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Terricolous lichen communities in *Thero-Airion* dry grasslands of the Po Plain (Northern Italy): syntaxonomy, ecology and conservation value

Erdflechtengesellschaften in *Thero-Airion* Trockenrasen der Po-Ebene (Norditalien): Syntaxonomie, Ökologie und Erhaltungswert

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Abstract

Terricolous lichen vegetation has been partially studied in Italy so far, particularly in the Po Plain. Here, pioneer acidic *Thero-Airion* dry grasslands host rich terricolous lichen communities which often include lichen species of conservation concern. Overall, 288 phytosociological relevés were carried out with the Braun-Blanquet method using standard plots of 30 cm × 30 cm in lichen-rich stands within *Thero-Airion* dry grasslands located in 16 localities of the western Po Plain, an area with continental climate. Relevés were manually sorted and species composition was analyzed through Principal Component Analysis (PCA) and non-parametric MANOVA. Biological, ecological, chorological and rarity spectra were computed and analyzed with Kruskal-Wallis tests to assess differences among the communities. Nine lichen communities were recognized. One community dominated by *Cladonia pulvinata* referred to the *Pycnothelio-Cladonietum cervicornis*. Three communities referred to the *Cladonietum foliaceae* are dominated respectively by *C. foliacea*, *C. furcata* and *C. rangiformis*. Three communities referred to the *Cladonietum rei* are dominated respectively by *C. rei*, *C. polycarpoides* and *C. coccifera*. Two communities dominated respectively by *C. peziziformis* and *C. cariosa* are referred to an undescribed association, temporarily attributed to the *Cladonion rei*. All communities significantly differ in the mean ecological indicator values – soil pH, light, aridity, eutrophication, poleotolerance. The communities *Pycnothelio-Cladonietum cervicornis*, *Cladonietum foliaceae* (*C. foliacea* facies) and the *C. peziziformis*-*C. cariosa* community are pioneer communities. The *Cladonietum rei* (*C. rei* facies) and the *Cladonietum foliaceae* (*C. rangiformis* facies) are the more mature communities, respectively in disturbed and undisturbed sites. This study shows that terricolous lichen communities represent an important component of biodiversity in *Thero-Airion* dry grasslands, due to their diversification in different *syntaxa* and, in some cases, to their role as microhabitats for lichen species of conservation concern. Thus, our study contributes to the knowledge on *Thero-Airion* dry grasslands, which is a key component in the choice of management and conservation strategies.

Keywords: *Cladonia*, *Cladonietum foliaceae*, *Cladonion rei*, lichen vegetation, *Pycnothelio-Cladonietum cervicornis*

Erweiterte deutsche Zusammenfassung am Ende des Artikels

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1. Introduction

The alliance *Thero-Airion* Tüxen ex Oberdorfer 1957 includes Atlantic and European nutrient-poor pioneer spring and early summer plant communities dominated by annual short herbs and grasses growing on xeric soils, on sands and arenaceous rocks. At higher syntaxonomical levels, the *Thero-Airion* is included in different orders and classes, following its geographical distribution: *Corynephoretalia canescentis* Klika 1934 and *Koelerio-Corynephoretea* Klika in Klika & V. Novák 1941 for Central Europe and Atlantic Regions; *Tuberarietalia guttatae* Br.Bl. in Br.-Bl., Molinier & Wagner 1940 and *Tuberarietea guttatae* (Br.-Bl. in Br.-Bl., Roussine & Nègre 1952) Rivas Goday & Rivas-Martínez 1963 for the Mediterranean Region (RIVAS-MARTÍNEZ et al. 2002).

Thero-Airion dry grasslands assume an important conservation value as relicts of past low-intensity farming and nutrient-poor pastures which are no longer profitable. Thus, they suffered from serious area declines in recent decades. The main drivers of this decline are afforestation, abandonment and under-grazing (BECKER et al. 2012, CHYTRÝ et al. 2019).

In the study area (the Po Plain, between the regions Piemonte and Lombardia), the situation is similar, with a loss of about 50% of dry grasslands, along the river valleys of the Ticino and the Sesia, in the last 40 years (Assini et al., unpubl. data). Here, the main threats are the invasion of non-native and native woody species, the increase in soil Nitrogen, the absence of an efficient management model and the abandonment. Along the river valleys, the distribution of dry grasslands and their river corridor plant species can be very useful to inform conservation strategy, as described by VAN LOOY & MEIRE (2009).

Thero-Airion plant communities show a peculiar floristic composition in the study area, which is located between the floristic Central European Region and the Mediterranean Region. Such composition is characterized by the co-occurrence of species with very different biogeographical ranges, such as *Armeria arenaria*, *Viscaria vulgaris*, *Achillea tomentosa*, *Jasione montana*, *Teesdalia nudicaulis*, *Festuca lachenalii*, *Tuberaria guttata*, *Fumana procumbens*, *Festuca incurva*, *Saponaria ocymoides*, *Anarrhinum bellidifolium*, *Linaria pellisseriana*, *Chrysopogon gryllus* (species with submediterranean-subatlantic or Mediterranean or South Siberian or mountain distribution range) (Assini, unpubl. data). Such a particular floristic composition, the localization of these *Thero-Airion* dry grasslands at the southern limit of their Atlantic-European distribution range and at the northern limit of their Mediterranean distribution range make them particularly worthy of protection in this area.

The presence of terricolous lichen vegetation furtherly emphasizes the biodiversity and the conservation value of *Thero-Airion* dry grasslands in the study area, even more if we consider that the Po Plain is one of the most human-impacted and polluted areas in Italy (GHEZA 2015). Therefore, a better knowledge of the composition and distribution of such terricolous communities is very important for management and conservation.

Although quite well-known in Northern and Central Europe (e.g. PAUS 1997, BÜLTMANN 2005a, b, GÜNZL 2005, ROLA et al. 2014), terricolous lichen vegetation has been very little studied in Italy, and the few studies carried out so far refer to the Alps or to coastal areas of the main islands (see GHEZA et al. 2016 for an overview). In the part of Italy with continental climate, which corresponds to the Po Plain (Northern Italy), GHEZA et al. (2016) reported an account of the terricolous lichen communities of all the grasslands attributable to the *Spergulo-Corynephoretum canescentis* found in the area. This is the only available contribution to the knowledge of the terricolous lichen vegetation of the Po Plain, which is therefore quite overlooked, since *Corynephorion* grasslands are extremely limited and represent only a small part of the dry habitats found in that area. Other dry grassland habitats occurring on acidic substrates in the Po Plain include lowland grasslands of the *Thero-Airion*, which are rich in terricolous lichen species of conservation concern and biogeographical interest (GHEZA 2015, 2018a, b).

The aim of this paper is therefore the study of the terricolous lichen communities occurring in the lichen-rich sites of the *Thero-Airion*, which is the most widespread vascular plant alliance including lichen-rich dry grasslands on acidic substrates in the western Po Plain, using a phytosociological approach. In particular, we addressed the study to disclose (1) if the lichen communities in *Thero-Airion* grasslands are differentiated by their species composition and ecology, (2) if these communities can also be referred to already described lichen vegetation types, and (3) if these communities host rare and/or endangered species which can increase their conservation value, and therefore the value of the grassland types in which they occur. In addition, we discussed management and conservation implications for *Thero-Airion* grasslands.

2. Materials and methods

2.1 Study area and study sites

The study area is located in the western Po Plain of Northern Italy, including the surroundings of the boundary between the regions Piemonte and Lombardia. Within this area, 16 sites hosting lichen-rich *Thero-Airion* grasslands were found and studied in the river valleys of the two main rivers: the Ticino (9 sites) and the Sesia (7 sites) (Table 1, Fig. 1). These 16 sites included all the best preserved situations of this grassland type located beneath 300 m a.s.l. in the western Po Plain.

The climate of the study area is continental, with annual temperatures ranging widely between cold winters and warm summers; the bioclimate is temperate (RIVAS-MARTÍNEZ et al. 2004).

Table 1. Study sites with lichen-rich *Thero-Airion* dry grasslands in the western Po Plain.

Tabelle 1. Untersuchungsstandorten mit flechtenreiche *Thero-Airion* Trockenrasen in der westlich Po-Ebene.

	Locality	Municipality and Province	Coordinates (UTM WGS84 32T)	Altitude (m a.s.l.)	Area (m^2)
	Ticino river valley				
1	Abandoned airfield La Promessa	Lonate Pozzolo (Varese)	479454.5046066	187	53,487
2	Cascina Rossa	Bernate Ticino (Milano)	484056.5035056	117	11,289
3	Tenuta La Fagiana	Pontevecchio di Magenta (Milano)	486446.5030673	108	14,637
4	Villa Giulia	Cerano (Novara)	487032.5027321	101	8377
5	Bosco del Modrone	Vigevano (Pavia)	494916.5015669	76	8066
6	Bosco Ronchi	Vigevano (Pavia)	495969.5013794	73	1498
7	Bosco Ronchi	Vigevano (Pavia)	495871.5013398	74	6413
8	Bosco della Ghisolfa	Vigevano (Pavia)	494934.5013801	75	4899
9	Molino d'Isella	Gambolò (Pavia)	496113.5012669	72	150
	Sesia river valley				
10	Riverbank	Lenta (Vercelli)	452730.5045161	220	961
11	Fishing lakes	Arborio (Vercelli)	452937.5036305	173	40,381
12	Canale Cavour	Greggio (Vercelli)	452896.5034283	164	183
13	Countryland	Greggio (Vercelli)	452426.5033997	165	1457
14	Riverbed	Greggio (Vercelli)	452850.5033760	159	32,360
15	Gerbido	Greggio (Vercelli)	452886.5032787	159	6093
16	Torrette di Frassineto	Frassineto Po (Alessandria)	467027.4998499	98	15,586

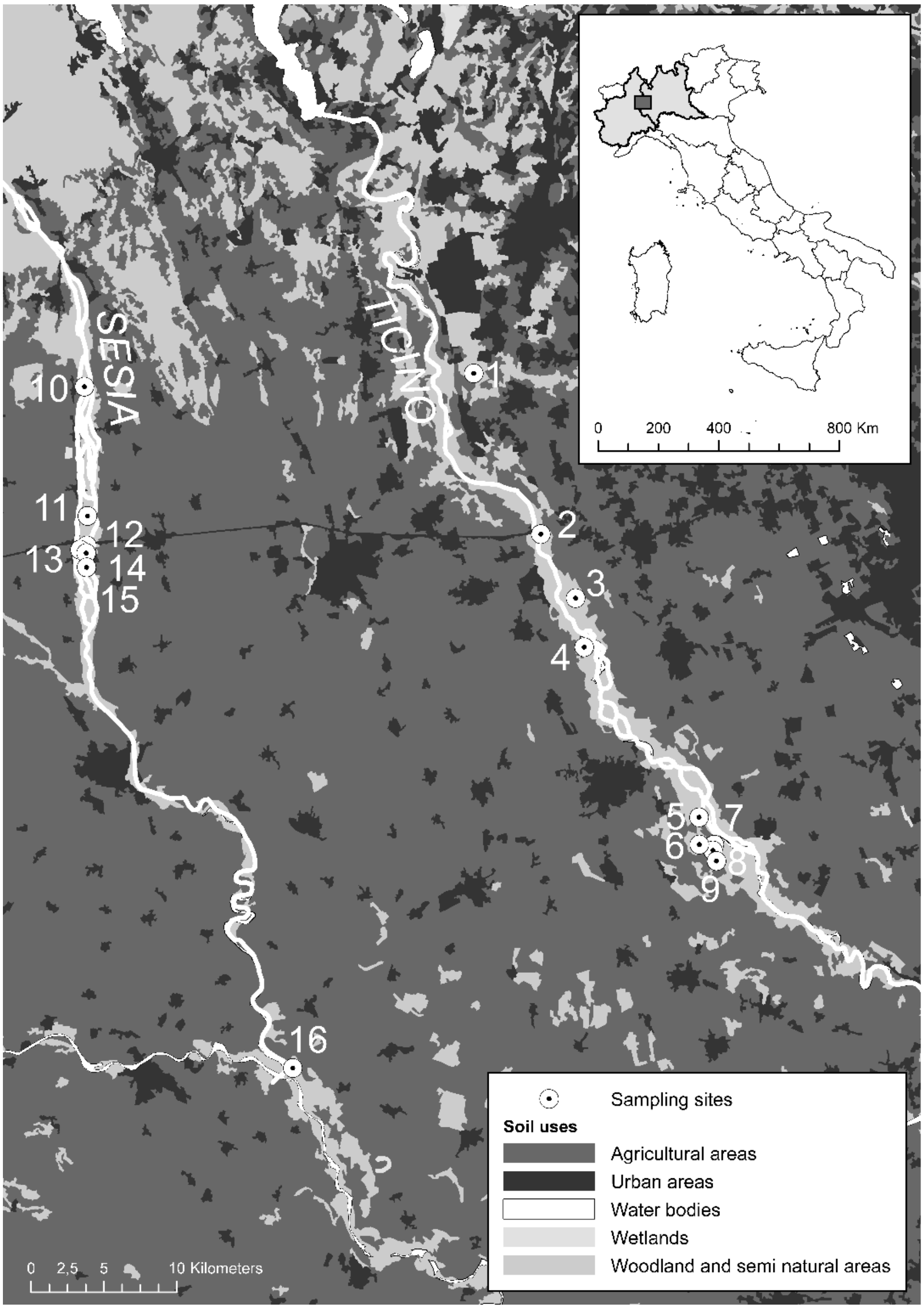

Fig. 1. Study area and study sites (modified from the CORINE LAND COVER [2012] cartography).
Abb. 1. Untersuchungsgebiet und Untersuchungsstandorten.

The climax vegetation of the Po Plain is a mesophilous mixed forest dominated by *Quercus robur* and *Carpinus betulus* (TOMASELLI et al. 1973), while the most mature vegetation in the river valleys is a mixed forest dominated by *Q. robur* and *Ulmus minor*. *Thero-Airion* grasslands are found in more or less wide clearings within these forests and at the edge of the active part of the riverbeds, where edaphic conditions allow their presence. These dry grasslands grow on acidic sandy-pebbly soils built up by coarse fluvial sediments, which are well drained and allow the occurrence of xerophilous species. ASSINI & SARTORI (2004) described three phytosociological associations for the study area: *Filagini-Vulpietum* Oberd. 1938, *Airo caryophylleae-Festucetum ovinae* Tx. 1955, and *Narduretum lachenalii* Korneck 1975. The same authors attributed the alliance *Thero-Airion* to the order *Corynephoretalia canescentis* and to the class *Koelerio-Corynephoretea*.

In this area of the Po Plain, *Thero-Airion* grasslands can be attributed to the Habitat 6210 (acidophilous sub type 34.34) of the Habitats Directive 1992/43/EEC (EUROPEAN COMMISSION 1992), because they often form a mosaic of vegetation with patches of perennial dry grasslands of the order *Brometalia erecti* Koch 1926 and the alliance *Koelerio-Phleion phleoides* Korneck 1974 (as described by ASSINI & SARTORI, 2004).

2.2 Sampling design

A total of 288 phytosociological relevés were carried out with the method of BRAUN-BLANQUET (1928) in May-June, in the years 2016 and 2017 within a movable standard plot with a size of 30 cm × 30 cm. This plot size has been used by several authors to study terricolous lichen vegetation in Central Europe (e.g. PAUS 1997, GÜNZL 2005) and also in Italy (GHEZA et al. 2016). The sampling followed the approach commonly used in phytosociological studies: firstly, floristically homogeneous elementary units were identified; then, relevés were carried out randomly within them. The number of relevés carried out in each study site was not fixed *a priori*, but depended on the diversity of the visually observed elementary units in the field in each of the sites and on the site's extent; i.e. if a large site hosted heterogeneous lichen communities we carried out various relevés until every situation was recorded, whereas in small sites with homogeneous lichen vegetation only few relevés were conducted. The elementary units were previously detected through a complete exploration of each study site. In the smallest sites (9 and 12) only one relevé was carried out, since lichen vegetation was very restricted and homogeneous. The number of relevés collected for each lichen community in each study site is reported in Table 2.

The cover-abundance scale of BRAUN-BLANQUET (1928) was used, with the following values: cover <1%: +; 1–5%: 1; >5–25%: 2; >25–50%: 3; >50–75%: 4; > 75%: 5. For data analysis, the scale was transformed according to VAN DER MAAREL (1979), as follows: cover <1%: 2; 1–5%: 3; >5–25%: 5; >25–50%: 7; >50–75%: 8; > 75%: 9.

Most of the species were identified in the field. Whenever necessary, specimens were collected and identified in the laboratory. The keys used include WIRTH et al. (2013) and GHEZA (2018b) for lichens, CORTINI PEDROTTI (2001, 2006) and ATHERTON et al. (2010) for bryophytes and PIGNATTI (1982) for vascular plants. Nomenclature follows NIMIS (2016) for lichens, CORTINI PEDROTTI (2001, 2006) for bryophytes and TISON & DE FOUCAULT (2014) for vascular plants. Nomenclature of lichen *syntaxa* follows PAUS (1997) and MUCINA et al. (2016). The name *Cladonietum rei* is accepted here according to the considerations expressed by ROLA et al. (2014).

2.3 Data analysis

Relevés were sorted manually according to the cover-abundance values of the character species. Syntaxonomic indicator function was inferred from DREHWALD (1993), PAUS (1997), GÜNZL (2005), BÜLTMANN (2005a, b), MÜLLER & OTTE (2007), SCHUBERT & STORDEUR (2011), GHEZA et al. (2016).

A matrix of the lichen part of all 288 relevés was prepared for multivariate analysis. Bryophytes and vascular plants were excluded from this dataset because of their occasional presence and low cover values.

Table 2. Number of relevés of each community in each site. 1: *Pycnothelio-Cladonietum cervicornis* (*C. pulvinata* facies). 2: *Cladonietum foliaceae* (a: *C. foliacea* facies; b: *C. furcata* facies; c: *C. rangiformis* facies). 3: *Cladonietum rei* (a: *C. polycarpoides* facies; b: *C. rei* facies; c: *C. coccifera* facies). 4: *Cladonia cariosa-Cladonia peziziformis* community (a: *C. cariosa* facies; b: *C. peziziformis* facies).

Tabelle 2. Anzahl Vegetationsaufnahmen pro Gesellschaft und Standort. 1: *Pycnothelio-Cladonietum cervicornis* (*C. pulvinata*-Fazies). 2: *Cladonietum foliaceae* (a: *C. foliacea*-Fazies; b: *C. furcata*-Fazies; c: *C. rangiformis*-Fazies). 3: *Cladonietum rei* (a: *C. polycarpoides*-Fazies; b: *C. rei*-Fazies; c: *C. coccifera*-Fazies). 4: *Cladonia cariosa-Cladonia peziziformis*-Gesellschaft (a: *C. cariosa*-Fazies; b: *C. peziziformis*-Fazies).

	1	2a	2b	2c	3a	3b	3c	4a	4b	Total
Total	4	49	17	56	39	27	8	48	40	288
Ticino river valley	4	44	16	54	14	15	7	5	4	163
Lonate Pozzolo: La Promessa	4	–	3	4	–	4	4	–	4	23
Bernate: Cascina Rossa	–	4	–	3	10	2	–	5	–	24
Magenta: La Fagiana	–	5	1	10	–	–	–	–	–	16
Cerano: Villa Giulia	–	4	–	3	–	–	3	–	–	10
Vigevano: Bosco del Modrone	–	5	3	7	1	2	–	–	–	18
Vigevano: Bosco Ronchi	–	–	–	2	–	6	–	–	–	8
Vigevano: Bosco Ronchi	–	18	2	16	3	–	–	–	–	39
Vigevano: Bosco della Ghisolfa	–	8	7	8	–	1	–	–	–	24
Gambolò: Molino d'Isella	–	–	–	1	–	–	–	–	–	1
Sesia river valley	0	5	1	2	25	12	1	43	36	125
Lenta: riverbank	–	3	1	1	–	–	–	2	3	10
Arborio: fishing lakes	–	1	–	–	19	10	1	9	3	43
Greggio: Canale Cavour	–	–	–	–	1	–	–	–	–	1
Greggio: countryland	–	1	–	–	–	–	–	2	2	5
Greggio: riverbed	–	–	–	–	3	2	–	21	14	40
Greggio: gerbido	–	–	–	–	2	–	–	9	3	14
Frassineto Po: Torrette di Frassineto	–	–	–	1	–	–	–	–	11	12

A Non-Parametric Multivariate Analysis of Variance (NP-MANOVA) (ANDERSON 2001) was performed on the groups obtained by means of manual sorting to evaluate their validity. The euclidean distance was used as distance measure and the statistical significance was established by means of a permutation test with 9999 permutations.

In order to characterize and differentiate the lichen communities, weighted spectra were calculated for several characteristics, described as follows.

1) **Growth forms**: foliose-squamulose (L), fruticose with simple podetia (Be), fruticose with ramified podetia (Cl). Data were retrieved from BÜLTMANN (2006) with the following additions and modifications: *C. caespiticia*, *C. polycarpoides* and *C. pulvinata* were attributed to L, *C. cariosa* and *C. peziziformis* to Be.
2) **Chorology**: arctic, boreal, south-boreal, temperate, submediterranean, mediterranean. Data were retrieved from WIRTH et al. (2013). Since species are defined not with a single chorology but with a distribution range (e.g. *C. foliacea*: temperate-mediterranean), when calculating the spectra each species has been considered for every chorological belt in which it occurs.
3) **Substrate ecology**: pioneer, humicolous, aerohygrophytic. Data were retrieved from BÜLTMANN (2005b, 2006), KETNER-OOSTRA & SÝKORA (2008), KETNER-OOSTRA et al. (2012), with the following additions: *C. cariosa*, *C. conista*, *C. peziziformis* and *C. polycarpoides* were considered pioneer, *C. caespiticia* was considered humicolous.

In addition, we calculated the following mean ecological indicator values and the rarity in the Po Plain based on NIMIS (2016):

4) **pH of the substrate** (pH): 1 (very acid substrates), 2 (rather acid substrates), 3 (subneutral substrates), 4 (rather basic substrates), 5 (basic substrates).
5) **Light requirements** (L): 1 (very skiophytic), 2 (moderately skiophytic), 3 (moderately photophytic), 4 (rather photophytic), 5 (photophytic).
6) **Humidity requirements** (H): 1 (hygrophytic), 2 (rather hygrophytic), 3 (mesophytic), 4 (rather xerophytic), 5 (xerophytic).
7) **Tolerance to eutrophication** (N): 1 (anitrophytic), 2 (moderately nitrophytic), 3 (rather nitrophytic), 4 (very nitrophytic), 5 (extremely nitrophytic).
8) **Poleotolerance** (P): 1 (species occurring in natural or semi-natural habitats), 2 (species occurring in moderately human-disturbed areas), 3 (species occurring also in heavily human-disturbed areas) (NIMIS 2016).
9) **Rarity in the Po Plain**: extremely rare, rather common, common, very common, extremely common (NIMIS 2016). Some species found during this study were new for the Po Plain, therefore in these cases the category "absent" has been merged in the category "extremely rare".

No other important biological characteristics (e.g. type of photobiont, reproduction strategy) were considered, because a preliminary evaluation showed that they were quite uniform among the different lichen vegetation types.

The Kruskal-Wallis test was performed to evaluate the discriminating value of biological, ecological and chorological characteristics in defining the differences among the lichen vegetation types.

A second matrix including only the ecological values of pH, L, H and N for the 288 relevés was also prepared. NP-MANOVA was performed also on this matrix.

A Principal Component Analysis (PCA) was performed on the two different matrices: the one with the floristic data to evaluate the effect of floristic diversity on the communities (variance explained by the first and second axes together: 50.93%), and the one with the ecological values to evaluate potential ecological diversity among communities (variance explained by the first and second axes together: 89.93%). Another PCA was performed again on the first matrix sorting the relevés per site instead of lichen community, to test possible spatial autocorrelation.

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

3. Results

3.1 Syntaxonomical scheme

Numbers refer to the groups as they are reported in the figures and in the synoptic table (Table 3).

Ceratodonto purpurei-Polytrichetea piliferi Mohan 1987 corr. Drehwald 1993
- *Peltigeretalia* Klement 1949
  - *Baomycetion rufi* Klement 1952
    - 1. *Pycnothelio-Cladonietum cervicornis* Paus 1997
      - *Cladonia pulvinata* facies
  - *Cladonion arbusculae* Klement 1949 corr. Bültmann 2016
    - 2. *Cladonietum foliaceae* Klement 1953 corr. Drehwald 1993
      - a) *Cladonia foliacea* facies (typical facies)
      - b) *Cladonia furcata* facies
      - c) *Cladonia rangiformis* facies

Cladonion rei Paus 1997
3. *Cladonietum rei* Paus 1997
a) *Cladonia rei* facies
b) *Cladonia polycarpoides* facies
c) *Cladonia coccifera* facies

4. *Cladonia cariosa*-*Cladonia peziziformis* community
a) *Cladonia cariosa* facies
b) *Cladonia peziziformis* facies

3.2 Lichen vegetation

The manual sorting of the 288 relevés allowed to establish four main groups, corresponding to the lichen communities reported in the syntaxonomical scheme above. A finer discrimination allowed to recognize nine groups, corresponding to different dominance facies within the four aforementioned communities.

The results of NP-MANOVA confirmed the validity of the groups from both floristic and ecological points of view, and showed a high statistical significance ($p < 0.001$) for almost all comparisons between them. A lower but still significant difference ($p < 0.01$) was found only for the *Pycnothelio-Cladonietum cervicornis* vs. the *Cladonietum rei* (*C. coccifera* facies) for both floristic and ecological variables.

3.2.1 *Pycnothelio-Cladonietum cervicornis* Paus 1997

The *Pycnothelio-Cladonietum cervicornis* is a pioneer community characterized by a very low number of cryptogam species (mean 2.5 per relevé, 3 in total) and a quite high lichen cover (mean 83%), distinctly dominated by *C. pulvinata*. Very acidophytic (pH: 1.5), very photophytic (L: 4.0), mesophytic (H: 3.0), very anitrophytic (N: 1.0), occurring in natural or semi-natural habitats (P: 1.0). This community is very rare in *Thero-Airion* grasslands, being more frequent in *Calluna* heathlands in the study area (Gheza et al. in prep.; see also GHEZA et al. 2018b).

3.2.2 *Cladonietum foliaceae* Klement 1953 corr. Drehwald 1993

This community is the most widespread community in the study area, where it occurred with three dominance facies.

The *C. foliacea* facies is a pioneer community characterized by a high total number of cryptogam species (mean 3.7 per relevé, 16 in total) and a high lichen cover (mean 91%), dominated by *C. foliacea*. Rather subneutrophytic (pH: 2.9), very photophytic (L: 4.4), mesophytic (H: 3.0), rather anitrophytic (N: 1.6), occurring in natural, semi-natural and also slightly anthropized habitats (P: 1.9). It can be rich in *C. furcata* or *C. rangiformis* when evolving towards one of the two other facies. In some cases also *C. polycarpoides*, *C. chlorophaea* and *C. pyxidata* can be frequent.

The *C. furcata* facies is a pioneer to intermediate community characterized by a quite high number of cryptogam species (mean 3.6 per relevé, 11 in total) and a very high lichen cover (mean 97%), dominated by *C. furcata*. Rather subneutrophytic (pH: 3.1), very photophytic (L: 3.8), mesophytic (H: 3.0), rather anitrophytic (N: 1.6), occurring in natural, semi-natural and also slightly anthropized habitats (P: 1.9). *C. foliacea* and *C. rangiformis* can be frequent but with low cover values, as well as *C. coccifera*, *C. portentosa* and *C. polycarpoides*.

The *C. rangiformis* facies is a mature community characterized by a high number of cryptogam species (mean 3.0 per relevé, 14 in total) and a very high lichen cover (mean 96%), distinctly dominated by *C. rangiformis*, which often forms monospecific stands. Subneutrophytic (pH: 3.5), very photophytic (L: 4.4), mesophytic (H: 3.0), not markedly anitrophytic (N: 1.8), occurring in natural, semi-natural and also slightly anthropized habitats (P: 1.9). Other *Cladonia* species can be frequent. This facies is the most mature and stable lichen community occurring in *Thero-Airion* grasslands, and could be considered a vicariant of the *Cladonietum mitis*.

3.2.3 *Cladonietum rei* Paus 1997

It is found mainly in disturbed situations, sometimes in patches with other lichen communities. Also this community occurred with three dominance facies.

The *C. polycarpoides* facies is a pioneer to intermediate community characterized by a high number of cryptogam species (mean 4.1 per relevé, 12 in total) and a high lichen cover (mean 86%), dominated by *C. polycarpoides*. Subneutrophytic (pH: 3.2), very photophytic (L: 3.9), mesophytic (H: 3.0), anitrophytic (N: 1.2), occurring in natural or semi-natural habitats (P: 1.2). Other species of the *Cladonion rei* can be frequent.

The *C. rei* facies is a pioneer to mature community characterized by a high number of cryptogam species (mean 3.4 per relevé, 15 in total) and a high lichen cover (mean 87%), distinctly dominated by *C. rei*, which can form monospecific stands in most mature situations. Rather subneutrophytic (pH: 2.5), not very photophytic (L: 3.3), mesophytic (H: 3.0), anitrophytic (N: 1.2), occurring in natural, semi-natural and also slightly anthropized habitats (P: 1.9). It can include other species typical for the *Cladonion rei*, but often only with very low cover values.

The *C. coccifera* facies is an intermediate community characterized by a rather high number of cryptogam species (mean 4.0 per relevé, 9 in total) and a moderate lichen cover (mean 76%), usually dominated by *C. coccifera*. Rather acidophytic (pH: 1.9), very photophytic (L: 4.4), mesophytic (H: 3.3), rather anitrophytic (N: 1.8), occurring in natural or semi-natural habitats (P: 1.2). It usually occurs in disturbed situations where the *Cladonietum foliaceae* and the *Cladonietum rei* can be found mixed in patches, and frequently hosts species of both *syntaxa*; it was attributed to the *Cladonietum rei* because species belonging to this *syntaxon* always show the higher lichen cover values.

3.2.4 *Cladonia cariosa-Cladonia peziziformis* community

This community, which is physiognomically and ecologically well-distinct from the *Cladonietum rei*, occurred with two dominance facies in the study area. It is found mainly in *Thero-Airion* grasslands of the Sesia river valley and in dry grasslands mixed with *Calluna* heathlands, i.e. another habitat in which this community can be frequent (Gheza et al. in prep.). The dominance facies described below can be species-rich or limited to monospecific stands of the character species, and often include other species of the *Cladonion rei* with low cover values (e.g. *C. chlorophaea*, *C. polycarpoides*, *C. rei*).

The *Cladonia cariosa* facies is characterized by a rather high number of cryptogam species (mean 3.1 per relevé, 13 in total) and a high cover (mean 84%), and is dominated by *C. cariosa*. Rather subneutrophytic (pH: 2.4), very photophytic (L: 3.8), mesophytic (H: 3.0), rather anitrophytic (N: 2.0), occurring in natural or semi-natural habitats (P: 1.2).

Table 3. Synoptic table with the percentual frequency of the species among the relevés in the particular group. 1: *Pycnothelio-Cladonietum cervicornis* (*C. pulvinata* facies). 2: *Cladonietum foliaceae* (a: *C. foliacea* facies; b: *C. furcata* facies; c: *C. rangiformis* facies). 3: *Cladonietum rei* (a: *C. polycarpoides* facies; b: *C. rei* facies; c: *C. coccifera* facies). 4: *Cladonia cariosa-Cladonia peziziformis* community (a: *C. cariosa* facies; b: *C. peziziformis* facies).

Tabelle 3. Übersichtstabelle mit der prozentualen Stetigkeit der Arten (Syntaxonomische Einheiten s. o.).

Lichen community	1	2a	2b	2c	3a	3b	3c	4a	4b
Number of relevés	4	49	17	56	39	27	8	40	48
Mean total cover (%)	83	91	97	96	86	87	76	82	84
Mean lichen cover (%)	74	79	79	86	77	69	37	73	77
Mean bryophyte cover (%)	6	12	15	9	9	15	34	6	6
Mean vascular plant cover (%)	35	14	14	20	13	16	8	14	12
Number of cryptogams	3	16	11	14	12	15	9	10	13
Number of vascular plants	11	28	22	39	28	26	11	27	24
Total number of species	14	44	33	53	40	41	20	37	37
Mean pH index	1.5	2.9	3.1	3.5	3.2	2.5	1.9	2.0	2.4
Mean L index	4.0	4.4	3.8	4.4	3.9	3.3	4.4	3.7	3.8
Mean H index	3.0	3.0	3.0	3.0	3.0	3.0	3.3	3.0	3.0
Mean N index	1.0	1.6	1.6	1.8	1.2	1.2	1.8	1.3	2.0
Mean P index	1.0	1.9	1.9	1.9	1.2	1.9	1.2	1.1	1.2
C ***Pycnothelio-Cladonietum cervicornis***									
Cladonia pulvinata	100	.	.	.	.	.	.	.	.
C ***Cladonietum foliaceae***									
Cladonia foliacea	.	100	59	66	28	11	38	.	4
Cladonia furcata	.	22	100	18	.	4	.	.	.
Cladonia rangiformis	.	88	71	100	15	19	13	33	4
Cladonia portentosa	.	4	6	5	.	.	.	.	.
C ***Cladonietum rei***									
Cladonia polycarpoides	.	31	6	9	100	15	13	15	17
Cladonia rei	.	6	.	5	46	100	13	13	48
Cladonia coccifera	.	2	6	2	3	11	100	.	.
Cladonia conista	.	.	6	5	3	7	.	3	.
C ***Cladonia cariosa-Cladonia peziziformis* community**									
Cladonia cariosa	.	2	.	2	10	11	.	100	42
Cladonia peziziformis	.	2	.	.	18	11	.	35	100
C ***Caratodonto-Polytrichetea, Peltigeretalia***									
Ceratodon purpureus	100	41	24	27	59	37	.	70	63
Polytrichum piliferum	50	47	35	29	28	22	88	3	29
Cladonia chlorophaea	.	4	.	.	.	4	.	3	6
Cladonia pyxidata	.	2	.	.	.	19	13	.	2
Other cryptogams									
Cladonia caespiticia	.	.	.	.	.	.	13	.	.
Cladonia fimbriata	.	2	.	4	.	.	.	.	2
Cladonia squamosa	.	.	.	.	3	.	.	.	.
Campylopus introflexus	.	8	12	9	3	7	.	.	2
Hypnum cupressiforme	.	.	6	5	.	19	13	.	.
Racomitrium canescens	.	4	.	.	.	.	.	.	.
Riccia ciliifera	.	.	.	.	.	.	.	8	2
Vascular plants									
Aira caryophyllea	100	12	41	18	8	4	25	43	42
Erigeron annuus	25	6	6	9	31	26	13	20	25
Logfia minima	75	22	12	18	33	4	25	78	71
Vulpia myurus	25	14	29	25	23	15	13	28	33
Rumex acetosella	.	41	41	48	21	33	38	30	17

Lichen community	1	2a	2b	2c	3a	3b	3c	4a	4b
Hypericum perforatum	.	2	.	7	5	4	38	3	4
Potentilla pusilla	25	2	.	2	3	4	.	5	2
Trifolium arvense	.	33	6	18	13	4	.	40	25
Eragrostis curvula	.	2	.	.	56	44	13	43	33
Jasione montana	25	2	.	9	5	22	.	.	6
Oxalys stricta	.	6	6	9	.	4	.	3	2
Scleranthus annuus	.	22	12	11	8	.	.	10	4
Teesdalia nudicaulis	.	4	24	11	3	4	25	0	0
Achillea tomentosa	.	8	6	2	.	.	.	8	2
Cerastium sp.	.	4	18	7	3	.	.	8	.
Pilosella officinarum	100	2	6	7	.	.	.	8	.
Hypochoeris glabra	.	51	35	43	8	4	.	.	.
Micropyrum tenellum	.	45	41	43	13	7	.	.	.
Poa bulbosa	.	33	6	16	3	7	.	.	.
Tuberaria guttata	.	35	6	14	15	.	.	.	10
Artemisia campestris	.	.	.	.	3	4	.	5	6
Carex caryophyllea	.	2	6	.	8	.	25	.	.
Sedum sexangulare	.	.	.	.	3	4	.	5	6
Silene italica	.	.	6	4	.	7	13	.	.
Teucrium chamaedrys	.	2	.	4	8	7	.	.	.
Thymus pulegioides	.	.	.	4	8	.	25	.	6
Centaurea deusta	.	.	.	4	8	.	.	8	.
Festuca filiformis	.	2	.	2	.	4	.	.	.
Galium sp.	50	.	.	.	.	4	.	.	2
Helianthemum nummularium	.	.	.	2	3	.	.	.	2
Solidago gigantea	50	.	.	4	.	.	.	5	.
Veronica arvensis	.	4	12	4	.	.	.	.	.
Anisantha sterilis	.	.	.	2	.	.	.	13	.
Armeria arenaria	.	2	.	11	.	.	.	.	.
Bromus hordeaceus	.	4	.	4	.	.	.	.	.
Calluna vulgaris	.	.	.	.	3	4	.	.	.
Centaurium erythraea	75	.	.	.	.	.	.	3	.
Euphorbia cyparissias	.	.	.	.	3	.	.	.	8
Euphorbia maculata	.	.	.	2	.	.	.	3	.
Geranium columbinum	.	.	12	5	.	.	.	.	.
Herniaria glabra	.	.	.	.	.	.	.	5	4
Hypochoeris radicata	.	.	.	2	.	4	.	.	.
Lotus corniculatus	75	.	.	.	.	.	.	8	.
Petrorhagia saxifraga	.	.	.	2	.	.	.	25	.
Potentilla argentea	.	2	.	4	.	.	.	0	.
Rubus caesius	.	.	6	.	.	4	.	0	.
Tragus racemosus	.	.	.	2	.	.	.	23	.
Ambrosia artemisiifolia	.	.	.	2	.	.	.	0	.
Arabidopsis thaliana	.	.	.	.	3	.	.	0	.
Corynephorus canescens	.	2	.	.	.	.	.	0	.
Crataegus monogyna	.	.	.	.	.	4	.	.	.
Cytisus scoparius	.	.	.	.	.	7	.	.	.
Conyza canadensis	.	.	.	2	.	.	.	.	.
Gnaphalium sp.	.	.	.	.	.	.	.	.	2
Luzula sp.	.	.	.	2	.	.	.	.	.
Oenothera sp.	.	.	.	.	.	.	.	.	2
Opuntia humifusa	.	.	.	.	5	.	.	.	.
Poterium sanguisorba	.	.	.	.	.	.	.	3	.
Prunus serotina	.	.	.	.	.	.	.	3	.
Robinia pseudoacacia	.	.	.	.	.	.	.	.	2
Scleranthus perennis	.	.	6	.	.	.	.	.	.

The *C. peziziformis* facies is characterized by a lower number of cryptogam species (mean 2.6 per relevé, 10 in total) and a high cover (mean 82%), and is dominated by *C. peziziformis*. Between acidophytic and subneutrophytic (pH: 2.0), very photophytic (L: 3.7), mesophytic (H: 3.0), anitrophytic (N: 1.3), occurring in well-preserved natural or semi-natural habitats (P: 1.1).

3.3 Ecological comparison

Biological spectra show some variability in the dominance of the growth forms among the surveyed lichen communities (Fig. 2). In general, the *Cladonietum foliaceae* has a higher cover of fruticose ramified species, whereas foliose-squamulose species and/or fruticose species with simple podetia prevail in the other communities.

The chorological spectra (Fig. 3) show that temperate and southern (submediterranean and mediterranean) elements play the main role in all the communities, with northern (arctic, boreal and south-boreal) elements being very less represented. Most of the species occurring in the surveyed communities have a broad distribution from the temperate to the (sub)mediterranean zone, while fewer species range from the arctic/boreal zone to the temperate or (sub)mediterranean zones.

The substrate ecology spectra (Fig. 4) show that most of the surveyed communities can be characterized as pioneer, whereas only the *Cladonietum foliaceae* (in particular the *C. rangiformis* facies) and the *C. coccifera* facies of the *Cladonietum rei* can be considered as mature communities, hosting a higher cover of humicolous and aerohygrophytic species – which can however occur also in other communities, but with lower cover values and abundances.

Mean ecological indicator values (Table 3: pH, L, H, N indexes) disclose a rather homogeneous situation, characterized by rather acidophytic to subneutrophytic, moderately to markedly photophytic, mesophytic and scarcely nitrophytic to anitrophytic communities.

Mean poleotolerance values (Table 3: P index) disclose a moderate to strong preference of the lichen communities for good quality habitats with high naturality and moderate or no human disturbance, which could be tolerated by only few communities.

The rarity spectra (Fig. 5) are useful to infer information for conservation priorities of lichen communities. The percentage of extremely rare species is high (> 70%) in most of the surveyed communities; only the *Cladonietum foliaceae* is characterized by high percentages (> 80%) of common species. The highest rarity values were observed for the communities with extremely rare character species in the Po Plain and also Italy-wide: the *Pycnothelio-Cladonietum cervicornis*, the *Cladonietum rei* (*C. polycarpoides* facies) and the *Cladonia cariosa-Cladonia peziziformis* community.

All the biological, ecological and chorological features considered contribute to the differentiation of the detected communities, according to the results of the Kruskall-Wallis test ($p < 0.01$ for each variable).

The scatterplots of the two PCA (Fig. 6) represent well the situation of the detected lichen communities. Although depleted, these communities are still quite different from a floristic point of view (Fig. 6a). This results in a good physiognomical characterization of each community even in the field. However, some species have a wide distribution and occur in many communities, whereas other species are very rare, and thus play a minor role in the differentiation of the lichen vegetation types. There are some overlaps among communities, which are useful to understand successional dynamics. Most of the studied communities seem quite similar ecologically (Fig. 6b).

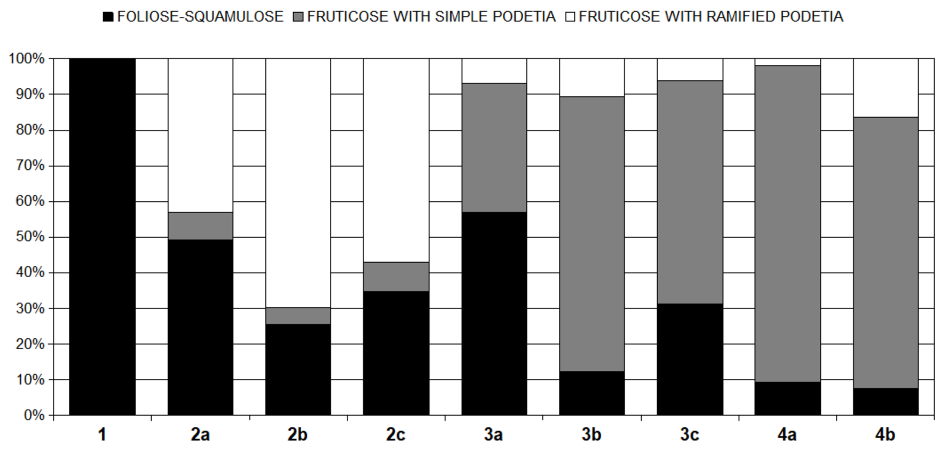

Fig. 2. Growth form spectra. 1: *Pycnothelio-Cladonietum cervicornis* (*C. pulvinata* facies). 2: *Cladonietum foliaceae* (a: *C. foliacea* facies; b: *C. furcata* facies; c: *C. rangiformis* facies). 3: *Cladonietum rei* (a: *C. polycarpoides* facies; b: *C. rei* facies; c: *C. coccifera* facies). 4: *Cladonia cariosa-Cladonia peziziformis* community (a: *C. cariosa* facies; b: *C. peziziformis* facies).

Abb. 2. Spektren des Wuchsformen (Syntaxonomische Einheiten s. o.).

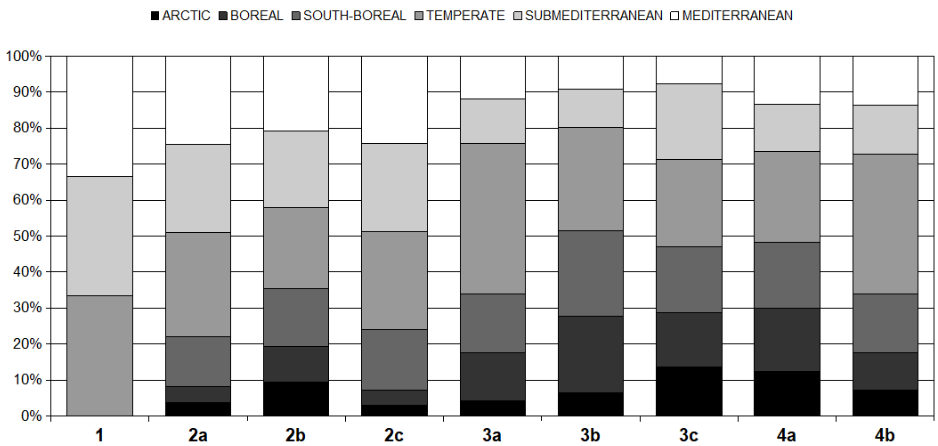

Fig. 3. Chorological spectra. 1: *Pycnothelio-Cladonietum cervicornis* (*C. pulvinata* facies). 2: *Cladonietum foliaceae* (a: *C. foliacea* facies; b: *C. furcata* facies; c: *C. rangiformis* facies). 3: *Cladonietum rei* (a: *C. polycarpoides* facies; b: *C. rei* facies; c: *C. coccifera* facies). 4: *Cladonia cariosa-Cladonia peziziformis* community (a: *C. cariosa* facies; b: *C. peziziformis* facies).

Abb. 3. Chorologische Spektren (Syntaxonomische Einheiten s. o.).

Finally, the PCA performed sorting the relevés per site (Fig. 7) seems to indicate that the relevés are generally more similar within the same site, and among sites within the same river valley, in terms of lichen vegetation composition. However, relevés from the same site are often spread, showing that more than one lichen community occurs in the same site. Indeed, no community exclusively occurred in only one site, nor in only one of the two river

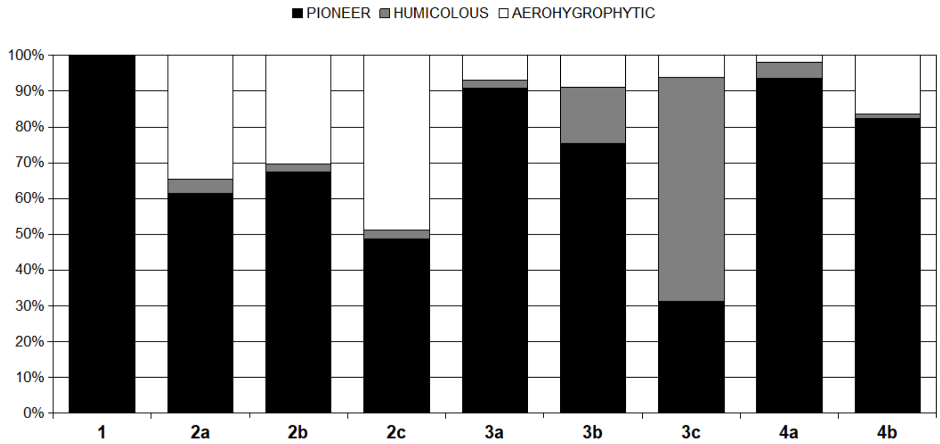

Fig. 4. Spectra of substrate ecology. 1: *Pycnothelio-Cladonietum cervicornis* (*C. pulvinata* facies). 2: *Cladonietum foliaceae* (a: *C. foliacea* facies; b: *C. furcata* facies; c: *C. rangiformis* facies). 3: *Cladonietum rei* (a: *C. polycarpoides* facies; b: *C. rei* facies; c: *C. coccifera* facies). 4: *Cladonia cariosa-Cladonia peziziformis* community (a: *C. cariosa* facies; b: *C. peziziformis* facies).

Abb. 4. Spektren der Substrat-Ökologie (Syntaxonomische Einheiten s. o.).

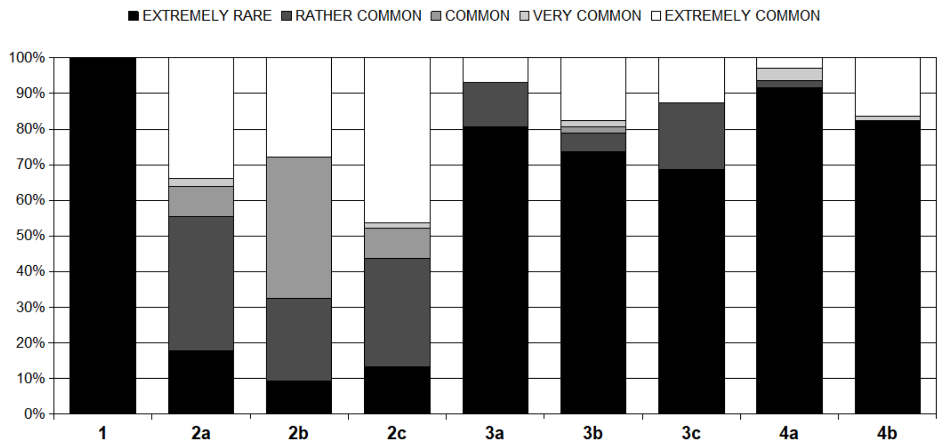

Fig. 5. Spectra of rarity in the Po Plain. 1: *Pycnothelio-Cladonietum cervicornis* (*C. pulvinata* facies). 2: *Cladonietum foliaceae* (a: *C. foliacea* facies; b: *C. furcata* facies; c: *C. rangiformis* facies). 3: *Cladonietum rei* (a: *C. polycarpoides* facies; b: *C. rei* facies; c: *C. coccifera* facies). 4: *Cladonia cariosa-Cladonia peziziformis* community (a: *C. cariosa* facies; b: *C. peziziformis* facies).

Abb. 5. Spektren der Seltenhein in der Po-Ebene (Syntaxonomische Einheiten s. o.).

valleys, except the *Pycnothelio-Cladonietum cervicornis*, which we found only in one site of the Ticino river valley (cf. Table 2). *Cladonietum foliaceae* communities are more widespread along the Ticino river valley, whereas *Cladonietum rei* and *C. cariosa-C. peziziformis* communities are more widespread along the Sesia river valley (cf. Table 2).

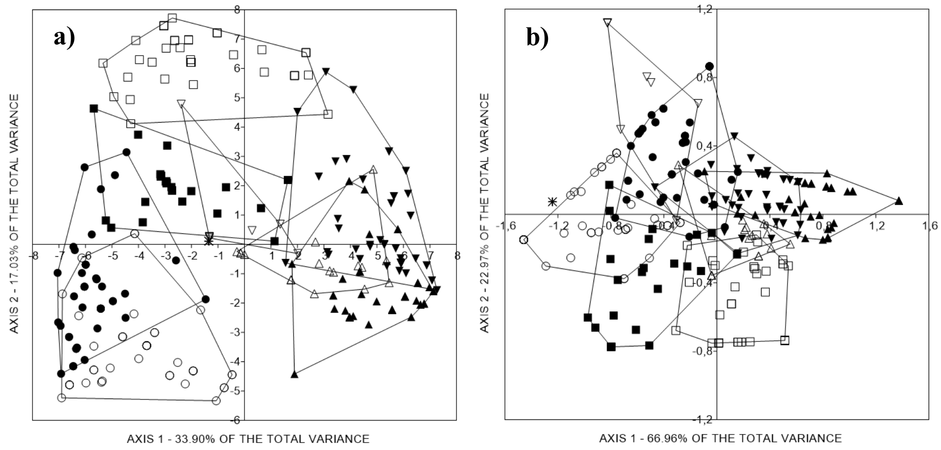

Fig. 6. PCA scatterplot of floristic **a)** and ecological **b)** variables. *Pycnothelio-Cladonietum cervicornis*: asterisks; *Cladonietum foliaceae* (*C. foliacea* facies: full inverse triangles; *C. furcata* facies: empty triangles; *C. rangiformis* facies: full triangles); *Cladonietum rei* (*C. polycarpoides* facies: empty squares; *C. rei* facies: full squares; *C. coccifera* facies: empty inverse triangles); *Cladonia cariosa-Cladonia peziziformis* community (*C. cariosa* facies: full dots; *C. peziziformis* facies: empty dots).

Abb. 6. PCA streudiagramm von floristischen **a)** und ökologischen **b)** Variablen. *Pycnothelio-Cladonietum cervicornis*: Sternchen; *Cladonietum foliaceae* (*C. foliacea* facies: gefüllte umgekehrte Dreiecke; *C. furcata* facies: leere Dreiecke; *C. rangiformis* facies: gefüllte Dreiecke); *Cladonietum rei* (*C. polycarpoides* facies: leere Quadrate; *C. rei* facies: gefüllte Quadrate; *C. coccifera* facies: leere umgekehrte Dreiecke); *Cladonia cariosa-Cladonia peziziformis* community (*C. cariosa* facies: gefüllte Punkte; *C. peziziformis* facies: leere Punkte).

4. Discussion

4.1 Overview in a European perspective

The identified lichen communities are well diversified from a floristic point of view, but are often ecologically quite similar. This is coherent with the sampling procedure of considering only plant communities of *Thero-Airion*, which are ecologically well characterized as xerophilous and oligotrophic (POTT 1992), and acidophilous (as measured in a previous work by GHEZA et al. 2018a), although slight ecological differences, probably due to the occurrence of differences at a microhabitat level, have been disclosed in some cases.

In the surveyed lichen communities, only squamulose or fruticose species belonging to genus *Cladonia* were found. This is quite atypical if compared to lichen communities surveyed in open acidic dry habitats of Central Europe, where also several crustose species occur (cf. DREHWALD 1993, PAUS 1997, BÜLTMANN 2005a, b, KETNER-OOSTRA & SÝKORA 2008). In the study area, such situation occurs only in *Thero-Airion* grasslands, since in *Corynephorion* grasslands also other fruticose genera (i.e. *Cetraria*, *Stereocaulon*) were recorded by GHEZA et al. (2016), while in heathlands and in calcareous grasslands also some crustose species occur (Gheza et al. in prep.).

In a comparison at local level, it can be highlighted that some lichen communities hosted by *Corynephorion* grasslands in the Po Plain, i.e. the *Stereocauletum condensati*, the *Cladonia portentosa*-dominated *Cladonietum mitis* and the *Cetraria aculeata* community

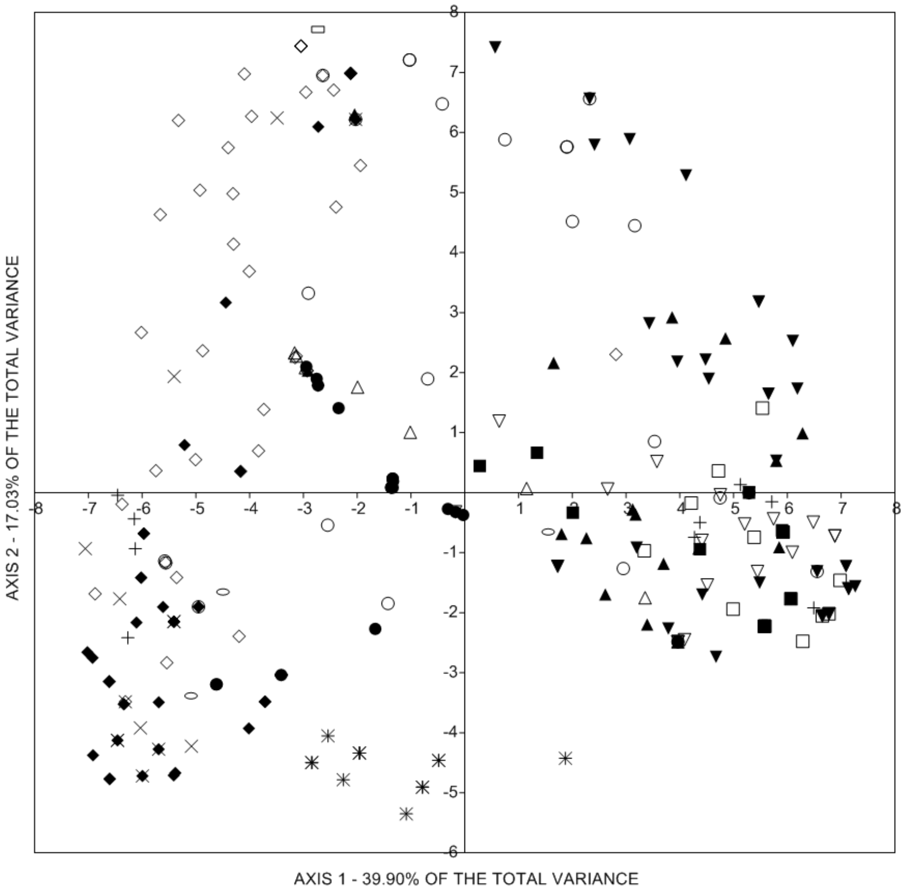

Fig. 7. PCA scatterplot of floristic variables sorted per sites. The sites are represented by full dots (1), empty dots (2), full squares (3), empty squares (4), full triangles (5), empty triangles (6), full inverted triangles (7), empty inverted triangles (8), vertical lines (9), + crosses (10), empty diamonds (11), horizontal lines (12), empty ovals (13), full diamonds (14), crosses (15), asterisks (16).

Abb. 7. PCA Streudiagramm von floristischen Variablen sortiert nach Standorten. Die Standorten werden durch vertreten: gefüllte Punkte (1), leere Punkte (2), gefüllte Quadrate (3), leere Quadrate (4), gefüllte Dreiecke (5), leere Dreiecke (6), gefüllte umgekehrte Dreiecke (7), leere umgekehrte Dreiecke (8), vertikale Linie (9), + Kreuze (10), leere Raute (11), horizontal Linie (12), leere Ovale (13), gefüllte Raute (14), x Kreuze (15), Sternchen (16).

(GHEZA et al. 2016), are not found in *Thero-Airion* grasslands in the same area. This could be mainly due to the high specificity of their character species, *Stereocaulon condensatum* and *Cetraria aculeata*, for sand dunes (KETNER-OOSTRA & SÝKORA 2008, KETNER-OOSTRA et al. 2012), while *C. portentosa* can rarely occur in *Thero-Airion* grasslands, but it never dominates lichen vegetation there. On the other hand, communities of the *Cladonion rei* seem to be more widespread in *Thero-Airion* rather than in *Corynephorion* grasslands (cf. GHEZA et al. 2016). Although these communities are generally regarded as ruderal, this is not always a symptom of degradation: in fact, some lichen communities attributed to this alliance can be in some cases dominated by species of high conservation value, i.e. *Cladonia peziziformis*, *C. polycarpoides*. Furthermore, under a chorological perspective, the arctic element is more represented in *Corynephorion* than in *Thero-Airion* lichen communities (cf. GHEZA et al. 2016), with the latter showing a stronger temperate to mediterranean character.

A comparison at broader level focused on *Thero-Airion* grasslands is more difficult. Unlike the lichen communities of *Corynehorion* grasslands, about which much literature was available (GHEZA et al. 2016), most of the available phytosociological analyses of *Thero-Airion* considered only vascular plants and, sometimes, the lichen component inside relevès focused on vascular plants (KORNECK 1974, CLEMENT & TOUFFET 1977, DELPECH 1977, FRILEUX 1977, PETIT 1977, ROYER 1977, WATTEZ 1977, WATTEZ et al. 1977, FOUCAULT 1999), while specific relevès of the lichen communities at an appropriate scale were not realized.

The *Pycnothelio-Cladonietum cervicornis* in the study sites is rare, dominated by *C. pulvinata* and void of any other character species (cf. PAUS 1997, GÜNZL 2005). This is in line with PAUS (1997), who described a facies of the *Pycnothelio-Cladonietum cervicornis* dominated by *C. pulvinata* from Central European heathlands, while DORT et al. (2017) placed some relevés dominated by this species in the *Cladonietum zopfii*, which is absent from Italy. However, this community occurs within richer and more structured stands in *Calluna* heathlands in the same area (Gheza et al. in prep.; cf. GHEZA et al. 2018b) and its sporadic occurrence in *Thero-Airion* grasslands is probably due to the proximity of heathlands to the grassland sites where it was recorded.

The *Cladonietum foliaceae* includes many of the character species cited by PAUS (1997), GÜNZL (2005) and GHEZA et al. (2016). The two facies dominated by *C. furcata* and *C. rangiformis* were attributed respectively to subass. *cladonietosum furcatae* and subass. *cladonietosum subrangiformis* by GHEZA et al. (2016) for *Corynephorion* grasslands. The most mature aspect of the latter facies could even be considered as an extremely depleted form of *Cladonietum mitis* where reindeer lichens are absent or rare (cf. the considerations about the affinity of a *C. rangiformis*-dominated community with the *Cladonietum mediterraneae* expressed by COGONI et al. 2011): *Cladonia portentosa* occurs in fact only rarely in *Thero-Airion* grasslands, unlike in *Corynephorion* grasslands of the same area, where a proper *Cladonietum mitis* was recorded by GHEZA et al. (2016).

In disturbed situations, the *Cladonietum rei* is the dominant or the only occurring community. It is generally considered ruderal and euhemerobic (BÜLTMANN 2005b). However it can be considered actually ruderal just under oceanic climate and can develop also in more natural habitats under continental climate (BÜLTMANN 2005b). This is corresponds to the anitrophytism deduced from the spectrum of our relevés and to previous results from the same area (GHEZA et al. 2016). The *C. rei* facies in the study area is often reduced to monospecific stands of the character species, while it occurs in more structured aspects in other areas of Europe (PAUS 1997, GÜNZL 2005, ROLA et al. 2014). Stands with a higher species richness occur in the *C. polycarpoides* and *C. coccifera* facies, although the rare *C. conista* occurs more often in stands dominated by *C. rei* (GHEZA et al. 2018b). A *C. polycarpoides* facies of the *Cladonietum rei* was never reported before, and this species is generally infrequent in lichen vegetation relevés from Central Europe (cf. PAUS 1997, BÜLTMANN 2005a, b, 2006, GÜNZL 2005, DORT et al. 2017). Since *C. rei* was frequently overlooked in the past and is probably more widespread than previously recorded (cf. GHEZA, 2015, 2018a, HAUGHLAND et al. 2018), also the *Cladonietum rei* is likely to be more widespread, probably occurring also in vascular plant communities other than *Thero-Airion* and *Corynephorion* grasslands.

Lichen communities dominated by *C. cariosa* have been reported in the past from calcareous substrates (ANDERS 1936, HAVEMAN & VAN DEN BERG 2007) and communities with high cover values of the same species (but attributed to the *Cladonietum rei*) were reported also from metal-enriched substrates in post-smelting dumps (OSYCZKA & ROLA 2013, ROLA et al. 2014). In contrast, lichen communities dominated by *C. peziziformis* have never been reported in the literature, probably because this species is very rare in Europe (e.g. WIRTH et al. 2013, NIMIS 2016). Due to the compositional and ecological similarities, we considered these two communities as two facies of a yet undescribed community well differentiated from the *Cladonietum rei*. This type of lichen vegetation occurs frequently also in *Calluna* heathlands in the western Po Plain and is currently under further study (Gheza et al. in prep.).

4.2 Importance for conservation and management recommendations

The surveyed terricolous lichen communities are of focal importance for the conservation of many lichen species. As highlighted also by the rarity spectra (Fig. 5), they represent suitable microhabitats for locally (i.e. *C. cariosa*, *C. coccifera*) and nationally (i.e. *C. conista*, *C. peziziformis*, *C. polycarpoides*, *C. portentosa*, *C. pulvinata*) rare species. Although in some cases they can occur in depleted forms, these communities are usually well diversified and therefore valuable for lichen diversity conservation and also useful for the assessment of dry grasslands quality (cf. ROSENTRETER & ELDRIDGE 2002, BÜLTMANN 2005b). Furthermore, since lichen species (and therefore lichen communities) have a broader distribution than vascular plants, the following considerations might be applied to a broader extent than the study area.

Not all lichen communities have a similar conservation value. The lowest value can be attributed to communities dominated by *C. rangiformis* and *C. rei*, which are common and widespread species. *C. rei* was not frequently reported in literature, but recent studies showed that it is common also in areas in which it was not recorded in historical times (GHEZA 2015, 2018a, HAUGHLAND et al. 2018). The conservation values can be inferred of the poleotolerance values (Table 3) and rarity spectra (Fig. 5). Communities with the lowest poleotolerance values are the most typical of natural or semi-natural situations, and thus the most likely to disappear with stronger human disturbances. Rarity spectra supplement the information indicating in which communities the rarest species occur. Following this approach, the lichen communities with conservation priority are the *Pycnothelio-Cladonietum cervicornis*, the *C. polycarpoides* and the *C. coccifera* facies of the *Cladonietum rei* and the *C. cariosa*-*C. peziziformis* community. Most of their character species are indeed nationally rare or very rare (cf. NIMIS 2016), and even accross Europe, e.g. in Germany (WIRTH et al. 2013). The eutrophication index (Table 3) also suggests that some of these communities can be also very sensitive to Nitrogen deposition, which is a major threat to cryptogam communities (BRITTON & FISHER 2010, BOCH et al. 2018a, b).

Some of the communities described here (i.e. the *C. polycarpoides* facies of the *Cladonietum rei* and the facies of the *C. cariosa*-*C. peziziformis* community dominated by the latter species) were never reported before in literature. A rare lichen vegetation dominated by *C. polycarpoides* was mentioned for two Swedish sites by CARLIN & OWE-LARSSON (1994), but it was not described in detail, while *C. peziziformis* was, to our best knowledge, never mentioned at all in terricolous lichen vegetation studies from Europe. Therefore, these two communities in particular deserve attention, since their character species are certainly rare, but also have a wide distribution range across Europe. It should be further noted that

Thero-Airion dry grasslands are very important for these two communities, since they represent the only habitat in which they are known to occur so far. Also *C. pulvinata* is at present extremely rare in Italy (cf. GHEZA et al. 2018b), but stands of the *Pynothelio-Cladonietum cervicornis* dominated by this species have already been reported from Central Europe (PAUS 1997).

Even if almost all lichen communities are represented in both studied river valleys, the *Cladonion arbusculae* communities are more widespread along the Ticino river valley, whereas *Cladonion rei* communities are more widespread along the Sesia river valley (Table 2). This points out a difference between the terricolous lichen biota of the two areas which is difficult to interpret, since the two river valleys have similar features in terms of climate, substrate and vegetation. The "dealpinization" phenomenon could have played a role (i.e. species arrived at low altitudes from the Alps through rivercourses) which already was observed for vascular plants in *Corynephorion* communities in the Ticino river valley (ASSINI et al. 2013). However, due to the differences in the distribution of the lichen communities, conservation priorities can vary from one area to another, focusing on the rarest and richest communities in each site.

The surveyed terricolous lichen communities play an important role in defining the value of the whole habitat represented by *Thero-Airion* dry grasslands (attributed to the Natura 2000 Habitat 6210 in the study area), enhancing and increasing their biodiversity and functionality. In fact, lichens perform several ecosystem functions, provide several ecosystem services (ZEDDA & RAMBOLD 2015) and are important parts of trophic networks (e.g. BOCH et al. 2016). On the other hand, the mere species diversity in lichen communities is already worth of attention, as part of the overall biodiversity.

The loss of both, the *Thero-Airion* grasslands and the lichen communities they host is an issue of conservation concern in the study area, as well as it is for the *Corynephorion* grasslands (ASSINI 2013). However, unlike the *Corynephorion* grasslands, the *Thero-Airion* grasslands have not yet been studied thoroughly in the Po Plain from a phytosociological perspective. Thus, the need for a detailed analysis of the different *syntaxa* included in this alliance is evident, since also vascular plant communities of the *Thero-Airion* include elements of conservation concern in the Po Plain (Assini, unpubl. data).

As stated in the introduction, habitat loss in the study area is mainly due to human disturbance, land reclamation for agricultural purposes and encroachment of invasive exotic woody species (*Robinia pseudoacacia*, *Ailanthus altissima*, *Prunus serotina*).

Both the vascular plant and lichen communities need therefore a proper management to be preserved. The most effective management action to prevent habitat loss in dry grasslands is the recreation of pioneer situations (i.e. bare ground) through mechanical disturbance (KETNER-OOSTRA & SÝKORA 2008, KETNER-OOSTRA et al. 2012, LEPPIK et al. 2013), e.g. sod-cutting and topsoil removal. However, this action should not be realized on wide areas, but on small scattered patches, to respect the natural mosaic of vegetation dynamics occurring in open dry habitats and particularly in the *Thero-Airion* grasslands with different dynamic facies. This is also aimed at offering a diversified situation suitable for lichen communities with different microhabitat requirements. In fact, a vegetation management aimed at keeping a mosaic of pioneer and mature situations can enhance species with different substrate ecology (cf. Fig. 4): bare ground substrates are well suitable for pioneer communities characterized by species such as *C. cariosa*, *C. peziziformis*, *C. polycarpoides* and *C. pulvinata*, while species like *C. coccifera* and *C. portentosa* require more stable situations and can develop better on more organic soils, as found in the communities which they characterize. The removal of seedlings and young woody plants should accompany mechanical disturbance (KETNER-OOSTRA et al. 2012, ASSINI 2013) to slow down succession.

Overall, considering that the major threats for *Thero-Airion* grasslands in the study area are practically similar to the ones of *Corynephorion* grasslands, compareable management techniques (cf. GHEZA et al. 2016) can be suggested.

Erweiterte deutsche Zusammenfassung

Einleitung – Gesellschaften des *Thero-Airion* wachsen auf trockenen, meist sandigen Böden in atlantischen bis mitteleuropäischen Klimaregionen und sind geprägt von einjährigen Kräutern und Gräsern, sowie Moosen und Flechten. Sie haben einen hohen Erhaltungswert, da sie in den vergangenen Jahrzehnten einen enormen Flächenverlust erlitten haben. Besonders die Intensivierung und die Nutzungsaufgabe der extensiven Beweidung haben dazu beigetragen.

Das Untersuchungsgebiet, die zentral-westlichen Poebene, bezeichnet einerseits die südliche Grenze des atlantisch-europäischen Verbreitungsgebietes und andererseits die nördliche Grenze des mediterranen Verbreitungsgebietes der *Thero-Airion*-Gesellschaften. Dies bedingt eine besondere Artenzusammensetzung aus Gefäßpflanzen mit unterschiedlichen Chorologien. *Thero-Airion*-Gesellschaften kommen im Untersuchungsgebiet vor allem entlang der Flusstäler auf sauren Substraten vor, also entlang der Flüsse Sesia und Tessin. Das Vorkommen von terricolen Flechtengesellschaften unterstreicht noch mehr den Schutzwert der *Thero-Airion*-Gesellschaften im Untersuchungsgebiet und dies besonders, da die Poebene eines der am stärksten vom Menschen veränderten und verschmutzten Gebiete Italiens ist. Zum Schutz dieser Vegetationstypen und der Entwicklung geeigneter Pflegepläne sind deshalb Informationen zu Verbreitung und Artenzusammensetzung unerlässlich.

Das Ziel dieser Studie ist daher die phytosoziologische Untersuchung und Charakterisierung der terricolen Flechtengesellschaften in Trockenrasen des Thero-Airion. Deshalb 1) klassifizierten wir die Vegetationsaufnahmen anhand bestehender phytosoziologischer Einheiten des *Thero-Airion*, 2) charakterisierten die Artenzusammensetzung und Ökologie der unterschiedlichen Flechtengesellschaften im Untersuchungsgebiet und 3) untersuchten, ob diese Gesellschaften seltene und/oder gefährdete Arten beherbergen, was ihren Erhaltungswert weiter erhöhen würde. Darüber hinaus diskutierten wir Maßnahmen zum Schutz der *Thero-Airion*-Trockenrasen.

Material und Methoden – Das Untersuchungsgebiet umfasst 16 Standorte mit flechtenreichen *Thero-Airion*-Gesellschaften entlang der Flüsse Tessin (9 Standorte) und Sesia (7 Standorte) (Tab. 1, Abb. 1). Das Klima des Untersuchungsgebietes ist kontinental, das Bioklima gemäßigt.

Wir führten 288 Vegetationsaufnahmen mit einer Fläche von 30 cm × 30 cm nach der Methode von BRAUN-BLANQUET (1928) von Mai bis Juni 2016 und 2017 durch. Die Auswahl der Flächen folgte einem phytosoziologischen Ansatz: zunächst wurden floristisch homogene Einheiten identifiziert, um danach an zufällig gewählten Stellen Vegetationsaufnahmen durchzuführen. Die Vegetationsaufnahmen wurden dann manuell nach den Deckungswerten der Charakterarten sortiert. Wir berechneten gewichtete Spektren von Wuchsformen, Chorologie, Substratökologie, pH-Wert des Substrats, Lichtanforderungen, Feuchtigkeitsanforderungen, Eutrophierungstoleranz, Toxitoleranz und Seltenheit in der Poebene und analysierten den Datensatz unter Einbezug dieser Werte mit multivariaten Tests (PCA). Diskriminierende Werte biologischer, ökologischer und chorologischer Merkmale zur Unterscheidung der Flechtenvegetationstypen wurden mithilfe von Kruskal-Wallis-Tests evaluiert.

Ergebnisse – Wir konnten unsere 288 Vegetationsaufnahmen vier Flechtengesellschaften zuordnen. Innerhalb dieser vier Gesellschaften unterschieden wir zusätzlich neun Dominanzfazies. Alle Gruppen unterschieden sich aus floristischer und ökologischer Sicht signifikant.

Das *Pycnothelio-Cladonietum cervicornis* ist eine Pioniergesellschaft, die von *Cladonia pulvinata* dominiert wird. Sie ist sehr selten in *Thero-Airion*-Trockenrasen zu finden und kommt öfter in *Calluna*-Heiden des Untersuchungsgebietes vor.

Das *Cladonietum foliaceae* ist die am weitesten verbreitete Flechtegesellschaft im Untersuchungsgebiet. Sie tritt mit drei Fazies auf: die *C. foliacea*-Fazies (die Pionier- und artenreichste Fazies), die *C. furcata*-Fazies (Pionier- bis Zwischenfazies) und die *C. rangiformis* Fazies (weiter fortgeschrittenes Sukkzessionsstadium; oft monospezifische oder artenarme Fazies; vermittelt zum *Cladonietum mitis*).

Das *Cladonietum rei* kommt hauptsächlich in gestörten Bereichen vor, teilweise auch im Mosaik mit anderen Flechtengesellschaften. Im Untersuchungsgebiet konnten drei Fazies unterschieden werden: die *C. polycarpoides*-Fazies (Pionier- bis Zwischenfazies; artenreich), die *C. rei*-Fazies (artenärmer als die vorherige) und die *C. coccifera*-Fazies (Zwischenfazies; artenreich).

Schließlich fanden wir eine Gesellschaft, die sich physiognomisch und ökologisch gut vom *Cladonietum rei* unterscheidet. Sie wird von *C. cariosa* und *C. peziziformis* dominiert. Es konnten zwei Fazies unterschieden werden, jeweils dominiert von einer der beiden Arten. Die hauptsächlich im Tal des Flusses Sesia auftraten.

Die Flechtengesellschaften unterschieden sich hinsichtlich der Wuchsformen der vorkommenden Flechten. Besonders gemäßigte und südliche Elemente prägten die Artengemeinschaften, während nördliche Elemente kaum eine Rolle spielten. Die meisten Flechtengesellschaften konnten als Pioniergesellschaften charakterisiert werden. Nur das *Cladonietum foliaceae* (*C. rangiformis*-Fazies) und die *C. coccifera*-Fazies des *Cladonietum rei* bilden ein fortgeschritteneres Sukkzessionsstadium. Die Analyse der mittleren ökologischen Zeigerwerte (Tab. 3: pH-, L-, H-, N) zeigten eine eher homogene Situation: saure bis subneutrale Böden mit mittleren Nährstoffverhältnissen unter lichten Bedingungen des Offfenlands. Mittlere Toxitoleranzwerte (Tab. 3: P) deuten auf eine moderate bis starke Präferenz der Flechten für qualitativ hochwertige Lebensräume hin. Der Anteil seltener Arten ist in den meisten der untersuchten Gesellschaften hoch (>70 %). Die Gesellschaften mit dem höchsten Anteil seltener Arten waren das *Pycnothelio-Cladonietum cervicornis*, das *Cladonietum rei* (*C. polycarpoides*-Fazies) und die *Cladonia cariosa-Cladonia peziziformis*-Gesellschaft. Alle berücksichtigten biologischen, ökologischen und chorologischen Merkmale trugen zur Differenzierung der Gesellschaften bei. Die Streudiagramme (PCAs, Abb. 6) visualisieren zudem die Unterschiede der Artenzusammensetzungen der Flechtengesellschaften (Abb. 6a), während diese ökologisch sehr ähnlich erscheinen (Abb. 6b).

Diskussion – Die vorkommenden Flechtengesellschaften sind floristisch gut differenziert, aber ökologisch sehr ähnlich. Dies spiegelt unser Stichprobenverfahren wider, bei dem nur Pflanzengesellschaften des *Thero-Airion* berücksichtigt wurden. Unterschiede zwischen den vorkommenden Gesellschaften sind wahrscheinlich auf Unterschiede auf Mikrohabitatebene zurückzuführen.

Das *Pycnothelio-Cladonietum cervicornis* ist im Untersuchungsgebiet sehr selten, während die anderen Gesellschaften mehr oder weniger weit verbreitet sind. Das *Cladonietum foliaceae* umfasst viele der in der Literatur genannten Charakterarten und ist weit verbreitet, insbesondere unter ungestörten Bedingungen. In gestörten Situationen ist das *Cladonietum rei* die dominante oder die einzige vorkommende Gesellschaft. Ein von *C. cariosa* dominierte Gesellschaft war zuvor vorwiegend von kalkhaltigen Substraten beschrieben. Flechtengesellschaften, die von *C. peziziformis* dominiert werden, sowohl die *C. polycarpoides*-Fazies des *Cladonietum rei*, fehlen hingegen gänzlich in der Literatur.

Da zahlreiche seltene Flechtenarten in den Thero-Airion-Trockenrasen geeignete Mikrohabitate finden, spielen diese Vegetationstypen eine zentrale Rolle für den Erhalt von Flechtenarten. Um den Verlust dieser schützenswerten Lebensräume zu stoppen und die charakteristischen Arten zu erhalten, ist ein angemessenes Management erforderlich. Die effektivste Maßnahme, um den Lebensraumverlust aufzuhalten und neuen Lebensraum für Pioniergesellschaften zu schaffen sind mechanische Störungen. Diese sollten in einem Mosaik mit späteren Sukkzessionsstadien angelegt werden.

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Author contribution statement

G.G. selected the study sites, planned the sampling design, carried out the relevés on the field and the statistical analyses, identified lichen and bryophyte species, wrote the manuscript. M.B. carried out the relevés on the field, identified vascular plant species, contributed to the statistical analyses, revised the manuscript. S.A. contributed to the sampling design, carried out the relevés on the field, identified vascular plant species, integrated and revised the manuscript.

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