsch**

7: on bark of *Q. robur* (GG).

An epiphytic species found in a very shaded broadleaf wood. It seems extremely rare, but it could be more widespread, especially in the northern part of the river valley.

***Dibaeis baeomyces* (L.f.) Rambold & Hertel**

8: on loamy soil (GG; RA17b).

A terricolous species typical of *Calluna* heathlands, found sterile in a single site. Reported by Biroli (1808) as common in heaths and by Cozzi (1917) for the heathlands near Gallarate, but not reported later neither by Giacomini (1958) nor by Valcuvia Passadore *et al*. (2002 b). Extremely rare, presently almost certainly limited to the locality reported here.

***Lecania turicensis* (Hepp) Müll.Arg.**

On the statues in the Botanical Garden of Pavia (RI07).

A saxicolous species of basic substrates. Probably more widespread in the river valley, also – if not mainly – on human artifacts.

***Lepraria membranacea* (Dicks.) Vain.**

9: on bark of *R. pseudoacacia* (GG).

Even if it is reported mainly as saxicolous, this species was found, in a single site, on the bark of several trees of *R. pseudoacacia* at the edge of a mixed deciduous wood. Extremely rare.

***Micarea prasina* Fr.**

1: on bark of *Pinus sp*. (GG).

An epiphytic species found in a single site, in a shady mixed wood with pines and oaks. Extremely rare, perhaps more widespread at least in the northern part of the river valley.

***Normandina pulchella*** **(Borrer) Nyl.**

1: on bark and logs of *Q. robur* (GG). 7: on bark of *Q. robur* (GG). 9: on bark of *Q. robur* (GG). 20: on bark of *Q. robur* (GG).

An epiphytic species generally found on epiphytic liverworts or mosses in shaded and humid situations, especially in open woods. The species was not reported by Valcuvia Passadore *et al*. (2002 b), but it was listed in the checklist of the epiphytic lichens by Roella (1999). It seems rather rare, but it is probably more widespread than found until now, especially in the northern part of the river valley.

***Sarcogyne regularis*** **Körb.**

On the statues in the Botanical Garden of Pavia (RI07).

A saxicolous species of basic substrates. Probably more widespread in the river valley, especially on human artifacts.

***Verrucaria macrostoma*** **DC.**

On the statues in the Botanical Garden of Pavia (RI07).

A saxicolous species of basic substrates. Probably more widespread in the river valley, mostly on human artifacts.

## Conclusions

The number of lichen species known for the Ticino river valley has increased to 151 from the 123 reported by Valcuvia Passadore *et al*. (2002 b). Other 19 species cited only in historical literature (Appendix 2) were not found during recent surveys, and could be considered as extinct in the river valley and its surroundings.

The great importance of the Ticino river valley and of the presence of two Parks protecting the whole rivercourse for the conservation of rare and endangered terricolous lichens was already highlighted by recent papers (Gheza, 2015; Gheza *et al*., 2018); the further, interesting new records reported in this contribution confirm the value of that area, not only for terricolous species.

The targeted researches carried out in dry grasslands, heathlands and oak woods resulted in the finding of several interesting species new to the study area, among which three which are rare nationwide (i.e. *Cladonia peziziformis*, *C. portentosa*, *C. verticillata*), five of particular biogeographical importance because usually limited to montane or alpine areas in Italy (i.e. *Cladonia coccifera*, *C. digitata*, *C. floerkeana*, *C. strepsilis*, *C. uncialis*) and even two new to Italy (i.e. *Cladonia conista*, *C. pulvinata*; Gheza *et al*., 2018). It is therefore probable that also other so far lichenologically overlooked habitats could host interesting species not yet recorded in the area (e.g. riparian woods, cf. Nascimbene *et al*., 2008).

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## Appendix 1

List of the 64 lichen species collected by the author in the Ticino river valley.

*Amandinea punctata* (Hoffm.) Coppins & Scheid., *Arthonia atra* (Pers.) A.Schneid., *Athallia pyracea* (Ach.) Arup, Frödén & Søchting, *Caloplaca teicholyta* (Ach.) J.Steiner, *Candelaria concolor* (Dicks.) Stein, *Candelariella reflexa* (Nyl.) Lettau, *Candelariella xanthostigma* (Ach.) Lettau, *Cladonia caespiticia* (Pers.) Flörke, *Cladonia cariosa* (Ach.) Spreng., *Cladonia cervicornis* (Ach.) Flot., *Cladonia chlorophaea* (Flörke ex Sommerf.) Spreng., *Cladonia coccifera* (L.) Willd., *Cladonia coniocraea* (Flörke) Spreng., *Cladonia conista* (Nyl.) Robbins, *Cladonia digitata* (L.) Hoffm., *Cladonia fimbriata* (L.) Fr., *Cladonia floerkeana* (Fr.) Flörke, *Cladonia foliacea* (Huds.) Willd., *Cladonia furcata* (Huds.) Schrad., *Cladonia macilenta* Hoffm., *Cladonia parasitica* (Hoffm.) Hoffm., *Cladonia peziziformis* (With.) J.R.Laundon, *Cladonia polycarpoides* Nyl., *Cladonia portentosa* (Dufour) Coem., *Cladonia pulvinata* (Sandst.) Herk & Aptroot, *Cladonia pyxidata* (L.) Hoffm., *Cladonia ramulosa* (With.) J.R.Laundon, *Cladonia rangiformis* Hoffm., *Cladonia rei* Schaer., *Cladonia squamosa* Hoffm., *Cladonia strepsilis* (Ach.) Grognot, *Cladonia uncialis* (L.) F.H.Wigg., *Cladonia verticillata* (Hoffm.) Schaer., *Coenogonium pineti* (Ach.) Lücking & Lumbsch, *Dibaeis baeomyces* (L.f.) Rambold & Hertel, *Evernia prunastri* (L.) Ach., *Flavoparmelia caperata* (L.) Hale, *Flavoplaca citrina* (Hoffm.) Arup, Frödén & Søchting, *Graphis scripta* (L.) Ach., *Hypocenomyce scalaris* (Ach.) M.Choisy, *Hypogymnia physodes* (L.) Nyl., *Lecania cyrtella* (Ach.) Th.Fr., *Lecanora campestris* (Schaer.) Hue, *Lecanora carpinea* (L.) Vain., *Lecanora chlarotera* Nyl., *Lecidella elaeochroma* (Ach.) M.Choisy, *Lepraria incana* (L.) Ach., *Lepraria membranacea* (Dicks.) Vain., *Micarea prasina* Fr., *Myriolecis hagenii* (Ach.) Śliwa, Zhao Xin & Lumbsch, *Normandina pulchella* (Borrer) Nyl., *Parmelina tiliacea* (Hoffm.) Hale, *Parmotrema perlatum* (Huds.) M.Choisy, *Phaeophyscia orbicularis* (Neck.) Moberg, *Physcia adscendens* H.Olivier, *Physcia tenella* (Scop.) DC, *Physconia grisea* (Lam.) Poelt, *Protoparmeliopsis muralis* (Schreb.) M.Choisy, *Punctelia subrudecta* (Nyl.) Krog, *Verrucaria nigrescens* Pers., *Xanthomendoza huculica* (S.Y.Kondr.) Diederich, *Xanthoparmelia conspersa* (Ach.) Hale, *Xanthoparmelia pulla* (Ach). O.Blanco, A.Crespo, Elix, D.Hawksw. & Lumbsch, *Xanthoria parietina* (L.) Th.Fr.

## Appendix 2

List of the 19 lichen species reported in historical literature (Biroli, 1808; Cozzi, 1917; Giacomini, 1958) not found during recent surveys in the Ticino river valley.

*Alyxoria varia* (Pers.) Ertz & Tehler (C17), *Anaptychia ciliaris* (L.) A.Massal. (C17), *Arthonia galactites* (DC.) Dufour (C17), *Baeomyces rufus* (Huds.) Rebent. (B08), *Cetraria aculeata* (Schreb.) Fr. (B08), *Cetraria islandica* (L.) Ach. (B08), *Chaenotheca hispidula* (Ach.) Zahlbr. (B08), *Cladonia amaurocraea* (Flörke) Schaer. (G58), *Cladonia arbuscula* (Wallr.) Flot. (B08; G58), *Cladonia gracilis* (L.) Willd. (G58), *Cladonia pleurota* (Flörke) Schaer. (G58), *Collema nigrescens* (Huds.) DC. (C17), *Lecanora varia* (Hoffm.) Ach. (C17), *Leptogium hildenbrandii* (Garov.) Nyl. (C17), *Peltigera canina* (L.) Willd. (C17), *Pseudoschismatomma rufescens* (Pers.) Ertz & Tehler (C17), *Physcia leptalea* (Ach.) DC. (C17), *Physcia stellaris* (L.) Nyl. (C17), *Usnea dasopoga* (Ach.) Nyl. (C17).

# Chapter 2

# Two *Cladonia* species new to Italy from dry habitats in the Po Plain

Gabriele GHEZA, Juri NASCIMBENE, Helmut MAYRHOFER,
Matteo BARCELLA, Silvia ASSINI

## Abstract

*Cladonia conista* and *C. pulvinata* occur at several sites in dry lowland–habitats in the Po Plain (Northern Italy). Vegetation relevés are provided in order to characterize the main lichen (*Cladonietum rei*, *Cladonietum foliaceae*, *Pycnothelio-Cladonietum cervicornis*) and vascular plant communities in which the two species were found in *Thero-Airion* dry acidic grasslands and in dry open *Calluna* heathlands.

## Keywords

Biodiversity, lichen communities, *Cladonietum foliaceae*, *Cladonietum rei*, *Pycnothelio-Cladonietum cervicornis*, *Calluna* heathlands, *Thero-Airion* dry grasslands.

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## Introduction

*Cladonia conista* and *C. pulvinata* are two terricolous lichens. Pino-Bodas *et al*. (2012) confirmed *C. conista* as a distinct species by phylogenetic analyses, and van Herk & Aptroot (2003) raised *C. pulvinata* to species level based on morphological and chemical characters. Both species can occur in dry and semidry habitats in Central Europe (Wirth *et al*. 2013).

*Cladonia conista* was included in the *C. chlorophaea* group in the past (Ahti 1966; Coassini Lokar *et al*. 1986), but recent genetic analyses showed that it is not strictly related with the species in that group (Pino-Bodas *et al*. 2012) possessing scyphose podetia with soredia or granules on the surface. *C. conista* is characterized chemically by the presence of bourgeanic and fumarprotocetraric acids, and is clearly separated from *C. humilis*, which contains fumarprotocetraric acid and atranorin (Pino-Bodas *et al*. 2012). The species is widespread, occurring in all continents except Antarctica (Kowalewska *et al*. 2008, Pino-Bodas *et al*. 2012).

*Cladonia pulvinata* belongs to the *C. cervicornis* group, whose species are characterized by scyphose podetia with central proliferations (Ahti 2007). *C. pulvinata* is characterized chemically by the presence of psoromic acid and it is clearly separated from *C. cervicornis* and *C. verticillata* which contain only fumarprotocetraric acid (van Herk & Aptroot 2003). The species occurs in western and central Europe (James 2009, Wirth *et al*. 2013).

Currently, the Italian lichen flora includes 80 *Cladonia* taxa (Nimis 2016). This genus has never been thoroughly investigated in Italy, except by Coassini Lokar *et al*. (1986), who studied the *C. chlorophaea-pyxidata* complex. Furthermore, terricolous lichens have been less studied than epiphytic and saxicolous lichens in several parts of Italy, especially in the Po Plain, a region traditionally considered to be poor in lichens due to heavy anthropogenic impact (Gheza 2015, Nimis 2016).

During recent surveys aimed at exploring remnants of lichen-rich dry habitats of conservation concern, namely *Corynephorus* grasslands (Natura 2000 code: 2330), *Thero-Airion* grasslands (Natura 2000 code: 6210) and *Calluna* heathlands (Natura 2000 code: 4030), *C. conista* and *C. pulvinata* were collected from seven sites in the western Po Plain (Northern Italy). The aim of this paper is to describe these collections and their habitats.

## Material and methods

Overall, 76 dry grasslands (64 on acidic substrates and 12 on calcareous substrates) and 29 *Calluna* heathlands located in the western Po Plain (Lombardy and Piedmont regions) were investigated for terricolous lichens during the winters of 2015–2016 and 2016–2017. *Cladonia* specimens were identified in the laboratory with the keys of Nimis & Martellos (2004), Kowalewska *et al*. (2008), James (2009) and Wirth *et al*. (2013). The presence of lichen substances was determined by means of thin-layer chromatography in solvents A, B' and C according to the protocols of White & James (1985) and Orange *et al*. (2010).

Eighteen relevés (30 × 30 cm plots) were carried out in June 2017 according to the Braun-Blanquet (1964) approach in homogeneous patches of lichen vegetation to characterize the main lichen communities that include *Cladonia* species. Furthermore, five larger relevés (9 × 9 m) were carried out to characterize the plant communities hosting well-developed lichen patches with relevant cover values of *C. conista* and *C. pulvinata*. The following cover-abundance scale was used: + = <1%, 1 = 1–5%, 2 = 6–25%, 3 = 26–50%, 4 = 51–75%, 5 = 76–100%. The classification of the relevés follows Paus (1997), nomenclature follows Nimis (2016) for lichens and Tison & De Foucault (2014) for vascular plants, and coordinates are given in the UTM WGS84 system.

## Results

***Cladonia conista*** (Nyl.) Robbins

Specimens examined: Tornavento heathland, Lonate Pozzolo (province of Varese, Lombardy), 32T 478210.5049154, 201 m a.s.l., on sandy-pebbly acidic soil, in an open *Calluna* heathland, 09/06/2017 (hb. Gheza, GZU). – Abandoned airfield La Promessa, Lonate Pozzolo (province of Varese, Lombardy), 32T 479558.5046005, 186 m a.s.l., on sandy-pebbly acidic soil, in a *Thero-Airion* dry grassland, 05/06/2017 (hb. Gheza, PAV). – Surroundings of Cascina Rossa, Bernate Ticino (province of Milano, Lombardy), 32T 484066.5035049, 117 m a.s.l., on sandy-pebbly acidic soil, in a *Thero-Airion* dry grassland, 14/06/2017 (hb. Gheza, GZU, PAV). – Bosco del Modrone, Vigevano (province of Pavia, Lombardy), 32T 494902.5015676, 76 m a.s.l., on sandy-pebbly acidic soil, in a *Thero-Airion* dry grassland, 10/06/2017 (hb. Gheza, GZU, PAV).

Primary squamules 1–3 mm wide, grey or greenish-grey on the upper side, whitish on the lower side, almost rounded, slightly incised, and decumbent. Podetia 6–17 mm tall, greenish-grey, with narrow to rather wide cups, with farinose soredia in the upper part and sometimes decorticated near the edge of the cups. Fumarprotocetraric and bourgeanic acids were present in all analysed specimens.

*Cladonia conista* was found in three *Thero-Airion* dry grasslands (7 relevés: tab. 1: 1–4, 6; tab. 2: 1–2), with a few thalli in open *Calluna* heathland (1 relevé: tab. 1: 5); it was associated mainly with *C. rei*, *C. rangiformis* and *C. foliacea*, in lichen communities of the *Cladonietum rei* Paus 1997 and the *Cladonietum foliaceae* Klement 1953 emend. Drehwald 1993. The substrate was always an acidic and shallow (0.5-1.5 cm) sandy-pebbly soil. All sites are located in the Lombardy Ticino Nature Park.

***Cladonia pulvinata*** (Sandst.) van Herk & Aptroot

Specimens examined: Tornavento heathland, Lonate Pozzolo (province of Varese, Lombardy), 32T 477985.5049338, 202 m a.s.l., on sandy-pebbly acidic soil, in an open *Calluna* heathland, 09/06/2017 (hb. Gheza, GZU, PAV). – Abandoned airfield La Promessa, Lonate Pozzolo (province of Varese, Lombardy), 32T 478606.5046292, 187 m a.s.l., on sandy-pebbly acidic soil, in an open *Calluna* heathland, 15/03/2017 (hb. Gheza, GZU, PAV). – Abandoned airfield La Promessa, Lonate Pozzolo (province of Varese, Lombardy), 32T 479554.5046022, 186 m a.s.l., on sandy-pebbly acidic soil, in a *Thero-Airion* dry grassland, 05/06/2017 (hb. Gheza). – Baraggione di Candelo near Cascina Bravetta, Massazza (province of Biella, Piedmont), 32T 436133.5037615, 243 m a.s.l., on clayey acidic soil, in an open *Calluna* heathland, 07/07/2017 (hb. Gheza, GZU, PAV). – Vauda Canavesana (province of Torino, Piedmont), 32T 389243.5013577, 421 m a.s.l., on clayey acidic soil, in an open *Calluna* heathland, 23/06/2017 (hb. Gheza, GZU).

Primary squamules 1–4 mm wide, green or brownish-green to light brown on the upper side, whitish on the lower side, slightly to deeply incised, often convex, usually erected or semi-erected. Podetia not observed in the aforementioned Italian material. TLC revealed the occurrence of psoromic acid in all analyzed specimens.

*Cladonia pulvinata* occurred with well-developed mats between *Calluna* shrubs in dry heathlands (8 relevés: tab.1: 9–10, 12–13, 17–18; tab. 2: 3–4), in a *Thero-Airion* dry grassland (3 relevés: tab.1: 7–8, 11), and also in the middle of a scarcely-frequented dirt road bordering an open *Calluna* heathland (4 relevés: tab.1: 14–16; tab. 2: 3). It was mainly associated with *Cladonia coccifera*, *Dibaeis baeomyces* and *Pycnothelia papillaria* in pioneer lichen communities of the *Pycnothelio-Cladonietum cervicornis* Paus 1997; it rarely occurred in more developed stages of this lichen vegetation dominated by

*Cladonia verticillata* (relevés not shown). The substrate was always acidic soil, sometimes sandy-pebbly and shallow (0.5–2 cm) (Ticino river valley), sometimes clayey and deep (>20 cm) (Piedmont heathlands).

## Discussion

*Cladonia conista* and *C. pulvinata* were found in four and five sites respectively, in pioneer stages within scattered remnants of dry habitats of the Po Plain, a region with a humid submediterranean bioclimate (Nimis & Martellos 2004). However, it cannot be excluded that further investigations will extend their Italian range to other bioclimatic regions, where, for example, similar habitats occur on acidic soils in higher altitudinal belts.

Both species occur on acidic substrates, but in different lichen communities and have different roles within them. *Cladonia conista* occurs in pioneer stands of *Cladonietum rei* and *Cladonietum foliaceae*, where it can be considered a companion species, generally with scattered thalli and only rarely with significant cover values. *C. rei* is most frequently associated with it in these communities, as well as *C. rangiformis* and *C. foliacea*. It was always found on shallow sandy-pebbly soil.

*Cladonia pulvinata* occurs in the pioneer *Pycnothelio-Cladonietum cervicornis* and, contrary to the previous species, often has a prominent role in determining the nature of the lichen community, forming extended mats of primary squamules. It is considered to be a characteristic species of this community (Paus 1997). *C. coccifera* and *Dibaeis baeomyces* are sometimes associated with it. It was found on both shallow sandy-pebbly and deeper loamy soils.

All the relevés have a rather poor diversity of cryptogamic species, a situation already reported for terricolous lichen communities in the Po Plain (Gheza *et al*. 2016), those with *C. pulvinata* being even poorer since it often forms monospecific stands. Remarkably, some species (*C. coccifera*, *Dibaeis baeomyces*, *Pycnothelia papillaria*) considered to be typical of high altitudinal belts in Italy can be found in these dry habitats in lowland areas (cf. Gheza 2015).

The habitats of both two species are similar: they both occur in *Thero-Airion* dry grasslands and in open *Calluna* heathlands, in disturbed as well as in undisturbed sites. However, *Cladonia conista* is more frequent in *Thero-Airion*, whereas *C. pulvinata* is more frequent and better developed in *Calluna* heathlands, and in the sites where the two species appear in both habitats, they are dynamically and physically connected. These vascular communities are characterized in the study area by the co-occurrence of very different chorotypes, being dominated by *Micropyrum tenellum*, *Pilosella officinarum*, *Silene italica* and *Rumex acetosella* in the grasslands and by *Calluna vulgaris* and *Molinia arundinacea* in the heathlands.

Some *Cladonia* species morphologically and ecologically similar to the two species reported in this paper occur in the same areas. *C. chlorophaea*, *C. fimbriata* and *C. humilis* have scyphose and sorediate podetia and occur in several dry grasslands in the western Po Plain (unpublished data). *C. conista* can be differentiated with certainty only chemically from *C. chlorophaea* and *C. fimbriata* (both of which also have farinose soredia, but contain only fumarprotocetraric acid and not bourgeanic acid) and also from *C. humilis* (which contains fumarprotocetraric acid and atranorin). *C. cervicornis* and *C. verticillata* also occur in the area, but *C. pulvinata* can mainly be differentiated chemically from them since they contain only fumarprotocetraric acid and no psoromic acid; furthermore, the morphology of the primary thallus is quite different: squamules are more incised and curled in *C. cervicornis* and *C. verticillata*, but are less incise and more erect in *C. pulvinata*.

Although the Po Plain is the most polluted and human impacted area of Italy (European Environment Agency 2004), the two new species were found at sites which still preserve a large measure of naturalness. However, it should be noted that *C. conista* can tolerate soil pollution, as reported by several authors who studied *Cladonia*-dominated ruderal communities on contaminated soils (Hajdúk & Lisická 1999; Osyczka & Rola 2013; Rola *et al*. 2014), and other *Cladonia* species tolerant to pollution and heavy metal accumulation reported by these authors (i.e. *C. rei*, *C. cariosa*, *C. furcata*) were also found in the same stands with *C. conista* in the study sites mentioned in this paper.

The discovery of two species new to Italy in the western Po Plain, only a few kilometres distant from Milan, highlights a gap in our knowledge of the distribution of terricolous lichens and *Cladonia* species, and indeed their diversity in Italy. This gap hinders the development of tools that are useful for conservation purposes, such as a national red list currently available for epiphytic lichens (Nascimbene *et al*. 2013) and for some species of conservation concern (Rossi *et al*. 2013). On the other hand, the new finds show that suitable habitat conditions for rare terricolous lichens still occur within protected lowland areas of the Po Plain (Gheza 2015).

However, dry acidic grasslands and dry *Calluna* heathlands, considered vulnerable throughout Europe (AA.VV. 2016), are particularly at risk in Italy, where their conservation status was deemed inadequate and their occurrence is declining (Genovesi *et al*. 2014); therefore, the lichen species associated with them should also be considered threatened (Ravera *et al*. 2016).

With the addition of *Cladonia conista* and *C. pulvinata*, the Italian lichen flora now includes 82 taxa belonging to the genus *Cladonia*. Apart from the contributions of Coassini Lokar *et al*. (1986) and Ravera *et al*. (2016), no taxonomic or ecological study has been focused on the genus *Cladonia* in Italy in recent years. A thorough revision of critical groups, such as the *C. chlorophaea-pyxidata* complex and the *C. coccifera* complex, (Kotelko & Piercey-Normore 2010; Pino-Bodas *et al*. 2013; Steinova et al. 2013), and species such as *C. rei* (Syrek & Kukwa 2008; Dolnik *et al*. 2010), the taxonomy of which will eventually be revised thanks to modern genetic techniques, is greatly needed to elucidate distributional patterns of these lichens in Italy.

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| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** |
|---|---|---|---|---|---|---|---|---|---|
| **Locality** | M | M | P | M | T | B | P | P | C |
| **Altitude a.s.l.** | 78 | 78 | 187 | 78 | 200 | 119 | 188 | 188 | 243 |
| **Soil type** | sp | sp | sp | sp | lg | sp | sp | sp | cl |
| **Vegetation type** | TA | TA | TA | TA | CG | TA | TA | TA | CG |
| **Cover: total (%)** | 85 | 80 | 70 | 85 | 93 | 85 | 95 | 95 | 95 |
| **Cover: lichens (%)** | 70 | 65 | 15 | 60 | 30 | 70 | 90 | 85 | 80 |
| **Cover: bryophytes (%)** | 15 | 10 | 30 | 7 | 63 | 10 | 4 | 10 | 1 |
| **Cover: herbaceous layer (%)** | 18 | 17 | 40 | 25 | 5 | 10 | 25 | 40 | 14 |
| **Cover: shrub layer (%)** | 20 | 0 | 0 | 0 | 30 | 0 | 0 | 0 | 15 |
| **Stoniness** | 5 | 10 | 0 | 15 | 7 | 15 | 0 | 0 | 0 |
| **pH** | 4 | 4 | 4 | 4 | 4.5 | 4 | 4 | 4 | 4 |
| **Lichen richness** | 2 | 5 | 3 | 3 | 2 | 2 | 1 | 1 | 1 |
| **Bryophyte richness** | 1 | 1 | 1 | 1 | 3 | 1 | 2 | 2 | 1 |
| **Vascular plant richness** | 5 | 4 | 6 | 4 | 2 | 3 | 6 | 5 | 4 |
| | | | | | | | | | |
| **Lichens and bryophytes** | | | | | | | | | |
| ***Ceratodonto purpurei-Polytrichetea piliferi* Mohan 1987 emend. Drehwald 1993** | | | | | | | | | |
| *Ceratodon purpureus* (Hedw.) Brid. | . | . | 3 | 2 | 2 | 2 | 1 | 2 | 1 |
| *Polytrichum piliferum* Hedw. | . | . | . | . | 3 | . | 1 | 1 | . |
| ***Baeomycetion rufi* Klement 1952** | | | | | | | | | |
| ***Pycnothelio-Cladonietum cervicornis* Paus 1997** | | | | | | | | | |
| *Dibaeis baeomyces* (L.f.) Rambold & Hertel | . | . | . | . | . | . | . | . | . |
| *Pycnothelia papillaria* Dufour | . | . | . | . | . | . | . | . | . |
| *Cladonia pulvinata* (Sandst.) Herk & Aptroot | . | . | . | . | . | . | 5 | 5 | 5 |
| ***Cladonion arbusculae* Klement 1949 emend. Bültmann 2016** | | | | | | | | | |
| ***Cladonietum foliaceae* Klement 1953 emend. Drehwald 1993** | | | | | | | | | |
| *Cladonia foliacea* (Huds.) Willd. | . | 1 | . | . | . | . | . | . | . |
| *Cladonia rangiformis* Hoffm. | . | 2 | . | 3 | . | . | . | . | . |
| ***Cladonion rei* Paus 1997** | | | | | | | | | |
| ***Cladonietum rei* Paus 1997** | | | | | | | | | |
| *Cladonia rei* Schaer. | 4 | 3 | 1 | 2 | 1 | 1 | . | . | . |
| *Cladonia conista* (Nyl.) Robbins | 1 | 2 | 2 | 2 | 3 | 4 | . | . | . |
| *Cladonia cariosa* (Ach.) Spreng. | . | . | 1 | . | . | . | . | . | . |
| **Other species** | | | | | | | | | |
| *Cladonia polycarpoides* Nyl. | . | + | . | . | . | . | . | . | . |
| *Cladonia coccifera* (L.) Willd. | . | . | . | . | . | . | . | . | . |
| *Campylopus introflexus* (Hedw.) Brid. | 2 | . | . | . | . | . | . | . | . |
| *Polytrichastrum formosum* (Hedw.) G.L.Smith | . | . | . | . | 1 | . | . | . | . |
| *Hypnum cupressiforme* Hedw. | . | 2 | . | . | . | . | . | . | . |
| | | | | | | | | | |
| **Vascular plants** | | | | | | | | | |
| **Koelerio-Corynephoretea Klika in Klika et Novák 1941, Corynephoretalia canescentis Klika 1934, Thero-Airion R. Tx. ex Oberd. 1957** | | | | | | | | | |
| *Rumex acetosella* L. | 2 | 1 | . | 1 | . | . | . | . | . |
| *Aira caryophyllea* L. | . | . | 1 | . | . | . | 1 | 1 | . |
| *Logfia minima* (Sm.) Dumort. | . | . | . | . | . | . | 1 | . | . |
| *Micropyrum tenellum* (L.) Link | 1 | 1 | . | 1 | . | . | . | . | . |
| *Teesdalia nudicaulis* (L.) R.Br. | 1 | . | . | . | . | . | . | . | . |
| ***Calluno-Ulicetea* Br.-Bl. Et R. Tx. ex Klika et Hadač 1944** | | | | | | | | | |
| ***Vaccinio-Genistetalia* Schubert 1960** | | | | | | | | | |
| ***Genistion pilosae* Duvigneaud 1942** | | | | | | | | | |
| *Calluna vulgaris* (L.) Hull (shrub) | . | . | . | . | 3 | . | . | . | 2 |
| *Calluna vulgaris* (L.) Hull (juv.) | . | . | . | . | 1 | . | . | . | 1 |
| *Pilosella officinarum* Vaill. | . | . | 2 | 2 | . | . | 2 | 2 | . |
| **Other species** | | | | | | | | | |
| *Silene* cf. *italica* (L.) Pers. | 1 | 2 | . | 2 | . | . | . | . | . |
| *Lotus corniculatus* L. | . | . | 2 | . | . | . | 1 | . | . |
| *Crataegus monogyna* Jacq. (shrub) | 2 | . | . | . | . | . | . | . | . |
| *Carex* sp. | . | . | 1 | . | . | . | . | . | . |
| *Rubus caesius* L. (juv.) | . | 1 | . | . | . | . | . | . | . |
| *Poterium sanguisorba* L. | . | . | 1 | . | . | . | . | . | . |
| *Helianthemum nummularium* (L.) Mill. | . | . | . | . | . | 1 | . | . | . |
| *Potentilla puberula* Krasan | . | . | . | . | . | 1 | . | . | . |
| *Hypericum perforatum* L. | . | . | + | . | . | . | . | . | 1 |
| *Stachys recta* L. | . | . | . | . | . | + | . | . | . |
| *Molinia arundinacea* Schrank | . | . | . | . | 1 | . | . | . | . |
| *Vulpia myuros* (L.) C.C.Gmel. | . | . | . | . | . | . | 1 | . | . |
| *Centaurium erythraea* Rafn | . | . | . | . | . | . | 2 | 2 | . |
| *Festuca filiformis* Pourr. | . | . | . | . | . | . | . | . | 2 |
| *Cynodon dactylon* (L.) Pers. | . | . | . | . | . | . | . | . | . |
| *Anarrhinum bellidifolium* (L.) Willd. | . | . | . | . | . | . | . | . | . |
| *Crysopogon gryllus* (L.) Trin. | . | . | . | . | . | . | . | . | . |
| *Solidago gigantea* Aiton | . | . | . | . | . | . | . | 2 | . |
| *Galium* sp. | . | . | . | . | . | . | . | . | . |
| *Hypochoeris radicata* L. | . | . | . | . | . | . | . | . | 1 |
| *Jasione montana* L. | . | . | . | . | . | . | . | + | . |

Table 1. Lichen vegetation relevés characterised by *C. conista* (1-6) and *C. pulvinata* (7-18). Localities: B Bernate Ticino; C Baraggia di Candelo; M Bosco del Modrone; P La Promessa; V Vauda Alta. Soil types: SP sandy-pebbly; LG loamy-gravelly; CL clayey. Vegetation types: TA Thero-Airion dry grassland; CG open *Calluna* heathland.

| | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|
| **Locality** | C | P | P | C | P | P | P | V | V |
| **Altitude a.s.l.** | 235 | 188 | 187 | 235 | 187 | 187 | 187 | 420 | 434 |
| **Soil type** | cl | sp | sp | cl | sp | sp | sp | cl | cl |
| **Vegetation type** | CG | TA | CG | CG | CG | CG | CG | CG | CG |
| **Cover: total (%)** | 90 | 70 | 100 | 95 | 80 | 70 | 60 | 95 | 65 |
| **Cover: lichens (%)** | 80 | 70 | 82 | 70 | 67 | 60 | 50 | 35 | 50 |
| **Cover: bryophytes (%)** | 15 | 2 | 18 | 20 | 13 | 10 | 10 | 20 | 0 |
| **Cover: herbaceous layer (%)** | 25 | 35 | 7 | 35 | 30 | 10 | 18 | 80 | 15 |
| **Cover: shrub layer (%)** | 20 | 0 | 2 | 10 | 0 | 0 | 0 | 15 | 45 |
| **Stoniness** | 0 | 20 | 0 | 0 | 0 | 0 | 15 | 0 | 0 |
| **pH** | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| **Lichen richness** | 1 | 1 | 3 | 1 | 2 | 1 | 1 | 1 | 3 |
| **Bryophyte richness** | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 0 |
| **Vascular plant richness** | 2 | 5 | 3 | 3 | 3 | 3 | 4 | 2 | 3 |
| | | | | | | | | | |
| **Lichens and bryophytes** | | | | | | | | | |
| ***Ceratodonto purpurei-Polytrichetea piliferi* Mohan 1987 emend. Drehwald 1993** | | | | | | | | | |
| *Ceratodon purpureus* (Hedw.) Brid. | . | 1 | . | . | 2 | 2 | 2 | . | . |
| *Polytrichum piliferum* Hedw. | . | . | 2 | . | . | 1 | . | . | . |
| ***Baeomycetion rufi* Klement 1952** | | | | | | | | | |
| ***Pycnothelio-Cladonietum cervicornis* Paus 1997** | | | | | | | | | |
| *Dibaeis baeomyces* (L.f.) Rambold & Hertel | . | . | . | . | . | . | . | . | 3 |
| *Pycnothelia papillaria* Dufour | . | . | . | . | . | . | | | 1 |
| *Cladonia pulvinata* (Sandst.) Herk & Aptroot | 5 | 4 | 4 | 4 | 4 | 4 | 3 | 3 | 1 |
| ***Cladonion arbusculae* Klement 1949 emend. Bültmann 2016** | | | | | | | | | |
| ***Cladonietum foliaceae* Klement 1953 emend. Drehwald 1993** | | | | | | | | | |
| *Cladonia foliacea* (Huds.) Willd. | . | . | . | . | . | . | . | . | . |
| *Cladonia rangiformis* Hoffm. | . | . | . | . | . | . | . | . | . |
| ***Cladonion rei* Paus 1997** | | | | | | | | | |
| ***Cladonietum rei* Paus 1997** | | | | | | | | | |
| *Cladonia rei* Schaer. | . | . | 1 | . | . | . | . | . | . |
| *Cladonia conista* (Nyl.) Robbins | . | . | . | . | . | . | . | . | . |
| *Cladonia cariosa* (Ach.) Spreng. | . | . | . | . | . | . | . | . | . |
| **Other species** | | | | | | | | | |
| *Cladonia polycarpoides* Nyl. | . | . | . | . | . | . | . | . | . |
| *Cladonia coccifera* (L.) Willd. | . | . | 2 | . | 1 | . | . | . | . |
| *Campylopus introflexus* (Hedw.) Brid. | 2 | . | . | 2 | . | . | . | 2 | . |
| *Polytrichastrum formosum* (Hedw.) G.L.Smith | . | . | . | . | . | . | . | . | . |
| *Hypnum cupressiforme* Hedw. | . | . | . | . | . | . | . | . | . |
| | | | | | | | | | |
| **Vascular plants** | | | | | | | | | |
| **Koelerio-Corynephoretea Klika in Klika et Novák 1941, Corynephoretalia canescentis Klika 1934, Thero-Airion R. Tx. ex Oberd. 1957** | | | | | | | | | |
| *Rumex acetosella* L. | . | . | . | . | . | . | . | . | . |
| *Aira caryophyllea* L. | . | 1 | . | . | . | . | . | . | . |
| *Logfia minima* (Sm.) Dumort. | . | + | . | . | 1 | 1 | 2 | . | . |
| *Micropyrum tenellum* (L.) Link | . | . | . | . | . | . | . | . | . |
| *Teesdalia nudicaulis* (L.) R.Br. | . | . | 1 | . | 1 | 1 | 1 | . | . |
| ***Calluno-Ulicetea* Br.-Bl. Et R. Tx. ex Klika et Hadač 1944** | | | | | | | | | |
| ***Vaccinio-Genistetalia* Schubert 1960** | | | | | | | | | |
| ***Genistion pilosae* Duvigneaud 1942** | | | | | | | | | |
| *Calluna vulgaris* (L.) Hull (shrub) | 2 | . | 1 | 2 | . | . | . | 2 | 3 |
| *Calluna vulgaris* (L.) Hull (juv.) | 2 | . | 1 | . | 2 | 1 | 2 | 2 | 1 |
| *Pilosella officinarum* Vaill. | . | 3 | . | . | . | . | . | . | . |
| **Other species** | | | | | | | | | |
| *Silene* cf. *italica* (L.) Pers. | . | . | . | . | . | . | . | . | . |
| *Lotus corniculatus* L. | . | 1 | . | . | . | . | . | . | . |
| *Crataegus monogyna* Jacq. (shrub) | . | . | . | . | . | . | . | . | . |
| *Carex* sp. | . | . | . | . | . | . | . | . | . |
| *Rubus caesius* L. (juv.) | . | . | . | . | . | . | . | . | . |
| *Poterium sanguisorba* L. | . | . | . | . | . | . | . | . | . |
| *Helianthemum nummularium* (L.) Mill. | . | . | . | . | . | . | . | . | . |
| *Potentilla puberula* Krasan | . | . | . | . | . | . | . | . | . |
| *Hypericum perforatum* L. | . | . | . | . | . | . | . | . | . |
| *Stachys recta* L. | . | . | . | . | . | . | . | . | . |
| *Molinia arundinacea* Schrank | . | . | . | . | . | . | . | . | 2 |
| *Vulpia myuros* (L.) C.C.Gmel. | . | . | . | 2 | . | . | . | . | . |
| *Centaurium erythraea* Rafn | . | . | . | . | . | . | . | . | . |
| *Festuca filiformis* Pourr. | . | . | . | . | . | . | . | . | 1 |
| *Cynodon dactylon* (L.) Pers. | 2 | . | . | 3 | . | . | . | . | . |
| *Anarrhinum bellidifolium* (L.) Willd. | . | . | 1 | . | . | . | 1 | . | . |
| *Crysopogon gryllus* (L.) Trin. | . | . | . | . | . | . | . | 4 | . |
| *Solidago gigantea* Aiton | . | . | . | . | . | . | . | . | . |
| *Galium* sp. | . | 1 | . | . | . | . | . | . | . |
| *Hypochoeris radicata* L. | . | . | . | . | . | . | . | . | . |
| *Jasione montana* L. | . | . | . | . | . | . | . | . | . |

Table 1 (continuation). Lichen vegetation relevés characterised by *C. conista* (1-6) and *C. pulvinata* (7-18). Localities: B Bernate Ticino; C Baraggia di Candelo; M Bosco del Modrone; P La Promessa; V Vauda Alta. Soil types: SP sandy-pebbly; LG loamy-gravelly; CL clayey. Vegetation types: TA Thero-Airion dry grassland; CG open *Calluna* heathland.

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| **Locality** | M | M | P | T | V |
| **Altitude a.s.l. (m)** | 76 | 76 | 187 | 202 | 421 |
| **Soil type** | Sandy-pebbly | Sandy-pebbly | Loamy-pebbly | Loamy-gravelly | Clayey |
| **Vegetation type** | TA | TA | CG | CG | CG |
| **Cover: total (%)** | 93 | 85 | 75 | 92 | 90 |
| **Cover: lichens (%)** | 45 | 80 | 50 | 20 | 6 |
| **Cover: bryophytes (%)** | 45 | 5 | 20 | 70 | 24 |
| **Cover: herbaceous layer (%)** | 85 | 35 | 30 | 15 | 40 |
| **Cover: shrub layer (%)** | 8 | 5 | 40 | 65 | 80 |
| **Stoniness** | 6 | 13 | 15 | 7 | 0 |
| **pH** | 5 | 5 | 4 | 4 | 4 |
| **Lichen richness** | 6 | 4 | 2 | 1 | 3 |
| **Bryophyte richness** | 2 | 2 | 2 | 1 | 1 |
| **Vascular plant richness** | 7 | 8 | 9 | 5 | 12 |
| | | | | | |
| **Lichens and bryophytes** | | | | | |
| ***Ceratodonto purpurei-Polytrichetea piliferi* Mohan 1987 emend. Drehwald 1993** | | | | | |
| *Ceratodon purpureus* (Hedw.) Brid. | . | 1 | 1 | . | . |
| *Polytrichum piliferum* Hedw. | 2 | 1 | 2 | 4 | . |
| ***Baeomycetion rufi* Klement 1952** | | | | | |
| ***Pycnothelio-Cladonietum cervicornis* Paus 1997** | | | | | |
| *Dibaeis baeomyces* (L.f.) Rambold & Hertel | . | . | . | . | 1 |
| *Pycnothelia papillaria* Dufour | . | . | . | . | 1 |
| *Cladonia pulvinata* (Sandst.) Herk & Aptroot | . | . | 3 | 2 | 1 |
| ***Cladonion arbusculae* Klement 1949 emend. Bültmann 2016** | | | | | |
| ***Cladonietum foliaceae* Klement 1953 emend. Drehwald 1993** | | | | | |
| *Cladonia foliacea* (Huds.) Willd. | 2 | 1 | . | . | . |
| *Cladonia furcata* (Huds.) Schrad. | 1 | . | . | . | . |
| *Cladonia rangiformis* Hoffm. | 2 | 4 | . | . | . |
| ***Cladonion rei* Paus 1997** | | | | | |
| ***Cladonietum rei* Paus 1997** | | | | | |
| *Cladonia rei* Schaer. | 2 | 1 | . | . | . |
| *Cladonia conista* (Nyl.) Robbins | 1 | 1 | . | . | . |
| **Other species** | | | | | |
| *Cladonia coccifera* (L.) Willd. | . | . | 2 | . | . |
| *Cladonia polycarpoides* Nyl. | 1 | . | . | . | . |
| *Campylopus introflexus* (Hedw.) Brid. | 2 | . | . | . | 2 |
| | | | | | |
| **Vascular plants** | | | | | |
| ***Koelerio-Corynephoretea* Klika in Klika et Novák 1941** | | | | | |
| ***Corynephoretalia canescentis* Klika 1934** | | | | | |
| ***Thero-Airion* R. Tx. ex Oberd. 1957** | | | | | |
| *Rumex acetosella* L. | 2 | . | . | . | . |
| *Micropyrum tenellum* (L.) Link | 2 | 1 | . | . | . |
| *Aira caryophyllea L.* | 1 | . | 1 | . | . |
| *Logfia minima (Sm.) Dumort.* | . | . | 2 | . | . |
| *Teesdalia nudicaulis (L.) R.Br.* | . | . | 1 | . | . |
| ***Calluno-Ulicetea* Br.-Bl. et R. Tx. ex Klika et Hadač 1944** | | | | | |
| ***Vaccinio-Genistetalia* Schubert 1960** | | | | | |
| ***Genistion pilosae* Duvigneaud 1942** | | | | | |
| *Calluna vulgaris* (L.) Hull (shrub) | . | . | 3 | 4 | 5 |
| *Calluna vulgaris* (L.) Hull (juv.) | . | . | 2 | 2 | . |
| *Luzula campestris* (L.) DC. | . | . | 1 | . | . |
| *Teucrium scorodonia* L. | . | . | + | . | . |
| *Danthonia decumbens* (L.) DC. | . | . | . | . | 1 |
| *Pilosella officinarum* Vaill. | 1 | 2 | . | . | 2 |
| *Potentilla erecta* (L.) Räuschel | . | . | . | . | 1 |
| *Genista germanica* L. (shrub) | . | . | . | . | 1 |
| **Other species** | | | | | |
| *Silene* cf. *italica* (L.) Pers. | 2 | 2 | . | . | . |
| *Hypericum perforatum* L. | . | 1 | + | . | . |
| *Stachys recta* L. | . | 1 | . | . | . |
| *Rubus caesius* L. juv | . | 1 | . | . | . |
| *Crataegus monogyna* Jacq. (shrub) | 1 | 1 | . | . | . |
| *Rubus caesius* L. (shrub) | 1 | . | . | . | . |
| *Populus nigra* L. (shrub) | . | 1 | . | . | . |
| *Molinia arundinacea* Schrank | . | . | 1 | 1 | 2 |
| *Genista tinctoria* L. (shrub) | . | . | . | . | 1 |
| *Cytisus scoparius* (L.) Link (shrub) | . | . | . | 1 | . |
| *Cytisus nigricans* L. (shrub) | . | . | . | . | 1 |
| *Rubus* sp. (shrub) | . | . | . | . | 2 |
| *Festuca filiformis* Pourr. | . | . | . | . | 2 |
| *Crysopogon gryllus* (L.) Trin. | . | . | . | . | 2 |
| *Agrostis capillaris* L. | . | . | . | . | 1 |
| *Cytisus scoparius* (L.) Link juv. | . | . | . | 1 | . |
| *Prunus serotina* Ehrh. juv | . | . | . | 1 | . |
| *Erigeron canadensis* L. | . | . | . | + | . |
| *Anarrhinum bellidifolium* (L.) Willd. | . | . | 2 | . | . |

Table 2. Vascular vegetation relevés with relevant presence of *C. conista* (1-2) and *C. pulvinata* (3-5). Localities: M Bosco del Modrone; P La Promessa; T Brughiera di Tornavento; V Vauda Alta. Vegetation types: TA Thero-Airion dry grassland; CG open *Calluna* heathland.

# Chapter 3

# Conservation of terricolous cryptogams in continental lowlands: the role of open dry habitats

Gabriele Gheza, Silvia Assini, Chiara Lelli,
Lorenzo Marini, Helmut Mayrhofer, Juri Nascimbene

## Abstract

Open dry habitats are of fundamental relevance for the conservation of terricolous cryptogams in human-impacted lowlands. However, these organisms are often not enough considered in the management of these habitats. To demonstrate this important role, we investigated richness and diversity of lichen and bryophyte communities in the three main dry habitats occurring in temperate lowlands of Europe, i.e. acidic dry grasslands, calcareous dry grasslands, *Calluna vulgaris* heathlands. Lichen and bryophyte species were recorded in 287 circular plots (radius = 3 m) placed in 76 sites of the central-western Po Plain (N Italy), together with the main environmental variables, i.e. vegetation structure, habitat type and dynamic stage (pioneer vs mature), soil pH and texture, annual temperature and rainfall. Data were analyzed at landscape (habitat) and local (dynamic stage) levels. Species assemblages were analyzed by means of a non-parametric MANOVA and a non-metric Multidimensional Scaling; character species of habitat types and dynamic stages were detected by means of an Indicator Species Analysis; the role of the enviromental variables in shaping species assemblages was tested by means of a PERMANOVA. Species assemblages differed significantly between the habitat types for both lichens and bryophytes, while pioneer stage differed significantly from mature stage only within heathlands. However, the ISA showed the presence of significant indicator species for each habitat type and for each dynamic stage within all the the three habitat types. Habitat type, dynamic stage, substrate texture, annual precipitation and cover of the shrub layer had a significant effect in shaping both bryophyte and lichen assemblages; substrate pH had an effect on lichens and the interaction between substrate pH and texture had an effect on bryophytes. The three considered habitats host habitat-specific terricolous cryptogam assemblages rich in total and rare species: therefore, their management should aim also to the conservation of lichens and bryophytes. Furthermore, in some cases cryptogam assemblages differ also in the different dynamic stages found within the same habitat type: therefore, an optimal management should guarantee the maintaining of a mosaic of pioneer and mature patches.

## Keywords

Bryophytes, Dry Grasslands, Dry Heaths, Lichens, Natura 2000 Network, Vegetation Management.

# Introduction

The management of overlooked organisms is a crucial goal that should be pursued in nature conservation. In fact, management actions and protected areas are often planned basing on the so-called "charismatic species", leaving other taxa neglected (Rubio-Salcedo *et al*. 2013).

Cryptogams are one of the frequently overlooked taxa. They are generally less studied than vascular plants, and, among them, terricolous ones are less frequently studied than epiphytes. In the last decades, however, a rising of interest for these organisms has been evident, due to the increasing awareness towards the so-called "biological soil crusts" (e.g. Weber *et al*. 2016), which are very important components of structure, biodiversity and ecosystem functioning mainly in dry habitats.

In the European Union, the Natura 2000 network (based on the "Habitat Directive" – Council Directive 92/43/EEC) is the most important network of protected areas, currently covering almost 18% of the terrestrial surface of the EU member States (plus over 217,000 square kilometres of marine area). The Natura 2000 Network has been proved to be not always effective for the conservation of cryptogams (Rubio-Salcedo *et al*. 2013). This depends also on the ecology of the assessed species, since in some cases protected areas established on the basis of "charismatic species" have been demonstrated to be effective also for certain lichen species (Martinez *et al*. 2006). Among the Natura 2000 habitats, only few ones are formally described by specific cryptogam taxa and not only by vascular plants. This is the case of habitats in which lichens and bryophytes play an important role in shaping the landscape (e.g. boreo-arctic and alpine tundras, Natura 2000 code 4060) and, in very rare cases, of habitats which are totally built-up by cryptogams (e.g. petrifying springs with moss vegetation of the *Cratoneurion*, Natura 2000 code 7220). The Interpretation Manual of the European Union Habitats indicates some specific cryptogam taxa for describing the Habitats 2130 ("fixed dunes with herbaceous vegetation ("grey dunes")), 2330 ("Inland dunes with open *Corynephorus* and *Agrostis* grasslands"), 2340 ("Pannonic inland dunes"). The Habitat 2330, together with other dry grasslands (Natura 2000 code 6210) and dry heaths (Natura 2000 code 4030) of continental lowlands, can host many terricolous cryptogams. Anyway, even if studies including information about the presence, abundance and role of cryptogams in such habitats are available (e.g. Chytrý *et al*. 2001; Matt & Legg 2008; Jüriado *et al*. 2012; Ketner-Oostra *et al*. 2012; Gheza *et al*. 2016), the management models developed by EU do not deserve sufficient attention on specific measures to these organisms (cf. ec.europe.eu/environment/nature/natura2000/management/habitats/models_eu.htm), while high attention and many measures are particularly focused on vascular vegetation and/or species. This could also possibly be due to the scarce basic knowledge or experience about the techniques suitable to promote and reinforce cryptogams and biological soil crusts in such habitats.

In the lowland areas of Europe, the aforementioned cryptogam-rich dry habitats are generally developed on arid or semiarid and oligotrophic soils and can still occupy large extents (JENTSCH & BEYSCHLAG 2003; KETNER-OOSTRA & SÝKORA 2008). While most research focused on single habitats, only a few studies focused on how the cryptogam assemblages differ in different coastal dry habitats (e.g. JÜRIADO *et al*. 2016) and, at our knowledge, no studies were devoted to disclose how cryptogam communities differ in different lowland inland dry habitat patches located in a human-impacted landscape.

Recent studies (GHEZA, 2015; GHEZA *et al*., 2018a, b) highlighted the importance of these habitats for rare terricolous lichens in the Po Plain (N Italy), which is one of the most human-impacted area of the whole Europe, but the actual role of habitat diversity in supporting terricolous cryptogam diversity in that context has not yet been fully demonstrated.

This paper aims therefore at showing the importance of dry grasslands and heathlands for the conservation of terricolous lichen and bryophyte diversity in anthropized landscapes, also in refence to the dynamic stage of the vegetation.

In particular, we addressed the following questions:

(1) are the inland dry habitats actually important for terricolous cryptogams in human-impacted lowland areas with temperate climate?

(2) do different dry habitats – *Calluna* heathlands, acidic grasslands, calcareous grasslands – host different cryptogam assemblages?

(3) are there any species, either of conservation concern or not, and species assemblages that significantly characterize one habitat type in particular?

(4) are there any differences not only at a landscape level (habitat type) but also at a local level (i.e. between pioneer and mature stages within each habitat)?

(5) are the answers to the previous questions useful to develop management models aimed at the conservation of the biodiversity in these habitats?

## Material and methods

### *Study area*

This study was carried out in the central-western Po Plain, in an area ranging from the surroundings of Turin in Piedmont to the boundary between Lombardy and Veneto. Mean annual temperature ranges between 11 °C and 13.5 °C. Annual rainfall ranges between 600 mm and 1200 mm. Soil pH varies from very acidic and acidic (pH = 4–5, north of the Po river) to subneutral (pH = 6, surroundings of the Po river) and basic (pH = 7, south of the Po river). Altitude ranges beetween 70 and 400 m a.s.l.

In this area, lichen-rich dry habitats include grasslands on both acidic (attributed to the Natura 2000 Habitats 2330, “Inland dunes with open *Corynephorus* and *Agrostis* grasslands”, and 6210, “Seminatural dry grasslands and scrubland facies on calcareous substrates”) and calcareous (Habitat 6110*, “Rupicolous calcareous or basophilic grasslands of the *Alysso-Sedion albi*”, and 6210*, prioritary when important for orchids) substrates and *Calluna vulgaris*-dominated heathlands (Habitat 4030, “European dry heaths”). In this area, habitats 2330 and 4030 are at the southernmost edge of their range (Assini *et al.*, 2013; Gheza, 2015) and they are often extremely fragmented, being usually located in marginal and unproductive areas and not actively managed. Furthermore, terricolous cryptogam communities in this area are known to be species-poorer and richer in species with more Mediterranean distribution in comparison to cryptogam communities found in the same habitats in central Europe (Gheza *et al*. 2016).

A preliminary site selection was performed checking the available maps in order to find all the areas with natural and semi-natural lichen-rich dry habitats. This process resulted in 17 areas, of which 13 potentially hosting dry grasslands distributed along the main river valleys (Ticino, Sesia, Dora Baltea, Stura di Demonte, Po, Orba, Scrivia, Lambro, Adda, Brembo, Serio, Oglio) and in the Lomellina, and 4 hosting *Calluna* heathlands distributed in the Upper Plain (Vaude Canavesane, Baragge Biellesi-Vercellesi, Brughiere Lonatesi, Groane Milanesi). In these areas, lichen-rich sites were preliminary identified by analyzing GIS maps and thanks to the cooperation with local botanists and Park managers. These sites were inspected during winters 2015–2016 and 2016–2017 in order to evaluate their suitability for this study. All the habitat patches attributable to the Natura 2000 Habitats targeted by this research were considered suitable. Overall, 39 acidic grasslands, 15 calcareous grasslands and 22 *Calluna* heathlands resulted suitable. For each site, mean annual temperature and precipitation were retrieved from the website of the Regional Environmental Agencies of Piedmont (www.arpa.piemonte.gov.it) and Lombardy (www2.arpalombardia.it), using the values of the nearest meteorological station.

### ***Sampling design***

In each site, plots were placed at regular spatial spans along a linear transect placed between the two furthest vertices of the habitat patch using Qgis (Qgis Development Team, 2009). The number of plots was proportional to the site area: 1 plot for sites between 100 and 1000 m$^2$; 2 plots between 1001 and 3000 m$^2$; 3 plots between 3001 and 5000 m$^2$; 5 plots between 5001 and 20,000 m$^2$; and 7 plots for areas larger than 20,000 m$^2$. This resulted in a total of 287 plots. The plots were circular, with a 3 m radius.

Vegetation was surveyed in each plot between April and June 2016 in grasslands and between May and July 2017 in heathlands. In each plot, the cover (%) and the mean height of the five vegetation layers (arboreal, higher-shrubby, lower-shrubby, herbaceous, cryptogamic) were recorded, as well as the cover (%) of each vascular plant, bryophyte and lichen species. Most species were identified in the Laboratory of Flora, Vegetation and Ecosystem Services of the University of Pavia, where voucher specimens are stored. Several lichen specimens, identifiable only on the basis of chemical analyses, were checked by thin-layer chromatography for secondary metabolites. Critical bryophyte specimens were checked by an expert bryologist. Nomenclature follows Cortini Pedrotti (2001, 2006) for bryophytes and Nimis (2016) for lichens.

In each plot, we also recorded: 1) soil pH, measured in the field with a portable kit; 2) soil texture, evaluated qualitatively in the following five categories: clayey, loamy, sandy, sandy-pebbly, organic; 3) the overall human trampling, estimated according to a categorical scale: 0 (no trampling), 1 (<5 m$^2$ showing evidence of trampling on vegetation and/or bare soil), 2 (5–10 m$^2$), 3 (10–15 m$^2$), 4 (>15 m$^2$); 4) the abundance of Lagomorphs fecal pellets (mainly belonging to the invasive *Sylvilagus floridanus*), estimated according to a categorical scale: 0 (no pellet), 1 (<2 pellet/m$^2$), 2 (3–5 pellet/m$^2$), 3 (>5 pellet/m$^2$). According to Clark *et al.* (2005), the amount of fecal pellets was used as a proxy for soil eutrophication. During the fieldwork we also quantified grazing activity by ungulates, boar rooting and damages due to floods, but these disturbances were found in only a few plots and therefore their effect was not considered.

Each plot was classified *a posteriori* as either pioneer or mature according to the percent cover of the main biological forms of vascular plants surveyed in it. Grassland plots were considered mature when less than 35% of plant cover was made by therophytes and more than 35% of plant cover was made by hemicryptophytes; otherwise, they were considered pioneer. Heathland plots were considered mature when *Molinia arundinacea* covered more than 25% and/or phanerophytes covered more than 25% in the shrub layer; otherwise, they were considered pioneer.

Since a Red List for cryptogam species is available in Italy only for epiphytic lichens (Nascimbene *et al*. 2013), information about commonness and rarity of the bryophyte and lichen species in the whole Italy were retrieved from Cortini Pedrotti (2001, 2006) and Nimis (2016). This information was simplified in two categories: rare (including the categories "extremely rare", "very rare", "rare" and "rather rare" by Nimis, 2016) and common (including the categories "rather common", "common", "very common" and "extremely common" by Nimis, 2016).

### ***Statistical analysis***

After have tested the normality of the data, the environmental variables and the number of total, rare and common species were compared between the habitat types and the dynamic stages by means of the Kruskal-Wallis test and plotted on boxplot graphs.

The differences within the overall, lichen and bryophyte composition between the three habitats and their dynamic stages were tested by means of a non-parametric one-way multivariate analysis of variance (NP-MANOVA) and plotted on a non-metric multidimensional scaling (NMDS) scatterplot. The euclidean distance was used as distance measure and statistical significance was given by a permutation test with 9999 permutations. For this analysis, the percent cover values of the species recorded in the field were re-scaled as follows: 1 (cover 0.1-10%), 2 (cover 11-20%), 3 (cover 21-30%), 4 (cover 31-40%), 5 (cover 41-50%), 6 (cover 51-60%), 7 (cover 61-70%), 8 (cover 71-80%), 9 (cover 81-90%), 10 (cover 91-100%).

The role of the habitat types and the dynamic stages in shaping lichen assemblages was tested by means of a PERMANOVA. Also the environmental, structural and climatic variables were included in this analysis, to test if also other variables than habitat type and dynamic stage can have an effect.

The indicator species of each habitat type and dynamic stage were established by means of an indicator species analysis (ISA). Statistical significance was given by a permutation test with 9999 permutations.

Statistical analyses were carried out with the softwares R (R Core Team 2015) and PAST (Hammer *et al.* 2001).

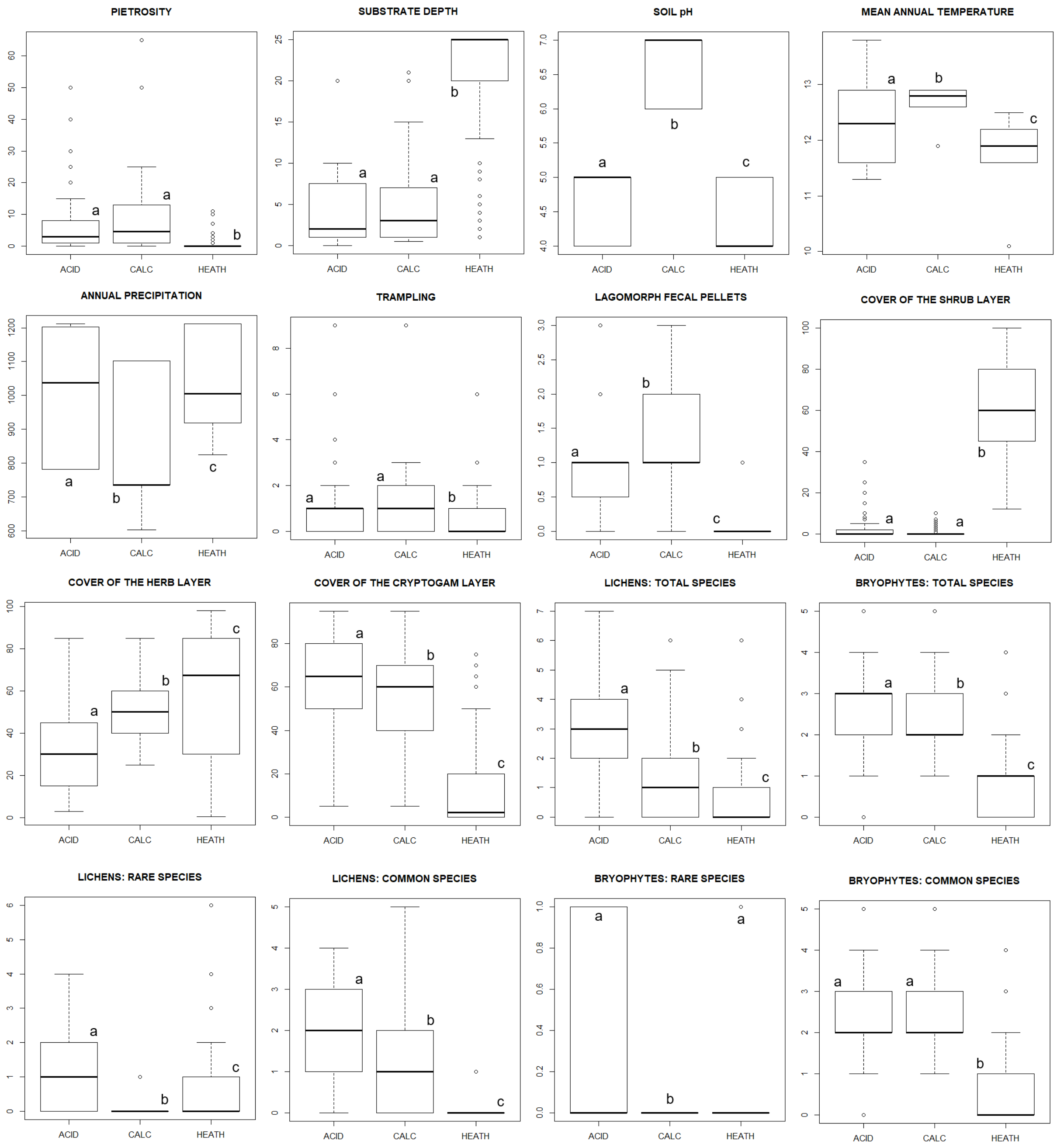

Figure 1. Boxplots of the environmental, structural and climatic variables and the number of total, rare and common species between the habitat types. Different letters indicate statistically significant differences ($p<0.05$). ACID: acidic grasslands. CALC: calcareous grasslands. HEATH: *Calluna* heathlands.

## Results

Overall, 33 lichen and 22 bryophyte species were surveyed. Among them, 4 species are of conservation concern according to the Habitat Directive – *Cladonia portentosa*, *Leucobryum glaucum*, *Sphagnum compactum*, *Sphagnum papillosum* – and 7 lichen species are of particular interest being very rare in lowland areas – *Cladonia coccifera*, *Cladonia strepsilis*, *Cladonia uncialis*, *Dibaeis baeomyces*, *Pycnothelia papillaria* – or in the whole Italy – *Cladonia peziziformis*, *Stereocaulon condensatum*.

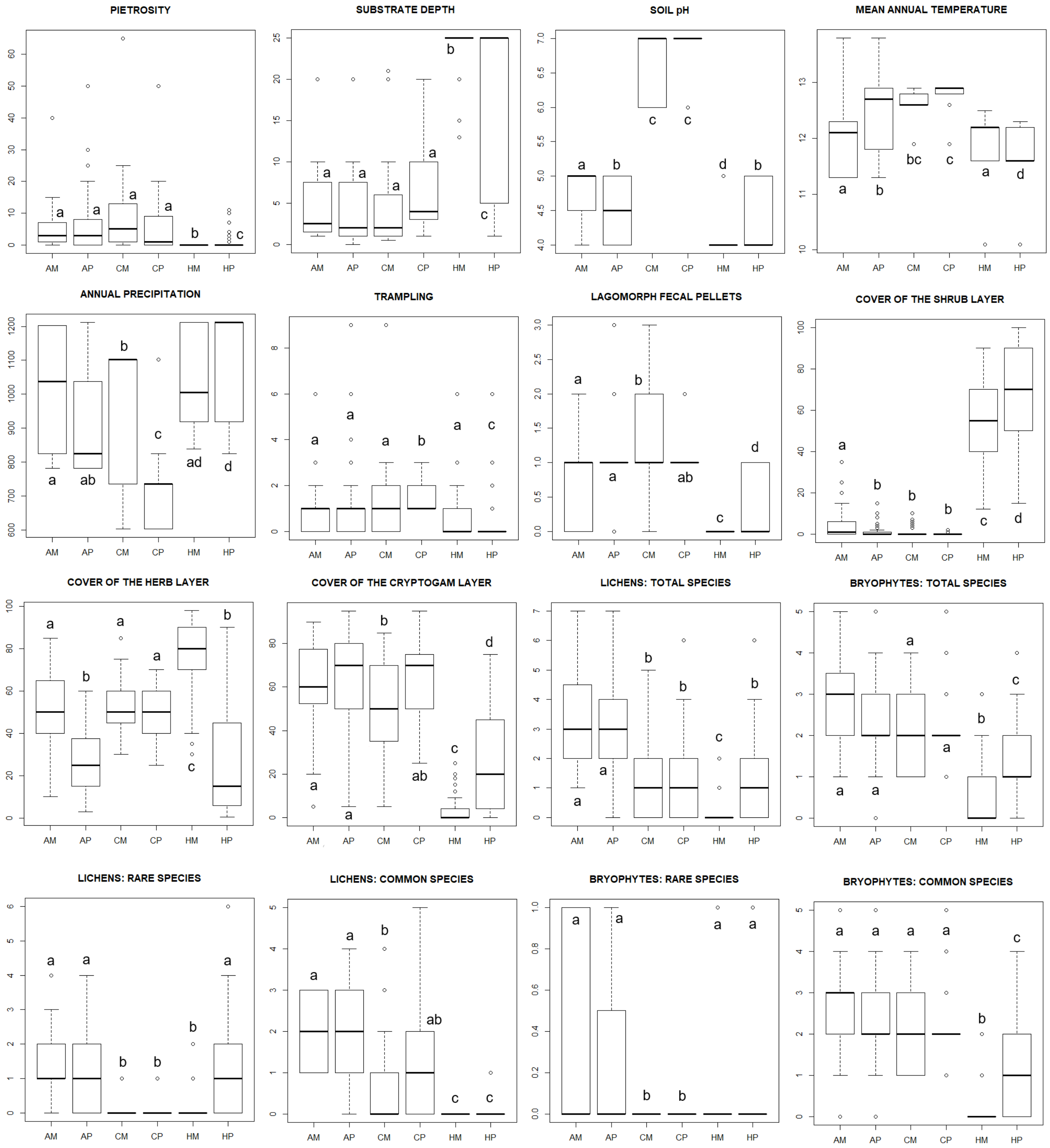

Figure 2. Boxplots of the environmental, structural and climatic variables and the number of total, rare and common species between the dynamic stages. Different letters indicate statistically significant differences (p<0.05). AM: mature acidic grasslands. AP: pioneer acidic grasslands. CM: mature calcareous grasslands. CP: pioneer calcareous grasslands. HM: mature heathlands. HP: pioneer heathlands.

The three habitat types differed significantly in all the considered variables (Fig. 1). The pairwise comparisons showed that most of these variables differed across all the three habitat types; only pietrosity, soil depth, total cover, cover of the shrub layer, number of common bryophytes and numer of common/total lichens differed between the heathlands and the two grassland types but did not differ between acidic and calcareous grasslands, whereas number of rare bryophytes and number of rare/total bryophytes did not differ between acidic grasslands and heathlands. Also the dynamic stages differed often within the same habitat or at least across the three habitat types for most the considered variables (Fig. 2).

| | **All dataset** | | **Lichens** | | **Bryophytes** | |
|---|---|---|---|---|---|---|
| **Habitat vs habitat (not separating between dynamic stages)** | | | | | | |
| Heathlands vs Acidic grasslands | 0.0003 | *** | 0.0003 | *** | 0.0003 | *** |
| Acidic grasslands vs Calcareous grasslands | 0.0003 | *** | 0.0003 | *** | 0.0003 | *** |
| Calcareous grasslands vs Heathlands | 0.0003 | *** | 0.0027 | ** | 0.0003 | *** |
| **Pioneer stage vs mature stage within the habitats** | | | | | | |
| Heathlands | 0.0015 | ** | 0.0015 | ** | 0.0015 | ** |
| Acidic grasslands | 0.9975 | N.S. | 1.0000 | N.S. | 1.0000 | N.S. |
| Calcareous grasslands | 1.0000 | N.S. | 0.1080 | N.S. | 1.0000 | N.S. |
| **Habitat vs habitat within the pioneer stage** | | | | | | |
| Heathlands vs Acidic grasslands | 0.0015 | ** | 0.0015 | ** | 0.0015 | ** |
| Acidic grasslands vs Calcareous grasslands | 0.0015 | ** | 0.2760 | N.S. | 0.0015 | ** |
| Calcareous grasslands vs Heathlands | 0.0015 | ** | 0.0030 | ** | 0.0015 | ** |
| **Habitat vs habitat within the mature stage** | | | | | | |
| Heathlands vs Acidic grasslands | 0.0015 | ** | 0.0015 | ** | 0.0015 | ** |
| Acidic grasslands vs Calcareous grasslands | 0.0015 | ** | 0.0015 | ** | 0.0015 | ** |
| Calcareous grasslands vs Heathlands | 0.0015 | ** | 0.0195 | * | 0.0015 | ** |

Table 1. Results of the NP-MANOVA.

According to the NP-MANOVA, the three habitats differed significantly between them in terms of overall, lichen and bryophyte composition (Tab. 1). Considering also the two dynamic stages of each habitat, the pioneer stage differed significantly from the mature stage only within the heathlands (p=0.0015), while no significant difference was found within the two grassland types (Tab. 1). Considering the same stage across the habitat types, the pioneer stage differed significantly across the habitats except in the case of the two grassland types for the lichen composition (p=0.2760) (Tab. 1), whereas the mature stage differed significantly across the habitat types in every case (Tab. 1).

In spite of the presence of a zone where the three groups partly overlap, the NMDS scatterplot shows a clear separation between the habitat types in terms of overall, lichen and bryophyte composition (Fig. 3), in accord with the NP-MANOVA. The separation between the two dynamic stages within each habitat type is less clear, except within the heathlands, backing also in this case the results of the NP-MANOVA.

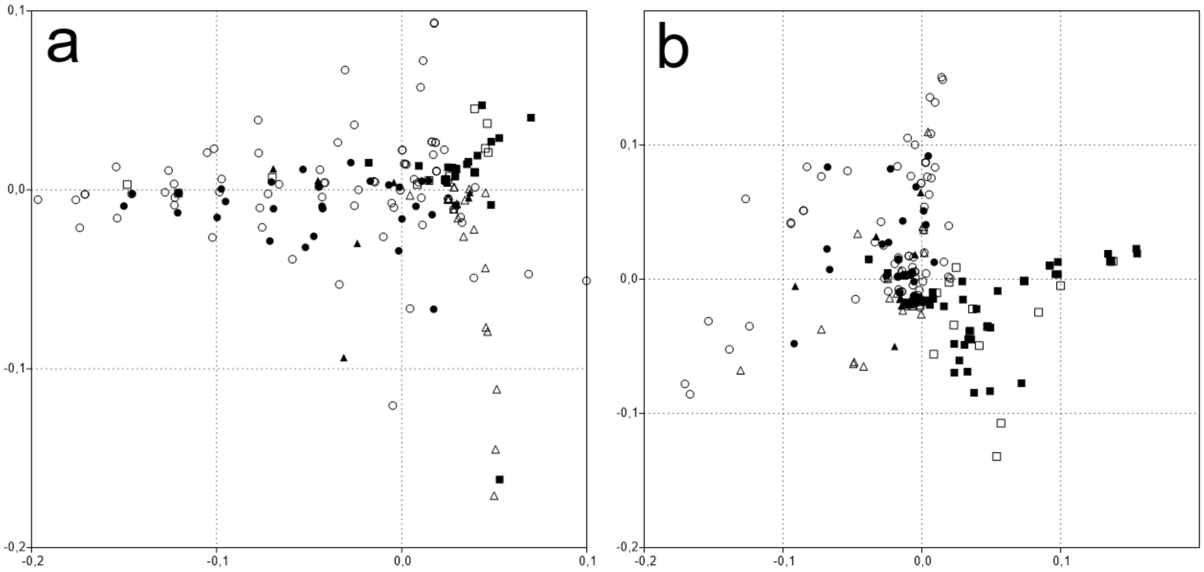

Figure 3. NMDS scatterplots of (a) lichen and (b) bryophyte assemblages. *Calluna* heathlands are reported with triangles, acidic dry grasslands with circles, calcareous dry grasslands with squares. Empty symbols indicate pioneer plots, full symbols indicate mature plots.

According to the PERMANOVA, habitat type, dynamic stage, substrate texture, annual precipitation and cover of the shrub layer had a significant effect in shaping both bryophyte and lichen assemblages (Tab. 2). Furthermore, substrate pH had an effect on the composition of lichen communities and the interaction between substrate pH and texture had an effect on bryophyte communities (Tab. 2). No significant effect was due to the cover of the herbaceous layer (Tab. 2).

The ISA showed the presence of several indicator species in each habitat type (Tab. 3) and dynamic stage (Tab. 4).

At habitat level, 33 significant indicator species overall were detected. *Calluna* heathlands had 13 exclusive species and 14 indicator species (2 statistically significant). Acidic grasslands had 10 exclusive species and 25 indicator species (17 significant).

Calcareous grasslands had 11 exclusive species and 16 indicator species (14 significant). Considering also the dynamic stages, the number of overall significant indicator species changes. Pioneer heathlands had 8 exclusive species and 12 indicator species (5 significant), whereas mature ones had 3 exclusive species and 5 indicator species (1 significant). Pioneer acidic grasslands had 6 exclusive species and 13 indicator species (6 significant), whereas mature ones had no exclusive species and 10 indicator species (7 significant). Pioneer calcareous grasslands had 1 exclusive species and 9 indicator species (6 significant), whereas mature ones had 1 exclusive species and 6 indicator species (5 significant).

| | **Lichens** | | | **Bryophytes** | | |
|---|---|---|---|---|---|---|
| | **$R^2$** | **p** | | **$R^2$** | **p** | |
| Habitat type | 0.2185 | 0.001 | *** | 0.3116 | 0.001 | *** |
| Dynamic stage | 0.0469 | 0.001 | *** | 0.0219 | 0.001 | *** |
| Macroarea | 0.1762 | 0.001 | *** | 0.1231 | 0.001 | *** |
| Substrate texture | 0.0191 | 0.017 | * | 0.0187 | 0.016 | * |
| Substrate pH | 0.0106 | 0.004 | ** | 0.0039 | 0.108 | N.S. |
| Substrate texture * pH | 0.0139 | 0.271 | N.S. | 0.0201 | 0.001 | *** |
| Precipitation | 0.0204 | 0.001 | *** | 0.0067 | 0.013 | * |
| Cover shrub layer | 0.0113 | 0.002 | ** | 0.0084 | 0.002 | ** |
| Cover herb layer | 0.0049 | 0.092 | N.S. | 0.0035 | 0.152 | N.S. |

Table 2. Results of the PERMANOVA.

## Discussion

Overall, 55 terricolous cryptogam species – 33 lichens and 22 bryophytes – were surveyed in this study. Only 3 bryophyte species (14%) are considered rare in Italy, whereas 20 lichen species (61%) are considered rare or very rare in Italy. This difference could be due to the scarce knowledge of terricolous lichens in Italy.

The occurrence in dry habitats of lichen species which have boreo-alpine distribution and are very rare in lowland areas with temperate climate increases their conservation value. In Italy, many of these species are found, at low altitude, only in these dry habitats (Gheza 2015; Gheza *et al.* 2018b), and some of them are rare or very rare on the whole national territory (cf. Nimis 2016). This value of dry habitats for rare lichen species is confirmed from the whole Europe (e.g. Aptroot *et al.* 2011; Adamska & Deptula 2015; Jüriado *et al.* 2016).

|  | Heathlands |  |  |  | Acidic grasslands |  |  |  | Calcareous grasslands |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | **Total** | **Exclusive** | **INDVAL** | **p-value** | **Total** | **Exclusive** | **INDVAL** | **p-value** | **Total** | **Exclusive** | **INDVAL** | **p-value** |
| *Cladonia caespiticia* | X | X | 0.87 | 1.0000 |  |  |  |  |  |  |  |  |
| *Cladonia cervicornis* | X | X | 2.63 | 0.1716 |  |  |  |  |  |  |  |  |
| *Cladonia pulvinata* | X | X | **3.51** | **0.0507** |  |  |  |  |  |  |  |  |
| *Cladonia verticillata* | X | X | 2.63 | 0.1628 |  |  |  |  |  |  |  |  |
| *Dibaeis baeomyces* | X | X | 0.88 | 1.0000 |  |  |  |  |  |  |  |  |
| *Pycnothelia papillaria* | X | X | 0.88 | 1.0000 |  |  |  |  |  |  |  |  |
| *Cetraria aculeata* |  |  |  |  | X | X | 3.47 | 0.0829 |  |  |  |  |
| *Cladonia cariosa* |  |  |  |  | X | X | **5.21** | **0.0240** |  |  |  |  |
| *Cladonia chlorophaea* | X |  |  |  | X |  | 5.04 | 0.0938 | X |  |  |  |
| *Cladonia coccifera* | X |  |  |  | X |  | **10.48** | **0.0456** |  |  |  |  |
| *Cladonia foliacea* |  |  |  |  | X | X | **60.86** | **0.0001** |  |  |  |  |
| *Cladonia furcata* |  |  |  |  | X | X | **26.09** | **0.0001** |  |  |  |  |
| *Cladonia peziziformis* | X |  |  |  | X |  | 4.98 | 0.1095 |  |  |  |  |
| *Cladonia polycarpoides* | X |  |  |  | X |  | **20.03** | **0.0001** |  |  |  |  |
| *Cladonia portentosa* | X |  |  |  | X |  | **11.36** | **0.0003** |  |  |  |  |
| *Cladonia pyxidata* |  |  |  |  | X | X | **22.61** | **0.0001** |  |  |  |  |
| *Cladonia rangiformis* | X |  |  |  | X |  | **63.54** | **0.0001** | X |  |  |  |
| *Cladonia rei* | X |  |  |  | X |  | **14.62** | **0.0098** | X |  |  |  |
| *Cladonia squamosa* |  |  |  |  | X | X | **8.69** | **0.0008** |  |  |  |  |
| *Cladonia strepsilis* | X |  |  |  | X |  | 1.56 | 105.54.00 |  |  |  |  |
| *Cladonia uncialis* |  |  |  |  | X | X | 0.87 | 1.0000 |  |  |  |  |
| *Stereocaulon condensatum* |  |  |  |  | X | X | **6.09** | **0.0084** |  |  |  |  |
| *Blennothallia crispa* |  |  |  |  |  |  |  |  | X | X | **3.45** | **0.0376** |
| *Cladonia convoluta* |  |  |  |  | X |  |  |  | X |  | **8.26** | **0.0021** |
| *Cladonia fimbriata* | X |  |  |  | X |  |  |  | X |  | 0.85 | 1.0000 |
| *Cladonia humilis* |  |  |  |  |  |  |  |  | X | X | **5.17** | **0.0093** |
| *Cladonia symphycarpa* |  |  |  |  |  |  |  |  | X | X | **8.62** | **0.0008** |
| *Enchylium tenax* |  |  |  |  |  |  |  |  | X | X | **6.89** | **0.0008** |
| *Gyalolechia fulgens* |  |  |  |  |  |  |  |  | X | X | **3.45** | **0.0399** |
| *Placidium squamulosum* |  |  |  |  |  |  |  |  | X | X | **25.86** | **0.0001** |
| *Psora decipiens* |  |  |  |  |  |  |  |  | X | X | **18.97** | **0.0001** |
| *Scytinium schraderi* |  |  |  |  |  |  |  |  | X | X | 1.72 | 0.1998 |
| *Toninia sedifolia* |  |  |  |  |  |  |  |  | X | X | **18.97** | **0.0001** |
| **Total lichens** | 15 | 6 | 6 | 1 | 18 | 8 | 16 | 11 | 14 | 9 | 11 | 9 |
| *Atrichum angustatum* | X | X | 0.88 | 1.0000 |  |  |  |  |  |  |  |  |
| *Calypogeia arguta* | X | X | 2.63 | 0.1714 |  |  |  |  |  |  |  |  |
| *Ditrichum heteromallum* | X | X | 0.88 | 1.0000 |  |  |  |  |  |  |  |  |
| *Eurhynchium hians* | X | X | 1.75 | 0.1912 |  |  |  |  |  |  |  |  |
| *Hypnum jutlandicum* | X | X | **3.51** | **0.0510** |  |  |  |  |  |  |  |  |
| *Leucobryum glaucum* | X |  | 2.35 | 0.2413 | X |  |  |  |  |  |  |  |
| *Sphagnum compactum* | X | X | 2.63 | 0.1760 |  |  |  |  |  |  |  |  |
| *Sphagnum papillosum* | X | X | 0.88 | 1.0000 |  |  |  |  |  |  |  |  |
| *Campylopus introflexus* | X |  |  |  | X |  | **17.07** | **0.0028** |  |  |  |  |
| *Ceratodon purpureus* | X |  |  |  | X |  | **65.45** | **0.0001** | X |  |  |  |
| *Dicranum scoparium* |  |  |  |  | X | X | 1.74 | 0.3498 |  |  |  |  |
| *Hypnum cupressiforme* | X |  |  |  | X |  | 7.15 | 0.1406 |  |  |  |  |
| *Polytrichastrum formosum* | X |  |  |  | X |  | **10.03** | **0.0480** |  |  |  |  |
| *Polytrichum piliferum* | X |  |  |  | X |  | **71.82** | **0.0001** |  |  |  |  |
| *Pseudocrossidium hornsuchianum* |  |  |  |  | X | X | 0.87 | 1.0000 |  |  |  |  |
| *Racomitrium canescens* |  |  |  |  | X |  | **10.66** | **0.0011** | X |  |  |  |
| *Riccia ciliifera* |  |  |  |  | X |  | **9.49** | **0.0009** | X |  |  |  |
| *Brachythecium albicans* |  |  |  |  | X |  |  |  | X |  | **7.83** | **0.0021** |
| *Didymodon fallax* |  |  |  |  |  |  |  |  | X | X | **75.86** | **0.0001** |
| *Rhynchostegium megapolitanum* |  |  |  |  |  |  |  |  | X | X | **20.69** | **0.0001** |
| *Syntrichia ruralis* |  |  |  |  | X |  |  |  | X |  | **23.29** | **0.0001** |
| *Tortella tortuosa* |  |  |  |  | X |  |  |  | X |  | **72.54** | **0.0001** |
| **Total bryophytes** | 13 | 7 | 8 | 1 | 13 | 2 | 9 | 6 | 8 | 2 | 5 | 5 |
| **Total species** | 28 | 13 | 14 | 2 | 31 | 10 | 25 | 17 | 22 | 11 | 16 | 14 |

Table 3. Number of total, exclusive, indicator and statistically significant indicator species for each habitat type.

| | **Heathlands** | | | | | | | | **Acidic grasslands** | | | | | | | | **Calcareous grasslands** | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Pioneer** | | | | **Mature** | | | | **Pioneer** | | | | **Mature** | | | | **Pioneer** | | | | **Mature** | | | |
| | **T** | **E** | **INDVAL** | **P** | **T** | **E** | **INDVAL** | **P** | **T** | **E** | **INDVAL** | **P** | **T** | **E** | **INDVAL** | **P** | **T** | **E** | **INDVAL** | **P** | **T** | **E** | **INDVAL** | **P** |
| *Cladonia caespiticia* | X | X | 2.22 | N.S. | | | | | | | | | | | | | | | | | | | | |
| *Cladonia cervicornis* | X | X | **6.67** | * | | | | | | | | | | | | | | | | | | | | |
| *Cladonia coccifera* | X | | **16.67** | ** | X | | | | X | | | | X | | | | | | | | | | | |
| *Cladonia pulvinata* | X | | 2.69 | N.S. | X | | | | | | | | | | | | | | | | | | | |
| *Cladonia strepsilis* | X | | 1.91 | N.S. | | | | | X | | | | X | | | | | | | | | | | |
| *Cladonia verticillata* | X | X | **6.67** | * | | | | | | | | | | | | | | | | | | | | |
| *Pycnothelia papillaria* | X | X | 2.22 | N.S. | | | | | | | | | | | | | | | | | | | | |
| *Dibaeis baeomyces* | | | | | X | X | 1.45 | N.S. | | | | | | | | | | | | | | | | |
| *Cetraria aculeata* | | | | | | | | | X | X | 4.59 | N.S. | | | | | | | | | | | | |
| *Cladonia cariosa* | | | | | | | | | X | | 3.54 | N.S. | X | | | | | | | | | | | |
| *Cladonia chlorophaea* | X | | | | | | | | X | | 5.12 | N.S. | | | | | X | | | | X | | | |
| *Cladonia foliacea* | | | | | | | | | X | | **32.32** | *** | X | | | | | | | | | | | |
| *Cladonia furcata* | | | | | | | | | X | X | **34.48** | *** | | | | | | | | | | | | |
| *Cladonia peziziformis* | X | | | | X | | | | X | | 2.60 | N.S. | X | | | | | | | | | | | |
| *Cladonia portentosa* | X | | | | | | | | X | | **10.77** | ** | X | | | | | | | | | | | |
| *Cladonia uncialis* | | | | | | | | | X | X | 1.15 | N.S. | | | | | | | | | | | | |
| *Stereocaulon condensatum* | | | | | | | | | X | X | **8.05** | ** | | | | | | | | | | | | |
| *Cladonia fimbriata* | X | | | | | | | | | | | | X | | 1.55 | N.S. | | | | | X | | | |
| *Cladonia polycarpoides* | X | | | | | | | | X | | | | X | | **20.02** | *** | | | | | | | | |
| *Cladonia pyxidata* | | | | | | | | | X | | | | X | | **27.30** | *** | | | | | | | | |
| *Cladonia rangiformis* | X | | | | | | | | X | | | | X | | **47.11** | *** | X | | | | X | | | |
| *Cladonia rei* | X | | | | | | | | X | | | | X | | **18.13** | ** | | | | | X | | | |
| *Cladonia squamosa* | | | | | | | | | X | | | | X | | **17.64** | *** | | | | | | | | |
| *Cladonia convoluta* | | | | | | | | | X | | | | | | | | X | | **17.38** | ** | X | | | |
| *Cladonia symphycarpa* | | | | | | | | | | | | | | | | | X | | **7.25** | * | X | | | |
| *Blennothallia crispa* | | | | | | | | | | | | | | | | | X | | 4.16 | N.S. | X | | | |
| *Enchylium tenax* | | | | | | | | | | | | | | | | | X | | **8.31** | * | X | | | |
| *Gyalolechia fulgens* | | | | | | | | | | | | | | | | | X | | 4.16 | N.S. | X | | | |
| *Scytinium schraderi* | | | | | | | | | | | | | | | | | X | X | 5.88 | N.S. | | | | |
| *Toninia sedifolia* | | | | | | | | | | | | | | | | | X | | **13.64** | ** | X | | | |
| *Cladonia humilis* | | | | | | | | | | | | | | | | | | | | | X | X | **7.31** | * |
| *Placidium squamulosum* | | | | | | | | | | | | | | | | | X | | | | X | | **14.29** | *** |
| *Psora decipiens* | | | | | | | | | | | | | | | | | X | | | | X | | **10.24** | ** |
| **Total lichen species** | 14 | 4 | 7 | 3 | 4 | 1 | 1 | 0 | 17 | 4 | 9 | 4 | 12 | 0 | 6 | 5 | 11 | 1 | 7 | 4 | 13 | 1 | 3 | 3 |
| *Atrichum angustatum* | X | X | 2.22 | N.S. | | | | | | | | | | | | | | | | | | | | |
| *Calypogeia arguta* | X | X | **6.67** | * | | | | | | | | | | | | | | | | | | | | |
| *Ditrichum heteromallum* | X | X | 2.22 | N.S. | | | | | | | | | | | | | | | | | | | | |
| *Eurhynchium hians* | X | X | 4.44 | N.S. | | | | | | | | | | | | | | | | | | | | |
| *Polytrichastrum formosum* | X | | **13.60** | ** | X | | | | X | | | | X | | | | | | | | | | | |
| *Hypnum jutlandicum* | X | | | | X | | 2.88 | N.S. | | | | | | | | | | | | | | | | |
| *Leucobryum glaucum* | | | | | X | | 3.19 | N.S. | X | | | | X | | | | | | | | | | | |
| *Sphagnum compactum* | | | | | X | X | **4.35** | * | | | | | | | | | | | | | | | | |
| *Sphagnum papillosum* | | | | | X | X | 1.45 | N.S. | | | | | | | | | | | | | | | | |
| *Ceratodon purpureus* | X | | | | | | | | X | | **32.94** | *** | X | | | | X | | | | X | | | |
| *Dicranum scoparium* | | | | | | | | | X | X | 2.29 | N.S. | | | | | | | | | | | | |
| *Polytrichum piliferum* | X | | | | | | | | X | | **38.16** | *** | X | | | | | | | | | | | |
| *Pseudocrossidium hornsuchianum* | | | | | | | | | X | X | 1.15 | N.S. | | | | | | | | | | | | |
| *Campylopus introflexus* | X | | | | X | | | | X | | | | X | | **12.95** | * | | | | | | | | |
| *Hypnum cupressiforme* | X | | | | X | | | | X | | | | X | | **10.00** | * | | | | | | | | |
| *Racomitrium canescens* | | | | | | | | | X | | | | X | | 6.45 | N.S. | X | | | | | | | |
| *Riccia ciliifera* | | | | | | | | | X | | | | X | | **17.28** | *** | X | | | | | | | |
| *Didymodon fallax* | | | | | | | | | | | | | | | | | X | | **43.61** | *** | X | | | |
| *Syntrichia ruralis* | | | | | | | | | X | | | | | | | | X | | **16.47** | ** | X | | | |
| *Brachythecium albicans* | | | | | | | | | X | | | | | | | | X | | | | X | | 5.67 | N.S. |
| *Rhynchostegium megapolitanum* | | | | | | | | | | | | | | | | | X | | | | X | | **22.00** | *** |
| *Tortella tortuosa* | | | | | | | | | X | | | | X | | | | X | | | | X | | **39.13** | *** |
| **Total bryophyte species** | 10 | 4 | 5 | 2 | 7 | 2 | 4 | 1 | 13 | 2 | 4 | 2 | 9 | 0 | 4 | 3 | 8 | 0 | 2 | 2 | 6 | 0 | 3 | 2 |
| **TOTAL SPECIES** | 24 | 8 | 12 | 5 | 11 | 3 | 5 | 1 | 30 | 6 | 13 | 6 | 21 | 0 | 10 | 8 | 19 | 1 | 9 | 6 | 19 | 1 | 6 | 5 |

Table 4. Number of total (T), exclusive (E), indicator and statistically significant indicator species for each dynamic stage. N.S.: p>0.05. *: 0.05<p<0.01. **: 0.01<p<0.001. ***: p<0.001.

The sporadic occurrence of typically hygrophilous species – i.e. *Sphagnum compactum*, *S. papillosum* – in some dry habitats is due to the presence of ponds in depressions within heathlands on clayey soils, which retain the rainwater on the soil surface. These habitats are therefore not optimal but only opportunistic for such organisms, which however contribute to the increase of their conservation value (the whole Genus *Sphagnum* is considered of conservation concern according to the Habitat Directive and to the laws of several European Countries).

At habitat level, the highest number of exclusive, indicator and significant indicator species was surveyed in the acidic grasslands, which is the habitat type richer in terricolous cryptogams. However, also the other two habitat types are well characterized by well-defined species assemblages including both lichen and bryophyte species. At dynamic stage level, the pioneer stages are richer in total, exclusive and indicator species for both lichens and bryophytes except in the calcareous grasslands, but only in the heathlands the composition of cryptogam assemblages differs significantly between pioneer and mature stages.

The overlaps beetween the three habitat types in the NMDS scatterplots are due to the frequent occurrence of a few species with a very wide ecology which can be found on both acidic and calcareous soils and in grasslands as well as in heathlands – namely *Cladonia chlorophaea*, *C. rangiformis*, *C. rei*. They are well-known to be ruderal and stress-tolerant species that can colonize not only natural and not impacted situations but also disturbed situations on a wide range of substrates, where they generally dominate cryptogam communites (Paus 1997). The wide occurrence of these species does not affect the conclusion that the overall species composition differs significantly between the three habitats, which is well supported by the NP-MANOVA and the NMDS scatterplots as a whole, as well as by the many indicator species resulted from the ISA.

A few species – i.e. *Cladonia coccifera*, *C. fimbriata*, *C. strepsilis*, *Polytrichastrum formosum* – switched habitat type in the ISA analysis from when considering only the habitat types to when considering also the dynamic stages (cf. Tabb. 3, 4). These species show in fact a constant but not highly frequent presence in both the dynamic stages of the habitat the first ISA considered them to be indicator of, whereas they show a high frequency in one of the stages of another habitat type when separating the dynamic stages and running the second ISA on them – e.g. *Cladonia coccifera* is distributed widely in both pioneer and mature stages of the acidic grasslands, thus resulting indicator of the overall acidic grassland habitat (Tab. 3), but, when running the analysis on the dynamic stages, its frequency in the pioneer heathlands makes it indicator of that stage of that habitat type (Tab. 4). Thus, also the dynamic stage of the vegetation has to be considered an important feature when taking in account the cryptogam assemblages, especially because in some of the studied habitats the whole assemblage can be significantly different between the two dynamic stages of the same habitat.

## Conclusions

With regard to the questions posed in the introduction, this study allowed to answer positively to all of them.

The three open dry habitats considered in this study – *Calluna* heathlands, acidic grasslands, calcareous grasslands – host well-defined terricolous cryptogam assemblages rich in total and, especially for lichens, rare species. Therefore, the management of these habitats should aim to the conservation of lichens and bryophytes, through the creation or the restoration of patches of bare substrate by means of suitable techniques, such as sod-cutting, burning, cutting, topsoil removal/inversion (Chytrý *et al*. 2001; Allison & Ausden 2004; Ausden 2007; Matt & Legg 2008; van Andel & Aronson; Glen *et al*. 2017). The conservation management of cryptogams should also consider the moss *Campylopus introflexus*, that is a neotropical species which had become invasive in dry habitats of central Europe (Ketner-Oostra *et al*. 2012). In fact, it resulted significant indicator species in the acidic dry grasslands in this study and occurred also in some heathlands. Sod-cutting and topsoil removal could be useful also to remove this carpet-forming moss.

The cryptogam assemblages occurring in the three dry habitats considered in this study have been demonstrated to be habitat-specific. Relying on this statement, each of these habitats should be preserved not only for its importance as a habitat itself and for the diversity of vascular plants, but also for the diversity of cryptogams it hosts, because many species of each assemblage can not be found in the other habitats and are therefore an irreplaceable part of biodiversity.

Furthermore, in some cases cryptogam assemblages differ not only in the different habitat types, but also in the different dynamic stages found within the same habitat type. Therefore, the conservation management in these habitats should guarantee the maintaining of a mosaic of pioneer and mature patches. Several management experiences have already proved that such solution can benefit diversity in cryptogam communities of dry habitats (e.g. Chytrý *et al*. 2001; Matt & Legg 2008; Ketner-Oostra *et al*. 2012). Furthermore, a management model aimed at maintaining different dynamic aspects of these habitats should guarantee a complessive protection of their integrity, focusing on the dynamic process that maintains all the elements, rather than focusing on the presence of particular elements (Angermeier & Karr 1994).

In conclusion, we strongly recommend that an optimal management aimed at the conservation of terricolous cryptogams and cryptogam-rich habitats must be carefully planned and carried out at both the landscape (habitat type) and the local (dynamic stage) scales.

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# Chapter 4

# Impact of an invasive herbivore and human trampling on lichen-rich dry grasslands: Soil-dependent response of multiple taxa

Gabriele Gheza, Silvia Assini, Lorenzo Marini, Juri Nascimbene

## Abstract

Dry grasslands are listed among the habitats of conservation concern in Europe. Here, based on a multitaxon approach including vascular plants, bryophytes and lichens, we explored the effects of small-scale disturbance on lichen-rich dry grassland vegetation by surveying 60 sites across the Po Plain (Northern Italy). In particular, we evaluated the impact of human trampling and fecal pellet deposition by the alien invasive herbivore *Sylvilagus floridanus*. We found a soil-dependent response of multiple taxa to the impact of the herbivore. For plants, beside a negative effect of trampling, the interaction between fecal pellet amount and soil pH indicates that the negative effect of the invasive herbivore is stronger on acidic soils. Bryophyte cover increased with increasing soil pH, annual rainfall and fecal pellet, while it was not affected by trampling. Lichen richness and cover decreased with increasing soil pH. The marginal interaction between soil pH and amount of fecal pellet indicates that the more negative effects on lichens may be expected on calcareous soils. Trampling did not affect lichen patterns and the rainfall gradient marginally affected lichen cover with a negative effect. Lichen species richness is also negatively affected by increasing vascular plant cover. The main implications of this study for improving conservation are: (1) conservation practices should be tailored to organism and substrate type; (2) bryophyte and lichen diversity patterns are influenced also by climatic conditions, suggesting that the impact on these organisms may be exacerbated by climate change; and (3) strict conservation, even through active exclusion of wild fauna, of the most species-rich sites should be recommended, even if previous literature and the negative plant cover-lichen richness relationship found in this study indicate that moderate mechanical disturbance could be a practical tool to enhance cryptogams.

## Keywords

Eutrophication, Human trampling, Multi-taxon approach, Soil pH, Vegetation conservation.

Science of the Total Environment 639: 633-639

# Introduction

Dry grasslands are important habitats for biodiversity conservation, hosting several rare species and species-rich communities of plants, invertebrates (Schirmel *et al.* 2014; Zulka *et al.* 2014), and vertebrates (Goriup *et al.* 1991). Furthermore, they host terricolous cryptogams, mostly lichens (lichen-rich dry grasslands) and bryophytes that greatly contribute to ecosystem functioning in arid environments (Maestre *et al.* 2011; Zedda & Rambold 2015). In Europe, dry grasslands on both siliceous (acidic) and calcareous (basic) substrates are listed among habitats of conservation concern according to the Habitat Directive (92/43/EEC; Jentsch & Beyschlag 2003), being threatened by multiple impacts.

Large-scale impacts include habitat loss and fragmentation (Jentsch & Beyschlag 2003), atmospheric nitrogen deposition (Sparrius *et al.* 2013; Stevens *et al.* 2012), and climate change (Jones 1997). Small-scale impacts are mainly related to invasive plant species (Assini 2008), overgrazing (Kohyani *et al.* 2008a; Kohyani *et al.* 2008b), and mechanical disturbance. In particular, human trampling usually impacts vascular plants, whose sensitiveness depends on the biological growth form (Pescott & Stewart 2014), and fruticose lichens that are the most sensitive group among cryptogams (Jägerbrand & Alatalo 2015; Grabherr 1982). However, a moderate trampling could even enhance the local dispersal of vegetative propagules of terricolous lichens (Heinken 1999).

Beside humans, herbivores also may contribute to trampling, even if their impact on natural and semi-natural vegetation (Pascual *et al.* 2017) is mainly associated with overgrazing (Kohyani et al. 2008a; Kohyani *et al.* 2008b) whose effects include soil eutrophication (Jentsch & Beyschlag 2003). Eutrophication is among the most important factors threatening plant diversity of herbaceous plant communities worldwide (Soons *et al.* 2017; Storkey *et al.* 2015), being highly detrimental also to lichens (Southon *et al.* 2012; Sparrius *et al.* 2013), with direct negative effects on their eco-physiology (Stevens *et al.* 2012) and community composition (Giordani *et al.* 2014).

Previous research carried out in the dry grasslands of the western Po Plain (Assini 2008) indicated that the activity of the alien invasive herbivore rabbit *Sylvilagus floridanus* can potentially threaten native vegetation by eutrophication related to fecal pellet deposition (Clark *et al.* 2005). This species, native to North America, was introduced in 1966 near Turin for hunting purposes, and quickly invaded the Po Plain in Piedmont and western Lombardy (Trocchi & Riga 2005; Angelici & Spagnesi 2008), forming dense populations in marginal habitats, such in the case of lichen-rich dry grasslands. However, the negative effects of this herbivore on lichen-rich dry grasslands have been never evaluated.

The impact of trampling and soil eutrophication can vary according with soil pH. For example, Stevens *et al.* (2010), demonstrated that the negative effects of eutrophication are exacerbated by increasing soil acidity. Also Löbel *et al.* (2006) showed that the interaction between environmental factors and soil pH could significantly affect species richness in lichen-rich dry grasslands vegetation. However, these interactive effects could differ among different organism groups composing the vegetation of dry grasslands. In this perspective, the multi-taxon approach is increasingly adopted to assess the effects of disturbance in natural and semi-natural habitats (Grabherr 1982; Löbel *et al.* 2006; Nascimbene *et al.* 2014; Zulka *et al.* 2014; Jägerbrand & Alatalo 2015). The simultaneous assessment of the response of multiple taxa to disturbance could therefore provide more robust information on biodiversity patterns and support more effective conservation compared to focusing on a single taxon. Despite the fact that in dry grasslands, beside vascular plants, both lichens and bryophytes may significantly contribute to ecosystem biodiversity and functioning (Maestre *et al.* 2011; Zedda & Rambold 2015), these organisms are still largely overlooked in conservation policies.

This work aims at exploring the effects of small-scale disturbances on lichen-rich dry grasslands on both acidic and calcareous soils. In particular, our multi-taxon approach tested: (1) the influence of trampling and fecal pellet deposition, assumed as proxy for eutrophication (Clark *et al.* 2005) by the alien invasive herbivore *Sylvilagus floridanus* on species richness and cover of vascular plants, lichens and bryophytes; (2) whether the effects of these disturbances vary depending on soil pH. Since the spatial distribution of our sites spanned a relatively large rainfall gradient, we also tested (3) the effect of climate on the three taxonomical groups. Due to their different ecological requirements and traits, the three taxa are expected to exhibit contrasting responses to disturbance that can be mediated by soil pH. In general, we expect that in our species-rich habitats cover and/or species richness decreases with increasing disturbance, and that this relationship could be modified by a taxon-specific interactive effect with soil pH. Moreover, due to their poikilohydric behavior (Green & Lange 1995), we expect that the patterns of lichens and bryophytes would be influenced also by rainfall, while this factor should not influence vascular plants due to the strong drainage capacity of the soils that may offset the effects of the rainfall gradient. Finally (4), we also accounted for the potential effect of vascular plant cover on bryophytes and lichens testing the hypothesis that increased vascular plant cover can outcompete lichen and bryophyte species

(Alatalo *et al.* 2017; Jägerbrand *et al.* 2012).

## Materials and methods

### *Study area*

The study was carried out in the central-western Po Plain, from the area surrounding Turin to the boundary between Lombardy and Veneto. Mean annual temperature ranges between 11 °C and 13.5 °C, and annual rainfall ranges between 600 mm and 1200 mm. Soil pH ranges from very acidic and acidic (pH = 4–5, north of the Po river) to subneutral (pH = 6, near the Po river), and basic (pH = 7, south of the Po river).

In this area, lichen-rich dry grasslands are at the southernmost edge of their range (Assini *et al.* 2013; Gheza 2015). This habitat is extremely fragmented and the few remnants are usually located in marginal, unproductive areas along rivers and are not actively managed. Interviews to Natural Park's managers carried out preliminarily to this study revealed that these fragments are only locally and sporadically used for human activities (e.g. trekking, biking, hunting, grazing). On the other hand, this condition increases their suitability for small-sized wild animals, including the alien invasive *Sylvilagus floridanus*, while larger herbivores (i.e. wild boar, *Sus scrofa*) only sporadically feed in these habitats.

### *Site selection*

Across the study area, we performed a preliminary site selection checking the available maps in order to find all the areas with natural and semi-natural lichen-rich dry grasslands. This process resulted in 12 areas distributed along the main river valleys: Ticino, Sesia, Dora Baltea, Stura di Demonte, Po, Orba, Scrivia, Lambro, Adda, Brembo, Serio and Oglio, and one site in the Lomellina area. In these areas, lichen-rich dry grassland sites were identified by analyzing GIS maps and thanks to the cooperation with local botanists and Park managers. The sites preliminarily identified were then inspected during winter 2015–2016 in order to evaluate their suitability for this study. Dry grasslands in rather pioneer dynamic stages and hosting cryptogams were considered suitable, while sites in more mature stages of the successions, characterized by well-developed soils and absence of cryptogams, were considered unsuitable. Overall, 84 grasslands sites were inspected and only 60 resulted suitable (Appendix 1). All these grasslands can be labeled under the EU habitat codes 2330 (“Inland dunes with open

*Corynephorus* and *Agrostis* grasslands") and 6210 ("Semi-natural dry grasslands and scrubland facies on calcareous substrates"). The suitable grassland sites are evenly distributed in Lomellina, Ticino, Sesia, Po, Orba, Scrivia, Serio; 55 are included in Regional Parks and/or Sites of Community Importance (SCI) according to the European Habitat Directive, while five are located outside protected areas. For each grassland site, mean annual precipitation was retrieved from the website of the Regional Environmental Agencies of Piedmont (www.arpa.piemonte.gov.it) and Lombardy (www2.arpalombardia.it), using the values of the nearest meteorological station.

### *Sampling design*

Vegetation, including vascular plants, lichens and bryophytes, was surveyed between April and June 2016 in 3 m radius circular plots. In each grassland site, the number of plots was proportional to the grassland area: 1 plot for sites between 100 and 1000 m2; 2 plots between 1001 and 3000 m2; 3 plots between 3001 and 5000 m2; 5 plots between 5001 and 20,000 m2; and 7 plots for areas larger than 20,000 m2. This resulted in a total of 185 plots (Appendix 1). In each site, plots were placed at regular spatial spans along the linear transect placed between the two furthest vertices of the grassland. This procedure was performed using Qgis (Qgis Development Team 2009).

In each plot, the cover (%) and the mean height of the five vegetation layers (arboreal, higher-shrubby, lower-shrubby, herbaceous, cryptogamic) were recorded, as well as the cover of each plant, lichen and bryophyte species. Most species were identified in the Laboratory of Flora, Vegetation and Ecosystem Services of the University of Pavia, where voucher specimens are stored. Several lichen specimens, identifiable only on the basis of chemical analyses, were checked with thin-layer chromatography for secondary metabolites. Critical bryophyte specimens were checked by an expert bryologist. Nomenclature follows Tison & de Foucault (2014) for vascular plants, Nimis (2016) for lichens, and Cortini Pedrotti (2001) for bryophytes.

Soil pH was measured in the field with a portable kit within each plot in a position not contaminated by the occurrence of fecal pellets. In each plot, we also recorded: 1) the overall human trampling, estimated according to a categorical scale: 0 (no trampling), 1 (<5 m2 showing evidence of trampling on vegetation and/or bare soil), 2 (5–10 m2), 3 (10–15 m2), 4 (>15 m2); 2) fecal pellet abundance of the invasive *S. floridanus* estimated according to a categorical scale: 0 (no pellet), 1 (<2 pellet/m2), 2 (3–5 pellet/m2), 3 (>5 pellet/m2). Fecal pellet of this herbivore are easily identifiable in the field from those of Lepus europapeus but are rather similar to those of *Oryctolagus cuniculus*. In this case, the attribution to *S. floridanus* was based on the direct observation of *S. floridanus* individuals in absence of both *O. cuniculus* individuals and holes (typically made by this species) in the whole site. To back this, the current distribution of *S. floridanus* was checked in detail, not only by means of published literature (ANGELICI & SPAGNESI 2008), but also through interviews with Park keepers, gamekeepers and zoologists with good knowledge of the wildlife occurring in our study sites. According with CLARK *et al*. (2005), the amount of fecal pellet was used as a proxy for soil eutrophication. During the fieldwork we also quantified grazing activity as well as boar rooting. However, these disturbances were found in only a few plots and their effect was therefore no longer considered.

### *Data analysis*

The effects of the independent explanatory variables (Appendix 2) on the three taxa were analyzed using general linear mixed-effect models. The response variables were: 1) vascular plant species richness and cover; 2) lichen species richness and cover; 3) bryophyte species richness and cover; 4) species richness and cover of alien vascular plants; 5) species richness and cover of plants, lichens, and bryophytes of conservation concern according to European (Habitat Directive) and National regulations. We used a Poisson distribution for species richness and a normal distribution for cover data. To make estimates comparable across predictors, the explanatory variables were standardized to mean 0 and standard deviation 0.5 (GELMAN 2008). All models included all the plots ($n = 185$) nested within the sites ($n = 60$) as random factors. This random structure accounted for the spatial dependence in the sampling design.

The full model included the following variables:

$$\text{Response variable (species richness or cover)} \sim$$
$$\text{pH} + \text{fecal pellet} + \text{trampling} + \text{fecal pellet} \times \text{pH} + \text{pH} \times \text{trampling} + \text{precipitation}$$

The full models were simplified with a backward deletion procedure ($p < 0.05$). P-values ranging between 0.05 and 0.1 were retained as indicative of marginal effects. The use of model selection based on p-values in ecological studies has been widely debated in recent years (JOHNSON & OMLAND 2004; GELMAN 2013). However, the best approach to analyze complex ecological data has still to be found (MURTAUGH 2014). The traditional null hypothesis testing approach (p-values selection) is still effectively used to test biological accurate hypotheses in studies characterized by low collinearity (Gelman 2013; Murtaugh 2014). All analyses were performed using R3.4.1 (R Core Team, 2015). For the linear mixed-effects model analyses the packages "lme4" (Bates *et al*. 2014) and "nlme" (Pinheiro *et al*. 2013) were used.

We also performed a model selection using an information theoretic approach to evaluate alternative competing models involving the variables included in the models explained above. Our information-theoretic approach compared the fit of all the possible candidate models nested within the full models (Burnham & Anderson 2002). Models were fitted using the maximum likelihood method. The fit of each model in the set was then evaluated using second-order Akaike's information criterion (AICc). The best fit is indicated by AICcMIN, the lowest value of AICc. In a set of n models each model i can be ranked using its difference in AICc score with the best-fitting model (ΔAICci = AICci − AICcMIN). A model in a set can be considered plausible if its ΔAICc is below 2 (Burnham & Anderson 2002). We also computed the model weight (wi) as the weight of evidence in favour of each model. The weights wi represent the relative likelihood of a model. For each model, we first calculated its likelihood as exp(−0.5 ∗ ΔAICci). The weight wi for a model is its likelihood divided by the sum of the likelihoods across all models. The multi-model inference analyses were performed using the 'MuMIn' package implemented in R version 2.13.0 using the functions dredge(), model.avg() and confint(). Since the results from the traditional p-value based analyses and the multi-model inference converged, we present only the former in the main text while the latter are reported in supplementary materials (Appendix 3).

As the three taxa are expected to respond to the same environmental factors we could not include them as predictors in the environmental model described above. However, the relationship between vascular plant cover and lichens and bryophytes was tested by a simple regression model.

## Results

A total of 255 vascular plants, 32 lichens and 15 bryophytes were recorded in 185 plots (Appendix 4). They included 17 alien vascular plants: two archaeophytes (species introduced before the year 1492) and 15 neophytes (species introduced after the year 1492) (Celesti-Grapow *et al*. 2010). Nine vascular plants, one lichen (*Cladonia portentosa* (Dufour) Coem.) and one bryophyte (*Leucobryum glaucum* (Hedwig) Ångström) are species of conservation concern according to Regional, National and/or European policies.

The explanatory variables included in the model did not affect neither species richness nor cover of both the species of conservation concern and alien species (data not shown). In contrast, trampling and fecal pellet amount and/or their interactions with soil pH (ranging between 4 and 7) significantly affected the cover and/or species richness of the three organism groups (Table 1).

| | | **Species richness** | | | **Cover** | | |
|---|---|---|---|---|---|---|---|
| | | **Estimate** | **Std error** | **p-value** | **Estimate** | **Std error** | **p-value** |
| **Vascular plants** | pH | 0.43407 | 0.11181 | 0.0001 | 22.60310 | 4.162971 | <0.0001 |
| | Fecal pellet | -0.14541 | 0.06088 | 0.0169 | -6.54439 | 2.540168 | 0.0114 |
| | Trampling | | | | -5.62896 | 2.263655 | 0.0142 |
| | Precipitation | | | | | | |
| | Fecal pellet * pH | 0.22391 | 0.10600 | 0.0346 | | | |
| | pH * Trampling | | | | | | |
| **Bryophytes** | pH | | | | 13.95643 | 4.647144 | 0.0032 |
| | Fecal pellet | | | | 11.32829 | 3.520046 | 0.0016 |
| | Trampling | | | | | | |
| | Precipitation | | | | 15.49566 | 4.535219 | 0.0012 |
| | Fecal pellet * pH | | | | | | |
| | pH * Trampling | | | | | | |
| **Lichens** | pH | -0.60841 | 0.15744 | 0.0001 | -27.1672 | 6.022182 | <0.0001 |
| | Fecal pellet | -0.18477 | 0.13592 | 0.1740 | | | |
| | Trampling | | | | | | |
| | Precipitation | | | | -11.6677 | 6.016371 | 0.0575 |
| | Fecal pellet * pH | -0.51635 | 0.28967 | 0.0747 | | | |
| | pH * Trampling | | | | | | |

Table 1. Final models of each response variable (species richness and cover for each taxonomical group). Only the significant explanatory factors and their interactions are shown after a backward deletion procedure (P > 0.05).

Trampling had a negative effect on vascular plant cover regardless of soil pH. On the other hand, cover of vascular plants increased at the increase of soil pH and decreased at the increase of fecal pellet amount, irrespectively of soil pH. In contrast, the interaction between fecal pellet and soil pH was significant for species richness, indicating that the negative effect of the invasive herbivore is stronger on acidic than on calcareous soils (Fig. 1a). Rainfall did not affect nor species richness, neither cover of vascular plants.

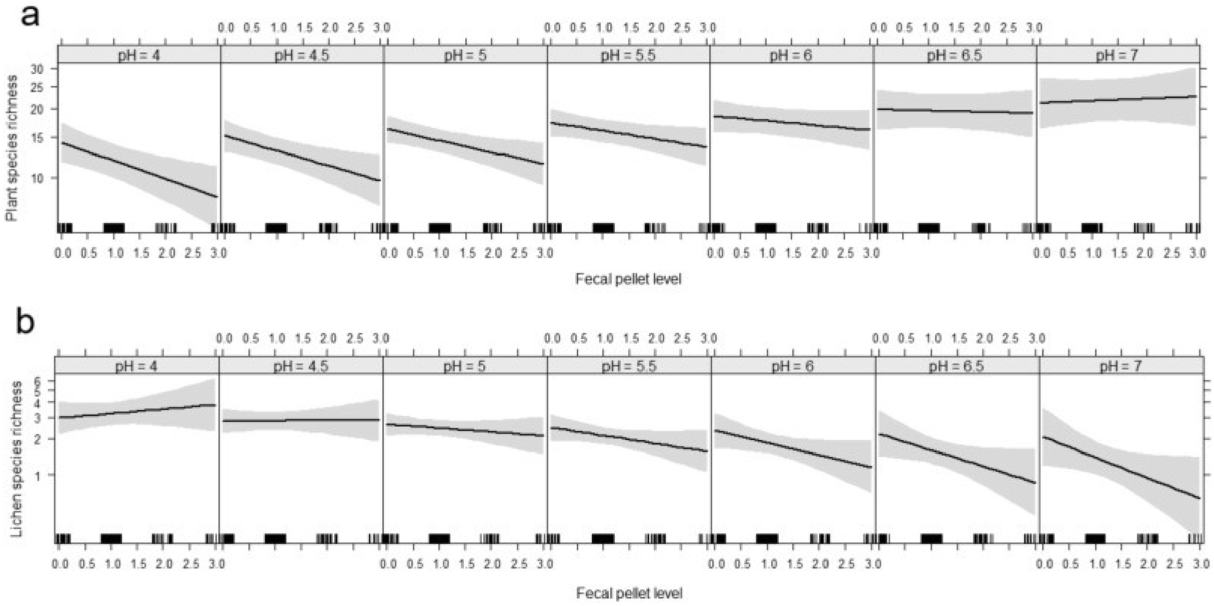

Figure 1. Interactive effect between soil pH and the fecal pellet levels by the alien invasive herbivore *Sylvilagus floridanus* on (a) plant species richness and (b) lichen species richness.

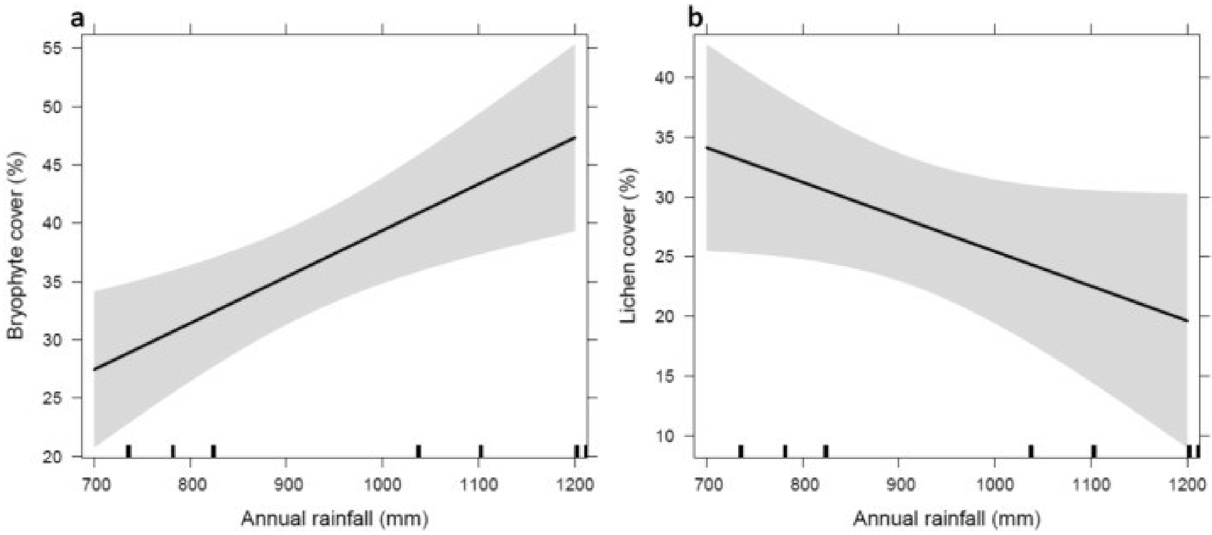

Figure 2. Relationship between annual rainfall (mm) and (a) bryophyte and (b) lichen species richness.

Bryophyte species richness did not respond to the local variables tested in this study. In contrast, bryophyte cover increased with increasing soil pH, mean annual rainfall (Fig. 2a), and fecal pellet, while it was not affected by trampling (Table 1). Plant cover did not influence bryophyte richness (Fig. 3a) and cover (not shown).

Lichen richness and cover decreased with increasing soil pH. Species richness was negatively affected also by increasing fecal pellet (Table 1). Lichen richness was also marginally affected by the interaction between soil pH and fecal pellet with a contrasting pattern as compared with that of vascular plants: fecal pellet produced more negative effects on lichens on calcareous soils than on acidic soils (Fig. 1b). Similarly to bryophytes, trampling did not affect lichen patterns, while rainfall had a marginal negative effect on lichen cover (Fig. 2b). Plant cover negatively affected lichen richness (Fig. 3b) while it did not influence lichen cover (not shown).

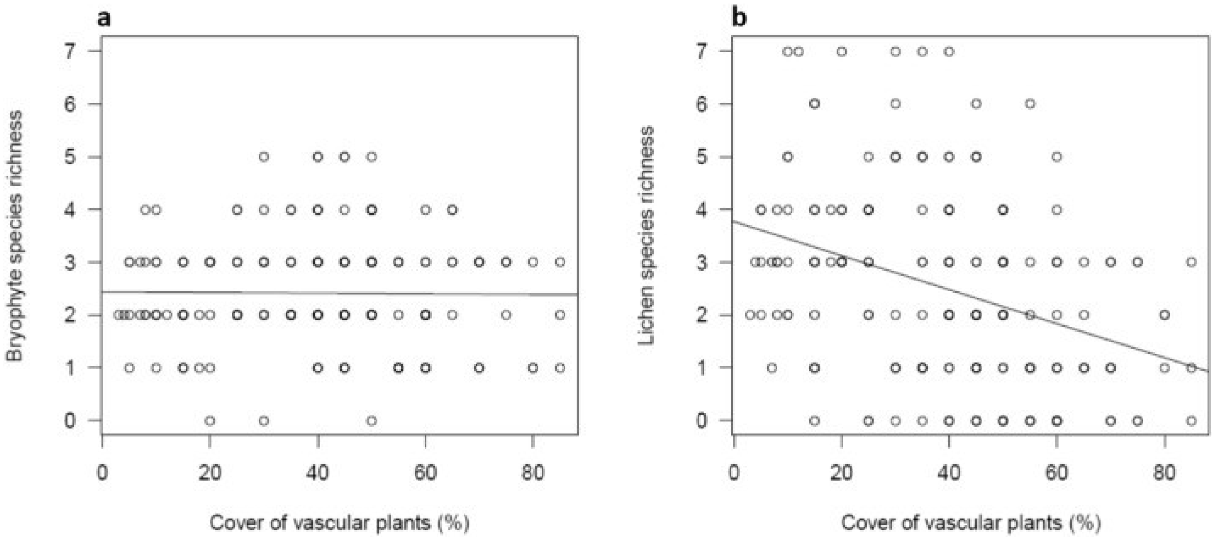

Figure 3. Relationship between the cover of vascular plants (%) and (a) bryophyte and (b) lichen species richness.

## Discussion

While only vascular plants were negatively affected by human trampling, our study provides support for a soil-dependent response of multiple taxa to the impact of the invasive herbivore *Sylvilagus floridanus* in lichen-rich dry grasslands. However, contrasting patterns were found among plants, bryophytes and lichens, confirming the view that the response to disturbance may differ among organisms with different traits and ecological requirements (Poschlod *et al.* 2005; Löbel *et al.* 2006) and stressing the importance of multiple taxa assessment to support science-based conservation.

In contrast with several previous studies (e.g. Grabherr 1982; Jägerbrand & Alatalo 2015), in our lichen-rich dry grasslands the moderate intensity of human disturbance and the rarity of large wild herbivores are likely responsible for the lack of impact of trampling on bryophytes and lichens. A moderate trampling, that implies mechanical soil disturbance, could even positively affect these components of dry grasslands vegetation, contributing to form gaps in which (re-)colonization by pioneers can take place. Moderate trampling could also positively affect the dispersal of lichen fragments, which are effective propagules for local colonization (Heinken 1999). On the other hand, the impact of trampling on vascular plant cover may corroborate the view that a moderate disturbance regime could be useful for the maintenance of lichen (and bryophyte)-rich vegetation, hindering the development of a continuous layer of vascular plant vegetation (Alatalo *et al*. 2017). The negative relationship found in this study between plant cover and lichen richness would support this hypothesis. This threshold between disturbance intensity and cryptogam development could be a reference for active conservation aiming at maximizing the co-occurrence of lichens, bryophytes and vascular plants in dry grasslands.

Moderate trampling could be even provided by small-sized herbivores such as the alien invasive *S. floridanus*. Our results highlight that the impact of this invasive herbivore on dry grassland vegetation is taxon- and soil-dependent with contrasting patterns among vascular plants, lichens and bryophytes. This impact is probably more related to eutrophication, associated with fecal pellet deposition, rather than to grazing and trampling, due to the small size of the species (Bakker *et al*. 2006). For vascular plant richness, the negative impact of the invasive herbivore was exacerbated on acidic soils, where plant communities have usually lower diversity and cover and are probably less productive. This pattern could fit with an eutrophication effect. For example, Storkey *et al*. (2015) suggested that nitrogen addition may impact plant diversity more heavily in acidic, compared to calcareous sites (see also Stevens *et al*. 2010). Under these circumstances, eutrophication could also impact ecosystem functioning by reducing plant cover with potential negative effects on the stability of vegetation productivity (Wang *et al*. 2017). This hypothesis is corroborated by the negative effect of pellet amount on vascular plant cover. For lichens, the marginal interactive effect of fecal pellet amount with soil pH had an opposite pattern compared with that of vascular plants, predicting a stronger impact of the invasive herbivore on calcareous dry grasslands, where lichen cover is lower. Also bryophyte cover is influenced by the impact of the invasive herbivore and soil pH. The positive effect of fecal pellet amount, as well as of increasing soil pH, suggest that in calcareous dry grasslands bryophytes may compensate the low contribution of lichens and the impact of eutrophication on plant diversity.

According with our expectations, both bryophytes and lichens were influenced by rainfall, even if with contrasting patterns. The positive effect of rainfall on bryophyte cover reflects their affinity to humid situations, their metabolic and ontogenetic activity being enhanced by water availability (Goffinet & Shaw 2008). In general, this framework could apply also to lichens, whose metabolism depends on thallus hydration (Green & Lange 1995). However, water availability may differently affect lichens, depending on their thallus growth form. For example, fruticose-filamentous species are hindered by excessive wetting that depresses net assimilation (Coxson & Coyle 2003). This could happen also for several tiny fruticose species composing lichen communities in dry grasslands that may be scarcely tolerant to prorogated thallus inundation. Moreover, high rainfall may disadvantage lichens due to their scarce competitiveness with the more fast-growing bryophytes.

## Conclusions

Results of this study provide key implications for improving biodiversity conservation in lichen-rich dry grasslands: (1) the contrasting patterns among different taxa in relation to disturbance highlight the usefulness of the multi-taxon approach in which overlooked organisms, such as bryophytes and lichens, are included in the assessment of the impacts on biodiversity (Grabherr 1982; Löbel *et al*. 2006; Jägerbrand & Alatalo 2015). While these organisms are likely to greatly contribute to dry grasslands biodiversity and functioning (e.g. Jentsch & Beyschlag 2003; Maestre *et al*. 2011), being also associated to relevant ecosystem services (e.g. Zedda & Rambold 2015), their diversity patterns in relation to disturbance have thus far been overlooked. (2) Conservation practices should be tailored to organism (Socolar *et al*. 2016) and substrate type, beside the general prediction that the most vulnerable conditions should be expected where vegetation cover is lower. In particular, results suggest that for vascular plant conservation efforts should be mainly assigned to acidic dry grasslands where they are expected to be less competitive and resilient. For similar reasons, priority for lichen conservation should be assigned to calcareous dry grasslands. On the other hand, calcareous and acidic sites host the highest richness of plants and lichens respectively, being therefore alternatively important to maximize the conservation of the regional species pool of these two taxa. This implies that, at the landscape level, patches of dry grassland should be protected on both acidic and calcareous soils. (3) While vascular plants are influenced mainly by local disturbance in interaction with soil pH, bryophyte and lichen patterns are influenced also by climatic conditions, suggesting that the local impacts on these organisms may be exacerbated by climate change. Increasing aridity may negatively affect bryophytes, while intensification of rain events may hinder lichen development, especially for inundation intolerant species. (4) Besides the threats already posed by the alien herbivore *S. floridanus* to the native wild fauna (Trocchi & Riga 2005; Angelici & Spagnesi 2008), this invasive species may also negatively affect plant and lichen diversity in lichen-rich dry grasslands. In this context, active habitat management is the main tool available to mitigate the impact by invasive fauna (see e.g. Barrios-Garcia & Ballari 2012 for wild boars) and strict conservation, even through active exclusion of wild fauna, of the most species-rich sites should be recommended. However, previous literature (e.g. Dostalek & Frantik 2008) and the negative plant cover-lichen richness relationship found in this study indicate that moderate mechanical disturbance could be a practical tool to locally enhance the occurrence of cryptogams within plant-dominated stands.

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## Appendix 1

Geographical details of the 60 lichen-rich dry grasslands distributed across 7 sites in the central-western Po Plain (northern Italy).

| Site | Area | Geographic coordinates | Elevation (m a.s.l.) | Surface area ($m^2$) | N of plots |
|---|---|---|---|---|---|
| Remondò West | Lomellina | 45°13’55.85”N, 8°48’8.96” E | 104 | 5113 | 5 |
| Remondò East | Lomellina | 45°13’55.13”N, 8°48’18.58”E | 103 | 14319 | 5 |
| Cergnago North | Lomellina | 45°11’48.48”N, 8°47’7.76”E | 103 | 1994 | 2 |
| Cergnago South | Lomellina | 45°11’35.7”N, 8°47’16.69”E | 103 | 6961 | 5 |
| Cergnago clearing | Lomellina | 45°11’42.72”N, 8°47’7.44”E | 103 | 100 | 1 |
| Cascina Casone East | Ticino | 45°38’12.52”N, 8°41’13.49”E | 171 | 8805 | 5 |
| Cascina Casone South | Ticino | 45°38’3.41”N, 8°40’49.48”E | 171 | 2993 | 2 |
| Castelnovate North | Ticino | 45°37’35.72”N, 8°40’0.91”E | 166 | 851 | 2 |
| Castelnovate West | Ticino | 45°37’33.56”N, 8°39’56.95”E | 164 | 3025 | 5 |
| Barbelera | Ticino | 45°37’9.01”N, 8°40’40.22”E | 161 | 3979 | 2 |
| Marcetto | Ticino | 45°36’52.96”N, 8°40’49.04”E | 159 | 12227 | 5 |
| La Promessa | Ticino | 45°34’13.26”N, 8°44’8.38”E | 187 | 128603 | 7 |
| La Promessa West clearing | Ticino | 45°34’17.44”N, 8°43’59.77”E | 187 | 995 | 1 |
| La Promessa East clearing | Ticino | 45°34’17.76”N, 8°43’56.1”E | 186 | 622 | 1 |
| La Promessa South clearing | Ticino | 45°34’4.19”N, 8°44’12.16”E | 185 | 1280 | 1 |
| Bornago North | Ticino | 45°33’15.95”N, 8°42’10.15”E | 142 | 2747 | 2 |
| Bornago South | Ticino | 45°33’7.49”N, 8°42’4.5”E | 141 | 12696 | 5 |
| Bornago clearing | Ticino | 45°33’11.88”N, 8°42’11.52”E | 143 | 100 | 1 |
| Bernate | Ticino | 45°28’7.68”N, 8°47’46.68”E | 117 | 2434 | 2 |
| La Chiocciola 1 | Ticino | 45°26’14.32”N, 8°48’26.35”E | 112 | 150 | 1 |
| La Chiocciola 2 | Ticino | 45°26’19.61”N, 8°48’18.25”E | 112 | 150 | 1 |
| La Chiocciola 3 | Ticino | 45°26’16.44”N, 8°48’19.8”E | 112 | 150 | 1 |
| La Fagiana North | Ticino | 45°26’2.36”N, 8°49’17.76”E | 109 | 1535 | 2 |
| La Fagiana South | Ticino | 45°25’47.53”N, 8°49’32.34”E | 108 | 28290 | 7 |
| La Fagiana clearing | Ticino | 45°26’7.44”N, 8°49’4.55”E | 109 | 100 | 1 |
| Villa Giulia | Ticino | 45°24’1.51”N, 8°50’1.39”E | 102 | 11771 | 5 |
| Bosco Ronchi North | Ticino | 45°16’30.14”N, 8°56’49.7”E | 74 | 10770 | 5 |
| Bosco Ronchi South | Ticino | 45°16’40.8”N, 8°56’5.86”E | 75 | 6251 | 5 |
| Bosco Ronchi clearing 1 | Ticino | 45°17’7.3”N, 8°56’16.22”E | 75 | 2251 | 2 |
| Bosco Ronchi clearing 2 | Ticino | 45°16’39.43”N, 8°56’55.9”E | 75 | 1772 | 2 |
| Bosco Ronchi clearing 3 | Ticino | 45°16’44.33”N, 8°56’46.32”E | 75 | 486 | 1 |
| Bosco Ronchi clearing 4 | Ticino | 45°16’26.76”N, 8°56’51.18”E | 75 | 100 | 1 |
| Cascina S Sofia | Ticino | 45°11’38.29”N, 9°4’47.03”E | 62 | 14681 | 5 |
| Canale Cavour | Sesia | 45°27’34.45”N, 8°23’45.06”E | 164 | 3200 | 3 |
| Canale Cavour clearing | Sesia | 45°27’37.62”N, 8°23’50.96”E | 167 | 425 | 1 |

| | | | | | |
|---|---|---|---|---|---|
| Greggio riverbed | Sesia | 45°27’21.35”N, 8°23’48.55”E | 160 | 17677 | 5 |
| Greggio | Sesia | 45°26’50.96”N, 8°23’46.32”E | 159 | 6619 | 3 |
| Greggio clearing | Sesia | 45°26’55.57”N, 8°23’50.14”E | 157 | 670 | 1 |
| Albano Vercellese clearing | Sesia | 45°25’44.76”N, 8°23’43.48”E | 152 | 89 | 1 |
| Gerbido di Villata | Sesia | 45°23’33.72”N, 8°23’59.35”E | 140 | 3429 | 3 |
| Torrette di Frassineto | Po | 45°8’18.02”N, 8°34’51.78”E | 99 | 15960 | 5 |
| Torrette clearing 1 | Po | 45°8’22.92”N, 8°35’11.65”E | 98 | 90 | 1 |
| Torrette clearing 2 | Po | 45°8’24.18”N, 8°35’11.65”E | 97 | 110 | 1 |
| Bosco del Mezzano | Po | 45°7’0.7”N, 8°35’53.3”E | 95 | 14848 | 5 |
| Gerbido di Valenza | Po | 45°2’10.5”N, 8°38’27.96”E | 88 | 8187 | 2 |
| Portanuova | Orba | 44°49’2.32”N, 8°38’36.64”E | 109 | 25454 | 7 |
| Posada | Orba | 44°47’47.04”N, 8°39’16.24”E | 114 | 2144 | 2 |
| Posada clearing | Orba | 44°47’50.6”N, 8°39’14.54”E | 115 | 150 | 1 |
| Castelnuovo | Scrivia | 44°57’33.62”N, 8°52’15.2”E | 87 | 63252 | 7 |
| Bettole di Tortona | Scrivia | 44°49’35.04”N, 8°50’21.16”E | 145 | 20471 | 5 |
| Villalvernia ringing station | Scrivia | 44°47’28.46”N, 8°51’17.53”E | 162 | 2209 | 2 |
| Villalvernia East | Scrivia | 44°47’32.06”N, 8°51’18.04”E | 162 | 1538 | 2 |
| Villalvernia South | Scrivia | 44°47’14.06”N, 8°51’10.73”E | 165 | 13584 | 5 |
| Villalvernia clearing 1 | Scrivia | 44°47’30.91”N, 8°51’19.33”E | 162 | 406 | 1 |
| Villalvernia clearing 2 | Scrivia | 44°47’38.15”N,, 8°51’10.3”E | 161 | 364 | 1 |
| Basella North | Serio | 45°36’39.13”N, 9°44’24.25”E | 178 | 109000 | 7 |
| Basella South | Serio | 45°36’23.87”N, 9°44’28.39”E | 174 | 10458 | 3 |
| Malpaga North | Serio | 45°36’42.59”N, 9°44’41.53”E | 182 | 15760 | 5 |
| Malpaga South | Serio | 45°37’3.25”N, 9°44’39.55”E | 185 | 30850 | 7 |
| Malpaga clearing | Serio | 45°37’22.08”N, 9°44’40.58”E | 180 | 120 | 1 |

## Appendix 2

Correlation matrix of the explanatory factors.

| | **pH** | **Fecal pellet** | **Trampling** | **Precipitation** |
|---|---|---|---|---|
| **pH** | | | | |
| **Fecal pellet** | 0.2510553 ** | | | |
| **Trampling** | 0.1588371 * | 0.01739656 | | |
| **Precipitation** | -0.4458198 ** | 0.09016962 | -0.19311672 ** | |

* P < 0.05 (n = 185)   ** P < 0.01 (n = 185)

## Appendix 3

Plausible models (ΔAICc < 7) obtained from the analysis based on an information theoretic approach. Models were fitted using the maximum likelihood method. The fit of each model in the set was then evaluated using second-order Akaike’s information criterion (AICc). For each variable we also reported the sum of the model weights ($\sum w_i$) of the models in which the variable occurs. Results are reported for vascular plant species richness (A), vascular plant cover (B), lichens species richness (C), lichen cover (D), bryophyte species richness (E), and bryophyte cover (F).

### A – Vascular plant species richness

| | (Int) | Trampling | Pellet | pH | Precipitation | Trampling *pH | Pellet *pH | df | logLik | AICc | delta | weight |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 40 | 2.724 | -0.04020 | -0.07221 | 0.2231 | | | 0.06299 | 6 | -557.998 | 1128.5 | 0.00 | 0.208 |
| 39 | 2.727 | | -0.07271 | 0.2170 | | | 0.05598 | 5 | -559.235 | 1128.8 | 0.34 | 0.176 |
| 48 | 2.729 | -0.03818 | -0.07706 | 0.2523 | 0.06697 | | 0.06354 | 7 | -557.468 | 1129.6 | 1.10 | 0.120 |
| 47 | 2.732 | | -0.07809 | 0.2495 | 0.07343 | | 0.05700 | 6 | -558.581 | 1129.6 | 1.17 | 0.116 |
| 56 | 2.727 | -0.03770 | -0.06925 | 0.2236 | | -0.014960 | 0.06483 | 7 | -557.783 | 1130.2 | 1.73 | 0.087 |
| 7 | 2.741 | | -0.05909 | 0.2183 | | | | 4 | -561.449 | 1131.1 | 2.65 | 0.055 |
| 64 | 2.731 | -0.03588 | -0.07415 | 0.2523 | 0.06567 | -0.014140 | 0.06525 | 8 | -557.276 | 1131.4 | 2.90 | 0.049 |
| 8 | 2.740 | -0.03038 | -0.05756 | 0.2229 | | | | 5 | -560.725 | 1131.8 | 3.32 | 0.040 |
| 15 | 2.746 | | -0.06392 | 0.2489 | 0.06917 | | | 5 | -560.879 | 1132.1 | 3.63 | 0.034 |
| 5 | 2.747 | | | 0.2053 | | | | 3 | -563.403 | 1132.9 | 4.47 | 0.022 |
| 16 | 2.745 | -0.02841 | -0.06207 | 0.2508 | 0.06394 | | | 6 | -560.248 | 1133.0 | 4.50 | 0.022 |
| 6 | 2.746 | -0.03257 | | 0.2107 | | | | 4 | -562.573 | 1133.4 | 4.90 | 0.018 |
| 24 | 2.742 | -0.02858 | -0.05538 | 0.2233 | | -0.009508 | | 6 | -560.638 | 1133.7 | 5.28 | 0.015 |
| 13 | 2.750 | | | 0.2266 | 0.05001 | | | 4 | -563.115 | 1134.5 | 5.99 | 0.010 |
| 22 | 2.749 | -0.02915 | | 0.2121 | | -0.016830 | | 5 | -562.293 | 1134.9 | 6.45 | 0.008 |
| 32 | 2.746 | -0.02679 | -0.06000 | 0.2508 | 0.06317 | -0.008771 | | 7 | -560.174 | 1135.0 | 6.51 | 0.008 |
| 14 | 2.749 | -0.03138 | | 0.2295 | 0.04468 | | | 5 | -562.348 | 1135.0 | 6.56 | 0.008 |

### B – Vascular plant cover

| | (Int) | Trampling | Pellet | pH | Precipitation | Trampling *pH | Pellet *pH | df | logLik | AICc | delta | weight |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8 | 39.65 | -2.801 | -3.264 | 11.28 | | | | 6 | -754.887 | 1522.2 | 0.00 | 0.316 |
| 40 | 39.82 | -2.711 | -3.240 | 11.36 | | | -0.8001 | 7 | -754.671 | 1524.0 | 1.73 | 0.133 |
| 24 | 39.56 | -2.801 | -3.330 | 11.24 | | 0.4426 | | 7 | -754.796 | 1524.2 | 1.98 | 0.117 |
| 16 | 39.69 | -2.772 | -3.336 | 11.63 | 0.7603 | | | 7 | -754.832 | 1524.3 | 2.05 | 0.113 |
| 56 | 39.74 | -2.706 | -3.312 | 11.32 | | 0.4905 | -0.8385 | 8 | -754.559 | 1525.9 | 3.69 | 0.050 |
| 48 | 39.87 | -2.681 | -3.312 | 11.72 | 0.7671 | | -0.8019 | 8 | -754.615 | 1526.0 | 3.80 | 0.047 |
| 7 | 39.69 | | -3.229 | 10.75 | | | | 5 | -757.903 | 1526.1 | 3.89 | 0.045 |
| 32 | 39.61 | -2.770 | -3.408 | 11.60 | 0.8024 | 0.4569 | | 8 | -754.735 | 1526.3 | 4.04 | 0.042 |
| 6 | 39.95 | -2.763 | | 10.57 | | | | 5 | -758.197 | 1526.7 | 4.48 | 0.034 |
| 39 | 39.94 | | -3.198 | 10.89 | | | -11.480 | 6 | -757.471 | 1527.4 | 5.17 | 0.024 |
| 15 | 39.76 | | -3.350 | 11.31 | 11.980 | | | 6 | -757.763 | 1528.0 | 5.75 | 0.018 |
| 64 | 39.79 | -2.675 | -3.391 | 11.69 | 0.8136 | 0.5051 | -0.8414 | 9 | -754.496 | 1528.0 | 5.78 | 0.018 |
| 14 | 39.93 | -2.773 | | 10.45 | -0.2607 | | | 6 | -758.191 | 1528.9 | 6.61 | 0.012 |
| 22 | 39.93 | -2.763 | | 10.56 | | 0.1052 | | 6 | -758.192 | 1528.9 | 6.61 | 0.012 |

## C – Lichen species richness

| | (Int) | Trampling | Pellet | pH | Precipitation | Trampling *pH | Pellet *pH | df | logLik | AICc | delta | weight |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 0.7775 | | | -0.3301 | | | | 3 | -324.753 | 655.6 | 0.00 | 0.199 |
| 39 | 0.7985 | | -0.09239 | -0.3042 | | | -0.1291 | 5 | -322.849 | 656.0 | 0.39 | 0.163 |
| 7 | 0.7759 | | -0.04882 | -0.3217 | | | | 4 | -324.461 | 657.1 | 1.50 | 0.094 |
| 6 | 0.7767 | -0.036070 | | -0.3236 | | | | 4 | -324.566 | 657.4 | 1.71 | 0.084 |
| 13 | 0.7743 | | | -0.3547 | -0.04760 | | | 4 | -324.609 | 657.4 | 1.80 | 0.081 |
| 40 | 0.7975 | -0.026470 | -0.09229 | -0.3001 | | | -0.1258 | 6 | -322.748 | 658.0 | 2.33 | 0.062 |
| 47 | 0.7967 | | -0.08838 | -0.3174 | -0.02407 | | -0.1280 | 6 | -322.812 | 658.1 | 2.46 | 0.058 |
| 8 | 0.7751 | -0.037200 | -0.04994 | -0.3149 | | | | 5 | -324.259 | 658.9 | 3.21 | 0.040 |
| 15 | 0.7737 | | -0.04362 | -0.3405 | -0.03459 | | | 5 | -324.385 | 659.1 | 3.47 | 0.035 |
| 14 | 0.7731 | -0.039160 | | -0.3503 | -0.05269 | | | 5 | -324.389 | 659.1 | 3.47 | 0.035 |
| 22 | 0.7729 | -0.025970 | | -0.3308 | | 0.03049 | | 5 | -324.448 | 659.2 | 3.59 | 0.033 |
| 56 | 0.7910 | -0.007146 | -0.10240 | -0.3110 | | 0.05575 | -0.1329 | 7 | -322.377 | 659.4 | 3.75 | 0.031 |
| 48 | 0.7954 | -0.028090 | -0.08764 | -0.3150 | -0.02763 | | -0.1243 | 7 | -322.699 | 660.0 | 4.39 | 0.022 |
| 24 | 0.7699 | -0.024210 | -0.05574 | -0.3232 | | 0.03913 | | 6 | -324.068 | 660.6 | 4.97 | 0.017 |
| 16 | 0.7725 | -0.039370 | -0.04403 | -0.3359 | -0.03942 | | | 6 | -324.161 | 660.8 | 5.15 | 0.015 |
| 30 | 0.7695 | -0.029200 | | -0.3564 | -0.05089 | 0.02951 | | 6 | -324.280 | 661.0 | 5.39 | 0.013 |
| 64 | 0.7894 | -0.008703 | -0.09838 | -0.3233 | -0.02295 | 0.05494 | -0.1317 | 8 | -322.341 | 661.5 | 5.86 | 0.011 |
| 32 | 0.7678 | -0.026610 | -0.05013 | -0.3418 | -0.03543 | 0.03758 | | 7 | -323.987 | 662.6 | 6.97 | 0.006 |

## D – Lichen cover

| | (Int) | Trampling | Pellet | pH | Precipitation | Trampling*pH | Pellet *pH | df | logLik | AICc | delta | weight |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 13 | 27.45 | | | -13.620 | -581.700 | | | 5 | -812.754 | 1635.8 | 0.00 | 0.117 |
| 14 | 27.39 | -2.214 | | -13.370 | -616.700 | | | 6 | -811.744 | 1636.0 | 0.12 | 0.110 |
| 47 | 27.86 | | -2.149 | -12.530 | -514.000 | | -2.523 | 7 | -810.809 | 1636.3 | 0.41 | 0.095 |
| 15 | 27.30 | | -2.433 | -12.830 | -505.600 | | | 6 | -811.896 | 1636.3 | 0.42 | 0.094 |
| 16 | 27.25 | -2.136 | -2.298 | -12.630 | -543.700 | | | 7 | -810.965 | 1636.6 | 0.72 | 0.081 |
| 48 | 27.77 | -1.932 | -2.061 | -12.380 | -547.600 | | -2.320 | 8 | -810.036 | 1636.9 | 1.05 | 0.069 |
| 39 | 28.16 | | -2.626 | -10.090 | | | -2.557 | 6 | -812.344 | 1637.2 | 1.32 | 0.060 |
| 7 | 27.58 | | -2.922 | -10.420 | | | | 5 | -813.453 | 1637.2 | 1.40 | 0.058 |
| 5 | 27.83 | | | -10.950 | | | | 4 | -814.677 | 1637.6 | 1.73 | 0.049 |
| 8 | 27.56 | -1.924 | -2.803 | -10.080 | | | | 6 | -812.709 | 1637.9 | 2.05 | 0.042 |
| 30 | 27.30 | -2.207 | | -13.430 | -614.200 | 0.5222 | | 7 | -811.675 | 1638.0 | 2.14 | 0.040 |
| 6 | 27.81 | -2.015 | | -10.570 | | | | 5 | -813.850 | 1638.0 | 2.19 | 0.039 |
| 40 | 28.10 | -1.721 | -2.550 | -9.808 | | | -2.380 | 7 | -811.739 | 1638.1 | 2.27 | 0.038 |
| 32 | 27.12 | -2.121 | -2.414 | -12.690 | -536.300 | 0.7569 | | 8 | -810.825 | 1638.5 | 2.63 | 0.031 |
| 64 | 27.63 | -1.909 | -2.197 | -12.430 | -538.900 | 0.8845 | -2.389 | 9 | -809.840 | 1638.7 | 2.87 | 0.028 |
| 24 | 27.40 | -1.909 | -2.937 | -10.180 | | 0.8764 | | 7 | -812.523 | 1639.7 | 3.84 | 0.017 |
| 56 | 27.93 | -1.698 | -2.702 | -9.918 | | 10.000 | -2.455 | 8 | -811.491 | 1639.8 | 3.96 | 0.016 |
| 22 | 27.71 | -2.009 | | -10.660 | | 0.5885 | | 6 | -813.764 | 1640.0 | 4.16 | 0.015 |

## E – Bryophyte species richness

| | **(Int)** | **Trampling** | **Pellet** | **pH** | **Precipitation** | **Trampling*pH** | **Pellet *pH** | **df** | **logLik** | **AICc** | **delta** | **weight** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.8816 | | | | | | | 2 | -292.406 | 588.9 | 0.00 | 0.118 |
| 5 | 0.8800 | | | -0.06615 | | | | 3 | -291.462 | 589.1 | 0.18 | 0.107 |
| 3 | 0.8801 | | -0.06531 | | | | | 3 | -291.497 | 589.1 | 0.25 | 0.104 |
| 11 | 0.8780 | | -0.07149 | | 0.06475 | | | 4 | -290.572 | 589.4 | 0.49 | 0.092 |
| 9 | 0.8800 | | | | 0.05878 | | | 3 | -291.653 | 589.4 | 0.56 | 0.089 |
| 7 | 0.8788 | | -0.05180 | -0.05342 | | | | 4 | -290.919 | 590.1 | 1.18 | 0.065 |
| 2 | 0.8815 | -0.026270 | | | | | | 3 | -292.258 | 590.6 | 1.77 | 0.049 |
| 13 | 0.8795 | | | -0.04960 | 0.03623 | | | 4 | -291.229 | 590.7 | 1.80 | 0.048 |
| 4 | 0.8798 | -0.025120 | -0.06455 | | | | | 4 | -291.360 | 590.9 | 2.06 | 0.042 |
| 6 | 0.8799 | -0.016630 | | -0.06365 | | | | 4 | -291.403 | 591.0 | 2.15 | 0.040 |
| 15 | 0.8778 | | -0.06347 | -0.02662 | 0.05228 | | | 5 | -290.462 | 591.3 | 2.38 | 0.036 |
| 12 | 0.8779 | -0.013410 | -0.07094 | | 0.06231 | | | 5 | -290.535 | 591.4 | 2.53 | 0.033 |
| 10 | 0.8800 | -0.015520 | | | 0.05569 | | | 4 | -291.603 | 591.4 | 2.55 | 0.033 |
| 8 | 0.8787 | -0.017720 | -0.05206 | -0.05072 | | | | 5 | -290.852 | 592.0 | 3.16 | 0.024 |
| 39 | 0.8828 | | -0.05224 | -0.05102 | | | -0.01671 | 5 | -290.875 | 592.1 | 3.21 | 0.024 |
| 14 | 0.8795 | -0.012500 | | -0.04859 | 0.03440 | | | 5 | -291.196 | 592.7 | 3.85 | 0.017 |
| 22 | 0.8766 | -0.014790 | | -0.06767 | | 0.02015 | | 5 | -291.318 | 593.0 | 4.09 | 0.015 |
| 47 | 0.8831 | | -0.06445 | -0.02237 | 0.05434 | | -0.02205 | 6 | -290.385 | 593.2 | 4.36 | 0.013 |
| 16 | 0.8777 | -0.012010 | -0.06327 | -0.02575 | 0.05052 | | | 6 | -290.432 | 593.3 | 4.46 | 0.013 |
| 24 | 0.8748 | -0.015430 | -0.05324 | -0.05496 | | 0.02285 | | 6 | -290.745 | 594.0 | 5.08 | 0.009 |
| 40 | 0.8823 | -0.016720 | -0.05244 | -0.04871 | | | -0.01522 | 6 | -290.815 | 594.1 | 5.22 | 0.009 |
| 30 | 0.8756 | -0.010320 | | -0.05208 | 0.03666 | 0.02294 | | 6 | -291.086 | 594.6 | 5.77 | 0.007 |
| 32 | 0.8731 | -0.009156 | -0.06529 | -0.02914 | 0.05360 | 0.02732 | | 7 | -290.279 | 595.2 | 6.31 | 0.005 |
| 48 | 0.8828 | -0.010450 | -0.06423 | -0.02182 | 0.05275 | | -0.02103 | 7 | -290.362 | 595.4 | 6.48 | 0.005 |

## F – Bryophyte cover

| | **(Int)** | **Trampling** | **Pellet** | **pH** | **Precipitation** | **Trampling *pH** | **Pellet *pH** | **df** | **logLik** | **AICc** | **delta** | **weight** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 15 | 35.69 | | 5.592 | 6.883 | 7.515 | | | 6 | -817.257 | 1647.0 | 0.00 | 0.340 |
| 16 | 35.70 | 1.908 | 5.588 | 6.722 | 7.791 | | | 7 | -816.559 | 1647.7 | 0.76 | 0.232 |
| 32 | 35.95 | 1.836 | 5.739 | 6.895 | 7.641 | -1.515 | | 8 | -816.075 | 1649.0 | 1.98 | 0.126 |
| 47 | 35.81 | | 5.604 | 6.981 | 7.535 | | -0.51880 | 7 | -817.215 | 1649.1 | 2.08 | 0.120 |
| 48 | 35.87 | 1.993 | 5.605 | 6.866 | 7.835 | | -0.78900 | 8 | -816.463 | 1649.7 | 2.76 | 0.086 |
| 64 | 36.08 | 1.904 | 5.746 | 7.003 | 7.681 | -1.464 | -0.62660 | 9 | -816.015 | 1651.1 | 4.07 | 0.044 |
| 11 | 35.46 | | 6.813 | | 4.484 | | | 5 | -821.600 | 1653.5 | 6.55 | 0.013 |

# Appendix 4

Floristic lists of vascular plants, lichens and bryophytes recorded in the 185 plots across 60 lichen-rich dry grasslands in the central-western Po Plain (northern Italy).

## Vascular plants

*Achillea millefolium*, *Achillea tomentosa*, *Aegylops cylindrica* (archaeophyte), *Aegilops geniculata*, *Agrostis capillaris*, *Agrostis stolonifera*, *Ailanthus altissima*, *Aira caryophyllea*, *Aira* sp., *Ajuga chamaepytis*, *Allium vineale*, *Allium sphaerocephalon*, *Allium* sp., *Alyssum alyssoides*, *Ambrosia artemisiifolia* (neophyte), *Amorpha fruticosa* (neophyte), *Anchusa officinalis*, *Anchusa* sp., *Anisantha sterilis*, *Anisantha tectorum*, *Anthoxanthum odoratum*, *Aphanes arvensis*, *Arabidopsis thaliana*, *Arabis glabra*, *Arenaria serpyllifolia*, *Armeria arenaria* (species of conservation value), *Arrhenatherum elatius*, *Artemisia alba*, *Artemisia campestris*, *Artemisia vulgaris*, *Artemisia* sp., *Asperula cynanchica*, *Asperula* sp., *Avena barbata*, *Biscutella laevigata*, *Blackstonia perfoliata* (species of conservation value), *Bombycilaena erecta* (species of conservation value), *Botriochlora ischaemum*, *Bromopsis erecta*, *Bromus hordeaceus*, *Bromus squarrosus*, *Bupleurum baldense*, *Calluna vulgaris*, *Cardus nutans*, *Cardus pycnocephalus*, *Carex caryophyllea*, *Carex contigua*, *Carex* sp., *Catapodium rigidum*, *Centaurea deusta* (species of conservation value), *Centaurea stoebe*, *Centaurea* sp., *Centaurium pulchellum*, *Centaurium erythraea*, *Cerastium brachypetalum*, *Cerastium glomeratum*, *Cerastium glutinosum*, *Cerastium pumilum*, *Cerastium semidecandrum*, *Cerastium* sp., *Chondrilla juncea*, *Cirsium vulgare*, *Cirsium* sp., *Clematis vitalba*, *Clinopodium acinos*, *Clinopodium nepeta*, *Convolvolus arvensis*, *Corylus avellana*, *Corynephorus canescens* (species of conservation value), *Crataegus monogyna*, *Crepis biennis*, *Crepis vesicaria*, *Cruciata pedemontana*, *Crupina vulgaris*, *Chrysopogon gryllus*, *Cuscuta epithymum*, *Cynodon dactylon*, *Cytisus scoparius*, *Dactylis glomerata*, *Dianthus carthusianorum* (species of conservation value), *Dianthus seguieri* (species of conservation value), *Digitaria sanguinalis*, *Diplotaxis tenuifolia*, *Diplotaxis verna*, *Echium vulgare*, *Elytrigia repens*, *Epilobium donadonei*, *Eragrostis curvula* (neophyte), *Erigeron annuus* (neophyte), *Erigeron canadensis* (neophyte), *Erodium cicutarium*, *Ervilia hirsuta*, *Eryngium campestre*, *Erysimum rhaeticum*, *Euonymus europaeus*, *Euphorbia cyparissias*, *Euphorbia falcata*, *Euphorbia helioscopia*, *Euphorbia maculata*, *Euphorbia* sp., *Fallopia* sp., *Festuca brevipila*, *Festuca filiformis*, *Festuca* sp., *Filago arvensis*, *Filago germanica*, *Fraxinus ornus*, *Fumana procumbens*, *Galium divaricatum*, *Galium lucidum*, *Galium parisiense*, *Galium* sp., *Geranium colombinum*, *Geranium molle*, *Globularia bisnagarica*, *Gnaphalium uliginosum* (species of conservation value), *Helianthemum nummularium*, *Herniaria glabra*, *Hippocrepis comosa*, *Hylotelephium maximum*, *Hypericum perforatum*, *Hypochoeris glabra*, *Hypochoeris radicata*, *Jasione montana*, *Juncus tenuis* (neophyte), *Koeleria macrantha*, *Koeleria pyramidata*, *Koeleria* sp., *Lactuca perennis*, *Lactuca serriola*, *Latyrus sphaericus*, *Leontodon crispus*, *Logfia minima*, *Lepidium* sp., *Leucanthemum vulgare*, *Ligustrum vulgare*, *Linaria pelisseriana*, *Linaria vulgaris*, *Linum bienne*, *Lotus corniculatus*, *Luzula campestris*, *Luzula multiflora*, *Luzula* sp., *Lysimachia arvensis*, *Medicago lupulina*, *Medicago minima*, *Melica ciliata*, *Melilotus albus*, *Micropyrum tenellum*, *Minuartia hubrida*, *Muscari comosum*, *Myosotis arvensis*, *Myosotis ramosissima*, *Myosotis* sp., *Oenothera* sp. (neophyte), *Ononis natrix*, *Opuntia humifusa* (neophyte), *Oreoselinum nigrum*, *Origanum vulgare*, *Orobanche* sp., *Oxalis dillenii*, *Oxalis fontana*, *Parentucellia latifolia*, *Petrorhagia prolifera*, *Petrorhagia saxifraga*, *Pilosella officinarum*, *Pilosella piloselloides*, *Pinus sylvestris*, *Plantago holosteum*, *Plantago lanceolata*, *Plantago sempervirens*, *Poa annua*, *Poa bulbosa*, *Poa pratensis*, *Poa* sp., *Polygonatum odoratum*, *Polygonatum* sp., *Populus canadensis* (neophyte), *Populus hybrida*, *Populus nigra*, *Potentilla argentea*, *Potentilla puberula*, *Potentilla recta*, *Poterium sanguisorba*, *Prunus serotina* (neophyte), *Prunus padus*, *Prunus spinosa*, *Psilurus incurvus*, *Pteridium aquilinum*, *Quercus robur*, *Reseda lutea* (species of conservation value), *Reynoutria japonica* (neophyte), *Rhamnus cathartica*, *Robinia pseudoacacia* (neophyte), *Rosa canina*, *Rosa* sp., *Rostraria cristata*, *Rubus caesius*, *Rubus* cf. *ulmifolius*, *Rubus* sp., *Rumex acetosella*, *Sagina procumbens*, *Sagina* sp., *Salvia pratensis*, *Saponaria ocymoides*, *Saponaria officinalis*, *Satureja montana*, *Scabiosa columbaria*, *Scabiosa* sp., *Scleranthus annuus*, *Scleranthus perennis*, *Scrophularia canina*, *Sedum acre*, *Sedum rubens*, *Sedum rupestre*, *Sedum sexangulare*, *Senecio inaequidens* (neophyte), *Senecio vulgaris*, *Sherardia arvensis*, *Silene nutans*, *Silene otites*, *Silene vulgaris*, *Solidago gigantea* (neophyte), *Sonchus asper*, *Sorghum halepense* (archaeophyte), *Stachys recta*, *Teesdalia nudicaulis*, *Teucrium chamaedrys*, *Teucrium montanum*, *Thymus longicaulis*, *Thymus pulegioides*, *Thymus vulgaris*, *Thymus* sp., *Trifolium arvense*, *Trifolium campestre*, *Trifolium nigrescens*, *Trifolium scabrum*, *Trifolium* sp., *Trigonella officinalis*, *Tuberaria guttata*, *Ulmus minor*, *Valerianella locusta*, *Verbascum lychnitis*, *Verbascum pulverulentum*, *Verbascum* sp., *Veronica annua*, *Veronica arvensis*, *Veronica* sp., *Vicia cracca*, *Vicia lutea*, *Vicia sativa*, *Vicia* sp., *Viola arvensis*, *Vulpia ciliata*, *Vulpia myurus*.

## Lichens

*Blennothallia crispa*, *Cetraria aculeata*, *Cladonia cariosa*, *Cladonia chlorophaea*, *Cladonia coccifera*, *Cladonia coniocraea*, *Cladonia convoluta*, *Cladonia fimbriata*, *Cladonia foliacea*, *Cladonia furcata*, *Cladonia humilis*, *Cladonia peziziformis*, *Cladonia polycarpoides*, *Cladonia portentosa* (species of conservation value), *Cladonia pyxidata*, *Cladonia rangiformis*, *Cladonia rei*, *Cladonia squamosa*, *Cladonia strepsilis*, *Cladonia symphycarpa*, *Cladonia uncialis*, *Enchylium tenax*, *Gyalolechia fulgens*, *Placidium squamulosum*, *Psora decipiens*, *Scytinium schraderi*, *Stereocaulon condensatum*, *Toninia sedifolia*.

## Bryophytes

*Brachythecium albicans*, *Campylopus introflexus*, *Ceratodon purpureus*, *Didymodon fallax*, *Dicranum scoparium*, *Hypnum cupressiforme*, *Leucobryum glaucum* (species of conservation value), *Polytrichastrum formosum*, *Polytrichum piliferum*, *Pseudocrossidium hornsuchianum*, *Racomitrium canescens*, *Rhynchostegium megapolitanum*, *Riccia ciliifera*, *Syntrichia ruralis*, *Tortella tortuosa*.

# Chapter 5

## Trap and release: are terricolous lichen mats suitable for storing and return vascular plant seeds? A case study with implications for dry grasslands restoration

Gabriele Gheza, Juri Nascimbene, Silvia Assini

### Abstract

Among the many lichen-plant interactions so far recorded in nature, the seed-trapping ability of fruticose lichen mats has been poorly investigated. This ability of lichens makes them particularly interesting in the perspective of restoration ecology. So far, terricolous lichens have rarely been used in habitat restoration, and only to restore lichen communities, not vascular vegetation. To test the ability of fruticose lichen mats to trap and store vascular plant seeds which are able to germinate when they reach soil, we selected 20 plots (5 plots x 4 sites) in acidic dry grasslands in the Ticino river valley. Vegetation relevés were carried out in spring 2016 to record the species occurring in the plots. In spring 2018, 20 lichen mat samples (30 x 30 cm) were collected in the 20 plots. Each sample was dryed and crumbled in a tank (100 x 70 x 20 cm) filled with sterile gardening soil and covered with a coarse knitted cloth, to avoid contamination. The tanks were placed in the Botanical Garden of Pavia and checked every 2 days to record all the germinated seedlings. The species lists of the donor plots were compared with the lists of the species germinated in the tanks taking into account all, native and non-native species. Overall, 2627 seedlings of 34 species (1328 seedlings of 24 native, 1299 seedlings of 10 non-native) were recorded. In the donor plots the number of species was higher. Some species were shared between the two situations, some species were exclusively recorded in the donor plots or in the tanks. The number of native species in the tanks was higher than the number of non-native species, whereas the number of individuals was higher for non-native species. Overall, the number of species was low, consistently with the low vascular plant diversity found in acidic dry grasslands in the study area. A strong recovery of the lichen fragments, which developed new thalli, and of moss carpets was also observed in the tanks. This test showed that terricolous lichen mats taken from acidic dry grasslands are able to store and release vascular plant seeds that are viable and can germinate when placed in proper conditions. Our results highlight the chance to use terricolous lichen mats for habitat restoration as vectors not only for lichen species themselves but also for vascular plants; however, the possible germination of non-native species which can develop from the material used in this kind of restoration needs to be carefully taken in account and further investigated.

### Keywords

Habitat restoration, Germination, Invasive species, Mat-forming lichens, Restoration ecology.

# Introduction

Lichen-plant interactions in lichen-rich habitats are many and complex (Favero-Longo & Piervittori 2010). Terricolous lichen crusts and mats can promote, inhibit or have negligible effects on vascular plants (Zhang *et al*. 2016).

In extreme environments, terricolous lichens can act as facilitators rather than inhibitors for vascular plants (Molina-Montenegro *et al*. 2013; Sundsal 2015), mitigating harsh environmental conditions and thus fostering seed germination. This happens mainly in cool deserts, while in hot deserts the effects of lichens on seed germination and establishment are more ambivalent (Zhang *et al*. 2016). In fact, it was observed that large mat-forming and shrub-like fruticose lichens can inhibit the establishments of vascular plant seeds (Hawkes & Menges 2003; Sundsal 2015). This is due mainly to their morphology, which prevents the seeds to reach the soil (by trapping them) or to develop in seedlings; furthermore, the expansion of thalli due to the morning dew can physically pull the seeds out of the soil or break root connections of the seedlings (Allen 1929). Thick lichen mats have therefore been regarded as a limiting factor for seedlings to develop (Sedia & Ehrenfeld 2003), but also lichen crusts dominated by thin crustose species can hinder seedling establishment (Deines *et al*. 2007). Yet, the seed trapping by lichens can be combined with a positive nursery effect (Riefner & Bowler 1995), which, however, to our best knowledge has never been explicitly addressed, even if it is known that lichen mats can increase water availability and protect seeds and seedlings from herbivores (Favero-Longo & Piervittori 2010). Finally, it should be considered that the actual effects of these interactions can be species-specific (Zamfir 2003; Escudero *et al*. 2007; Zhang *et al*. 2016) and mediated by environmental factors (Zamfir 2003), thus very variable and difficult to generalize.

Terricolous lichens have rarely been used in habitat restoration, and in those rare cases the purpose was to restore lichen communities and not vascular vegetation (Jeschke 2012; Smith 2014; Brackel & Brackel 2016; Rapai *et al*. 2017). The material used for species introductions and reintroductions included mainly fragments of lichen thalli (Brackel & Brackel 2016; Rapai *et al*. 2017) or entire cryptogam swards (Jeschke 2012; Rapai *et al*. 2017).

The ability of lichens to trap seeds of vascular plants makes them particularly interesting in the perspective of restoration ecology. Even if a preliminary test was carried out on the field by Gheza & Assini (2018), the possibility to use lichen mats to restore not only cryptogamic but also vascular species has never been explicitly tested before.

This study aims at provinding a first insight in the ability of fruticose lichen mats to trap and store vascular plant seeds which are able to germinate when they reach soil, considering if this ability could be used in the restoration of vascular plant vegetation in lichen-rich habitats. In particular, we addressed the following questions: (1) do fruticose lichen thalli from extensive and thick lichen mats actually trap and store vascular plant seeds; (2) are these seeds actually able to germinate once they are allowed to reach the soil; (3) is the number of species and seedlings obtained from fruticose lichen mats suitable to hypothesize their use in the restoration of their habitats?

## Materials and methods

### *Experiment*

Four donor sites of lichen-rich *Thero-Airion* acidic dry grasslands with a similar extent, but different temperature/rainfall conditions, were selected along the Ticino river valley (western Po Plain, Northern Italy; Tab. 1). These grasslands are locate on sandy-pebbly substrates, which are very draining and thus define the xerophilous character of the vegetation.

| **Locality** | **Coordinates** | **Altitude (m a.s.l.)** | **Patch surface ($m^2$)** | **Mean annual temperature (°C)** | **Mean annual rainfall (mm)** |
|---|---|---|---|---|---|
| Marcetto<br>(Oleggio, Novara) | 45°36’52.96”N<br>8°40’49.04”E | 159 | 12227 | 11.4 | 1088 |
| La Fagiana<br>(Magenta, Milano) | 45°25’47.53”N<br>8°49’32.34”E | 108 | 28290 | 12.4 | 1054 |
| Bosco Ronchi<br>(Vigevano, Pavia) | 45°16’30.14”N<br>8°56’49.7”E | 74 | 10770 | 12.5 | 1003 |
| Santa Sofia<br>(Torre d'Isola, Pavia) | 45°11’38.29”N<br>9°4’47.03”E | 62 | 14681 | 13.0 | 968 |

Table 1. Study sites.

In spring 2016, vegetation was recorded in five circular plots (radius = 3 m) in each site. Plots were placed at regular spans along the transects drawn between the two furthest vertices of the polygons drawn around each site by means of Qgis (QGIS DEVELOPMENT TEAM, 2009). This resulted in a total of twenty plots. All vascular plants, lichen and bryophyte species were recorded, together with their percentage cover values.

In each site, lichen material for the experiment was collected in March 2018 site. A lichen sward of 30 x 30 cm was collected in the centre of each plot. The dominant species in each sample was the fruticose *Cladonia rangiformis* Hoffm.; occasional negligible occurrences of fragments of other lichen species included the fruticose *Cladonia furcata* (Huds.) Schrad. and the squamulose *Cladonia foliacea* (Huds.) Willd. and *Cladonia polycarpoides* Nyl. In some samples also the acrocarpous moss *Polytrichum piliferum* Schreb. ex Hedw. occurred.

Twenty experimental tanks (100 x 70 cm and 20 cm of depth) were prepared at the Botanical Garden of Pavia in March 2018, filling them with sterile gardening soil. They were covered with a coarse knitted cloth aimed at avoiding contamination by seeds of the plants occurring in the surroundings of the experimental site. The cloth allowed light and water to reach the soil in the tanks, which were placed in an open position allowing them to get full illumination and rain, to simulate as far as possible the environmental conditions occurring in the donor sites where dry grasslands are located in the study area.

Lichen material taken from the donor sites was dryed at 22° C and then it was dispersed in the tanks after having been fragmented by hand in 1-1.5 cm long pieces, forming a homogeneous cover on the soil. Every sample was dispersed in a tank marked with a reference code recalling the corresponding donor plot.

From March to August 2018 the tanks were checked every 2 days to detect the presence of seedlings. During the first month the tanks were watered, to enhance the probability of germination. To avoid the risk of death of the seedlings due to the overcrowding in the tanks, each seedling was transplanted singularly in a pot marked with a reference code, where it was able do develop properly until its identification was possible. The number of seedlings of each species in each tank was recorded.

### ***Data analysis***

The species lists of the donor plots were compared with the lists of the species germinated in the experimental tanks, taking into account (1) all the species, (2) only native species, and (3) only non-native species.

The number of species was compared between the donor plots and the corresponding tanks (Kruskal-Wallis test). The number of species and the total number of seedlings were compared among the four groups of tanks.

A linear regression model was performed between the number of species recorded in the donor plots and that recorded in the tanks, to test their relationship.

The statistical analyses were performed with the software PAST (Hammer et al. 2001).

## Results

Overall, 2627 seedlings belonging to 34 species (1328 seedlings of 24 native species and 1299 seedlings of 10 non-native species) were recorded in the 20 experimental tanks (Appendix 1). Native species germinated with a mean of 55.3 seedlings per species, whereas non-native species had a higher rate with a mean of 129.9 seedlings per species. In the donor plots we found a higher number of species than in the tanks (Tab. 2, Fig. 1). In the donor plots, the number of species was significantly higher for native and all species, but not for non-native species, except in one site (Tab. 3). Some species were shared between the two situations, whereas some species were exclusively recorded in the donor plots or in the tanks. However, the species recorded only in the tanks occurred also in the donor sites, but outside the recorded plots (this was checked by means of field inspections carried out in May-June 2018, after having found them in the tanks).

| | Marcetto | | La Fagiana | | Bosco Ronchi | | Santa Sofia | |
|---|---|---|---|---|---|---|---|---|
| | Donor plots | Tanks | Donor plots | Tanks | Donor plots | Tanks | Donor plots | Tanks |
| Donor plots and tanks | 5 | 5 | 5 | 5 | 9 | 9 | 7 | 7 |
| Only donor plots | 30 | | 27 | | 17 | | 16 | |
| Only tanks | | 1 | | 5 | | 9 | | 8 |
| Total (partial) | 35 | 6 | 32 | 10 | 26 | 18 | 23 | 15 |
| Total | 36 | | 37 | | 35 | | 31 | |

Table 2. Overall number of species recorded in the donor plots and in the tanks.

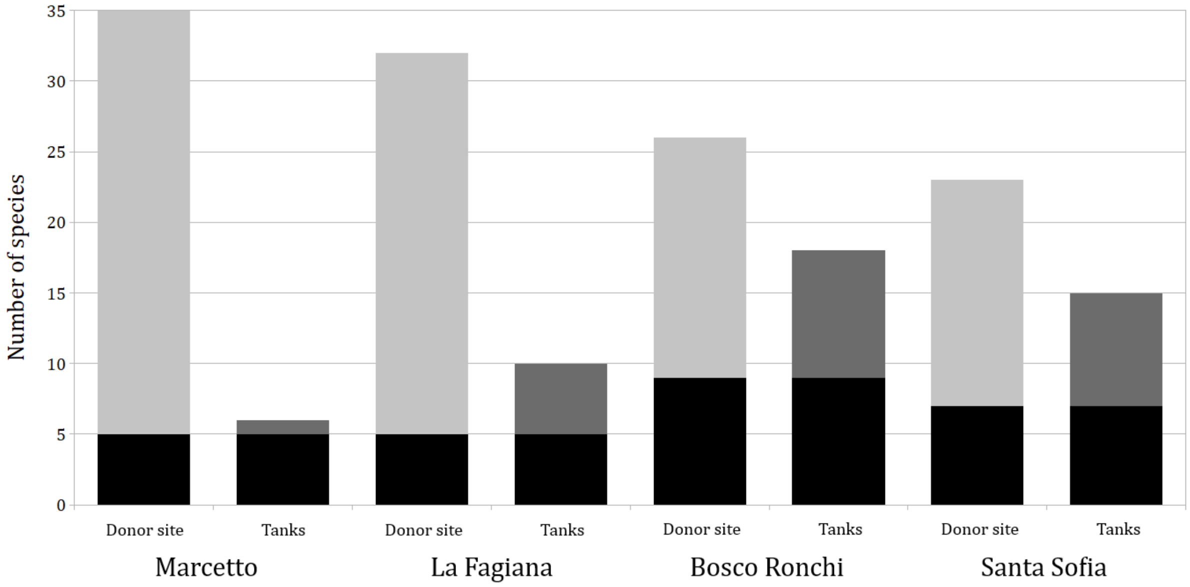

Figure 1. Overall number of species recorded in the donor plots and in the tanks. Black: species recorded both in the donor plots and in the tanks; light grey: species recorded only in the donor plots; dark grey: species recorded only in the tanks.

| | Marcetto | La Fagiana | Bosco Ronchi | Santa Sofia |
|---|---|---|---|---|
| Native species | **0.0114** | **0.0109** | **0.0119** | **0.0114** |
| Non-native species | 0.4028 | 0.6005 | **0.0254** | 0.5152 |
| All species | **0.0119** | **0.0153** | **0.0439** | **0.0109** |

Table 3. P-values of the Kruskal-Wallis tests for the number of species between the donor plots and the experimental tanks. Significant p-values are reported in bold.

On average, the number of native species in the tanks was higher than the number of non-native species (Tab. 4, Fig. 2), whereas the number of individuals was higher for non-native species (Tab. 5, Fig. 3). The total number of species (all, native, non-native) germinated in each tank was, however, rather low (Tab. 4).

| | | Marcetto | | La Fagiana | | Bosco Ronchi | | Santa Sofia | |
|---|---|---|---|---|---|---|---|---|---|
| | | Native | Non-native | Native | Non-native | Native | Non-native | Native | Non-native |
| Tank | 1 | 3 | 1 | 2 | 1 | 5 | 5 | 4 | 2 |
| Tank | 2 | 0 | 2 | 4 | 1 | 3 | 1 | 5 | 1 |
| Tank | 3 | 2 | 1 | 1 | 0 | 7 | 2 | 5 | 4 |
| Tank | 4 | 0 | 1 | 1 | 1 | 6 | 2 | 4 | 4 |
| Tank | 5 | 2 | 0 | 1 | 1 | 8 | 3 | 2 | 4 |
| Mean | | 1.4 | 1 | 1.8 | 0.8 | 5.8 | 2.6 | 4 | 3 |
| Total | | 5 | 2 | 9 | 1 | 13 | 6 | 9 | 7 |
| Overall mean | | 2.4 | | 2.6 | | 8.4 | | 7 | |
| Overall total | | 7 | | 10 | | 19 | | 16 | |
| Native/Non-native ratio | | 2.5 | | 9 | | 2.2 | | 2.3 | |

Table 4. Number of species recorded in the experimental tanks.

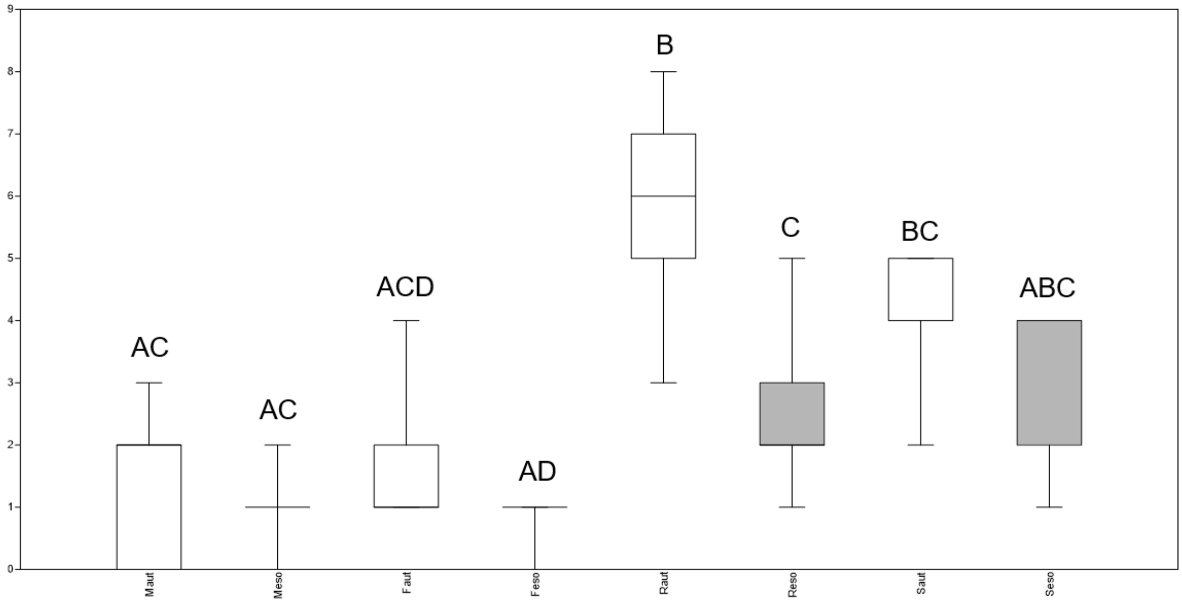

Figure 2. Number of species recorded in the experimental tanks, sorted by site. White: native species; grey: non-native species. Different letters mark significant differences according to the Kruskal-Wallis test results (p>0.05).

| | | Marcetto | | La Fagiana | | Bosco Ronchi | | Santa Sofia | |
|---|---|---|---|---|---|---|---|---|---|
| | | Native | Non-native | Native | Non-native | Native | Non-native | Native | Non-native |
| Tank | 1 | 14 | 33 | 6 | 1 | 31 | 20 | 7 | 153 |
| Tank | 2 | 0 | 12 | 6 | 3 | 3 | 9 | 27 | 193 |
| Tank | 3 | 23 | 3 | 1 | 0 | 18 | 13 | 49 | 245 |
| Tank | 4 | 0 | 3 | 1 | 1 | 19 | 168 | 20 | 133 |
| Tank | 5 | 4 | 0 | 1 | 1 | 1096 | 25 | 2 | 283 |
| Mean | | 8.2 | 10.2 | 3 | 1.2 | 233.4 | 47 | 21 | 201.4 |
| Total | | 41 | 51 | 15 | 6 | 1167 | 235 | 105 | 1007 |
| Overall mean | | 18.4 | | 4.2 | | 280.4 | | 222.4 | |
| Overall total | | 92 | | 21 | | 1402 | | 1112 | |
| Native/Non-native ratio | | 0.8 | | 2.5 | | 4.9 | | 0.1 | |
| Mean | | 131.35 | | | | | | | |
| Total | | 2627 | | | | | | | |
| Native/Non-native ratio | | 1.02 | | | | | | | |

Table 5. Number of seedlings recorded in the experimental tanks.

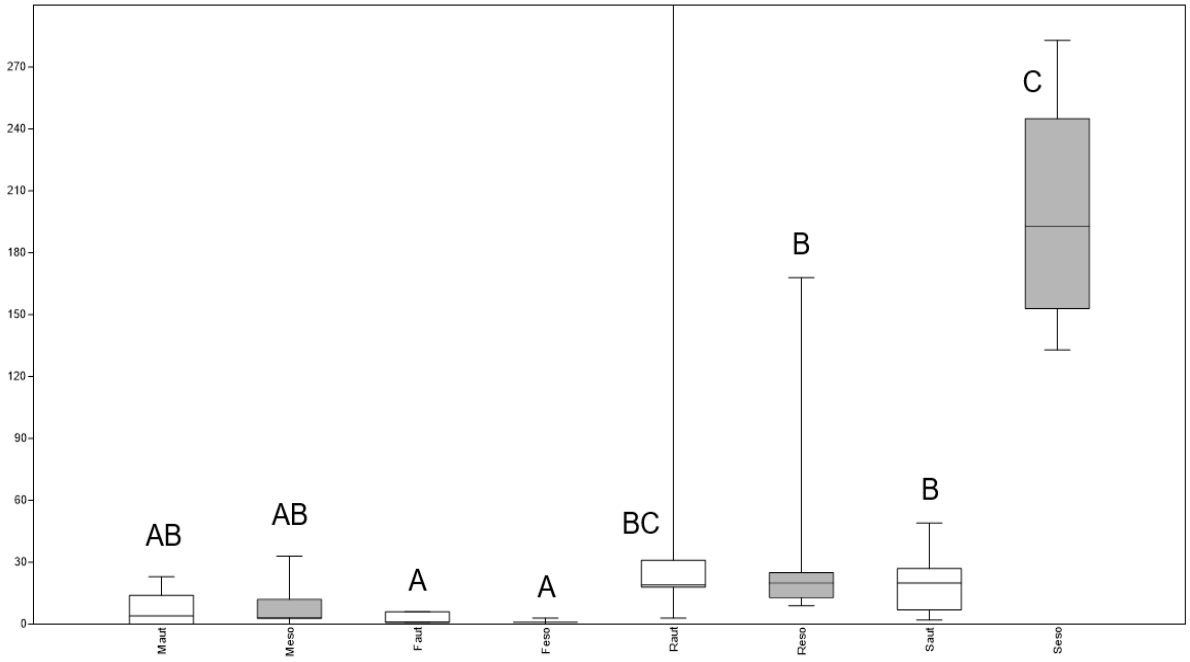

Figure 3. Number of seedlings recorded in the experimental tanks, sorted by site. White: native species; grey: non-native species. Different letters mark significant differences according to the Kruskal-Wallis test results (p>0.05).

No relationship was detected between the number of species recorded in the donor plots and that recorded in the tanks for the number of all (R=−0.086, R2=0.007, p=0.717; graph not shown) and native (R=−0.252, R2=0.064, p=0.283; graph not shown) species, while a significant relationship was found for the number of non-native species (R=0.510, R2=0.261, p=0.022; Fig. 4).

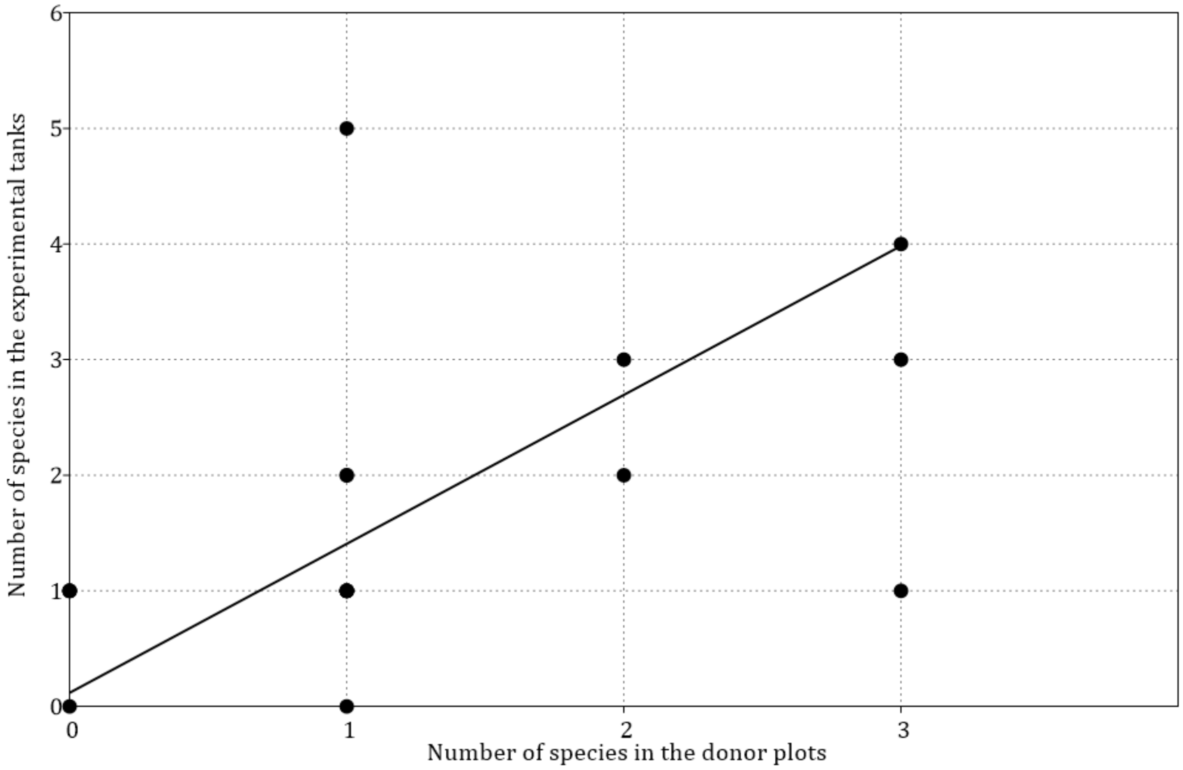

Figure 4. Linear regression between the number of non-native species recorded in donor plots (x) and in the tanks (y).

Finally, a strong recovery of the lichen fragments was observed in the tanks: 4 months since the beginning of the experiment, the fragments of *C. rangiformis* produced primary squamules and rooted to the soil in all the tanks. Also small primary thalli of *C. foliacea* and *C. polycarpoides* were observed rooted to the soil. Furthermore, carpets of *P. piliferum* developed in several tanks.

## Discussion and conclusions

The low number of species recorded in the tanks is consistent with the low vascular plant diversity found in acidic dry grasslands in the study area. On the other hand, the higher diversity of native species and the lower diversity of non-native ones recorded in the tanks is in accord with their diversity in the donor sites: in the surveyed dry grasslands, non-native plants occur with low number of species (cf. Appendix 2).

Also the low number of individuals of most of the native species is in accord with the situation recorded in the donor sites. The most abundant species in the tanks were also some of the most abundant in donor sites, i.e. *Aira caryophyllea*, *Arabidopsis thaliana*, *Hypochoeris glabra*, *Logfia minima*, *Rumex acetosella*, *Tillaea muscosa* (cf. Appendix 1). The *exploit* of *T. muscosa*, which germinated with 1027 seedlings in total in a single tank, indicates a high ability of this species to germinate from seeds trapped on lichen mats.

On the other hand, some invasive non-native species (*Erigeron annuus*, *Eurphorbia maculata*, *Oenothera sp*.) showed a high germination rate. This can be explained by their R or CR Grime strategy (Grime 2001; Vukovic *et al*. 2010), which implies the production and dispersion of a high number of seeds, with a consequent high colonization rate in nature and therefore the presence of many seeds trapped on lichen thalli. Furthermore, the water retention of the tanks could have played a role in this: in fact, in the donor sites the substrate is very draining, and the dominant species are xerophilous (cf. Appendix 2).

This experimental test showed that terricolous lichen mats taken from acidic dry grasslands seem to be able to store and release seeds of vascular plants typical of such habitats. These seeds are viable and can germinate when placed in proper conditions. At the same time, this test also showed that lichen fragments are able to root and develop new thalli, which is an ability already known from literature (e.g. Heinken 1999; Jeschke 2012; Brackel & Brackel 2016). Furthermore, also mosses showed to be able to recover and form new carpets.

Our results highlight the chance to use terricolous lichen mats for habitat restoration as vectors not only for lichen species themselves, but also for vascular plants. This possible use should be tested also under controlled conditions, to understand which factors can influence germination of trapped seeds, and also for other lichen-rich habitat types, e.g. alpine heaths, Mediterranean garrigues.

The problem of the non-native species which can develop from the material used for this kind of restoration needs to be carefully taken in account. It should be noted that the occurrence of invasive non-native species cannot be fully removed, due to their features and strategies (Celesti-Grapow *et al*. 2010), and that this is a problem mainly for lowland areas (Celesti-Grapow *et al*. 2010). The widespread occurrence of non-native species also in dry habitats can hinder the possibility to get material from sites void of them, which would be the best solution for trying to avoid the problem. However, this issue should be studied more deeply.

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# Appendix 1

Number of vascular plant seedlings germinated in the esperimental tanks.

Non-native species are marked with an asterisk.

M: Marcetto. F: La Fagiana. R: Bosco Ronchi. S: Santa Sofia.

The five tanks per site are marked with letters from A to E.

| | | MA | MB | MC | MD | ME | FA | FB | FC | FD | FE | RA | RB | RC | RD | RE | SA | SB | SC | SD | SE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Aira_caryophyllea | | 0 | 0 | 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
| Alyssum_alyssoides | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Arabis_glabra | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Aphanes_arvensis | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 3 | 14 | 0 | 0 | 0 | 0 | 0 |
| Arabidopsis_thaliana | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 19 | 17 | 15 | 0 |
| Artemisia_annua | * | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Ailanthus_altissima | * | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bromus_hordeaceus | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Botriochloa_ischaemum | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Carex_caryophyllea | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Carex_sp | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cerastium_glutinosum | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Chenopodium_botrys | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 5 | 19 | 0 | 0 |
| Chondrilla_juncea | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Corynephorus_canescens | | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Crataegus_monogyna | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cynodon_CF | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 |
| Crysopogon_gryllus | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Conyza_sp | * | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 5 | 1 | 0 | 0 | 0 | 1 | 0 |
| Corylus_avellana | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cruciata_pedemontana | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cerastium_semidecandrum | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Dactylis_glomerata | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Echinochloa_crus-galli | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Echium_vulgare | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| Erigeron_annuus | * | 33 | 11 | 3 | 3 | 0 | 1 | 3 | 0 | 1 | 1 | 4 | 9 | 12 | 163 | 23 | 2 | 0 | 1 | 1 | 2 |
| Erodium_cicutarium | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Euphorbia_maculata | * | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 0 | 0 | 151 | 193 | 228 | 130 | 255 |
| Festuca_brevipila | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Festuca_filiformis | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Festuca_sp | | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 2 | 1 |
| Galium_divaricatum | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Fumana_procumbens | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Galium_sp | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Geranium_molle | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Hypericum_perforatum | | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 1 | 0 |
| Hypochoeris_glabra | | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 3 | 0 | 0 | 0 | 0 | 0 |
| Hypochoeris_radicata | | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Jasione_montana | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Juncus_bufonius | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 42 | 0 | 1 | 0 | 0 | 0 |
| Lactuca_perennis | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Linaria_vulgaris | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Lindernia_dubia | * | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Luzula_campestris | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Luzula_multiflora | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Micropyrum_tenellum | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Mollugo_verticillata | * | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 25 |
| Oenothera_sp | * | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 15 | 1 | 0 |
| Oglypha_minima | | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 4 | 1 | 0 | 1 | 4 | 4 | 1 | 0 | 0 | 0 |
| Oxalis_fontana | * | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| Oreoselinum_nigrum | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Panicum_dichotomiflorum | * | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Pilosella_piloselloides | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Pinus_sylvestris | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Poa_bulbosa | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Polygonum_lapatifolium | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| Populus_nigra | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Portulaca_oleracea | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Potentilla_puberula | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Prunus_padus | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Psilurus_incurvus | | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Prunus_serotina | * | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Pilosella_officinarum | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Polygonatum_odoratum | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Plantago_sempervirens | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Quercus_robur | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Robinia_pseudoacacia | * | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Rosa_canina | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Rubus_caesius | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Rumex_acetosella | | 1 | 0 | 9 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 15 | 0 | 0 | 0 | 0 | 1 | 0 | 5 | 2 | 1 |
| Scleranthus_annuus | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| Scleranthus_perennis | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Silene_nutans | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Teesdalia_nudicaulis | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Teucrium_chamaedrys | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Tillaea_muscosa | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 0 | 0 | 8 | 1027 | 0 | 0 | 0 | 0 | 0 |
| Trifolium_arvense | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Trifolium_scabrum | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Thymus_sp | | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Tuberaria_guttata | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Valerianella_locusta | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Veronica_persica | * | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| Vulpia_ciliata | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Vulpia_myurus | | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 3 | 0 | 0 | 0 | 0 | 0 |
| Viola_arvensis | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

# Appendix 2

Percentage cover values of the vascular plant recorded in the donor plots.

Non-native species are marked with an asterisk.

M: Marcetto. F: La Fagiana. R: Bosco Ronchi. S: Santa Sofia.

The five plots per site are marked with letters from A to E.

| | | MA | MB | MC | MD | ME | FA | FB | FC | FD | FE | RA | RB | RC | RD | RE | SA | SB | SC | SD | SE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Aira_caryophyllea* | | 8 | 5 | 2 | 7 | 0 | 0 | 5 | 5 | 4 | 15 | 0 | 0 | 0 | 0,5 | 1 | 3 | 2 | 7 | 5 | 8 |
| *Alyssum_alyssoides* | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0,5 | 0 |
| *Arabis_glabra* | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0,5 | 0 | 0 | 0 | 0 | 0 |
| *Aphanes_arvensis* | | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Arabidopsis_thaliana* | | 0,5 | 0,5 | 0 | 0 | 0 | 0,5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Artemisia_annua* | * | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Ailanthus_altissima* | * | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
| *Bromus_hordeaceus* | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0,5 | 0,5 | 0 | 2 | 1 | 0 | 0 | 0 | 0 | 0 |
| *Botriochloa_ischaemum* | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 13 | 8 | 3 | 4 |
| *Carex_caryophyllea* | | 0 | 0 | 0 | 0 | 0 | 2 | 0,5 | 2 | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Carex_sp* | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| *Cerastium_glutinosum* | | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0,5 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Chenopodium_botrys* | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Chondrilla_juncea* | | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0,5 | 0 | 0 | 0 | 2 | 0 |
| *Corynephorus_canescens* | | 5 | 25 | 20 | 15 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Crataegus_monogyna* | | 2 | 0 | 0 | 0 | 0 | 0,5 | 1 | 0 | 0 | 3 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Cynodon_CF* | | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Crysopogon_gryllus* | | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Conyza_sp* | * | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Corylus_avellana* | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Cruciata_pedemontana* | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0,5 | 0 | 0 | 0 | 0 | 0 |
| *Cerastium_semidecandrum* | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0,5 | 1 |
| *Dactylis_glomerata* | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0,5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Echinochloa_crus-galli* | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Echium_vulgare* | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 9 | 5 | 10 |
| *Erigeron_annuus* | * | 5 | 0,5 | 0 | 0 | 0 | 0,5 | 0 | 0,5 | 0 | 0 | 0 | 0,5 | 0,5 | 0 | 0 | 0 | 2 | 1 | 0 | 3 |
| *Erodium_cicutarium* | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0,5 | 0 | 0 | 0 | 1 | 0 | 1 | 2 |
| *Euphorbia_maculata* | * | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 8 | 1 | 4 | 0 |
| *Festuca_brevipila* | | 0 | 0 | 0 | 2 | 0,5 | 3 | 0 | 5 | 0 | 0,5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Festuca_filiformis* | | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Festuca_sp* | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Galium_divaricatum* | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0,5 | 0 |
| *Fumana_procumbens* | | 4 | 2 | 0,5 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Galium_sp* | | 0 | 0 | 0 | 0,5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Geranium_molle* | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0,5 | 0 | 0 | 0 | 0 | 0 |
| *Hypericum_perforatum* | | 0,5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0,5 | 2 | 4 | 9 | 7 | 4 |
| *Hypochoeris_glabra* | | 0 | 0 | 0 | 0,5 | 0 | 4 | 1 | 2 | 0,5 | 1 | 4 | 2 | 2 | 4 | 2 | 7 | 5 | 10 | 8 | 9 |
| *Hypochoeris_radicata* | | 0 | 0 | 2 | 1 | 0 | 1 | 1 | 2 | 0 | 0,5 | 0,5 | 0 | 0 | 0,5 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Jasione_montana* | | 0 | 0 | 1 | 1 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Juncus_bufonius* | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Lactuca_perennis* | | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Linaria_vulgaris* | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0,5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Lindernia_dubia* | * | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Luzula_campestris* | | 0 | 0 | 0 | 0 | 0 | 0,5 | 0 | 0,5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Luzula_multiflora* | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0,5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Micropyrum_tenellum* | | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 2 | 7 | 2 | 3 | 7 | 3 | 0 | 7 | 0 | 0 | 0 | 0 | 0 |
| *Mollugo_verticillata* | * | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Oenothera_sp* | * | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 0,5 | 5 | 13 | 5 |
| *Oglypha_minima* | | 0 | 0 | 0 | 0 | 13 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0,5 | 4 | 4 | 1 | 3 | 3 |
| *Oxalis_fontana* | * | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0,5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Oreoselinum_nigrum* | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Panicum_dichotomiflorum* | * | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Pilosella_piloselloides* | | 0,5 | 0,5 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Pinus_sylvestris* | | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Poa_bulbosa* | | 0,5 | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 0 | 0,5 | 5 | 1 | 0 | 2 | 4 | 0 | 0 | 0 | 0 | 0 |
| *Polygonum_lapatifolium* | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Populus_nigra* | | 0 | 0 | 0 | 0 | 0,5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Portulaca_oleracea* | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Potentilla_puberula* | | 3 | 0,5 | 1 | 4 | 0,5 | 0,5 | 0 | 0,5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| *Prunus_padus* | | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Psilurus_incurvus* | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Prunus_serotina* | * | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Pilosella_officinarum* | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0,5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Polygonatum_odoratum* | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0,5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Plantago_sempervirens* | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| *Quercus_robur* | | 0 | 0 | 0,5 | 4 | 4 | 0 | 0 | 0,5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Robinia_pseudoacacia* | * | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| *Rosa_canina* | | 0 | 0 | 0,5 | 0,5 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Rubus_caesius* | | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0,5 | 0 | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 |
| *Rumex_acetosella* | | 4 | 2 | 1 | 7 | 5 | 2 | 0 | 0 | 1 | 0,5 | 5 | 1 | 1 | 1 | 3 | 15 | 11 | 13 | 1 | 9 |
| *Scleranthus_annuus* | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 1 | 3 | 10 | 0,5 | 6 | 0 | 0 | 2 | 0 |
| *Scleranthus_perennis* | | 0 | 0 | 0,5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Silene_nutans* | | 0 | 0 | 0 | 0,5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Teesdalia_nudicaulis* | | 0,5 | 0,5 | 1 | 2 | 0,5 | 4 | 2 | 0,5 | 0,5 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Teucrium_chamaedrys* | | 2 | 5 | 0 | 1 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Tillaea_muscosa* | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Trifolium_arvense* | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0,5 | 0 | 0 | 0 | 0 | 0 |
| *Trifolium_scabrum* | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Thymus_sp* | | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Tuberaria_guttata* | | 0 | 0 | 0,5 | 0 | 0,5 | 2 | 3 | 3 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 3 | 5 | 0 | 0 | 1 |
| *Valerianella_locusta* | | 0 | 0 | 0 | 0,5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Veronica_persica* | * | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Vulpia_ciliata* | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 8 | 8 | 7 | 8 |
| *Vulpia_myurus* | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0,5 | 0,5 | 3 | 8 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Viola_arvensis* | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0,5 | 0,5 |

# Conclusions

## Main results

**Chapter 1** showed that the western Po Plain – in particular the valley of the Ticino river, which is a protected area recently designated as biosphere reserve, and thus with a worldwide importance – is a focal area for lichen diversity within a strongly human-impacted landscape considered lichenologically depleted. This area hosts several rare species of biogeographical interest, even if some species recorded in the past seem to have disappeared. This important role is further increased by the presence of many terricolous species, which are regarded as the most sensitive and easily impacted cryptogams and are one of the main constituents of Cryptogam Soil Crusts (CSC). Other floristic records further supporting this conclusion are reported in **Appendix I**.

**Chapter 2** showed that some lichen species new to Italy have been found in this area. These are terricolous species which highly characterize lichen vegetation, thus contributing to CSCs diversity and functioning and also in shaping at a small scale the habitats in which they occur.

**Chapters 1** and **2** also highlighted a gap of knowledge about the lichen genus *Cladonia* in Italy. Tools developed also thank to the studies presented here are aimed at being a strong scientific basis to begin a methodical study of this important and overlooked genus in Italy (**Appendix II** and **III**).

**Chapters 1** and **2** and **Appendix I** highlighted the potential role of dry habitats as important sites for CSC diversity and, consequently, for their conservation.

**Chapter 3** deepened the real role of these habitats – acidic dry grasslands, calcareous dry grasslands, *Calluna vulgaris* heathlands – in the conservation of terricolous cryptogams (i.e. lichens and bryophytes) in human-impacted lowlands. It was demonstrated that different dry habitats host different and habitat-specific lichen and bryophyte assemblages which are characterized by exclusive species and include several species of conservation concern. Furthermore, it was shown that not only the habitat type, but also the dynamic stage – i.e. pioneer vs mature – can influence the hosted cryptogam assemblages, together with climate, soil features and vegetation structure. Acidic grasslands are the richest habitat, and the pioneer stage is the richest dynamic stage across the three considered habitat types.

**Chapter 4** explored the role of environmental factors and small-scale disturbance in influencing dry grasslands vegetation, considering a multi-taxon approach, since different taxa can show different responses to the same factors. Small-scale disturbance factors in the study area are represented by human trampling (which is, however, never very intensive) and eutrophication due to massive fecal pellet deposition by the alien invasive lagomorph *Sylvilagus floridanus*. The effects of these variables were tested on the three main taxa shaping the landscape in dry grasslands, i.e. vascular plants, lichens and bryophytes. Human trampling showed a negative impact only on vascular plants, while the effects of fecal pellet deposition harmed both vascular plants and lichens and had instead a positive effect on bryophytes. Rainfall had a positive effect on bryophytes and a negative effect on lichens, while increasing soil pH was beneficial for vascular plants and bryophytes and detrimental for lichens. Particularly interesting was the interactive effect of fecal pellet levels and soil pH: the effect of the eutrophication caused by fecal pellets was more negative for vascular plants on acidic substrates and almost positive on calcareous soils, whereas it was the opposite for lichens, which were almost favoured by it on acidic soils and more negatively impacted on calcareous substrates.

**Chapter 5** showed that terricolous lichen mats are able to store and release vascular plant seeds which are viable and can germinate when placed in proper conditions. Furthermore, new lichen mats are able to develop from fragments used as propagation material, as well as moss carpets can develop from small propagules contained in lichen mats. However, attention must be paid to the occurrence of seeds of non-native species, which can be present with high abundance in this type of material.

## The role of dry habitats in the conservation of CSCs

The occurrence in dry habitats of cryptogam communities and species which have boreo-alpine distribution and are very rare in lowland areas with temperate climate (Gheza 2015; **Chapters 1**, **2**, **Appendix I**) increases their conservation value. In Italy, many of these species are found, at low altitude, only in these dry habitats (Gheza 2015; **Chapters 1**, **2**, **Appendix I**), and some of them are rare or very rare on the whole national territory (cf. Nimis 2016). This value of dry habitats for rare lichen species has been stressed in several regions of Europe (Aptroot *et al.* 2011; Leppik *et al.* 2013; Adamska & Deptula 2015; Jüriado *et al.* 2016).

Different dry habitats host different cryptogam assemblages (**Chapter 3**), including several rare and protected species. Also different dynamic stages within the same habitat type can host different assemblages (**Chapter 3**). This makes dry habitats a fundamental stronghold for the conservation of terricolous cryptogam diversity.

The relevance of such habitats increases in human-impacted areas. For example, even if the Po Plain is the most polluted and human-impacted area of Italy (European Environment Agency 2004), several remarkable lichen species have been discovered here; however, they occur only in sites which still preserve suitable habitat conditions (Gheza 2015; **Chapters 1**, **2**, **Appendix I**). This highlights also the great importance of protected areas – which allow the persistence of suitable habitats – for the conservation of rare and endangered terricolous cryptogams.

Lowland dry habitats – i.e. dry grasslands and open dry *Calluna* heathlands – are habitats of conservation concern according to environmental policies in Europe, and are listed in the "Habitats Directive" (Directive 1992/43/EEC) under the codes 2330 ("Inland dunes with open *Corynephorus* and *Agrostis* grasslands"), 2340 ("Pannonic inland dunes"), 4030 ("European dry heaths"), 6110 ("Rupicolous calcareous or basophilic grasslands of the *Alysso-Sedion albi*"), 6210 ("Semi-natural dry grasslands and scrubland facies on calcareous substrates (*Festuco-Brometalia*)"). These habitats are considered vulnerable in the whole Europe (AA.VV. 2016), and are particularly at risk in Italy, where their conservation status is inadequate and their occurrence is declining (Genovesi *et al.* 2014). It follows that the lichen species strictly associated with them should also be considered threatened (Ravera *et al.* 2016).

All these habitats are more or less pioneer in the vegetation dynamics, and therefore they need an active management to be preserved.

## Management of cryptogam-rich dry habitats

The importance of cryptogam communities hosted in lowland dry habitats in the conservation of biodiversity is evident for several reasons. They represent microhabitats for rare species (Aptroot *et al.* 2011; Sparrius 2011; Ketner-Oostra & Sýkora 2008; Leppik *et al.* 2013; Gheza 2015; **Chapters 1**, **2**, **Appendix I**), often including phytogeographical elements at the southern or lower-altitudinal margin of their distribution range (**Chapters 1**, **2**, **Appendix I**). Furthermore, they can be diagnostic elements for the vascular plant communities in which they occur, as well as for the assessment of the quality of their habitats (Rosentreter & Eldridge 2002; Bültmann 2005). Finally, they provide microhabitats for invertebrates (Merkens 2002; Vogels *et al.* 2005; Riksen *et al.* 2006) and several ecosystem functions and services (Maestre *et al.* 2011; Zedda & Rambold 2015; **Chapter 5**).

Cryptogam-rich habitats should be preserved not only for their intrinsic importance as habitats and for the diversity of vascular plants, but also for the diversity of cryptogams and cryptogam communities they host. It must also be considered that cryptogam assemblages occurring in dry habitats can be habitat-specific (Leppik *et al.* 2013; **Chapter 3**), and thus many species of each assemblage can not be found in many habitats, which makes them an irreplaceable part of biodiversity.

For all these reasons, cryptogam communities deserve a carefully planned management aimed at their conservation as a fundamental component of vegetation, carried out at both the local and the landscape scales.

The contrasting responses found in different taxa to the same environmental, climatic and disturbance factors (Grabherr, 1982; Poschlod *et al.*, 2005; Löbel *et al.*, 2006; Jägerbrand & Alatalo, 2015; **Chapter 4**) suggest that conservation practices should be tailored to organism and substrate type (Socolar *et al.*, 2016; **Chapters 3**, **4**). The main efforts should be focused on the situations in which each organism type is less competitive and resilient in first instance, e.g. vascular plants on acidic substrates and lichens on calcareous substrates (**Chapter 4**). On the other hand, efforts should be aimed also at maximizing diversity, always considering in which situation each taxon is usually richer in species, e.g. lichens on acidic substrates and vascular plants on calcareous substrates (**Chapters 3**, **4**). This implies that, at a landscape level, patches of dry grasslands should be preserved on both acidic and calcareous soils and managed taking in account both the taxa at the same time (**Chapters 3**, **4**) with appropriate procedures.

The most effective management action, aimed at preventing habitat loss and vegetation encroachment by means of the recreation of bare soil patches, is mechanical disturbance of the substrate (Ketner-Oostra & Sýkora 2008; Ketner-Oostra *et al.* 2012; Leppik *et al.* 2013). The availability of bare ground surfaces reverses the succession to its pioneer stages and is therefore recommended to preserve pioneer communities. This task can be achieved by means of well established techniques, such as vegetation burning or cutting, sod-cutting, topsoil removal, topsoil inversion, scraping of mature CSC (Chytrý *et al.* 2001; Jentsch *et al.* 2002; Allison & Ausden 2004; Ausden 2007; Assini, 2008; Matt & Legg 2008; van Andel & Aronson; Glen *et al.* 2017).

While massive trampling is reported as detrimental for all the vegetation components (Grabherr 1982; Jägerbrand & Alatalo 2015), a moderate trampling, which implies small-scale and low intensity mechanical soil disturbance, could even positively affect cryptogams in dry grasslands vegetation, contributing to form gaps in the vegetation and hindering the development of a continuous herb layer (Alatalo *et al.* 2017; **Chapter 4**). This balance between disturbance intensity and cryptogam development could be taken as a reference when aiming at maximizing the co-occurrence of lichens, bryophytes and vascular plants in dry habitats.

However, it must be taken in account that cryptogam assemblages can differ between pioneer and mature dynamic stages within the same habitat type (**Chapter 3**). Therefore, the conservation management in these habitats should guarantee the maintaining of a mosaic of pioneer and mature patches, which can greatly benefit cryptogam diversity (Chytrý *et al.* 2001; Matt & Legg 2008; Ketner-Oostra *et al.* 2012). A management model aimed at maintaining different dynamic aspects can guarantee an overall protection of habitat integrity. In fact, conserving the dynamic processes that maintain all the elements is better than address conservation towards the maintenance of particular elements (Angermeier & Karr 1994).

The removal of seedlings and young woody plants is also suggested to accompany mechanical disturbance (Assini 2008; Ketner-Oostra et al. 2012).

Low-intensity grazing would be a useful form of mechanical disturbance to maintain vegetation patches with pioneer conditions (Kooijman & De Haan 1995; Schwabe et al. 2002, 2013; Leppik et al. 2013). However, grazers should be chosen carefully, since they provide multiple effects, i.e. grazing, trampling and eutrophication due to faeces deposition. These effects are also known to be dependent on the grazers, the grazed taxon and the soil pH (Bakker *et al.*, 2006; Kohyani *et al.* 2008; **Chapter 4**). A high density of grazers should be avoided in any case, since it can have negative effects due to overgrazing (Kohyani *et al.* 2008) and massive deposition of fecal pellets (**Chapter 4**).

Invasive non-native animal species represent a threat that can be contrasted, at least in part, with active management and strict conservation, e.g. through active exclusion of wild fauna from the species-richest stands (Barrios-Garcia & Ballari, 2012). Invasive plant species can have on these habitats similar effects than native species, which can be controlled by means of the aforementioned management techniques. In continental lowland dry habitats, management should also consider the occurrence of the invasive moss *Campylopus introflexus*, which is known to be a threat in Central Europe (Sparrius 2011; Ketner-Oostra *et al.* 2012) and is significantly present also in Italian acidic grasslands (**Chapter 3**). Sod-cutting and topsoil removal/inversion could be useful also to remove this carpet-forming moss (cf. Sparrius 2011).

Finally, the ability of terricolous lichens to propagate through thallus fragments (Bayfield et al. 1981; Heinken 1999) makes them suitable for (re)introductions of cryptogams (Jeschke 2012; Brackel & Brackel 2016; Gheza & Assini 2018; **Chapter 5**). Furthermore, terricolous lichen mats taken from acidic dry grasslands are able to store and release seeds of vascular plants typical of such habitats, which are viable and can germinate when placed in proper conditions (Gheza & Assini 2018; **Chapter 5**). This abilities disclose the chance to use terricolous lichen mats in habitat restoration as vectors not only for lichen species themselves, but also for vascular plants. However, the problem of the non-native vascular species which can develop from the material used for this kind of restoration (**Chapter 5**) needs to be carefully taken in account and studied more deeply.

## Future perspectives

The studies presented in this thesis – especially in **Chapters 3** and **4** – addressed important conservation issues useful for improving management of cryptogam-rich habitats. However, some patterns and drivers of biodiversity in these habitats still remain unclear and should therefore be better explored. For example, the roles of landscape (Zulka *et al.* 2014; Paušič *et al.* 2017) and past land use (Zulka *et al.* 2014; Chylová & Münzbergová 2008) are recognized as fundamental drivers of biodiversity in continental dry habitats, and their effects on terricolous cryptogams have rarely been investigated (e.g. Leppik *et al.* 2013). Another important need is to explore β-diversity (Socolar *et al.* 2016) of all the main taxa occurring in dry habitats. In particular, it would be useful to explore whether β-diversity patterns follow mechanisms of nestedness or substitution (Socolar *et al.* 2016), which would be another information useful for planning a conservation-aimed management. In fact, β-diversity in dry grasslands has been investigated mainly about vascular plants so far (e.g. Bartha *et al.* 2011; Burrascano *et al.* 2013), whereas cryptogams have been considered only rarely and recently (e.g. Cuk *et al.* 2015) and should still be better investigated.

The role of non-native species is another issue which deserves attention and further studies. No significant effects of the environmental and disturbance factors considered in **Chapter 4** were detected on non-native vascular plant species, but on the other hand it is well-known that invasive species can have detrimental effects on vegetation (Celesti-Grapow *et al.* 2010). The massive occurrence of non-native species can also alter β-diversity patterns in grasslands (Martin & Wilsey 2015). In European lowland dry habitats, attention must be paid also to the invasive moss *Campylopus introflexus*, which is a threat for these habitats (Sparrius 2011; Ketner-Oostra *et al.* 2012) and whose real role has not been deepened in continental Italy, even if it resulted significantly frequent in acidic dry grasslands (**Chapter 3**). Furthermore, the massive occurrence of invasive vascular species could hinder restoration practices based on reintroduction of CSCs fragments (**Chapter 5**), if not handled carefully. This potential technique should therefore be studied more deeply before testing its application in nature.

The lichen genus *Cladonia*, which is represented by 82 species in Italy (**Appendix II**), is another promising research field to address future research towards. The discovery of two species new to Italy (**Chapter 2**) and of several others outside their previously known biogeographical range (**Chapter 1**, **Appendix I**) in the western Po Plain highlights a gap in our knowledge of the real distribution and diversity of these lichens in Italy. This gap hinders the development of tools useful for conservation actions, such as a national red list, which is currently available only for epiphytic lichens (Nascimbene *et al*. 2013) – even if *Cladonia* subgenus *Cladina* has been assessed according to IUCN criteria by Ravera *et al*. (2016). Apart from the contributions of Coassini Lokar *et al*. (1986) and Ravera *et al*. (2016), no original studies focused on the genus *Cladonia* have been carried out in Italy in recent years. A deeper knowledge would be desirable at least for the most problematic groups – e.g. the *C. cariosa* complex (Bültmann & Lünterbusch 2008; Osyczka & Skubala 2011; Pino-Bodas *et al*. 2012.), the *C. chlorophaea-pyxidata* complex (Coassini-Lokar *et al*. 1986; Kowalewska & Kukwa 2004, 2007; Kowalewska *et al*. 2008; Tsurykau & Golubkov 2015), the *C. coccifera* complex (Tønsberg 1975, 1995; Stenroos 1989a, b, 1990; Kowalewska & Kukwa 2004; Kukwa 2005; Burgaz 2009; Osyczka 2009, 2011; Osyczka & Koscielniak 2009), the *C. gracilis* complex (Ahti 1980; Fontaine *et al*. 2010; Pino-Bodas *et al*. 2011) – and species – e.g. *C. furcata* (Pino-Bodas *et al*. 2015), *C. pseudopityrea* (Ahti & Puntillo 1995), *C. rei-C. subulata* (Paus *et al*. 1993; Syrek & Kukwa 2008; Dolnik *et al*. 2010; Pino-Bodas *et al*. 2010; Osyczka *et al*. 2014; Haughland *et al*. 2018). This would be the first step, whose continuation could address ecological and conservation issues (cf. Yahr *et al*. 2013; Osyczka & Rola 2013a, b; Osyczka *et al*. 2015, 2017; Haughland *et al*. 2018). Tools developed from the studies presented in this thesis, which are reported in **Appendix II** and **III**, are aimed at being a basis to improve the study and the knowledge of the genus *Cladonia* in Italy.

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# Appendix I

## Floristic records of lichen species of biogeographical and conservation interest

# *Cladonia cariosa* (Ach.) Spreng.
# (Cladoniaceae)

Gabriele Gheza

PIEMONTE: Greggio (Vercelli), within the Lame del Sesia Natural Park, on sandy-pebbly soil in a dry grassland (*Thero-Airion*) developed in the active riverbed of the Sesia river (UTM WGS84: 32T 452817.5033781), 159 m, 4 March 2016, G. Gheza (Herb. Gheza); San Giacomo al Bosco, Masserano (Biella), surroundings of the farmhouse "Lo Chalet", on bare soil at the side of a dirt road between a field and a patch of heathland and deciduous wood (UTM WGS84: 32T 441675.5044948), 240 m, 16 January 2016, G. Gheza (Herb. Gheza); "Vauda" of San Carlo Canavese (Torino), on bare soil among *Calluna vulgaris* (L.) Hull shrubs, in a degraded heathland encroached by grasses (UTM WGS84: 32T 392345.5012651), 366–369 m, 8 March 2016, G. Gheza (Herb. Gheza).

LOMBARDIA: Bernate Ticino (Milano), within the Valle del Ticino Lombardo Natural Park, surroundings of the Ticino river on bare sandy soil in a dry grassland (Thero-Airion) (UTM WGS84: 32T 484052.5035066), 117 m, 25 March 2016, G. Gheza (Herb. Gheza); Tornavento heathland, Lonate Pozzolo (Varese), on bare soil among shrubs of C. vulgaris in an unmanaged heathland (UTM WGS84: 32T 478302.5049318), 200 m, 25 March 2016, G. Gheza (Herb. Gheza); Livigno (Sondrio), surroundings of the artificial lake on soil inside a bush of *Pinus mugo* Turra (UTM WGS84: 32T 589565.5160342), about 1840 m, 18 September 2012, G. Gheza (Herb. Gheza).

Historical records of *C. cariosa* from both Piemonte and Lombardia refer almost exclusively to montane and alpine localities (Nimis 1993, Nimis & Martellos 2008); only Nocca & Balbis (1823) reported it for the Po Plain, in fields near Pavia ("*in campis sterilibus prope Papiam*"), while Re (1825) reported it for the Parco della Mandria near Torino, but both these records have not been confirmed in recent times. The new records reported here are, therefore, an important confirmation of the persistence of *C. cariosa* in planitial northeastern Italy after almost two centuries. In Piemonte, Baglietto & Carestia (1867, 1880) reported the species along the gravels of the Sesia river near Riva. The record from Greggio, in the Sesia riverbed, comes from a similar context, though having different substrate, altitude, and climate; transport by the river could be plausible, since the species was not found in other nearby lichen-rich sites placed above the level of the riverbed. Baglietto (1863) recorded it also on peaty soil at the Sempione Pass. In Lombardia, the most recent record is by Rivellini & Valcuvia Passadore (1996) for the Province of Sondrio, while all the others are antecedent to the 1940s. *Cladonia cariosa* is a circumboreal species with a wide distribution, typically on mineral (from sandy to gravelly) soils with low acid to base reaction, in more or less disturbed sites. It can form wide monospecific mats extending for up to several square metres.

In: Sonia Ravera, Annalena Cogoni, Cecilia Totti, Michele Aleffi, Silvia Assini, Stefania Caporale, Zuzana Fačkovcová, Giorgia Filippino, Gabriele Gheza, Nicola Olivieri, Mauro Ottonello, Luca Paoli, Silvia Poponessi, Ivan Pišút, Roberto Venanzoni. 2016. Notulae to the Italian flora of Algae, Bryophytes, Fungi and Lichens 2. Italian Botanist 2: 43-54.

# *Cladonia conista* (Nyl.) Robbins
# (Cladoniaceae)

Gabriele Gheza, Helmut Mayrhofer

LOMBARDIA: surroundings of Sant'Alberto di Butrio, Abbadia Sant'Alberto, Ponte Nizza (Pavia), on calcareous soil at the edge of a footpath in a chestnut wood (UTM WGS84: 32T 511581.4966732), 679 m, 14 April 2017, leg. G. Gheza, det. H. Mayrhofer (Herb. Gheza).

*Cladonia conista* has been considered for long just a chemotype of *Cladonia humilis* (With.) J.R.Laundon, but a recent study by Pino-Bodas et al. (2012) confirmed that the two species are well separated. The species has been reported so far in Italy only from acidic dry grasslands in the Po Plain (Gheza et al. 2018). The record reported here is the first for the Apennines and for calcareous substrates, therefore widening the knowledge about the geographical distribution and the ecology of the species in Italy. The analyzed specimen contained fumarprotocetraric and bourgeanic acids, and differed slightly in morphology from those reported by Gheza et al. (2018), having short and wide podetia and soredia along the margin of the primary squamules, whereas the specimens from the Po Plain had more slender podetia and esorediate squamules.

In: Sonia Ravera et al. 2019. Notulae to the Italian flora of Algae, Bryophytes, Fungi and Lichens 7. Italian Botanist 7.

## *Cladonia furcata* (Huds.) Schrad. subsp. *subrangiformis* (L. Scriba ex Sandst.) Pišút (Cladoniaceae)

Gabriele Gheza, Matteo Barcella, Silvia Assini

PIEMONTE: Portanuova, Casal Cermelli (Alessandria), surroundings of Cascina Merlana, on basic sandy-pebbly soil in a dry grassland (UTM WGS84: 32T 471806.4962778), 109 m, 10 May 2016, G. Gheza, S. Assini (Herb. Gheza); between Villalvernia and Cassano Spinola (Alessandria), bird ringing station near the Scrivia river, on calcareous sandy-pebbly soil (UTM WGS84: 32T 488531.4959878), 162 m, 14 April 2016, G. Gheza, S. Assini (Herb. Gheza); Gremiasco (Alessandria), surroundings of the Osservatorio Astronomico di Guardamonte, on sandstone outcrops (UTM WGS84: 32T 506270.4962306), 682-687 m, 9 December 2016, G. Gheza (Herb. Gheza).

LOMBARDIA: Cecima (Pavia), surroundings of the Osservatorio Astronomico di Guardamonte, on soil in a dry grassland (UTM WGS84: 32T 506264.4962342), 690 m, 9 December 2016, G. Gheza (Herb. Gheza); Fontana di Nivione, Varzi (Pavia), on clay soil on badlands (UTM WGS84: 32T 514388.4962082), 490-501 m, 10 November 2016, G. Gheza, M. Barcella (Herb. Gheza, Herb. Barcella); San Michele di Nivione, Varzi (Pavia), on calcareous soil (UTM WGS84: 32T 514671.4960675), 503-508 m, 10 November 2016, G. Gheza, M. Barcella (Herb. Gheza, Herb. Barcella); Cella di Varzi (Pavia) surroundings of Castello Malaspina, on arenaceous soil (UTM WGS84: 32T 514394.4958621), 705-710 m, 10 November 2016, G. Gheza, M. Barcella (Herb. Gheza, Herb. Barcella).

EMILIA ROMAGNA: Bobbio (Piacenza), ophiolite outcrop east of the mount Pan Perduto, on soil (UTM WGS84: 32T 528845.4963028), 995-997 m, 25 June 2013, G. Gheza (Herb. Gheza).

*Cladonia furcata* subsp. *subrangiformis* is a terricolous species found typically on basic-calcareous soil, with a rather continental distribution (Nimis 1993). It was previously known in two localities in Piemonte and three in Emilia Romagna (see literature cited by Nimis 1993, 2016) and never reported before from Lombardia; moreover, all the records from Piemonte are very old. The new records reported here extend the range of the species to planitial calcareous dry grasslands located south of the Po river in Piemonte and to the Appennino Pavese in the southernmost part of Lombardia. The species seems rather common in terricolous cryptogam communities on pioneer calcareous, arenaceous and clayey substrates and, therefore, it is probably more widespread than believed until now in the northern Apennines, especially in lichen communities of the *Toninion sedifoliae* Hadač 1948 emend. Wirth 1995 on badlands, calcareous rock outcrops and similar substrates.

In: Sonia Ravera, Annalena Cogoni, Alfredo Vizzini, Michele Aleffi, Silvia Assini, Matteo Barcella, Wolfgang von Brackel, Stefania Caporale, Zuzana Fačkovcová, Giorgia Filippino, Gabriele Gheza, Daniela Gigante, Luca Paoli, Giovanna Potenza, Silvia Poponessi, Filippo Prosser, Domenico Puntillo, Michele Puntillo, Roberto Venanzoni. 2017. Notulae to the Italian flora of Algae, Bryophytes, Fungi and Lichens 3. Italian Botanist 3: 17-27.

## *Cladonia humilis* (With.) J.R.Laundon
## (Cladoniaceae)

Gabriele Gheza, Helmut Mayrhofer, Juri Nascimbene

LOMBARDIA: Malpaga (Bergamo), on sandy-pebbly calcareous soil in a dry grassland (UTM WGS84: 32T 558079.5051190), 183 m, 23 June 2016, G. Gheza (Herb. Gheza); Basella (Bergamo), on sandy-pebbly calcareous soil in a dry grassland (UTM WGS84: 32T 557803.5050480), 176 m, 21 June 2016, G. Gheza (Herb. Gheza).

*Cladonia humilis* is a terricolous species with a mainly Thyrrenian distribution in Italy (Nimis 2016). The two localities reported here are located in the nature reserve of Malpaga-Basella, within the Serio Regional Park, in wide calcareous dry grasslands near the rivercourse. The specimens analysed by thin layer chromatography always contained fumarprotocetraric acid and atranorin.

In: Sonia Ravera, Alfredo Vizzini, Annalena Cogoni, Michele Aleffi, Silvia Assini, Giovanni Bergamo Decarli, Ilaria Bonini, Wolfgang von Brackel, Francesco Cheli, Valeriy Darmostuk, Zuzana Fačkovcová, Lyubov Gavrylenko, Gabriele Gheza, Anna Guttová, Helmut Mayrhofer, Juri Nascimbene, Luca Paoli, Silvia Poponessi, Giovanna Potenza, Filippo Prosser, Davide Puddu, Domenico Puntillo, Diego Rigotti, Francesco Sguazzin, Alessia Tatti, Roberto Venanzoni. 2017. Notulae to the Italian flora of Algae, Bryophytes, Fungi and Lichens 4. Italian Botanist 4: 73-86.

# *Cladonia incrassata* Flörke
# (Cladoniaceae)

Gabriele Gheza, Mauro Ottonello

LIGURIA: Valle del Rio Gavano, Molini di Triora (Imperia), on rotting wood at the base of an old chestnut tree, in an unmanaged chestnut wood, about 450 m a.s.l., 17 March 2016, Leg. M. Ottonello, Det. G. Gheza (Herb. Gheza).

*Cladonia incrassata* has a very little known distribution in Italy, and a half of the few records of the species are rather old. It was recorded until now only in Piemonte, Lombardia, Toscana and Calabria (Nimis & Martellos 2008). In Lombardia it has not been recorded for more than a century: Rivellini & Valcuvia Passadore (1996) only report a very generic record by Jatta (1909-1911) for the Province of Sondrio, while Anzi (1866) reported the species in the Province of Como on the mount of Capiago. In Piemonte, aside from a historical record by Baglietto (1863) for Mergozzo, a recent record comes from the Conca di Oropa (Isocrono et al. 2006). Rather recent are also the records from Toscana (Tereglio: Nimis, 1993) and Calabria (Monte Gariglione: Puntillo, 1996). *C. incrassata* is a species with suboceanic affinity found in Europe, Northeastern America and Eastern Asia (Nimis 1993), whose ecological optimum is found on rotting wood and on humus-rich soil, but which is rarely found also on bark at the base of old trees. In the new site reported here the species was found on a single trunk on rotting wood at the base of an old chestnut tree together with *C. digitata* (L.) Hoffm. and *C. squamosa* Hoffm.. Rotting chestnut wood is the same substrate on which it was found by Baglietto (1863), Anzi (1866) and Coppins (Nimis 1993). Due to the very scarce records and the specific ecological requirements, the species is considered extremely rare in Italy, where it has been found since now only in the submediterranean and montane belts (Nimis & Martellos 2008).

In: Sonia Ravera, Annalena Cogoni, Cecilia Totti, Michele Aleffi, Silvia Assini, Stefania Caporale, Zuzana Fačkovcová, Giorgia Filippino, Gabriele Gheza, Nicola Olivieri, Mauro Ottonello, Luca Paoli, Silvia Poponessi, Ivan Pišút, Roberto Venanzoni. 2016. Notulae to the Italian flora of Algae, Bryophytes, Fungi and Lichens 2. Italian Botanist 2: 43-54.

# *Cladonia peziziformis* (With.) J.R.Laundon
# (Cladoniaceae)

Gabriele Gheza

PIEMONTE: Torrette di Frassineto, Frassineto Po (Alessandria), surroundings of the confluence between the rivers Sesia and Po, within the Fluvial Natural Park of Po and Orba, on sandy-silty soil in a dry grassland (*Thero-Airion*) developed on a former dirt road (UTM WGS84: 32T 467109.4998260), 99 m, 20 June 2012, G. Gheza (Herb. Gheza); Greggio (Vercelli), within the Lame del Sesia Natural Park, on sandy-pebbly soil in a dry grassland (*Thero-Airion*) developed in the active riverbed of the Sesia river (UTM WGS84: 32T 452817.5033781), 159 m, 4 March 2016, G. Gheza (Herb. Gheza); San Giacomo al Bosco, Masserano (Biella), surroundings of the farmhouse "Lo Chalet", on bare soil at the side of a dirt road between a field and a patch of heathland and deciduous wood (UTM WGS84: 32T 441675.5044948), 240 m, 16 January 2016, G. Gheza (Herb. Gheza); "Vauda" of San Francesco al Campo (Torino), on bare soil among burnt *Calluna vulgaris* shrubs, in a heathland managed with prescribed fire (UTM WGS84: 32T 397692.5009259), 295 m, 8 March 2016, G. Gheza (Herb. Gheza); "Vauda" of San Carlo Canavese (Torino), on bare soil among *Calluna vulgaris* shrubs, in a degraded heathland encroached by grasses (UTM WGS84: 32T 392345.5012651), 370 m, 8 March 2016, G. Gheza (Herb. Gheza).
LOMBARDIA: Lonate Pozzolo (Varese), within the Valle del Ticino Lombardo Natural Park, on soil among a thick carpet of bryophytes at the edge of a dry grassland (*Thero-Airion*) evolving towards heathland and shrubland (UTM WGS84: 32T 479440.5046068), 186 m, 13 May 2016, G. Gheza (Herb. Gheza).

*Cladonia peziziformis* is considered rare in Europe (Wirth et al. 2013), even though it has a wide distribution, reaching as far as the southern hemisphere (Nimis 1993). In Italy, it was known until now for only four localities, all in Liguria, and not confirmed after the 1960s (Valcuvia Passadore & Vittadini Zorzoli 1982), although Nimis (2016) stated that the species has probably been overlooked in Italy so far. Jatta (1909-1911) also reported this species, but only very generically for "peaty soil in the Alps". All the records reported here come from disturbed stands. Well-developed monospecific mats several square metres wide, occur only in two stands: on the sandy-pebbly riverbed of the Sesia – encroached by the allochtonous grass *Eragrostis curvula* (Schrad.) Nees – and a dry grassland developed on a dirt road close to an abandoned quarry. In both sites, vascular vegetation belongs to the *Thero-Airion* Tüxen ex Oberdorfer 1957. Few underdeveloped thalli were found in the other sites, all located in more or less degraded heathlands or along their edges. In the "Vauda" of San Francesco al Campo heathland, the species was found in a site regularly managed with prescribed fire, a situation similar to that described for Norway (Tønsberg & Øvstedal 1995) where the species was reported as one of the first colonizers after a fire. In the other heathlands, grass and moss-encroachment have been found to overcome *C. peziziformis*, which is an uncompetitive species (Tønsberg & Øvstedal 1995).

In: Sonia Ravera, Annalena Cogoni, Cecilia Totti, Michele Aleffi, Silvia Assini, Stefania Caporale, Zuzana Fačkovcová, Giorgia Filippino, Gabriele Gheza, Nicola Olivieri, Mauro Ottonello, Luca Paoli, Silvia Poponessi, Ivan Pišút, Roberto Venanzoni. 2016. Notulae to the Italian flora of Algae, Bryophytes, Fungi and Lichens 2. Italian Botanist 2: 43-54.

## *Cladonia polycarpoides* Nyl.
## (Cladoniaceae)

Gabriele Gheza

PIEMONTE: Cascina Casone, Pombia (Novara), within the Natural Park Valle del Ticino, on sandy-pebbly soil in a dry grassland (UTM WGS84: 32T 475582.5054277), 172 m, 10 June 2016, G. Gheza (Herb. Gheza); Barbelera, Oleggio (Novara), within the Natural Park Valle del Ticino, on sandy-pebbly soil in a dry grassland (UTM WGS84: 32T 474874.5051835), 161 m, 21 April 2016, G. Gheza (Herb. Gheza); Marcetto, Oleggio (Novara), within the Natural Park Valle del Ticino, on sandy-pebbly soil in a dry grassland (UTM WGS84: 32T 475072.5051295), 158 m, 21 April 2016, G. Gheza (Herb. Gheza); Tenuta Bornago, Cameri (Novara), within the Natural Park Valle del Ticino, on sandy-pebbly soil in a dry grassland (UTM WGS84: 32T 476694.5044401), 141 m, 17 June 2016, G. Gheza (Herb. Gheza); Villa Giulia, Cerano (Novara), within the Natural Park Valle del Ticino, on sandy-pebbly soil in a dry grassland (UTM WGS84: 32T 487030.5027303), 99 m, 25 March 2016, G. Gheza (Herb. Gheza); surroundings of Canale Cavour, Greggio (Vercelli), near the boundary of the Natural Park Lame del Sesia, on soil in a pioneer dry grassland (UTM WGS84: 32T 452897.5034279), 167 m, 3 May 2016, G. Gheza (Herb. Gheza); Gerbido di Greggio (Vercelli), within the Natural Park Lame del Sesia, on soil in an evolved dry grassland (UTM WGS84: 32T 452849.5032860), 160 m, 4 March 2016, G. Gheza (Herb. Gheza); Gerbido di Villata (Vercelli), within the Natural Park Lame del Sesia, on sandy-pebbly soil in a dry grassland (UTM WGS84: 32T 453022.5026746), 138 m, 4 March 2016, G. Gheza (Herb. Gheza); Torrette di Frassineto, Frassineto Po (Alessandria), surroundings of the confluence between the rivers Sesia and Po, within the River Park "Parco fluviale del Po tratto vercellese/alessandrino e Riserva Naturale del Torrente Orba", on sandy-silty soil in a dry grassland (UTM WGS84: 32T 467121.4998255), 99 m, 17 February 2016, G. Gheza (Herb. Gheza).

LOMBARDIA: Ansa di Castelnovate, Vizzola Ticino (Varese), within the Natural Park Valle del Ticino, on sandy soil in a dry grassland (UTM WGS84: 32T 473961.5052563), 164 m, 16 June 2016, G. Gheza (Herb. Gheza); surroundings of the Ticino river near Bernate Ticino (Milano), within the Natural Park Valle del Ticino, on sandy soil in a dry grassland (UTM WGS84: 32T 484052.5035066), 117 m, 25 March 2016, G. Gheza (Herb. Gheza); Tenuta La Fagiana, Pontevecchio di Magenta (Milano), within the Natural Park Valle del Ticino, on sandy soil in a dry grassland (UTM WGS84: 32T 486481.5030650), 109 m, 26 April 2016, G. Gheza (Herb. Gheza); Bosco Ronchi, Vigevano (Pavia), within the Natural Park Valle del Ticino, on sandy soil in a dry grassland (UTM WGS84: 32T 495866.5013406), 78 m, 30 May 2016, G. Gheza (Herb. Gheza).

*Cladonia polycarpoides* is known from only few administrative regions in Italy (Nimis 2016). The only literature record in Lombardia, from the lower Valtellina (Rossi 1991), refers to a single site, while the species is new for Piemonte. On the basis of the new records reported here, which extend the Italian range of the species to the Po Plain, *C. polycarpoides* seems to be well distributed in dry grasslands of the *Thero-Airion* Tüxen ex Oberdorfer 1957 located on acidic substrates along the course of two main rivers (Sesia and Ticino). It was always found in the *Cladonietum foliaceae* Klement 1953 emend. Drehwald 1993.

In: Sonia Ravera, Annalena Cogoni, Alfredo Vizzini, Michele Aleffi, Silvia Assini, Matteo Barcella, Wolfgang von Brackel, Stefania Caporale, Zuzana Fačkovcová, Giorgia Filippino, Gabriele Gheza, Daniela Gigante, Luca Paoli, Giovanna Potenza, Silvia Poponessi, Filippo Prosser, Domenico Puntillo, Michele Puntillo, Roberto Venanzoni. 2017. Notulae to the Italian flora of Algae, Bryophytes, Fungi and Lichens 3. Italian Botanist 3: 17-27.

# *Cladonia portentosa* (Dufour) Coem.
# (Cladoniaceae)

Gabriele Gheza, Silvia Assini

PIEMONTE: Villa Giulia, Cerano (Novara), within the Valle del Ticino Piemontese Natural Park, in a dry grassland (*Thero-Airion*) (UTM WGS84: 32T 487030.5027303), 99 m, on acid sandy-pebbly soil, 25 March 2016, G. Gheza (Herb. Gheza); Greggio (Vercelli), wood southwest of the underpass of Canal Cavour under the Sesia river, near the northern boundary of the Lame del Sesia Natural Park, in a wide clearing with *Thero-Airion* and *Corynephorion* grasslands (UTM WGS84: 32T 452785.5034282), 163-165 m, on acid sandy-pebbly soil, 3 May 2016, G. Gheza, S. Assini (Herb. Gheza).

In the Po Plain, *Cladonia portentosa* has been recorded formerly only in recent years in the Valle del Ticino Piemontese Natural Park (Gheza 2015) and in the inland sand dunes of Lomellina in Lombardia (Gheza 2015, Gheza et al. 2015). All the formerly known sites are located west of the Ticino river. Those located in the fluvial valley of Ticino, more similar to the two reported here for habitat physiognomy and substrate characteristics, are more northern than that from Cerano, while those found in inland dunes are found at lower altitudes and are more southern. The stand in Cerano is located in a wide clearing in a mixed deciduous wood hosting a dry grassland referable to the *Thero-Airion* Tüxen ex Oberdorfer 1957, in which lichen and moss cover is relevant. Here, *C. portentosa* is never dominant in lichen vegetation, but is found in an evolved stage of the *Cladonietum foliaceae* Klement 1953 emend. Drehwald 1993 dominated by *Cladonia rangiformis* Hoffm. (see Gheza et al. 2016). This is the only site in the Po Plain in which the species is found in plant communities of the *Thero-Airion* and not of the *Corynephorion canescentis* Klika 1931. The stand in Greggio is more similar to the others: the species is found in a grassland referable to the *Spergulo-Corynephoretum canescentis* (R.Tx. 1928) Libbert 1933. This vegetation is threatened because of the ongoing invasion of *Robinia pseudoacacia* L. and *Ailanthus altissima* (Mill.) Swingle, which is likely to compromise the conservation of the entire habitat already in the short term. All the other records of *C. portentosa* in Piemonte, except those reported above for the Po Plain, refer to montane and alpine sites (Nimis 1993, 2016).

In: Sonia Ravera, Annalena Cogoni, Cecilia Totti, Michele Aleffi, Silvia Assini, Stefania Caporale, Zuzana Fačkovcová, Giorgia Filippino, Gabriele Gheza, Nicola Olivieri, Mauro Ottonello, Luca Paoli, Silvia Poponessi, Ivan Pišút, Roberto Venanzoni. 2016. Notulae to the Italian flora of Algae, Bryophytes, Fungi and Lichens 2. Italian Botanist 2: 43-54.

# *Cladonia pulvinata* (Sandst.) Herk & Aptroot (Cladoniaceae)

Gabriele Gheza, Helmut Mayrhofer

PIEMONTE: "Vauda" of San Francesco al Campo (Torino), on bare clayey soil among burnt *Calluna vulgaris* shrubs, in a heathland managed with prescribed fire (UTM WGS84: 32T 397692.5009259), 295 m, 8 March 2016, G. Gheza (Herb. Gheza); "Vauda" of San Carlo Canavese (Torino), on bare clayey soil among *Calluna vulgaris* shrubs, in a degraded heathland encroached by grasses and woody shrubs (UTM WGS84: 32T 392345.5012651), 370 m, 8 March 2016, G. Gheza (Herb. Gheza).

LOMBARDIA: trail between Pianezza and the Diga del Gleno, Vilminore di Scalve (Bergamo), on soil at the edge of the trail in a small clearing in a coniferous wood (UTM WGS84: 32T 583715.5095347), 1480 m, 30 April 2018, leg. G. Gheza, det. H. Mayrhofer (Herb. Gheza, GZU); trail verging the peat bog of Pian Gembro, Trivigno (Sondrio), on soil in a clearing with shrubs of *Erica carnea* and schist outcrops at the edge of the trail (UTM WGS84: 588899.5113126), 1375 m, 18 August 2018, G. Gheza (Herb. Gheza).

*Cladonia pulvinata* is a taxon of the *Cladonia cervicornis* group raised at species level by Herk & Aptroot (2003) whose distinction from *C. cervicornis* is confirmed also by genetic data (Pino-Bodas et al. 2010, 2013). It is characterized by greenish-brown, slightly or not incised squamules which are often erected and not curled upwards when dry and by the presence of psoromic acid (P+ yellow) (Herk & Aptroot 2003). This species was reported from only one of the heathlands in the Canavese ("Vaude") by Gheza et al. (2018), but a deeper check on previously neglected specimens and new field surveys allowed to confirm its presence also in the two other main heathlands of that area, reported here. The records from Vilminore di Scalve (Val di Scalve, Orobian Prealps) and Pian Gembro (Valtellina, Rhaetic Alps) widen the Italian range of the species, which was known so far only from dry habitats in lowland areas (Gheza et al. 2018). They are also the first records of the species for the Alps (cf. Nimis et al. 2018). Furthermore, the specimen from Vilminore di Scalve had some podetia, being the first fertile one found in Italy. The two clearings in which the species was recorded had a semi-dry vegetation dominated by ericaceous shrubs (*Erica carnea* L., *Vaccinium myrtillus* L.) and a lichen vegetation dominated, besides *C. pulvinata* itself, by *Cladonia floerkeana* (Fr.) Flörke in the first site and by *Cladonia cervicornis* (Ach.) Flot. in the second site.

In: Sonia Ravera et al. 2019. Notulae to the Italian flora of Algae, Bryophytes, Fungi and Lichens 7. Italian Botanist 7.

# *Cladonia strepsilis* (Ach.) Grognot
# (Cladoniaceae)

Gabriele Gheza, Helmut Mayrhofer, Juri Nascimbene

PIEMONTE: Tenuta Bornago, Cameri (Novara), on sandy-pebbly soil in a dry *Corynephorus* grassland (UTM WGS84: 32T 476694.5044401), 171 m, 17 June 2016, G. Gheza (Herb. Gheza).
LOMBARDIA: Ansa di Castelnovate, Vizzola Ticino (Varese), on sandy-pebbly soil in a dry *Corynephorus* grassland (UTM WGS84: 32T 473961.5052563), 164 m, 16 June 2016, G. Gheza (Herb. Gheza); "La Promessa", Lonate Pozzolo (Varese), on sandy-pebbly soil in a small open *Calluna* heathland, (UTM WGS84: 32T 478604.5046292), 188 m, 15 March 2017, G. Gheza (Herb. Gheza).

*Cladonia strepsilis* is a terricolous species, which was considered restricted to the Alps in Italy (Nimis 2016). These new records show that, like other *Cladonia* species with a montane-alpine distribution in Italy (see Gheza 2015), *C. strepsilis* reaches the planitial belt following the rivercourse of the Ticino river. It was found associated with *Cladonia foliacea* (Huds.) Willd. or *Cladonia cervicornis* (Ach.) Flot. and, sometimes, also with *Cladonia polycarpoides* Nyl., in the *Cladonietum foliaceae* Klement, 1953 emend. Drehwald, 1993 and in the *Pycnothelio-Cladonietum cervicornis* Paus, 1997. The specimens analysed by thin layer chromatography always contained baeomycesic acid, squamatic acid and strepsilin.

In: Sonia Ravera, Alfredo Vizzini, Annalena Cogoni, Michele Aleffi, Silvia Assini, Giovanni Bergamo Decarli, Ilaria Bonini, Wolfgang von Brackel, Francesco Cheli, Valeriy Darmostuk, Zuzana Fačkovcová, Lyubov Gavrylenko, Gabriele Gheza, Anna Guttová, Helmut Mayrhofer, Juri Nascimbene, Luca Paoli, Silvia Poponessi, Giovanna Potenza, Filippo Prosser, Davide Puddu, Domenico Puntillo, Diego Rigotti, Francesco Sguazzin, Alessia Tatti, Roberto Venanzoni. 2017. Notulae to the Italian flora of Algae, Bryophytes, Fungi and Lichens 4. Italian Botanist 4: 73-86.

# *Dibaeis baeomyces* (L.f.) Rambold & Hertel (Icmadophilaceae)

Gabriele Gheza, Juri Nascimbene, Silvia Assini

PIEMONTE: “Vauda” of Vauda Canavese (Torino), on bare clayey soil among *Calluna vulgaris* shrubs, in a dry *Calluna* heathland (UTM WGS84: 32T 388776.5013995), 434 m, 8 March 2016, G. Gheza, S. Assini (Herb. Gheza); “Vauda” of San Carlo Canavese (Torino), on bare clayey soil among *Calluna vulgaris* shrubs, in a dry *Calluna* heathland (UTM WGS84: 32T 392345.5012651), 370 m, 8 March 2016, G. Gheza, S. Assini (Herb. Gheza); Verrone (Biella), on bare clayey soil at the edge of a trail, in a dry *Calluna* heathland (UTM WGS84: 32T 431668.5036758), 250 m, 3 April 2017, G. Gheza, S. Assini (Herb. Gheza); Baraggione di Candelo near Cascina Bravetta, Massazza (Biella), on bare clayey soil among *Calluna vulgaris* shrubs, in a dry *Calluna* heathland (UTM WGS84: 32T 435996.5037555), 245 m, 7 July 2017, G. Gheza (Herb. Gheza).
LOMBARDIA: Brughiera di Tornavento, Lonate Pozzolo (Varese), on bare soil among *Polytrichum sp.*, at the edge of a dry *Calluna* heathland (UTM WGS84: 32T 478357.5049083), 202 m, 9 June 2017, G. Gheza (Herb. Gheza).

*Dibaeis baeomyces* is a terricolous species typical of pioneer and, often, disturbed areas (Nimis 2016). It has been always reported for montane-alpine localities in both Piemonte and Lombardia (see literature cited by Nimis 1993, 2016). Therefore, the records reported here are important to show that the species still exists in the Po Plain where well-preserved *Calluna* heathlands, which are one its main habitats (Nimis 2016), are still found. The record from the Brughiera di Tornavento confirms its occurrence in the area a long time after the last record by Cozzi (1917). It was always found sterile.

In: Sonia Ravera, Alfredo Vizzini, Annalena Cogoni, Michele Aleffi, Silvia Assini, Giovanni Bergamo Decarli, Ilaria Bonini, Wolfgang von Brackel, Francesco Cheli, Valeriy Darmostuk, Zuzana Fačkovcová, Lyubov Gavrylenko, Gabriele Gheza, Anna Guttová, Helmut Mayrhofer, Juri Nascimbene, Luca Paoli, Silvia Poponessi, Giovanna Potenza, Filippo Prosser, Davide Puddu, Domenico Puntillo, Diego Rigotti, Francesco Sguazzin, Alessia Tatti, Roberto Venanzoni. 2017. Notulae to the Italian flora of Algae, Bryophytes, Fungi and Lichens 4. Italian Botanist 4: 73-86.

# *Scytinium schraderi* (Ach.) Otálora, P.M.Jørg. & Wedin (Collemataceae)

Gabriele Gheza

PIEMONTE: between Villalvernia and Cassano Spinola (Alessandria), bird ringing station near the Scrivia river, on calcareous sandy-pebbly soil (UTM WGS84: 32T 488531.4959878), 162 m, 5 May 2016, G. Gheza (Herb. Gheza).
LOMBARDIA: Basella (Bergamo), in the Nature Reserve Basella-Malpaga, near the Serio river, on calcareous soil (UTM WGS84: 32T 557658.5051025), 182 m, 31 March 2016, G. Gheza (Herb. Gheza).

*Scytinium schraderi* is a cyanolichen found on calcareous soil and rock. It was previously known for Piemonte and only from one locality (Nimis 2016), while it is new for Lombardia. The two sites described here are rather similar, being located in dry grasslands on calcareous substrates along the planitial course of two main rivers. *Scytinium schraderi* was sampled within rather pioneer stands of a lichen-moss community referable to the *Toninio-Psoretum decipientis* Stodieck, 1973.

In: Sonia Ravera, Annalena Cogoni, Alfredo Vizzini, Michele Aleffi, Silvia Assini, Matteo Barcella, Wolfgang von Brackel, Stefania Caporale, Zuzana Fačkovcová, Giorgia Filippino, Gabriele Gheza, Daniela Gigante, Luca Paoli, Giovanna Potenza, Silvia Poponessi, Filippo Prosser, Domenico Puntillo, Michele Puntillo, Roberto Venanzoni. 2017. Notulae to the Italian flora of Algae, Bryophytes, Fungi and Lichens 3. Italian Botanist 3: 17-27.

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# Appendix II

## Key to the Italian species of genus *Cladonia*

# Chiave alle specie italiane del genere *Cladonia*

Gabriele Gheza

**Abstract**

Viene presentata una chiave alle 82 specie licheniche appartenenti al genere *Cladonia* rinvenute finora in Italia. Nella parte introduttiva del lavoro vengono discusse le caratteristiche morfologiche e chimiche da prendere in considerazione ai fini dell'identificazione. Viene inoltre riportato un glossario dei termini specialistici più frequentemente utilizzati nelle chiavi relative a *Cladonia*.

N.B. Il presente capitolo viene riportato in italiano, in quanto la chiave qui presentata è intesa come uno strumento ad uso dei lichenologi italiani e si è pertanto ritenuto più efficace e comodo a fini pratici redigerla in italiano.

Notiziario della Società Lichenologica Italiana 31: 70-96.

## Introduzione

Il genere *Cladonia* (Hill) P.Browne (famiglia Cladoniaceae, ordine Lecanorales) include circa 500 *taxa* diffusi in tutto il mondo (Nimis, 2016). Si tratta di licheni facilmente riconoscibili a livello di genere, ma spesso problematici da determinare a livello infragenerico, a causa dell'elevata variabilità morfologica e chimica che li caratterizza.

La recente monografia sulle Cladonie italiane di Valcuvia Passadore & Gheza (2017) non contiene una chiave di determinazione in quanto il taglio dell'opera è intenzionalmente divulgativo: gli autori hanno ritenuto controproducente l'eventuale inserimento di una chiave semplificata, comunque troppo complicata per un pubblico non specialistico e troppo semplicistica per i lichenologi esperti. Tuttavia, una prima bozza di chiave era stata messa a punto nella fase iniziale della stesura dell'opera e, una volta terminata la monografia, è stata ripresa e sviluppata dallo scrivente in modo da includere tutti gli 82 *taxa* ad oggi noti per l'Italia – gli 80 riportati da Nimis (2016) e Valcuvia Passadore & Gheza (2017) ai quali si sono aggiunti i due segnalati da Gheza et al. (2018): *Cladonia conista* (Nyl.) Robbins e *Cladonia pulvinata* (Sandst.) Herk & Aptroot.

Questo contributo ha il proposito di fornire uno strumento per incrementare nel tempo la conoscenza delle Cladonie italiane, sulle quali "ancor oggi c'è molto da scoprire" (Nimis in Valcuvia Passadore & Gheza, 2017).

## Materiali e metodi

### *Erbari e letteratura consultati*

La chiave è basata in parte sull'analisi di campioni di *Cladonia* conservati negli erbari crittogamici delle Università di Pavia (PAV) e Graz (GZU) e in quello privato dello scrivente. È stato inoltre necessario consultare la letteratura lichenologica, specialmente per raccogliere informazioni su specie rare non in possesso degli erbari sopra citati.

Oltre alle principali flore più recenti (Nimis, 1986; Nimis & Martellos, 2004; Burgaz & Ahti, 2009; James, 2009; Wirth *et al.*, 2013), sono stati consultati scritti relativi a gruppi problematici. A tale riguardo, si segnalano lavori contenenti chiavi e descrizioni utili per la determinazione di specie appartenenti a tali gruppi: *Cladonia coccifera* gr. (Asperges, 1985; Stenroos, 1989a, b; Burgaz, 2009; Osyczka, 2011), *Cladonia pyxidata-chlorophaea* s. lat. (Coassini-Lokar et al., 1986; Kowalewska et al., 2008; Matwiejuk, 2017), *Cladonia cervicornis* gr. (Herk & Aptroot, 2003), *C. gracilis* gr. (Ahti, 1980), *Cladonia rei* (Dolnik et al., 2010) e il sottogenere *Cladina* (Ahti, 1961; Burgaz & Martìnez, 2008).

Relativamente all'iconografia, oltre ad alcune delle opere già citate (Burgaz & Ahti, 2009; Wirth et al., 2013; Valcuvia Passadore & Gheza, 2017), si segnalano le guide illustrate delle *Cladonia* della Gran Bretagna (Hodgetts, 1992) e dei licheni terricoli degli habitat aperti aridi dei Paesi Bassi (Aptroot *et al.*, 2011), che forniscono un'ottima panoramica corredata da chiavi ed illustrazioni per molte specie presenti anche in Italia, e la monografia fotografica di Schumm (2017), le cui schede sono disponibili singolarmente sul sito web dell'autore (http://fschumm.bplaced.net/Schumm_Flechtenbilder/).

## ***Nomenclatura***

La nomenclatura dei taxa menzionati nella chiave segue Nimis (2016).

È stata mantenuta la divisione tra *foliacea* e *convoluta* come due *taxa* separati subordinati a *C. foliacea*, qui considerati con il rango di forme. Similmente, nell'ambito di *C. furcata,* sono stati considerati come *taxa* separati, con il rango di sottospecie, *furcata* e *subrangiformis*. Al contrario, *C. conista* e *C. humilis*, ben distinte dal punto di vista genetico oltre che chimico (Pino-Bodas *et al.*, 2012), sono state invece considerate come specie distinte, così come i tre *taxa* segnalati in Italia del gruppo *cervicornis: C. cervicornis, C. pulvinata, C. verticillata* (Herk & Aptroot, 2003).

## ***Struttura e utilizzo della chiave***

La chiave si propone di operare la massima discriminazione possibile a livello morfologico, avvalendosi comunque delle necessarie precisazioni riguardo agli spot-test e ai metaboliti secondari indagabili tramite cromatografia su strato sottile (TLC). Per l'allestimento della TLC si può fare riferimento ai lavori di White & James (1985), Orange *et al.* (2010) e Schumm & Elix (2015). In alcuni casi la morfologia può essere sufficiente per un'identificazione attendibile, ma nella chiave vengono riportati quasi sempre anche i risultati degli spot-test e della TLC. In altri casi, soprattutto quando sono presenti solamente le squamule del tallo primario, l'esatta identificazione degli esemplari può essere impossibile anche tramite l'analisi dei metaboliti secondari (es. squamule primarie terricole contenenti acido usnico e zeorina potrebbero appartenere a *C. coccifera*, *C. deformis*, *C. diversa* o *C. pleurota*), pertanto nella chiave vengono elencate in un'unica opzione tutte le specie possibili.

Alcune specie particolarmente polimorfiche, che si possono presentare con morfologie differenti a seconda delle condizioni ecologiche, o molto variabili chimicamente, compaiono più volte all'interno della chiave. Si è cercato, per quanto possibile, di contemplare tutte le possibili casistiche. Alcune chiavi danno infatti per scontata la presenza di apoteci o picnidi sui podezi, quando di fatto spesso non se ne trovano. Un altro problema riguarda la presenza di coppe all'apice dei podezi: in alcune specie (*C. coniocraea*, *C. gracilis*, *C. macroceras*, *C. ochrochlora*, *C. rei*, *C. subulata*) non è infrequente incontrare, all'interno di uno stesso popolamento, podezi provvisti di strette coppe e podezi di forma appuntita; tutte le specie che presentano una tale variabilità sono state considerate più volte all'interno della chiave, in modo che l'identificazione sia possibile anche in caso di raccolta di poco materiale. Si raccomanda comunque di raccogliere sempre campioni sufficientemente significativi, nei quali sia riscontrabile una buona parte della variabilità espressa, nel sito di raccolta, dall'entità che si vuole identificare.

Si è cercato inoltre di evitare di utilizzare come caratteri diagnostici quelli legati all'ecologia delle specie, come il substrato, l'habitat o la distribuzione altitudinale; molte specie, infatti, sono molto variabili anche da questo punto di vista e si possono trovare su differenti substrati, in un'ampia gamma di habitat e talvolta in aree geografiche e altitudinali diverse da quelle ritenute ottimali o addirittura esclusive per la specie (es. alcune specie che in Italia erano considerate limitate alle zone montuose sono invece state recentemente ritrovate in Pianura Padana, cf. GHEZA, 2015; RAVERA *et al*., 2017). Le rare eccezioni riguardano alcuni *taxa* chimicamente uguali e molto difficili da distinguere morfologicamente (es. *C. foliacea* f. *foliacea* e f. *convoluta*, ad ora discriminabili unicamente secondo l'ecologia del substrato – acidofila la prima, calcifila la seconda).

Prima di procedere con l'identificazione degli esemplari tramite questa chiave, valgono le precauzioni comunemente adottate in lichenologia su condizioni del materiale da prendere in esame (esemplari essiccati e non umidi), preparazione ed utilizzo dei reagenti, ecc.

## Chiave

### *Caratteristiche morfologiche da considerare ai fini della determinazione*

Il tallo primario della maggior parte delle Cladonie è costituito da squamule bifacciali appiattite in cui la pagina superiore è provvista di *cortex* mentre quella inferiore non lo è. Nella maggior parte delle specie le squamule non sono sorediate, mentre nelle specie che presentano soredi (es. *C. digitata*, *C. incrassata*, *C. parasitica*, *C. polydactyla*), questi sono generalmente sulla pagina inferiore, i cui bordi talvolta si ripiegano verso l'alto mostrando i soredi molto chiaramente. Le squamule possono avere margine più o meno profondamente inciso oppure intero e possono essere appressate al substrato, parzialmente sollevate o completamente erette; possono inoltre ripiegarsi oppure no quando secche. Squamule simili a quelle del tallo primario, solitamente più piccole, possono essere presenti anche sui podezi. Nella maggior parte delle specie con podezi corticati ramificati, le squamule del tallo primario scompaiono in fretta, mentre rimangono alcune squamule rarefatte solamente alla base del podezio, o talvolta anche più in alto. Le specie con podezi ramificati privi di cortex (sottogenere *Cladina*) hanno tallo primario crostoso effimero, che viene rinvenuto solo molto raramente, e podezi mai squamulosi.

I podezi possono presentare una gran varietà di forme: bacillari, clavati, scififeri, più o meno ramificati a partire dalla base oppure presso l'estremità, ecc. In alcuni casi possono essere estremamente variabili all'interno della stessa specie. Ad esempio, *C. rei* può presentare podezi bacillari o con strette coppe terminali, da quasi completamente sorediati (confondibili con *C. subulata*) a sorediati solo nella parte superiore (confondibili con *C. coniocraea*, *C. cornuta* o *C. ochrochlora*), da poco squamulosi almeno nella parte basale (confondibili con *C. gracilis*) a fittamente squamulosi quasi fino all'apice (confondibili con *C. squamosa*), oppure piuttosto ramificati (confondibili con *C. furcata* ssp. *furcata* o *C. scabriuscula*). Lo studio dei metaboliti secondari tramite TLC diventa quindi fondamentale per una corretta identificazione, dato che spesso gli spot-test non sono sufficienti. In alcuni gruppi di specie i podezi, oltre a mostrare una elevata variabilità intraspecifica, sono anche estremamente simili tra specie affini, come nei già citati gruppi di *C. chlorophaea-pyxidata* s. lat. o *C. coccifera*. Anche in questi casi è fondamentale la TLC.

I soredi presenti sui podezi di alcune specie possono essere molto fini (farinosi) (es. *C. coniocraea*, *C. cornuta*, *C. fimbriata*, *C. subulata*) o più grossolani (granulosi) (es. *C. acuminata*, *C. chlorophaea*, *C. decorticata*). Possono essere presenti anche schizidi (es. *C. pyxidata*), blastidi (es. *C. borealis*, *C. coccifera*) o placche bullate (es. *C. monomorpha*). Non sono invece mai presenti veri isidi (Burgaz & Ahti, 2009).

Gli apoteci, di tipo lecideino, nella maggior parte dei casi vengono portati all'apice dei podezi; in alcuni casi (*C. caespiticia*) possono invece essere sessili direttamente sulle squamule, oppure portati da brevi peduncoli. Nella maggior parte delle specie sono di colore bruno chiaro o scuro, in alcune (sezione *Cocciferae*) di colore rosso e in due (*C. botrytes*, *C. carneola*) di colore rosato o beige chiaro. In alcuni casi, nelle specie ad apoteci e picnidi rossi (colore determinato dalla presenza di acido rhodocladonico), questi possono presentarsi invece di colore bruno scuro o nero; un confronto con altri podezi simili presenti nel sito di raccolta può risolvere eventuali dubbi in attesa della TLC.

### ***Glossario***

Si riporta di seguito un breve glossario comprensivo di alcuni termini che descrivono alcune caratteristiche anatomiche e morfologiche utili per l'identificazione delle specie di *Cladonia*, corredati dalla rispettiva traduzione in inglese, utile in caso di consultazione della letteratura.

**Aracnoide** – *arachnoid*: aspetto ragnateloso o feltroso della superficie dei podezi privi di cortex (es. sottogenere *Cladina*).

**Bacillare** (podezio) – *bacillar*: di forma allungata, stretta e appuntita (es. *C. coniocraea*).

**Bullata** (placca) – *bullate*: di forma convessa (es. *C. monomorpha*).

**Capitato** (podezio) – *capitate*: terminante con un unico apotecio molto più largo del podezio (es. *C. peziziformis*).

**Clavato** (podezio) – *club-shaped*: a forma di clava, allungato ma leggermente rigonfio verso la metà o l'estremità superiore, non appuntito come un podezio bacillare (es. *C. macilenta*).

**Corimboso** (apotecio) – *corymbose*: quando più apoteci portati all'apice del podezio si sviluppano fino a fondersi insieme (es. *C. cariosa*).

**Decumbente** – *decumbent*: con portamento non eretto ma inclinato, talvolta fino a piuttosto appressato al substrato.

**Dicotomica** (ramificazione) – *dichotomous*: suddivisa in due parti.

**Farinoso** (soredio) – *farinose*: molto fine.

**Fessurato** (podezio) – *fissurate*: percorso da una (es. *C. glauca*) o più (es. *C. cariosa*, *C.*

*sulphurina*) lacerazioni longitudinali.

**Fillopodiato** (podezio) – *phyllopodiate*: che si sviluppa da squamule del tallo primario rigonfie (es. *C. pseudopityrea*).

**Granuloso** (soredio) – *granulose*: piuttosto grossolano.

**Peltata** (squamula) – *peltate*: a forma di scudo (es. *C. macrophylla*).

**Podezio** – *podetium* (pl. *podetia*: struttura tridimensionale cava che prende origine dal tessuto generativo dell'apotecio e ha la funzione di portare gli apoteci stessi e, in molti casi, i picnidi.

**Politomica** (ramificazione) – *polytomous*: suddivisa in più di due parti.

**Proliferazione** – *proliferation*: escrescenza di forma variabile che si dirama generalmente da un podezio a forma di coppa, dai margini (es. specie del gruppo *chlorophaea-pyxidata* e del gruppo *coccifera*) oppure dal centro (es. specie del gruppo *cervicornis*).

**Pulvinato** (tallo primario) – *pulvinate*: a forma di cuscinetto.

**Ramificato** (podezio) – *branched*: provvisto di ramificazioni, che possono essere numerose e fitte fino a conferire al podezio l'aspetto complessivo di un piccolo cespuglio (es. *C. rangiformis*, *C. furcata*, sottogenere *Cladina*) oppure più rade verso l'apice di podezi semplici (es. *C. botrytes*, *C. cariosa*, *C. symphycarpa*).

**Scifero** (podezio) – *scyphipherous*, *scyphose*: a forma di trombetta (es. *C. fimbriata*) o coppa più o meno svasata (es. specie del gruppo *chlorophaea-pyxidata* e del gruppo *coccifera*).

**Scifo** – *scyphus*: coppa (nei podezi sciferi).

**Squamuloso** (podezio) – *squamulose*: ricoperto, totalmente o almeno in parte, da squamule.

**Subulata** (proliferazione) – *subulate*: lunga e appuntita, e spesso contorta (es. *C. subulata*).

**Tallo primario** – *primary thallus*: parte basale del tallo, dalla morfologia squamulosa (sottogenere *Cladonia*) o crostosa (sottogenere *Cladina*), che è la prima a svilupparsi sul substrato.

**Tallo secondario** – *secondary thallus*: parte tridimensionale del tallo, dalla morfologia fruticosa, che si sviluppa secondariamente; in *Cladonia* coincide con i podezi, e in molte specie è l'unica osservabile a maturità.

**Tetracotomica** (ramificazione) – *tetrachotomous*: suddivisa in quattro parti.

**Tricotomica** (ramificazione) – *trichotomous*: suddivisa in tre parti.

**Verticillato** (podezio) – *verticillate*: con proliferazioni che si dipartono dal centro delle coppe.

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## CHIAVE GENERALE

**1)** Podezi assenti, presenti solo le squamule del tallo primario..........................................**Sottochiave I**
**1)** Podezi presenti, tallo primario presente o assente.........................................................................................**2**

**2)** Podezi ben sviluppati e molto ramificati, a forma di cespuglietto; tallo primario generalmente assente, ma talvolta presente...........................................................................................................**Sottochiave II**
**2)** Podezi non o poco ramificati, ma comunque mai a forma di cespuglietto; tallo primario spesso presente o, più raramente, assente............................................................................................................**3**

**3)** Podezi prevalentemente scififeri (eventualmente presenti solamente pochi podezi bacillari, appuntiti o poco ramificati e non scififeri), con coppe da molto ampie a molto strette; tallo primario presente o assente.........................................................................................................**Sottochiave III**
**3)** Podezi semplici, bacillari, clavati o di forma irregolare, in alcuni casi poco ramificati verso l'apice, ma prevalentemente non scififeri (eventualmente presenti solamente pochi podezi provvisti di coppe molto strette tra molti podezi non scififeri); tallo primario presente o assente.....................................................................................................................................**Sottochiave IV**

## Sottochiave I

Podezi assenti, tallo costituito dalle sole squamule del tallo primario.

**1)** Apoteci bruni o rosati sessili presenti sulla pagina superiore di squamule verdi glauche o verdastre, con margini incisi e ripiegati verso l'alto, formanti cuscinetti anche spessi..........................
..........................................................................................................................................***C. caespiticia***
**1)** Apoteci assenti, eventualmente presenti picnidi..............................................................................**2**

**2)** Su terra o terriccio sopra alla roccia....................................................................................................**3**
**2)** Su scorza o legno morto.......................................................................................................................**28**

**3)** Squamule piuttosto cospicue, formanti cuscinetti grandi…........................................................**4**
**3)** Squamule piuttosto incospicue, tappezzanti, o, se formanti cuscinetti, piuttosto piccole..........**15**

**4)** Faccia superiore delle squamule da verde olivastra a brunastra, squamule con margine piuttosto inciso formanti cuscinetti compatti; C+ verde brillante; acido baeomicesico e strepsilina presenti.........................................................................................................................***C. strepsilis***
**4)** Faccia superiore delle squamule di vari colori, squamule formanti cuscinetti o tappezzanti; C–; acido baeomicesico e strepsilina assenti..............................................................................................**5**

**5)** Faccia inferiore delle squamule bianca o biancastra.......................................................................**6**
**5)** Faccia inferiore delle squamule di altro colore..................................................................................**9**

**6)** Faccia superiore delle squamule da verde olivastra a brunastra, squamule con margine piuttosto intero, tappezzanti o formanti cuscinetti lassi, erette, con i margini poco ripiegati verso il basso; K–; acido psoromico presente, atranorina assente.....................................................***C. pulvinata***
**6)** Squamule formanti cuscinetti fitti, suberette, imbricate o decumbenti, con i margini ripiegati verso l'alto; K+ giallo o giallo poi rosso; acido psoromico assente, atranorina presente.....................**7**

**7)** K+ giallo poi rosso (reazione lenta!); acido fumarprotocetrarico assente, acido norstictico presente...........................................................................................................................***C. symphycarpa***
**7)** K+ giallo; acido fumarprotocetrarico presente, acido norstictico assente...................................**8**

**8)** Squamule piuttosto incise, con faccia superiore brunastra chiara, con margini marcatamente ripiegati verso l'alto da secche...........................................................................................***C. macrophyllodes***
**8)** Squamule profondamente divise in lobi arrotondati, con faccia superiore verdastra, verde-

glauca o grigio-verdastra, con margini non marcatamente ripiegati verso l'altro da secche............................................................................................................................................***C. turgida***

**9)** Squamule grandi, faccia superiore verde brillante o verde-giallastra, faccia inferiore bianco-giallastra; KC+ giallo o giallastro; acido usnico presente....................................................(*C. foliacea*) **10**
**9)** Squamule medio-piccole, faccia superiore da verdastra a brunastra, faccia inferiore biancastra, brunastra, rossastra o rosata, ma mai bianco-giallastra; K–; acido usnico assente......**11**

**10)** Squamule grandi poco incise, spesso con fibrille nere sul margine; su substrati acidi.......................................................................................................................***C. foliacea* f. *foliacea***
**10)** Squamule molte grandi ed incise, spesso con fibrille generalmente bianche (ma talvolta nere!) sul margine; su substrati basico-calcarei.....................................................***C. foliacea* f. *convoluta***

**11)** Faccia inferiore delle squamule grigiastra o grigio-bluastra.................................................................**12**
**11)** Faccia inferiore delle squamule rosata, rossastra o brunastra............................................................**14**

**12)** Zona nerastra presente sulla faccia inferiore alla base delle squamule; K+ giallo; atranorina presente..........................................................................................................................***C. subcervicornis***
**12)** Zona nerastra alla base delle squamule assente; K–; atranorina assente........................................**13**

**13)** Squamule fortemente incise, molto ricurve verso l'alto quando secche, con margine piatto.........................................................................................................................................***C. cervicornis***
**13)** Squamule poco incise o con margine intero, non ricurve quando secche, con margine brunastro leggermente incurvato verso il basso.........................................................................***C. verticillata***

**14)** Faccia inferiore delle squamule rossastra o brunastra; K+ giallo poi rosso (reazione lenta!); acido norstictico presente, acido fumarprotocetrarico e atranorina assenti...........***C. polycarpoides***
**14)** Faccia inferiore delle squamule rosata o rossastra, ciglia nere spesso presenti al margine delle squamule; K+ giallo; acido norstictico assente, acido fumarprotocetrarico e atranorina presenti.........................................................................................................................................***C. firma***

**15)** Squamule verde-giallastre; acido usnico o iso-usnico presente.........................................................**16**
**15)** Squamule di altro colore, senza sfumature giallastre; acido usnico o iso-usnico assente........**18**

**16)** Zeorina presente...................................................................***C. coccifera/deformis/diversa/pleurota***
**16)** Zeorina assente, ma presenti altre sostanze.................................................................................................**17**

**17)** Acido barbatico presente.........................................................................................................***C. borealis***
**17)** Acido squamatico presente.................................................................................................***C. bellidiflora***

**18)** Faccia superiore delle squamule verde-glauca o grigio-glauca, verde-azzurrognola da umida.......................................................................................................................................................**19**
**18)** Faccia superiore delle squamule da verde a grigiastra, ma non verde-azzurrognola, nemmeno da umida...............................................................................................................................**20**

**19)** Squamule tappezzanti, imbricate o anche formanti cuscinetti, con margini incisi e ripiegati verso l'alto; K–; acido fumarprotocetrarico presente, atranorina assente........................***C. caespiticia***
**19)** Squamule tappezzanti, generalmente erette ma non con margini ripiegati; K+ giallo; acido fumarprotocetrarico occasionalmente presente, atranorina presente....................................***C. cariosa***

**20)** Squamule piccole (1-3 mm), tondeggianti o a forma di orecchio, con margine intero e faccia superiore verde o verde-grigiastra, verde brillante da umide............................................***C. peziziformis***
**20)** Squamule più grandi (3-6 mm), di forma diversa, con margine almeno un po' inciso, di vari colori..........................................................................................................................................................**21**

**21)** Acido fumarprotocetrarico presente come unica sostanza (occasionalmente possono essere

presenti anche tracce di acido protocetrarico e/o acido confumarprotocetrarico)............................**22**
**21)** Acido fumarprotocetrarico presente o assente, ma non unica sostanza presente......................**23**

**22)** Vene da rosate a brunastre distintamente visibili sulla faccia inferiore delle squamule................ ...............................................................................................................................................***C. cyathomorpha***
**22)** Faccia inferiore delle squamule completamente biancastra o bianco-grigiastra e priva di vene..........................................................***C. pyxidata/pocillum/monomorpha/chlorophaea/fimbriata***

**23)** K–, C–, KC–........................................................................................................................................**24**
**23)** Almeno una delle reazioni positiva...............................................................................................**25**

**24)** Acido bourgeanico presente, acido grayanico assente..........................................................***C. conista***
**24)** Acido bourgeanico assente, acido grayanico presente...............................................................***C. grayi***

**25)** K– o K+rosso; acido meroclorofeico e acido 4-0-metilcriptoclorofeico presenti.......................**26**
**25)** K+ giallo o rosso; acido meroclorofeico e acido 4-0-metilcriptoclorofeico assenti....................**27**

**26)** Acido fumarprotocetrarico presente, acido perlatolico assente..................***C. merochlorophaea***
**26)** Acido fumarprotocetrarico assente, acido perlatolico presente.................................***C. perlomera***

**27)** K+ giallo poi rosso; acido criptoclorofeico presente, atranorina assente............................................ .......................................................................................................................................***C. cryptochlorophaea***
**27)** K+ giallo; acido criptoclorofeico assente, atranorina presente..........................................***C. humilis***

**28)** Soredi presenti almeno su una delle due facce delle squamule, generalmente quella inferiore, con squamule che spesso si incurvano verso l'alto ai margini..................................................................**29**
**28)** Soredi completamente assenti.......................................................................................................**31**

**29)** Squamule grandi (5-10 mm), con faccia superiore verde-glauca, talvolta con macchie arancio alla base, con margine piuttosto intero, piatto o crenulato, incurvato verso l'alto.............***C. digitata***
**29)** Squamule piccole (1-3 mm), con faccia superiore grigio-verdastra o grigio-verde-giallastra, con margine variamente inciso..........................................................................................................**30**

**30)** Picnidi rossi o rosati; K–, KC+ giallo, P–; acido tamnolico generalmente assente, acido squamatico e acido usnico presenti.........................................................................................***C. incrassata***
**30)** Picnidi bruni o comunque scuri; K+ giallo, KC–, P+ giallo-arancio; acido tamnolico presente, acido squamatico e acido usnico assenti...............................................................................***C. parasitica***

**31)** Acido fumarprotocetrarico presente come unica sostanza........................................................... .....................................................................***C. coniocraea/fimbriata/pyxidata/chlorophaea/caespiticia***
**31)** Acido fumarprotocetrarico assente, presenti altre sostanze.............................................................**32**

**32)** Squamule con faccia superiore verde-giallastra; acidi usnico e/o iso-usnico presenti.................. .........................................................................................................***C. coccifera/deformis/diversa/sulphurina***
**32)** Squamule con faccia superiore verde-glauca, verde-grigiastra o glauco-grigiastra; acidi usnico e/o iso-usnico assenti...............................................................................................................**33**

**33)** Presente più di un composto secondario.................................................................................... .................................................................................***C. floerkeana/macilenta/squamosa* var. *subsquamosa***
**33)** Presente un solo composto secondario..........................................................................................**34**

**34)** Acido barbatico presente...................................................................................................................**35**
**34)** Acido barbatico assente.....................................................................................................................**36**

**35)** Squamule con margine inciso, grigio-verdastre, spesso con macchie arancioni alla base............ ...............................................................................................................................................***C. norvegica***

**35)** Squamule intere o poco incise, grigiastre, prive di macchie arancioni......................***C. floerkeana***

**36)** Acido thamnolico presente.....................................................................................................***C. polydactyla***
**36)** Acido squamatico presente......................................................***C. cenotea/squamosa* var. *squamosa***

### Sottochiave II

Podezi ben sviluppati e molto ramificati, a forma di cespuglietto; tallo primario generalmente assente, ma talvolta presente.

**1)** Podezi provvisti almeno parzialmente di *cortex*, tallo primario squamuloso talvolta presente............................................................................................................................................**2**
**1)** Podezi completamente privi di *cortex*, tallo primario quasi sempre assente, crostoso se presente......................................................................................................(sottogenere *Cladina*) **16**

**2)** Podezi squamulosi almeno alla base......................................................................................................**3**
**2)** Podezi completamente privi di squamule.........................................................................................**11**

**3)** Podezi fittamente ricoperti di squamule quasi fino all'apice.......................................(*C. squamosa*) **4**
**3)** Podezi con squamule limitate alla parte basale, o, se più in alto, non fitte.........................................**5**

**4)** K–, P–; acido squamatico..................................................................................***C. squamosa* var. *squamosa***
**4)** K+ giallo, P+ giallo-arancio; acido barbatico, acido tamnolico........................................................................
.................................................................................................................***C. squamosa* var. *subsquamosa***

**5)** Soredi o granulosità generalmente presenti almeno su parte dei podezi............................................**6**
**5)** Soredi o granulosità generalmente assenti.............................................................................................**7**

**6)** Podezi sempre terminanti a punta o con piccole ramificazioni, mai con coppe strette; K+ giallastro o brunastro, P+ rosso; acidi omosekikaico e/o sekikaico assenti................***C. scabriuscula***
**6)** Podezi terminanti a punta o con coppe molto strette; K–, P+ giallo poi arancio-rosso; acidi omosekikaico e/o sekikaico presenti.........................................................................................................***C. rei***

**7)** Podezi generalmente non squamulosi, perforazioni presenti all'ascella delle ramificazioni o entro strette coppe terminali; K–, P–; acidi barbatico e squamatico presenti.................(*C. crispata*) **8**
**7)** Podezi generalmente squamulosi almeno alla base, perforazioni assenti; K– o + giallastro o brunastro, P– o + rosso, ma mai K– e P– contemporaneamente; acidi barbatico e squamatico assenti.............................................................................................................................................................**9**

**8)** Podezi poco ramificati, con parti terminali provviste di strette coppe perforate al centro, spesso con proliferazioni laterali...............................................................................***C. crispata* var. *crispata***
**8)** Podezi molto ramificati, con parti terminali sprovviste di coppe evidenti, con perforazioni all'ascella delle ramificazioni e corte spine intorno all'apice.............***C. crispata* var. *cetrariiformis***

**9)** Podezi fittamente areolati fino quasi all'apice, che tende generalmente ad essere più scuro (brunastro) rispetto al resto del tallo (grigio-verdastro); acido rangiformico presente........................
..........................................................................................................................................................***C. rangiformis***
**9)** Podezi areolati poco fittamente, spesso solamente nella parte basale, o non areolati, da grigio-verdastri a brunastri ma con apici generalmente non nettamente più scuri del resto; acido rangiformico assente.........................................................................................................................................**10**

**10)** Parte basale dei podezi priva di lacerazioni; atranorina generalmente assente, talvolta presente in tracce; su substrati acidi o basici..........................................................***C. furcata* ssp. *furcata***
**10)** Parte basale dei podezi provvista di lacerazioni dalle quali la medulla bianca fuoriesce formando dei bozzi tondeggianti; atranorina presente; su substrati basico-calcarei..............................

........................................................................................................................................***C. furcata* ssp. *subrangiformis***

**11)** Perforazioni presenti all'ascella delle ramificazioni o entro strette coppe terminali................**12**
**11)** Perforazioni assenti..........................................................................................................................................**15**

**12)** KC–; acido usnico assente.............................................................................................................(*C. crispata*) **8**
**12)** KC+ giallo o giallastro; acido usnico presente..........................................................................................**13**

**13)** Strette coppe terminali con corte proliferazioni laterali appuntite presenti almeno su parte dei podezi, perforazioni all'ascella delle ramificazioni o all'interno delle coppe talvolta poco evidenti; acido barbatico presente..........................................................................................***C. amaurocraea***
**13)** Podezi sempre privi di coppe terminali, perforazioni all'ascella delle ramificazioni bene evidenti; acido barbatico assente..............................................................................................(*C. uncialis*) **14**

**14)** Ramificazioni terminali tricotomiche o tetracotomiche, perforazioni molto frequenti; acido squamatico presente solo occasionalmente...........................................................***C. uncialis* ssp. *uncialis***
**14)** Ramificazioni terminali dicotomiche, perforazioni poco frequenti; acido squamatico regolarmente presente..........................................................................................***C. uncialis* ssp. *biuncialis***

**15)** Stretta coppe terminali con corte proliferazioni laterali appuntite presenti almeno su parte dei podezi; K–, KC+ giallastro, P–; acido usnico presente, acido fumarprotocetrarico assente............
.........................................................................................................................................***C. amaurocraea***
**15)** Coppe terminali mai presenti all'apice delle ramificazioni; K– o K+ giallastro, KC–, P– o P+ rosso; acido usnico assente, acido fumarprotocetrarico presente..............................................................**9**

**16)** Podezi di colore grigiastro; K+ giallo, P+ rosso; atranorina presente, acido usnico sempre assente..........................................................................................................................................................**17**
**16)** Podezi di colore giallastro, verdastro o biancastro; K–, P– o +; atranorina assente, acido usnico spesso (ma non sempre) presente.........................................................................................................**18**

**17)** Zona nera necrotica alla base dei podezi assente, gelatina picnidiale incolore...***C. rangiferina***
**17)** Zona nera necrotica alla base dei podezi evidente, gelatina picnidiale rossastra...........***C. stygia***

**18)** Podezi ramificati molto fittamente soprattutto nella parte superiore, formanti caratteristici cuscinetti a forma di cupola compatta...............................................................................................***C. stellaris***
**18)** Podezi meno fittamente ramificati, a forma di cespuglietto, ma mai di cupola compatta........**19**

**19)** Podezi robusti e con ramificazioni terminali orientate per la maggior parte nella stessa direzione; generalmente al di sopra della fascia montana.............................................................................**20**
**19)** Podezi robusti e con ramificazioni terminali orientate in tutte le direzioni o esili e con ramificazioni terminali orientate per la maggior parte nella stessa direzione; generalmente al di sotto della fascia montana....................................................................................................................................**21**

**20)** P+ giallo o rosso; acido psoromico generalmente presente, acido rangiformico assente..............
.........................................................................................................................................................***C. arbuscula***
**20)** P–; acido psoromico assente, acido rangiformico presente......................................................***C. mitis***

**21)** Podezi robusti, ramificazioni terminali non ricurve, orientate in tutte le direzioni, dicotomiche o politomiche, con apici di colore non molto diverso dal resto dei podezi; P–; acido fumarprotocetrarico assente................................................................................................................................**22**
**21)** Podezi esili, ramificazioni terminali ricurve, orientate per la maggior parte nella stessa direzione, dicotomiche, con apici di colore brunastro; P+ rosso; acido fumarprotocetrarico presente.................................................................................................................................(*C. Ciliata*) **23**

**22)** Ramificazioni terminali generalmente dicotomiche.................................................***C. mediterranea***
**22)** Ramificazioni terminali generalmente tricotomiche o tetracotomiche...................***C. portentosa***

**23)** KC–; acido usnico generalmente assente (talvolta presente in tracce)........***C. ciliata* var. *ciliata***
**23)** KC+ giallo o giallastro; acido usnico sempre presente.........................................***C. ciliata* var. *tenuis***

### Sottochiave III

Podezi prevalentemente scififeri (eventualmente presenti solamente pochi podezi bacillari, appuntiti o poco ramificati e non scififeri), con coppe da molto ampie a molto strette; tallo primario presente o assente.

**1)** Podezi proliferanti dal centro (verticillati) (controllare con attenzione: talvolta podezi giovani hanno proliferazioni centrali molto piccole)..............................................................**2**
**1)** Podezi proliferanti dai margini delle coppe o non proliferanti..............................................**7**

**2)** Podezi poco cospicui rispetto al tallo primario..............................................................**3**
**2)** Podezi molto cospicui rispetto al tallo primario.............................................................**5**

**3)** Squamule piuttosto incise e variamente ripiegate, faccia inferiore bianca, margini delle coppe frequentemente squamulosi; K+ giallo; atranorina presente.....................................***C. macrophyllodes***
**3)** Squamule incise con faccia inferiore grigiastra o grigio-bluastra oppure non incise con faccia inferiore biancastra, margini delle coppe raramente o non squamulosi; K–; atranorina assente....**4**

**4)** Podezi robusti, con fino a 7 livelli di coppe, squamule del tallo primario incise con faccia inferiore grigiastra o grigio-bluastra; P+ rosso; acido fumarprotocetrarico presente, acido psoromico assente..............................................................................***C. cervicornis***
**4)** Podezi gracili, con al massimo 2 livelli di coppe, squamule del tallo primario non o poco incise con faccia inferiore biancastra; P+ giallo; acido fumarprotocetrarico assente, acido psoromico presente..............................................................................***C. pulvinata***

**5)** Proliferazioni generalmente ramificate e strette, podezi anneriti alla base; K+ giallo; atranorina presente..............................................................................***C. trassii***
**5)** Proliferazioni non ramificate; K–; atranorina assente.......................................................**6**

**6)** Squamule del tallo primario fortemente incise, molto ricurve verso l'alto quando secche, con margine piatto..............................................................................***C. cervicornis***
**6)** Squamule del tallo primario poco incise o con margine intero, non ricurve quando secche, con margine brunastro leggermente incurvato verso il basso.....................................................***C. verticillata***

**7)** Podezi fertili..............................................................................**8**
**7)** Podezi sterili..............................................................................**48**

**8)** Apoteci e picnidi rossi..............................................................................**9**
**8)** Apoteci rosati o bruni, picnidi bruni o scuri..............................................................................**16**

**9)** Podezi sorediati..............................................................................**10**
**9)** Podezi non sorediati..............................................................................**14**

**10)** Podezi e faccia superiore delle squamule verde-giallastro; K–, P–; acido usnico e/o isousnico presenti..............................................................................**11**
**10)** Podezi e faccia superiore delle squamule grigio-verdastro glaucescente, squamule talvolta chiazzate di arancio alla base; K+ giallo, P+ arancio; acido tamnolico presente.................................**13**

**11)** Podezi spesso fessurati, con peduncolo lungo e coppe molto strette, irregolari; zeorina assente, acido squamatico presente..............................................................................***C. sulphurina***
**11)** Podezi generalmente non o poco fessurati, con coppe piuttosto ampie; zeorina presente, acido squamatico assente..............................................................................**12**

**12)** Podezi non fessurati e piuttosto regolari, coppe molto ampie con margine irregolare e denticolato........................................................................................................................................***C. pleurota***
**12)** Podezi talvolta fessurati, spesso storti e irregolari, coppe molto strette con margine intero o debolmente denticolato..........................................................................................................................***C. deformis***

**13)** Squamule del tallo primario piuttosto grandi, con margine intero spesso ripiegato verso l'alto, molto sorediate sulla faccia inferiore..................................................................................***C. digitata***
**13)** Squamule del tallo primario di dimensioni medie, con margine variamente inciso, generalmente poco o non sorediate sulla faccia inferiore.....................................................***C. polydactyla***

**14)** Podezi generalmente poco areolati; acido barbatico presente, zeorina assente........***C. borealis***
**14)** Podezi spesso areolati; acido barbatico assente, zeorina presente..................................................**15**

**15)** Podezi non o poco squamulosi alla base, placche corticate presenti all'interno delle coppe.......
........................................................................................................................................................***C. coccifera***
**15)** Podezi spesso squamulosi alla base, granulosità e microsquamule presenti all'interno delle coppe............................................................................................................................................***C. diversa***

**16)** Coppe perforate al centro............................................................................................................**17**
**16)** Coppe non perforate.....................................................................................................................**20**

**17)** K+ giallo, P+ arancio o rosso; acido squamatico assente............................................................**18**
**17)** K–, P–; acido squamatico presente...............................................................................................**19**

**18)** Podezi generalmente non o poco squamulosi, con ramificazioni terminali appuntite e raramente portanti strette coppe; P+ rosso; acido fumarprotocetrarico e atranorina presenti..........
......................................................................................................................................................***C. turgida***
**18)** Podezi generalmente molto squamulosi; P+ arancio; acido fumarprotocetrarico e atranorina assenti..................................................................................................***C. squamosa* var. *subsquamosa***

**19)** Podezi generalmente non o poco squamulosi, grigiastri, con proliferazioni non o poco ramificate intorno alle coppe, frequentemente presenti.............................................................***C. cenotea***
**19)** Podezi generalmente molto squamulosi, glauco-verdastri o glauco-grigiastri, spesso con ramificazioni, raramente con coppe.................................................................***C. squamosa* var. *squamosa***

**20)** Podezi molto piccoli, poco visibili, portati su squamule molto più grandi, che formano cuscinetti..........................................................................................................................................**21**
**20)** Podezi medio-grandi rispetto alle squamule, ben visibili.............................................................**23**

**21)** Squamule medio-grandi, con faccia inferiore rosata o rossastra; K+ giallo, KC–; acido fumarprotocetrarico e atranorina presenti, acido usnico assente.................................................***C. firma***
**21)** Squamule da grandi a molto grandi, con faccia inferiore bianco-giallastra; K–, KC+ giallastro; acido fumarprotocetrarico e acido usnico presenti, atranorina assente.........................(*C. foliacea*) **22**

**22)** Squamule grandi poco incise, spesso con fibrille nere sul margine; su substrato acido........................................................................................................................***C. foliacea* f. *foliacea***
**22)** Squamule molte grandi ed incise, spesso con fibrille generalmente bianche (ma talvolta nere!) sul margine; su substrato basico.........................................................***C. foliacea* f. *convoluta***

**23)** Podezi con peduncolo lungo e coppe molto strette......................................................................**24**
**23)** Podezi con peduncolo corto e coppe più o meno ampie..............................................................**30**

**24)** Podezi sorediati..............................................................................................................................**25**
**24)** Podezi non sorediati.......................................................................................................................**28**

**25)** Podezi con coppe generalmente prive di proliferazioni........................................................................**26**
**25)** Podezi con coppe generalmente provviste di proliferazioni laterali...............................................**27**

**26)** Coppe molto strette all'apice di podezi molto sottili, spesso presenti anche podezi bacillari privi di coppe...................................................................................................................................***C. ochrochlora***
**26)** Coppe strette all'apice di podezi con peduncoli più o meno stretti, generalmente assenti podezi bacillari...............................................................................................................................***C. fimbriata***

**27)** Podezi generalmente squamulosi almeno alla base e poco sorediati, proliferazioni regolari generalmente brevi e dritte; P+ giallo poi arancio-rosso; acido omosekikaico presente............***C. rei***
**27)** Podezi generalmente privi di squamule e ricoperti quasi interamente di soredi, proliferazioni irregolari generalmente allungate e con andamento contorto; P+ rosso; acido omosekikaico assente.........................................................................................................................***C. subulata***

**28)** Zona basale giallastra; K+ giallo; atranorina presente......................................................***C. ecmocyna***
**28)** Zona basale non giallastra; K– o K+ brunastro; atranorina assente.................................................**29**

**29)** Zona basale scura presente, podezi robusti, generalmente semplici e raramente con strette coppe terminali...........................................................................................................................***C. macroceras***
**29)** Zona basale scura assente, podezi gracili, spesso semplici ma non infrequentemente provvisti di strette coppe terminali.........................................................................................***C. gracilis***

**30)** Podezi non sorediati.......................................................................................................................................**31**
**30)** Podezi sorediati..............................................................................................................................................**38**

**31)** Podezi con coppe generalmente provviste di molte proliferazioni..................................................**32**
**31)** Podezi con coppe generalmente provviste di poche proliferazioni o non proliferanti.............**35**

**32)** Proliferazioni laterali delle coppe dall'aspetto ramificato e terminanti a punta o con piccoli apoteci, spesso fessurate, morfologicamente simili a podezi fertili di *C. furcata*.............***C. dimorpha***
**32)** Proliferazioni non come sopra.....................................................................................................................**33**

**33)** Proliferazioni semplici, spesso alternate a squamule lungo il margine delle coppe.......................
.......................................................................................................................................................***C. prolifica***
**33)** Proliferazioni ramificate...............................................................................................................................**34**

**34)** Podezi generalmente non areolati, coppe di ampiezza variabile rispetto all'altezza del podezio, con proliferazioni ramificate o semplici spesso terminanti con apoteci, zona annerita alla base dei podezi assente...........................................................................................................***C. ramulosa***
**34)** Podezi generalmente areolati, coppe piuttosto strette rispetto all'altezza del podezio, con proliferazioni piuttosto ramificate terminanti con strette coppe, presente una zona annerita alla base dei podezi.........................................................................................................................***C. phyllophora***

**35)** Vene da rosate a brunastre distintamente visibili sulla faccia inferiore delle squamule del tallo primario.......................................................................................................................***C. cyathomorpha***
**35)** Faccia inferiore delle squamule completamente biancastra o bianco-grigiastra e priva di vene..................................................................................................................................................................**36**

**36)** Podezi muniti di placche bullate..........................................................................................***C. monomorpha***
**36)** Podezi muniti di placche piatte....................................................................................................................**37**

**37)** Squamule del tallo primario imbricate o sparse ma mai disposte a rosetta; su substrato acido o basico......................................................................................................................................***C. pyxidata***
**37)** Squamule del tallo primario distintamente disposte a rosetta; su substrato basico......................
.......................................................................................................................................................***C. pocillum***

**38)** Soredi presenti solo all'interno delle coppe, vene da rosate a brunastre distintamente visibili sulla faccia inferiore delle squamule del tallo primario..........***C. cyathomorpha***
**38)** Soredi presenti anche o solo sulla parte esterna delle coppe e sul peduncolo, vene assenti dalla faccia inferiore delle squamule..........**39**

**39)** Apoteci rosati o bruni molto chiari..........**40**
**39)** Apoteci bruni..........**41**

**40)** KC+ giallastro, P–; acido usnico e zeorina..........***C. carneola***
**40)** KC–, P+ rosso; acido fumarprotocetrarico..........***C. fimbriata***

**41)** Acido fumarprotocetrarico sempre presente come unico metabolita secondario..........**42**
**41)** Acido fumarprotocetrarico presente o assente, mai come unico metabolita secondario..........**43**

**42)** Soredi farinosi; coppe generalmente strette..........***C. fimbriata***
**42)** Soredi generalmente granulosi; coppe dall'ampiezza molto variabile..........***C. chlorophaea***

**43)** K–, C–, KC–..........**44**
**43)** Almeno una delle reazioni K, C, KC positiva..........**45**

**44)** Acido bourgeanico presente, acido grayanico assente..........***C. conista***
**44)** Acido bourgeanico assente, acido grayanico presente..........***C. grayi***

**45)** K– o K+rosso; acido meroclorofeico e acido 4-0-metilcriptoclorofeico presenti..........**46**
**45)** K+ giallo o rosso; acido meroclorofeico e acido 4-0-metilcriptoclorofeico assenti..........**47**

**46)** Acido fumarprotocetrarico presente, acido perlatolico assente..........***C. merochlorophaea***
**46)** Acido fumarprotocetrarico assente, acido perlatolico presente..........***C. perlomera***

**47)** K+ giallo poi rosso; acido criptoclorofeico presente, atranorina assente..........***C. cryptochlorophaea***
**47)** K+ giallo; acido criptoclorofeico assente, atranorina presente..........***C. humilis***

**48)** Podezi molto piccoli, poco visibili, portati su squamule molto più grandi, che formano cuscinetti..........**21**
**48)** Podezi medio-grandi rispetto alle squamule, ben visibili..........**49**

**49)** Podezi sorediati..........**50**
**49)** Podezi non sorediati..........**67**

**50)** Podezi lunghi e con coppe molto strette..........**51**
**50)** Podezi corti con coppe più o meno ampie..........**54**

**51)** Podezi spesso provvisti di proliferazioni laterali dal bordo delle coppe o di ramificazioni verso l'apice..........**27**
**51)** Podezi semplici o con rare proliferazioni laterali dal bordo delle coppe..........**52**

**52)** Coppe molto o piuttosto strette, soredi generalmente farinosi..........**53**
**52)** Coppe più o meno strette (molto variabili), soredi generalmente granulosi..........***C. chlorophaea***

**53)** Podezi giallastri o giallastro-verdastri, spesso fessurati; KC+ giallo, P–; acidi usnico e squamatico..........***C. sulphurina***
**53)** Podezi verdastri o grigio-verdastri; KC–, P+ rosso; acido fumarprotocetrarico..........**26**

**54)** KC+ giallo o giallastro; zeorina presente..........**55**
**54)** KC–; zeorina assente..........**58**

**55)** Acido usnico assente, acido barbatico talvolta presente........................................................***C. carneola***
**55)** Acido usnico presente, acido barbatico sempre assente.................................................................................**56**

**56)** Podezi talvolta fessurati, storti, coppe molto strette con margine intero o debolmente denticolato.................................................................................................................................................***C. deformis***
**56)** Podezi mai fessurati, coppe generalmente piuttosto ampie.........................................................................**57**

**57)** Base dei podezi non squamulosa, soredi farinosi, margine delle coppe spesso dentellato e generalmente regolare.......................................................................................................................................***C. carneola***
**57)** Base dei podezi spesso squamulosa, soredi da farinosi a granulosi, granulosità presenti sui podezi, margine delle coppe spesso irregolare....................................................................................***C. pleurota***

**58)** P– o P+ arancio; acido fumarprotocetrarico assente...................................................................................**59**
**58)** P+ rosso; acido fumarprotocetrarico presente..............................................................................................**61**

**59)** Macchie arancio talvolta presenti alla base delle squamule del tallo primario; K+ giallo, P+ arancio; acido tamnolico presente..................................................................................................................**13**
**59)** Macchie arancio mai presenti alla base delle squamule del tallo primario; K– o K+ rossastro, P–; acido tamnolico assente.................................................................................................................................**60**

**60)** K–; acido grayanico presente, acido perlatolico assente.................................................................***C. grayi***
**60)** K– o K+ rossastro; acido grayanico assente, acido perlatolico presente....................***C. perlomera***

**61)** Acido fumarprotocetrarico come unica sostanza presente...........................................................................**62**
**61)** Presenti anche altre sostanze oltre all'acido fumarprotocetrarico..........................................................**65**

**62)** Soredi generalmente presenti su gran parte della superficie dei podezi.......................................**42**
**62)** Soredi generalmente presenti solo su alcune parti dei podezi.................................................................**63**

**63)** Soredi presenti solo all'interno delle coppe, vene da rosate a brunastre distintamente visibili sulla faccia inferiore delle squamule del tallo primario.................................................***C. cyathomorpha***
**63)** Soredi presenti anche o solo sulla parte esterna delle coppe e sul peduncolo, vene assenti dalla faccia inferiore delle squamule.....................................................................................................................**64**

**64)** Podezi estremamente variabili, non fillopodiati, provvisti di granuli, talvolta sparsamente squamulosi, soredi granulosi rari, coppe frequenti, con molte proliferazioni che conferiscono spesso un aspetto ramificato; generalmente sul terreno, raramente su legno morto....***C. ramulosa***
**64)** Podezi fillopodiati, parzialmente decorticati, con cortex che si solleva formando squamule o granuli, soredi piuttosto rari, coppe e ramificazioni rare; generalmente su legno morto....................................................................................................................................................***C. pseudopityrea***

**65)** K–..................................................................................................................................................................**66**
**65)** K+ giallo o giallo poi rosso.............................................................................................................................**67**

**66)** Acido grayanico................................................................................................................................***C. grayi***
**66)** Acidi meroclorofeico e 4-0-metilcriptoclorofeico...............................................***C. merochlorophaea***

**67)** K+ giallo; atranorina.......................................................................................................................***C. humilis***
**67)** K+ giallo poi rosso; acido cryptoclorofeico...........................................................***C. cryptochlorophaea***

**68)** Coppe perforate al centro.................................................................................................................................**17**
**68)** Coppe non perforate...........................................................................................................................................**69**

**69)** Podezi lunghi e con coppe molto strette.......................................................................................................**70**
**69)** Podezi corti con coppe più o meno ampie......................................................................................................**71**

**70)** P+ giallo poi arancio o rosso; acido fumarprotocetrarico assente, acidi homosekikaico e/o sekikaico presenti........***C. rei***
**70)** P+ rosso; acido fumarprotocetrarico presente, acidi omosekikaico e/o sekikaico assenti.....**28**

**71)** KC+ giallo, P–; acido usnico presente, acido fumarprotocetrarico assente........**14**
**71)** KC–, P+ rosso; acido usnico assente, acido fumarprotocetrarico presente........**72**

**72)** Coppe abbastanza svasate, regolari........**73**
**72)** Coppe più o meno svasate, generalmente irregolari........**74**

**73)** Proliferazioni laterali delle coppe dall'aspetto ramificato e terminanti a punta, spesso fessurate, morfologicamente simili a podezi fertili di *C. furcata*........***C. dimorpha***
**73)** Proliferazioni non come sopra........**35**

**74)** Podezi generalmente areolati e non granulosi, con proliferazioni piuttosto ramificate terminanti con strette coppe, presente una zona annerita alla base dei podezi.........***C. phyllophora***
**74)** Podezi generalmente non areolati ma talvolta granulosi, con proliferazioni ramificate o semplici spesso terminanti con apoteci, zona annerita alla base dei podezi assente........**75**

**75)** Podezi corticati e non granulosi, con proliferazioni semplici, spesso alternate a squamule lungo il margine delle coppe........***C. prolifica***
**75)** Podezi talvolta decorticati e spesso granulosi, con proliferazioni semplici o ramificate non alternate a squamule lungo i margini delle coppe........**64**

### Sottochiave IV

Podezi semplici, bacillari, clavati o di forma irregolare, in alcuni casi poco ramificati verso l'apice, ma prevalentemente non sciferi (eventualmente presenti solamente pochi podezi provvisti di coppe molto strette tra molti podezi non sciferi); tallo primario presente o assente.

**1)** Podezi provvisti di apoteci o picnidi........**2**
**1)** Podezi privi sia di apoteci sia di picnidi........**39**

**2)** Apoteci rossi........**3**
**2)** Apoteci bruni o rosati........**14**

**3)** Podezi sorediati........**4**
**3)** Podezi non sorediati........**11**

**4)** Soredi granulosi........***C. floerkeana***
**4)** Soredi farinosi........**5**

**5)** Podezi incospicui rispetto alle squamule del tallo primario........***C. incrassata***
**5)** Podezi cospicui rispetto alle squamule del tallo primario........**6**

**6)** Squamule del tallo primario sorediate sulla faccia inferiore........**7**
**6)** Squamule del tallo primario non sorediate o assenti........**8**

**7)** Squamule del tallo primario piuttosto grandi, con margine intero spesso ripiegato verso l'alto, molto sorediate sulla faccia inferiore........***C. digitata***
**7)** Squamule del tallo primario di dimensioni medie, con margine variamente inciso, generalmente poco o non sorediate sulla faccia inferiore........***C. polydactyla***

**8)** Podezi giallastri o giallo-verdastri, talvolta fessurati; K–, KC+ giallo o giallastro, P–; acido

usnico presente, acido tamnolico assente.......................................................................................................**9**
**8)** Podezi grigiastri, verde-grigiastri o glaucescenti, mai fessurati; K+ giallo, KC–, P+ arancio; acido usnico assente, acido tamnolico presente...................................................................................................**10**

**9)** Podezi raramente privi di coppe e raramente fessurati; zeorina presente......................***C. deformis***
**9)** Podezi generalmente privi di coppe e visibilmente fessurati, fino ad essere in alcuni casi lacerati per quasi tutta la loro lunghezza; zeorina assente.....................................................***C. sulphurina***

**10)** Podezi generalmente squamulosi almeno nella parte basale, generalmente non tutti bacillari o clavati ma anche almeno con coppe strette, squamule spesso macchiate di arancio alla base; acido tamnolico come unica sostanza presente........................................................................***C. polydactyla***
**10)** Podezi generalmente non squamulosi o poco squamulosi solo alla base, tutti bacillari o clavati, squamule senza macchie arancio; spesso presenti anche altre sostanze oltre all'acido tamnolico.......................................................................................................................................***C. macilenta***

**11)** Podezi incospicui rispetto alle squamule del tallo primario, non squamulosi...................................
.........................................................................................................................................................***C. incrassata***
**11)** Podezi cospicui rispetto alle squamule, parzialmente o molto squamulosi..................................**12**

**12)** Podezi non squamulosi, granuloso-verrucosi, spesso tozzi e contorti........................***C. incrassata***
**12)** Podezi parzialmente o molto squamulosi, generalmente snelli e piuttosto dritti.......................**13**

**13)** Podezi talvolta squamulosi soprattutto nella parte basale, alti fino a 3-4 cm, talvolta irregolarmente ramificati verso l'apice; acidi barbatico e/o tamnolico............................***C. floerkeana***
**13)** Podezi completamente squamulosi, alti anche fino a 5 cm, generalmente non ramificati; acidi usnico e squamatico.......................................................................................................................***C. bellidiflora***

**14)** Apoteci rosati, podezi non sorediati; acidi usnico e barbatico..........................................***C. botrytes***
**14)** Apoteci bruni, se rosati allora non contemporaneamente con podezi non sorediati e presenza di acidi usnico e barbatico..................................................................................................................**15**

**15)** Apoteci sorretti da cortissimi peduncoli, veri podezi assenti.......................................***C. caespiticia***
**15)** Veri podezi presenti.........................................................................................................................**16**

**16)** Podezi sorediati..............................................................................................................................**17**
**16)** Podezi non sorediati.......................................................................................................................**27**

**17)** Fessurazioni longitudinali presenti sul lato dei podezi; acido squamatico presente......................
.................................................................................................................................................................***C. glauca***
**17)** Fessurazioni longitudinali assenti; acido squamatico assente.......................................................**18**

**18)** Soredi granulosi, podezi generalmente squamulosi almeno in parte...........................................**19**
**18)** Soredi farinosi, podezi generalmente non squamulosi o con squamule limitate alla parte basale.................................................................................................................................................**20**

**19)** K–, P–; acido perlatolico...........................................................................................***C. decorticata***
**19)** K+ giallo poi rosso, P+ giallo; acido norstictico e atranorina........................................***C. acuminata***

**20)** KC+ giallo........................................................................................................................................**21**
**20)** KC–..................................................................................................................................................**22**

**21)** Podezi alti fino a 3 cm, mai ramificati, base dei podezi spesso parzialmente decorticata; acido usnico presente, zeorina assente; generalmente su scorza o legno morto......***C. bacilliformis***
**21)** Podezi alti fino a 8 cm, talvolta ramificati verso l'apice; acido usnico sempre assente, zeorina talvolta presente; generalmente sul terreno..................................................................***C. cyanipes***

**22)** Podezi percorsi da lacerazioni dalle quali fuoriesce la medulla rossa, squamule del tallo primario spesso macchiate di arancione o rossastro; P–..........***C. norvegica***
**22)** Podezi privi di lacerazioni, medulla non rossa, squamule del tallo primario prive di macchie arancioni o rossastre; P+ giallo, arancio o rosso..........**23**

**23)** P+ giallo poi arancio o rosso; acidi omosekikaico e/o sekikaico presenti, acido fumarprotocetrarico assente..........***C. rei***
**23)** P+ rosso; acidi omosekikaico e/o sekikaico assenti, acido fumarprotocetrarico presente..........**24**

**24)** Podezi alti fino a 3 cm, parzialmente decorticati, con *cortex* che si solleva formando squamule o granuli, soredi rari..........***C. pseudopityrea***
**24)** Podezi spesso più alti di 3 cm, non come sopra..........**25**

**25)** Parte basale dei podezi corticata o areolata, soredi limitati alla parte più alta..........***C. cornuta***
**25)** Soredi non limitati alla parte più alta dei podezi..........**26**

**26)** Podezi quasi completamente sorediati, generalmente solo bacillari..........***C. coniocraea***
**26)** Podezi privi di soredi almeno nel primo terzo, sia bacillari sia con coppe terminali molto strette..........***C. ochrochlora***

**27)** Podezi ricoperti almeno in parte di squamule..........**28**
**27)** Podezi completamente privi di squamule..........**35**

**28)** Podezi completamente squamulosi..........**29**
**28)** Squamule limitate alla parte basale..........**32**

**29)** Squamule peltate; P+ giallo; acido psoromico presente..........***C. macrophylla***
**29)** Squamule non peltate; P– o P+ giallo o giallo poi arancio o rosso; acido psoromico assente..........**30**

**30)** P+ giallo poi arancio o rosso; acido omosekikaico e/o sekikaico..........***C. rei***
**30)** P– o P+ giallo-arancio; acido omosekikaico e/o sekikaico assente..........(*C. squamosa*) **31**

**31)** K–, P–; acido squamatico..........***C. squamosa* var. *squamosa***
**31)** K+ giallo, P+ giallo-arancio; acido barbatico, acido tamnolico..........
..........***C. squamosa* var. *subsquamosa***

**32)** P+ giallo poi arancio o rosso; acido omosekikaico e/o sekikaico..........***C. rei***
**32)** P+ rosso; acido fumarprotocetrarico..........**33**

**33)** Zona basale giallastra; K+ giallo; atranorina presente..........***C. ecmocyna***
**33)** Zona basale non giallastra; K– o K+ brunastro; atranorina assente..........**34**

**34)** Zona basale scura presente, podezi robusti, generalmente semplici e raramente con strette coppe terminali..........***C. macroceras***
**34)** Zona basale scura assente, podezi gracili, spesso semplici ma non infrequentemente provvisti di strette coppe terminali..........***C. gracilis***

**35)** Podezi parzialmente decorticati, con *cortex* che si solleva formando squamule o granuli, soredi rari; generalmente su legno morto..........***C. pseudopityrea***
**35)** Podezi fessurati o granulosi, ma generalmente non decorticati; generalmente sul terreno..........**36**

**36)** Podezi semplici, capitati, talvolta con apoteci corimbosi se ramificati, squamule del tallo primario piccole e tappezzanti; K– o K+ giallo; acido norstictico solo occasionalmente presente..........**37**
**36)** Podezi semplici con apoteci larghi quanto il podezio, talvolta poco ramificati e con apoteci

separati all'apice delle ramificazioni, squamule del tallo primario cospicue e spesso formanti cuscinetti; K+ giallo poi lentamente rosso; acido norstictico regolarmente presente........................**38**

**37)** Podezi generalmente non fessurati e talvolta granulosi, apoteci molto più larghi del podezio, squamule del tallo primario adese al substrato, tondeggianti o a forma di orecchio, con margine intero, da verde-giallastre (da umide) a grigio-verdastre (da secche); K–; atranorina assente............................................................................................................................................***C. peziziformis***
**37)** Podezi spesso fessurati e/o granulosi, apoteci di poco più larghi del podezio, squamule del tallo primario erette, con margine inciso, da glaucescenti (da umide) a glauco-grigiastre (da secche); K+giallo; atranorina presente........................................................................................***C. cariosa***

**38)** Faccia inferiore delle squamule del tallo primario rossastra o brunastra; atranorina assente.........................................................................................................................................***C. polycarpoides***
**38)** Faccia inferiore delle squamule del tallo primario bianca o biancastra; atranorina presente.........................................................................................................................................***C. symphycarpa***

**39)** Podezi sorediati.........................................................................................................................**40**
**39)** Podezi non sorediati.................................................................................................................**52**

**40)** KC+ giallo o giallastro; acido usnico presente.............................................................................**41**
**40)** KC–; acido usnico assente..........................................................................................................**44**

**41)** Acido usnico come unica sostanza presente........................................................................***C. sulphurina***
**41)** Presenti anche altre sostanze oltre all'acido usnico.......................................................................**42**

**42)** Acido barbatico presente............................................................................................***C. bacilliformis***
**42)** Acido barbatico assente..............................................................................................................**43**

**43)** Podezi generalmente privi di coppe e visibilmente fessurati, fino ad essere in alcuni casi lacerati per quasi tutta la loro lunghezza; acido squamatico presente, zeorina assente.........................................................................................................................................***C. sulphurina***
**43)** Podezi raramente privi di coppe e raramente fessurati; acido squamatico assente, zeorina presente..................................................................................................................................***C. deformis***

**44)** Podezi con evidenti fessurazioni longitudinali..............................................................................**45**
**44)** Podezi privi di fessurazioni........................................................................................................**46**

**45)** Presente una lunga fessurazione che percorre quasi tutto il podezio, squamule del tallo primario non macchiate di arancio o rossastro..........................................................................***C. glauca***
**45)** Presenti numerose fessurazioni più brevi dalle quali si intravede la medulla rossa, squamule del tallo primario spesso macchiate di arancio o rossastro.....................................................***C. norvegica***

**46)** Soredi granulosi.........................................................................................................................**19**
**46)** Soredi farinosi...........................................................................................................................**47**

**47)** P+ rosso; acido fumarprotocetrarico presente...............................................................................**24**
**47)** P–, P+ giallo, arancio o giallo poi rosso; acido fumarprotocetrarico assente.....................................**48**

**48)** Podezi di colore verde-grigiastro o grigiastro glaucescente; acido tamnolico presente; generalmente su scorza o legno morto...................................................................................................**49**
**48)** Podezi di colore giallastro, verdastro o grigiastro non glaucescente; acido tamnolico assente, presenti altre sostanze; generalmente sul terreno.................................................................................**51**

**49)** Podezi tutti bacillari o clavati, squamule del tallo primario prive di macchie arancioni; spesso presenti altre sostanze oltre all'acido tamnolico.........................................................................***C. macilenta***
**49)** Podezi generalmente non tutti bacillari o clavati ma anche almeno con coppe strette,

squamule del tallo primario spesso macchiate di arancio alla base; acido tamnolico presente come unica sostanza........................................................................................................................................... **50**

**50)** Squamule del tallo primario grandi e sorediate sulla faccia inferiore, che è spesso visibile a causa dei margini ripiegati verso l'alto, margine piuttosto intero e arrotondato................***C. digitata***
**50)** Squamule del tallo primario più piccole e non o poco sorediate, margine inciso.............................
..............................................................................................................................................***C. polydactyla***

**51)** Podezi di colore giallastro, giallo-verdastro o grigiastro chiaro, generalmente non squamulosi; KC+ giallo, P–; acido barbatico.....................................................................................***C. cyanipes***
**51)** Podezi di colore grigiastro o grigio-verdastro, spesso squamulosi almeno alla base; KC–, P+ giallo poi arancio o rosso; acido omosekikaico e/o acido sekikaico....................................................***C. rei***

**52)** Podezi squamulosi per tutta la loro lunghezza o quasi.......................................................................... **53**
**52)** Podezi non squamulosi o squamulosi solo nella parte basale.............................................................. **56**

**53)** Squamule peltate; P+ giallo; acido psoromico presente.............................................***C. macrophylla***
**53)** Squamule non peltate; P– o P+ giallo o giallo poi arancio o rosso; acido psoromico assente................................................................................................................................................................... **54**

**54)** P+ giallo poi arancio o rosso; acido omosekikaico e/o sekikaico presenti...............................***C. rei***
**54)** P– o P+ giallo-arancio; acido omosekikaico e/o sekikaico assente................................................... **55**

**55)** KC+ giallo; acido usnico presente..............................................................................................***C. bellidiflora***
**55)** KC–; acido usnico assente...........................................................................................................(*C. squamosa*) **31**

**56)** P+ rosso; acido fumarprotocetrarico presente.......................................................................................... **57**
**56)** P–, P+ giallo o P+ arancio; acido fumarprotocetrarico assente............................................................ **58**

**57)** Podezi alti fino a 3 cm, parzialmente decorticati, con *cortex* che si solleva formando squamule o granuli; generalmente su legno morto..........................................................***C. pseudopityrea***
**57)** Podezi più alti di 3 cm (fino a 10-15 cm), generalmente non decorticati nemmeno parzialmente; generalmente sul terreno................................................................................................................. **33**

**58)** P+ giallo poi arancio o rosso; acido omosekikaico e/o sekikaico presenti...............................***C. rei***
**58)** P– o P+ arancio; acido omosekikaico e/o sekikaico assenti.................................................................. **59**

**59)** Podezi areolati, non squamulosi, verdastro-giallastri; acido usnico presente............***C. botrytes***
**59)** Podezi generalmente squamulosi, non areolati, grigiastri; acido usnico assente.............................
..............................................................................................................................................***C. floerkeana***

# Appendix III

## Iconography of the Cladonias of Italy

# Iconografia delle Cladonie d'Italia

Mariagrazia Valcuvia-Passadore, Gabriele Gheza
Tavole di Dario Passadore

## Abstract

The book describes the eighty taxa of *Cladonia* – a very interesting but difficult lichen genus – recorded in Italy so far.

*Cladonia* is a cosmopolitan genus spread from polar to tropical zones. Most of the species prefer humid situations, but some of them also live in semi-arid areas, but generally avoiding desert areas. These lichens grow mainly on soil, but also on wood and bark, over bryophytes and mossy rocks.

Cladonias provide very important ecosystem services for man and environment and they can give a great deal of more general information on the other lichens and on the area where they live.

The lichens in the genus *Cladonia* have a double thallus: the primary thallus, disappearing or persistent, is crustose, squamulose or foliose, while the secondary thallus consists of fruticose structures called podetia, which can have very different forms: spikes, clubs, cups, shrubs.

Cladonias reproduce asexually – by thallus fragmentation or by vegetative propagules, e.g. blastidia, schizidia, soredia, or by conidia produced in pycnidia at the tips of the podetia or on the upper surface of the primary squamules – or sexually – by spores produced in lecideine apotecia generally located at the apices of the podetia.

The great morphological and often also chemical variability in many species can cause troubles in their identification. Morphological approach is often unsatisfactory and the analysis of chemical characters is very useful and often essential in this genus. Sometimes the chemical reagents usually used in Lichenology are sufficient, sometimes more specialized analyses are required, such as the thin-layer chromatography (TLC).

In this work we only give an introductory key which divides Italian Cladonias into six groups. The Italian *Cladonia* taxa are presented in forms reported alphabetically within each group.

For each taxon the following data – mainly inferred by literature, but in part also by the authors' personal experience – are provided in a form accompanied by a colour plate:

- name, basionym and eventual synonyms;
- morphology related to primary thallus, secondary thallus (podetia), apothecia, pycnidia;
- main differences from similar species;
- chemistry, i.e. reactions to spot-tests and presence of secondary compounds;
- ecological notes about reproductive strategy, substrates mainly colonized by the taxon, habitat, lichen communities where the taxon occurs more frequently;
- occurrence in administrative regions of Italy, altitudinal distribution and conservation status in Italy;
- distribution in the latitudinal zones of Europe;
- collecting site of the specimen drawn in the corresponding plate;
- literature records showing pictures of the taxon;
- colour plate of the taxon.

The book presents sixty-five plates concerning the most common Italian taxa of *Cladonia* drawn with tempera on black cardboard from specimens provided by Professor Pier Luigi Nimis (University of Trieste).

The text is extremely accurate from the scientific point of view, but it is written in a simple and educational manner, being suitable for both expert lichenologists and people interested about nature lacking of specific lichenological studies.

The book is a good example of collaboration between the artistic and the scientific world.

PIME Editrice, Pavia, Dicembre 2017, 200 pp.

# ICONOGRAFIA DELLE CLADONIE D'ITALIA

MARIAGRAZIA VALCUVIA PASSADORE

GABRIELE GHEZA

TAVOLE DI
DARIO PASSADORE

# Appendix IV

## List of the species mentioned in the thesis

## Vascular plants

Nomenclature follows Tison & de Foucault (2014).

*Achillea millefolium* L.; *Achillea tomentosa* L.; *Aegylops cylindrica* Host; *Aegilops geniculata* Roth.; *Agrostis capillaris* L.; *Agrostis stolonifera* L.; *Ailanthus altissima* (Mill.) Swingle; *Aira caryophyllea* L.; *Aira* sp.; *Ajuga chamaepytis* (L.) Schreb.; *Allium vineale* L.; *Allium sphaerocephalon* L.; *Allium* sp.; *Alyssum alyssoides* (L.) L.; *Ambrosia artemisiifolia* L.; *Amorpha fruticosa* L.; *Anarrhinium bellidifolium* (L.) Willd.; *Anchusa officinalis* L.; *Anchusa* sp.; *Anisantha sterilis* (L.) Nevski; *Anisantha tectorum* (L.) Nevski; *Anthoxanthum odoratum* L.; *Aphanes arvensis* L.; *Arabidopsis thaliana* (L.) Heynh.; *Arabis glabra* (L.) Bernh.; *Arenaria serpyllifolia* L.; *Armeria arenaria* (Pers.) Schult. in Roem. & Schult.; *Arrhenatherum elatius* (L.) P.Beauv. ex J. & C. Presl; *Artemisia alba* Turra; *Artemisia campestris* L.; *Artemisia vulgaris* L.; *Artemisia* sp.; *Asperula cynanchica* L.; *Asperula* sp.; *Avena barbata* Potter; *Biscutella laevigata* L.; *Blackstonia perfoliata* (L.) Huds. (conservation value); *Bombycilaena erecta* (L.) Smoljan.; *Botriochlora ischaemum* (L.) Keng; *Bromopsis erecta* (Huds.) Fourr.; *Bromus hordeaceus* L.; *Bromus squarrosus* L.; *Bupleurum baldense* Turra; *Calluna vulgaris* (L.) Hull; *Carduus nutan*s L.; *Carduus pycnocephalus* L.; *Carex caryophyllea* Latourr.; *Carex contigua* Hoppe; *Carex* sp.; *Catapodium rigidum* (L.) C.E.Hubb.; *Centaurea deusta* Ten.; *Centaurea stoebe* L.; *Centaurea* sp.; *Centaurium pulchellum* (Swartz) Druce; *Centaurium erythraea* Rafn; *Cerastium brachypetalum* Desp. ex Pers.; *Cerastium glomeratum* Thuill.; *Cerastium glutinosum* Fr.; *Cerastium pumilum* Curtis; *Cerastium semidecandrum* L.; *Cerastium* sp.; *Chenopodium botrys* L.; *Chondrilla juncea* L.; *Cirsium vulgare* (Savi) Ten.; *Cirsium* sp.; *Clematis vitalba* L.; *Clinopodium acinos* (L.) Kuntze; *Clinopodium nepeta* (L.) Kuntze; *Convolvolus arvensis* L.; *Corylus avellana* L.; *Corynephorus canescens* (L.) P.Beauv.; *Crataegus monogyna* Jacq.; *Crepis biennis* L.; *Crepis vesicaria* L.; *Cruciata pedemontana* (Bellardi) Ehrend.; *Crupina vulgaris* Cass.; *Chrysopogon gryllus* (L.) Trin.; *Cuscuta epithymum* (L.) L.; *Cynodon dactylon* (L.) Pers.; *Cytisus nigricans* L.; *Cytisus scoparius* (L.) Link; *Dactylis glomerata* L.; *Dianthus carthusianorum* L.; *Dianthus seguieri* Vill.; *Digitaria sanguinalis* (L.) Scop.; *Diplotaxis tenuifolia* (L.) DC.; *Echinochloa crus-galli* (L.) P.Beauv.; *Echium vulgare* L.; *Elytrigia repens* (L.) Beauv.; *Epilobium dodonaei* (Vill.) Schur ex Fuss; *Eragrostis curvula* (Schrad.) Nees; *Erigeron* *annuus* (L.) Desf.; *Erigeron canadensis* L.; *Erodium cicutarium* (L.) L'Hér.; *Ervilia hirsuta* (L.) Opiz; *Eryngium campestre* L.; *Erysimum rhaeticum* (Schleich.) DC.; *Euonymus europaeus* L.; *Euphorbia cyparissias* L.; *Euphorbia falcata* L.; *Euphorbia helioscopia* L.; *Euphorbia maculata* L.; *Euphorbia* sp.; *Fallopia* sp.; *Festuca brevipila* Tracey; *Festuca filiformis* Pourr.; *Festuca* sp.; *Filago arvensis* L.; *Filago germanica* (L.) Huds.; *Fraxinus ornus* L.; *Fumana procumbens* (Dunal) Gren. & Godr.; *Galium divaricatum* Lam.; *Galium lucidum* All.; *Galium parisiense* L.; *Galium* sp.; *Genista tinctoria* L.; *Geranium columbinum* L.; *Geranium molle* L.; *Globularia bisnagarica* L.; *Gnaphalium uliginosum* L.; *Helianthemum nummularium* (L.) Mill.; *Herniaria glabra* L.; *Hippocrepis comosa* L.; *Hylotelephium maximum* (L.) Holub; *Hypericum perforatum* L.; *Hypochoeris glabra* L.; *Hypochoeris radicata* L.; *Jasione montana* L.; *Juncus bufonius* L.; *Juncus tenuis* Willd.; *Koeleria macrantha* (Ledeb.) Spreng.; *Koeleria pyramidata* (Lam.) Domin; *Koeleria* sp.; *Lactuca perennis* L.; *Lactuca serriola* L.; *Latyrus sphaericus* Retz.; *Leontodon crispus* Vill.; *Logfia minima* (Sm.) Pers.; *Lepidium* sp.; *Leucanthemum vulgare* (Vaill.) Lam.; *Ligustrum vulgare* L.; *Linaria pelisseriana* (L.) Mill.; *Linaria vulgaris* Mill.; *Linum bienne* Mill.; *Lotus corniculatus* L.; *Luzula campestris* (L.) DC.; *Luzula multiflora* (Ehrh.) Lej.; *Luzula* sp.; *Lysimachia arvensis* (L.) U.Manns & Anderb.; *Medicago lupulina* L.; *Medicago minima* (L.) Bartal; *Melica ciliata* L.; *Melilotus albus* Medik.; *Micropyrum tenellum* (L.) Link; *Minuartia hybrida* (Vill.) Shishkoff; *Molinia arundinacea* Schrank; *Mollugo verticillata* L.; *Muscari comosum* (L.) Mill.; *Myosotis arvensis* (L.) Hill; *Myosotis ramosissima* Rochel ex Schult.; *Myosotis* sp.; *Oenothera* sp.; *Ononis natrix* L.; *Opuntia humifusa* (Raf.) Raf.; *Oreoselinum nigrum* Delarbre; *Origanum vulgare* L.; *Orobanche* sp.; *Oxalis dillenii* Jacq.; *Oxalis fontana* Bunge; *Panichum dichotomiflorum* Michx.; *Parentucellia latifolia* (L.) Caruel; *Petrorhagia prolifera* (L.) P.W.Ball & Heywood; *Petrorhagia saxifraga* (L.) Link; *Pilosella officinarum* Vaill.; *Pilosella piloselloides* (Vill.) Sojak; *Pinus sylvestris* L.; *Plantago holosteum* Scop.; *Plantago lanceolata* L.; *Plantago sempervirens* Crantz; *Poa annua* L.; *Poa bulbosa* L.; *Poa pratensis* L.; *Poa* sp.; *Polygonatum odoratum* (Mill.) Druce; *Polygonatum* sp.; *Polygonum lapatifolium* L.; *Populus canadensis* Moench; *Populus x hybrida* Rchb.; *Populus nigra* L.; *Portulaca oleracea* L.; *Potentilla argentea* L.; *Potentilla puberula* Krašan; *Potentilla recta* L.; *Poterium sanguisorba* L.; *Prunus serotina* Ehrh.; *Prunus padus* L.; *Prunus spinosa* L.; *Psilurus incurvus* (Gouan) Sch. & Th.;

*Pteridium aquilinum* (L.) Kuhn; *Quercus robur* L.; *Reseda lutea* L.; *Reynoutria japonica* Houtt; *Rhamnus cathartica* L.; *Robinia pseudoacacia* L.; *Rosa canina* L.; *Rosa* sp.; *Rostraria cristata* (L.) Tzvelev; *Rubus caesius* L.; *Rubus* cf. *ulmifolius* Schott; *Rubus* sp.; *Rumex acetosella* L.; *Sagina procumbens* L.; *Sagina* sp.; *Salvia pratensis* L.; *Saponaria ocymoides* L.; *Saponaria officinalis* L.; *Satureja montana* L.; *Scabiosa columbaria* L.; *Scabiosa* sp.; *Scleranthus annuus* L.; *Scleranthus perennis* L.; *Scrophularia canina* L.; *Sedum acre* L.; *Sedum rubens* L.; *Sedum rupestre* L.; *Sedum sexangulare* L.; *Senecio inaequidens* DC.; *Senecio vulgaris* L.; *Sherardia arvensis* L.; *Silene italica* (L.) Pers.; *Silene nutans* L.; *Silene otites* (L.) Wibel; *Silene vulgaris* (Moench) Garcke; *Solidago gigantea* Aiton; *Sonchus asper* (L.) Hill; *Sorghum halepense* (L.) Pers.; *Stachys recta* L.; *Teesdalia nudicaulis* (L.) R.Br.; *Teucrium chamaedrys* L.; *Teucrium montanum* L.; *Thymus longicaulis* C.Presl; *Thymus pulegioides* L.; *Thymus vulgaris* L.; *Thymus* sp.; *Tillaea muscosa* L.; *Trifolium arvense* L.; *Trifolium campestre* Schreb.; *Trifolium nigrescens* Viv.; *Trifolium scabrum* L.; *Trifolium* sp.; *Trigonella officinalis* (L.) Coulote & Rabaute; *Tuberaria guttata* (L.) Fourr.; *Ulmus minor* Mill.; *Valerianella locusta* (L.) Laterr.; *Verbascum lychnitis* L.; *Verbascum pulverulentum* Vill.; *Verbascum* sp.; *Veronica arvensis* L.; *Veronica persica* Poir.; *Veronica* sp.; *Vicia cracca* L.; *Vicia lutea* L.; *Vicia sativa* L.; *Vicia* sp.; *Viola arvensis* Murray; *Vulpia ciliata* Dumort.; *Vulpia myurus* (L.) C.C.Gmel.

## Bryophytes

Nomenclature follows CORTINI PEDROTTI (2001, 2006).

*Atrichum angustatum* (Brid.) Bruch & Schimp.; *Brachythecium albicans* (Hedw.) Schimp.; *Calypogeia arguta* Nees & Mont. ex Nees; *Campylopus introflexus* (Hedw.) Brid.; *Ceratodon purpureus* (Hedw.) Brid.; *Didymodon fallax* (Hedw.) R.H.Zander; *Dicranum scoparium* Hedw.; *Ditrichum heteromallum* (Hedw.) E.Britton; *Eurhynchium hians* (Hedw.) Sande Lac.; *Hypnum cupressiforme* Hedw.; *Hypnum jutlandicum* Holmen & E.Warncke; *Leucobryum glaucum* (Hedw.) Ångstr.; *Polytrichastrum formosum* (Hedw.) G.L.Sm.; *Polytrichum piliferum* Hedw.; *Pseudocrossidium hornsuchianum* (Schultz) R.H.Zander; *Racomitrium canescens* (Hedw.) Brid.; *Rhynchostegium megapolitanum* (Blandow ex F.Weber & D.Mohr) Schimp.; *Riccia ciliifera* Link ex Lindenb.; *Sphagnum compactum* Lam. & DC.; *Sphagnum papillosum* Lindb.; *Syntrichia ruralis* (Hedw.) F.Weber & D.Mohr.; *Tortella tortuosa* (Hedw.) Limpr.

## Lichens

Nomenclature follows Nimis (2016).

*Blennothallia crispa* (Huds.) Otálora, P.M.Jørg. & Wedin; *Cetraria aculeata* (Schreb.) Fr.; *Cladonia caespiticia* (Pers.) Flörke; *Cladonia cariosa* (Ach.) Spreng.; *Cladonia cervicornis* (Ach.) Flot.; *Cladonia chlorophaea* (Sommerf.) Spreng.; *Cladonia coccifera* (L.) Willd.; *Cladonia coniocraea* (Flörke) Spreng.; *Cladonia conista* (Nyl.) Robbins; *Cladonia convoluta* (Lam.) Anders; *Cladonia fimbriata* (L.) Fr.; *Cladonia foliacea* (Huds.) Willd.; *Cladonia furcata* (Huds.) Schrad.; *Cladonia humilis* (With.) J.R.Laundon; *Cladonia peziziformis* (With.) J.R.Laundon; *Cladonia polycarpoides* Nyl.; *Cladonia portentosa* (Dufour) Coem.; *Cladonia pulvinata* (Sandst) van Herk & Aptroot; *Cladonia pyxidata* (L.) Hoffm.; *Cladonia rangiformis* Hoffm.; *Cladonia rei* Schaer.; *Cladonia squamosa* Hoffm.; *Cladonia strepsilis* (Ach.) Grognot; *Cladonia symphycarpa* (Flörke) Fr.; *Cladonia uncialis* (L.) F.H.Wigg.; *Cladonia verticillata* (Hoffm.) Schaer.; *Enchylium tenax* (Sw.) Gray; *Gyalolechia fulgens* (Sw.) Søchting; Frödén & Arup; *Placidium squamulosum* (Ach.) Breuss; *Psora decipiens* (Hedw.) Hoffm.; *Pycnothelia papillaria* Dufour; *Scytinium schraderi* (Ach.) Otálora, P.M.Jørg. & Wedin; *Stereocaulon condensatum* Hoffm.; *Toninia sedifolia* (Scop.) Timdal.

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# Affiliations of coauthors

Gabriele Gheza, Silvia Assini, Matteo Barcella
Section of Landscape Ecology, Department of Earth and Environmental Sciences, University of Pavia.
Via S. Epifanio 14, I-27100 Pavia, Italy.
gabri.gheza@gmail.com
silviapaola.assini@unipv.it
matteo.barcella@unipv.it

Juri Nascimbene, Chiara Lelli
Department of Biological, Geological and Environmental Sciences, University of Bologna.
Via Irnerio 42, I-40126 Bologna, Italy.
juri.nascimbene@unibo.it
chiara.lelli6@gmail.com

Lorenzo Marini
Department of Agronomy, Food, Natural Resources, Animals and Environment, University of Padova.
Viale dell'Università 16, I-35020 Legnaro (Padova), Italy.
lorenzo.marini@unipd.it

Helmut Mayrhofer
Division of Plant Sciences, Institute of Biology, Karl-Franzens University of Graz.
Holteigasse 6, A-8010 Graz, Austria.
helmut.mayrhofer@uni-graz.at

Mariagrazia Valcuvia Passadore, Dario Passadore
dario.grazia@libero.it

# List of publications

## Scientific articles on peer-reviewed journals related to this thesis

1. **Gheza G.**, Nascimbene J., Assini S. Trap and release: are terricolous lichen mats suitable for storing and return vascular plant seeds? A case study with implications for dry grasslands restoration. To be submitted to: *Journal of Plant Interactions*.
2. **Gheza G.**, Assini S., Lelli C., Marini L., Mayrhofer H., Nascimbene J. Conservation of terricolous cryptogams in continental lowlands: the role of open dry habitats. To be submitted to: *Biological Conservation*.
3. **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. *Science of the Total Environment* 639: 633–639.
4. **Gheza G.**, Nascimbene J., Mayrhofer H., Barcella M., Assini S. 2018. Two *Cladonia* species new to Italy from dry habitats in the Po Plain. *Herzogia* 31 (1): 293–303.
5. **Gheza G.** 2018. Addenda to the lichen flora of the Ticino river valley (western Po Plain). *Natural History Sciences* 5 (2): 33-40.
6. **Gheza G.** 2018. Chiave alle specie italiane del genere *Cladonia*. *Notiziario della Società Lichenologica Italiana* 31: 70-96.
7. Ravera S., Vizzini A., Cogoni A., Aleffi M., Assini S., Bergamo Decarli G., Bonini I., Brackel W.v., Cheli F., Darmostuk V., Fačkovcová Z., Gavrylenko L., **Gheza G.**, Guttová A., Mayrhofer H., Nascimbene J., Paoli L., Poponessi S., Potenza G., Prosser F., Puddu D., Puntillo D., Rigotti D., Sguazzin F., Tatti A., Venanzoni R. 2017. Notulae to the Italian flora of Algae, Bryophytes, Fungi and Lichens 4. *Italian Botanist* 4: 73–86.
8. Ravera S., Cogoni A., Vizzini A., Aleffi M., Assini S., Barcella B., Brackel W.v., Caporale S., Fačkovcová Z., Filippino G., **Gheza G.**, Gigante D., Paoli L., Potenza G., Poponessi S., Prosser F., Puntillo D., Puntillo M., Venanzoni R. 2017. Notulae to the Italian flora of Algae, Bryophytes, Fungi and Lichens 3. *Italian Botanist* 3: 17–27.
9. Galasso G., Domina G., Ardenghi N.M.G., Assini S., Banfi E., Bartolucci F., Bigagli V., Bonari G., Bonivento E., Cauzzi P., D'Amico F.S., D'Antraccoli M., Dinelli D., Ferretti G., Gennai M., **Gheza G.**, Guiggi A., Guzzon F., Iamonico D., Iberite M., Latini M., Lonati M., Mei G., Nicolella G., Olivieri N., Peccenini S., Peraldo G., Perrino E.V., Prosser F., Roma-Marzio F., Russo G., Selvaggi A., Stinca A., Terzi M., Tison J.-M., Vannini J., Verloove F., Wagensommer R.P., Wilhalm T., Nepi C. 2017. Notulae to the Italian alien vascular flora 3. *Italian Botanist* 3: 49–71.

**10.** Ravera S., Cogoni A., Totti C., Aleffi M., Assini S., Caporale S., Fačkovcová Z., Filippino G., **Gheza G.**, Olivieri N., Ottonello M., Paoli L., Poponessi S., Pišút I., Venanzoni R. 2016. Notulae to the Italian flora of Algae, Bryophytes, Fungi and Lichens 2. *Italian Botanist* 2: 43–54.

## Scientific articles on peer-reviewed journals not related to this thesis

**11.** Ravera S. et al. 2019. Notulae to the Italian flora of Algae, Bryophytes, Fungi and Lichens 7. Submitted to: *Italian Botanist* 7.

**12.** **Gheza G.** 2018. Aggiunte alle conoscenze sul genere *Cladonia* (Hill) P.Browne (Ascomycota: Lecanorales: Cladoniaceae) in Valtellina (Alpi Retiche, Lombardia). To be submitted.

**13.** **Gheza G.** 2018. Aggiunte alla flora lichenica della Val Camonica. Submitted to: *Natura Bresciana*.

**14.** Ravera S., Cogoni A., Vizzini A., Benesperi R., Bianchi E., Bonini I., Brunialti G., Cheli F., Fačkovcova Z., Fascetti S., **Gheza G.**, Giordani P., Guttova A., Mair P., Mayrhofer H., Miserere L., Nascimbene J., Pandeli G., Paoli L., Potenza G., Prosser F., Puntillo D., Puntillo M., Rosati L., Selvaggi A., Spitale D., Tratter W. 2018. Notulae to the Italian flora of Algae, Bryophytes, Fungi and Lichens 6. *Italian Botanist* 6: 97-109.

**15.** Isocrono D., Benesperi R., Catalano I., **Gheza G.**, Matteucci E., Ongaro S., Potenza G., Puntillo D., Ravera S., Pittao E. 2018. Lichenes Italici Exsiccati ex Società Lichenologica Italiana. Fascicle II (Nos. 13-24). *Notiziario della Società Lichenologica Italiana* 31: 97-99.

**16.** Ravera S., Vizzini A., Cogoni A., Aleffi M., Benesperi R., Bianchi E., Brackel W.v., Cataldo D., D'Antonio C., Di Nuzzo L., Favero-Longo S.E., **Gheza G.**, Isocrono D., Matteucci E., Martellos S., Morosini L., Nimis P.L., Ongaro S., Poponessi S., Puntillo D., Sguazzin F., Tretiach M. 2018. Notulae to the Italian flora of Algae, Bryophytes, Fungi and Lichens 5. *Italian Botanist* 5: 31–43.

**17.** **Gheza G.** 2017. Segnalazioni recenti di alcuni macrolicheni interessanti in Alta Valtellina (Alpi Retiche, Lombardia). *Il Naturalista Valtellinese – Atti del Museo Civico di Storia Naturale di Morbegno* 28: 57-64.

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

**19.** Caporale S., Benesperi R., Bianchi E., Fačkovcová Z., Favero-Longo S.E., Giordani P., **Gheza G.**, Isocrono D., Matteucci E., Munzi S., Paoli L., Puntillo D., Ravera S., Vannini A., Catalano I. 2016. Contributo alle conoscenze lichenologiche della RNR Cascate del Verde e del Bosco di Montalto (Borrello, Chieti). *Notiziario della Società Lichenologica Italiana* 29: 87–94.

**20.** **Gheza G.**, Assini S., Valcuvia Passadore M. 2015. Contribution to the knowledge of lichen flora of inland sand dunes in the western Po Plain (N Italy). *Plant Biosystems* 149 (2): 307–314.

**21.** **Gheza G**. 2015. Terricolous lichens of the western Padanian Plain: new records of phytogeographical interest. *Acta Botanica Gallica – Botany Letters* 162 (4): 339–348.

## Scientific books and chapters in scientific books

**22.** Valcuvia Passadore M., **Gheza G.**, Passadore D. 2017. *Iconografia delle Cladonie d'Italia*. Pime Editrice, Pavia. 200 pp.

**23.** Ravera S., **Gheza G.** 2016. *Cladonia* L. subgenus *Cladina* (Nyl.) Vain. In: Ercole S., Giacanelli V., Bacchetta G., Fenu G., Genovesi P. (eds). *Manuali per il monitoraggio di specie e habitat di interesse comunitario (Direttiva 92/43/CEE) in Italia: specie vegetali*. ISPRA, Serie Manuali e Linee Guida, Roma. pp. 28–31.

## Presentations at congresses

**24.** **Gheza G.**, Assini S., Lelli C., Marini L., Mayrhofer H., Nascimbene J. 2018. *Il ruolo degli habitat aridi planiziali nella conservazione delle crittogame terricole*. 31° Convegno della Società Lichenologica Italiana, Pistoia, 26-28 September 2018. Oral presentation.

**25.** Lelli C., Nascimbene J., Bresciani A., Fani A., **Gheza G.**, Salvatelli E., Spitale D., Marei V.M., Ziviani E., Chiarucci A. 2018. *Effect of stand structure, topography and climate on vascular plants and epiphytes in mountain beech forests of the Northern Apennines (Italy)*. 31° Convegno della Società Lichenologica Italiana, Pistoia, 26-28 September 2018. Oral presentation.

**26.** **Gheza G.**, Assini S. 2018. *Ripristino della componente lichenica terricola in un sito di introduzione dell'Habitat 2330*. 31° Convegno della Società Lichenologica Italiana, Pistoia, 26-28 September 2018. Poster presentation.

**27.** Chiarucci A., Lelli C., Bresciani A., Fani A., **Gheza G.**, Salvatelli E., Spitale D., Marei M.V., Ziviani E., Nascimbene J. 2018. *Effect of stand structure, topography and climate on vascular plants and epiphytes in mountain beech forests of the Northern Apennines (Italy)*. 113° Convegno della Società Botanica Italiana, Fisciano (SA), 12-15 September 2018. Poster presentation.

**28.** **Gheza G.**, Barcella M., Assini S. 2018. *Terricolous lichen communities in* Thero-Airion *dry grasslands of the Po Plain (N Italy)*. 15° Eurasian Grassland Conference, Sulmona (AQ), 4-8 June 2018. Poster presentation.

**29.** **Gheza G.**, Assini S., Marini L., Nascimbene J. 2018. *Impact of an invasive herbivore and trampling on lichen-rich dry grasslands: soil-dependent response of multiple taxa*. 15°

Eurasian Grassland Conference, Sulmona (AQ), 4-8 June 2018. Oral presentation.

30. **Gheza G.**, Assini S., Marini L., Nascimbene J. 2017. *L'impatto di lagomorfi alloctoni e del calpestio umano nelle praterie aride ricche di crittogame*. 30° Convegno della Società Lichenologica Italiana, Torino, 13-15 September 2017. Oral presentation.

31. **Gheza G.**, Assini S., Marini L., Nascimbene J. 2017. *L'impatto di lagomorfi alloctoni e del calpestio umano nelle praterie aride ricche di crittogame*. 51° Congresso della Società Italiana di Scienze della Vegetazione, Bologna, 20-21 April 2017. Oral presentation.

32. **Gheza G.**, Assini S. 2016. *Licheni terricoli nei pratelli aridi lungo i principali fiumi della pianura piemontese*. 5° Convegno dell''Associazione Naturalistica Piemontese e del Gruppo Piemontese di Studi Ornitologici, Asti, 12 November 2016. Oral presentation.

33. **Gheza G**. 2015. *Comunità licheniche delle praterie a* Corynephorus canescens *(Habitat 2330 – Direttiva 1992/43/CEE) dell'Italia Settentrionale*. 28° Convegno della Società Lichenologica Italiana, Lanciano (CH), 9-11 September 2015. Oral presentation.

34. **Gheza G.**, Assini S. 2015. *Comunità licheniche delle praterie a* Corynephorus canescens *(Habitat 2330 – Direttiva 1992/43/CEE) dell'Italia Settentrionale*. Workshop of the Società Italiana di Scienze della Vegetazione, Pavia, March 2015. Oral presentation.

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35. Favero-Longo S.E., Isocrono D., Matteucci E., Bianchi E., Cecconi E., **Gheza G.**, Morando M. (eds.). 2017. Atti del XXX Convegno della Società Lichenologica Italiana – Poster. *Notiziario della Società Lichenologica Italiana* 30: 33-54.

## Divulgative books and chapters in divulgative books

36. **Gheza G.** 2018. Licheni e boschi. In: Bona E. (ed.). *Flora di pregio delle valli Camonica e di Scalve. III. I signori del tempo e la flora erbacea dei boschi*. Tipografia Brenese, Breno. pp. 12–13.

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