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ECOLOGY AND CONSERVATION OF BRYOPHYTES

The bryophyte flora of six gypsum outcrops in the Northern Apennines (Nature 2000 Network, Emilia Romagna Region, Italy)

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Abstract
A study of the bryophyte flora of the gypsum outcrops in six sites of the Nature 2000 Network of the Emilia-Romagna Region was conducted in order to contribute to the conservation of the biodiversity of these sites. Subsequently, the main ecological and chorological aspects of the areas were analyzed, and with this information a series of target species was identified as indicators of the conditions of naturality or of progressive anthropization and deterioration of the areas.

Keywords: *Bryoflora, gypsum outcrops, Nature 2000 Network, Emilia-Romagna, Italy*

Introduction

The Messinian "Gypsum-Sulphurous Bank" is the most extensive gypsum formation in the Italian peninsula. This bank crops out occasionally from Piedmont to Calabria and even in Sicily (Ricci Lucchi 1994). The Messinian gypsum outcrops are scattered along the northern Apennines. In this region the gypsum rock had a long history of human use – especially as building material – and abuse, which led to the need of protection policies to prevent further degradation.

The Gypsum karstic ecosystems are of remarkable naturalistic interest because of their high environmental heterogeneity (Aleffi & Silenzi 2000). The physical and chemical features of gypsum influence not only the geomorphologies, but also – directly and indirectly – the biological components. The environmental heterogeneity (at coarse and fine scale) contributes to maintaining species diversity (Zedler & Zedler 1969; Ricklefs 1977; Grime 1979; Tilman 1982; Palmer & White 1994; Brady & Weil 2002), and the chemical composition plays an important role in plant recruitment because of the limited nutrient availability, and excess of Ca, Mg, and S (Guerrero-Campo et al. 1999; Escudero et al. 1999, 2000; Rubio & Escudero 2000; Pe 2004; Palacio et al. 2006). The result of these driving forces on the vegetation is a set of peculiar plant communities.

In Emilia-Romagna, karstic areas were recently included in the project Life + Natura "*Gypsum*" (Gypsum LIFE08 NAT IT 000369), with the contribution of the LIFE financial instrument of the European Community (Life Gypsum 2010), to provide strict protection of "Caves not open to the public" (8310* habitat) and to improve management of other threatened habitats (6110*, 8210).

In the context of this project, the bryophyte flora of the gypsum outcrops in six sites of the Nature 2000 Network of the Emilia Romagna Region was studied, with the goal of using the information in efforts to conserve the biodiversity of this area, which is characterized by conditions of anthropization and by areas of high naturalistic value. The surveys and samplings were done in the following areas (Figure 1)

SIC IT4030009	Gessi Triassici
SIC IT4030017	Cà del Vento, Cà del Lupo, Gessi di Borzano
SIC IT4050027	Gessi di Monte Rocca, Monte Capra and Tizzano
SIC IT4050001	Gessi Bolognesi, Calanchi dell'Abbadessa
SIC IT4070011	Vena del Gesso Romagnola
SIC IT4090001	Onferno

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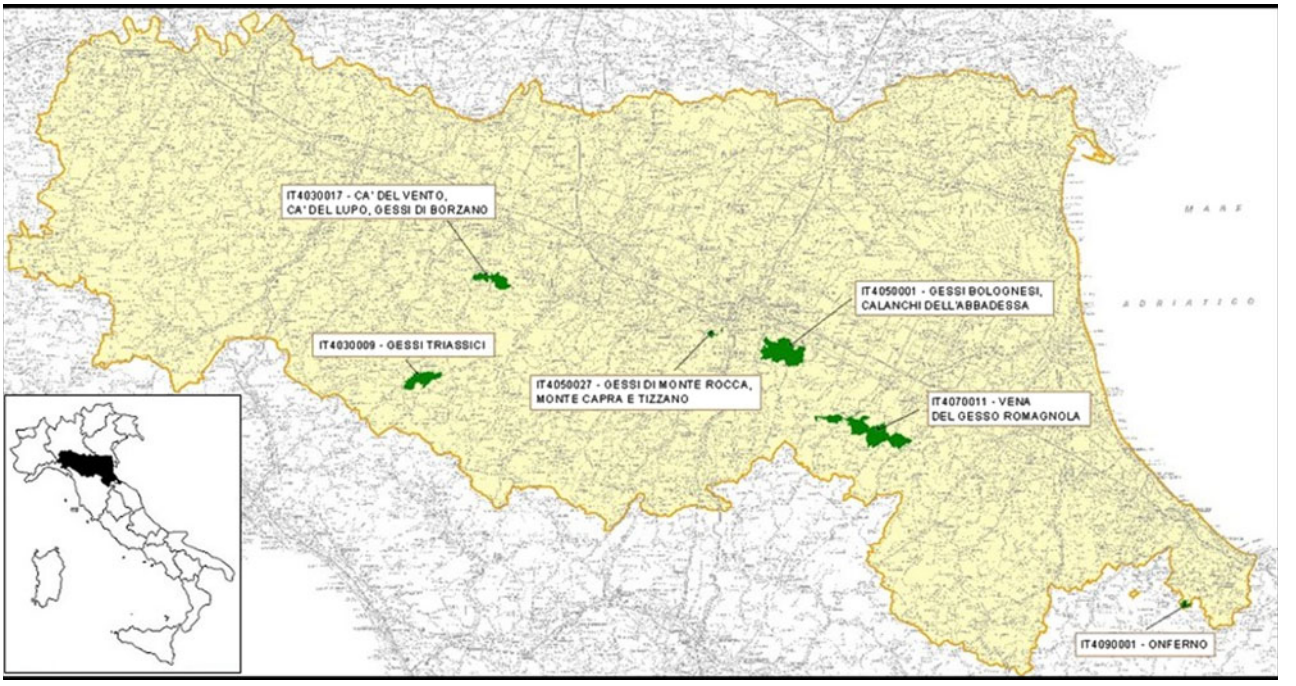

Figure 1. The six sites of the Nature 2000 Network of the Emilia-Romagna Region.

In particular, the studies concentrated on sectors of these areas where the following priority habitats are found

6110*	Rupicolous calcareous or basophilic grasslands of the Alysso-Sedion albi.
8210	Calcareous rocky slopes with chasmophytic vegetation.
8310*	Caves not open to the public

Materials and methods

Research gave first priority to the bryophyte flora that characterizes the habitats studied, inasmuch as these areas have for some time been known for the rarity and biogeographical interest of their floristic and vegetational elements (Zangheri 1959).

In order to formulate ecological characterizations of the individual areas, parameters of light, temperature, moisture, and pH value of the substratum were identified, processed, and attributed, with values ranging from 1 to 9. Light values $L = 1$ indicate species that live in scantly illuminated environments such as hollows and caves, while values close to $L = 9$ were attributed to species that live in strongly sunlit areas. For temperature, the values range from $T = 1$ for species that are indicators of a cold climate to values of $T = 9$ that characterize species that are indicators of extreme aridity; concerning moisture, the descriptors range from species that live in conditions of dryness ($M = 1$) to species that colonize permanently in humid environments (such as water courses and waterfalls) ($M = 9$); and finally, the values about the nature and pH of the substratum go from values of $R = 1$, an indicator of strong acidity, to values of $R = 9$, for species that live in strongly basic substrata.

In addition, we took into consideration for each species the chorological elements drawn from Düll (1983, 1984, 1985), grouped into categories according to Sérgio et al. (1994), and applied to our bryofloristic categories. The chorological data from the individual areas were compared with each other in order to ascertain the role that latitudinal and altitudinal factors, alongside the ecological factors already identified, can play in the distribution of the species.

On the basis of this information, it was possible to identify a series of target species, indicators of the conditions of naturality or progressive anthropization and deterioration of the areas studied, and in this way proceed to an ecological characterization of the areas studied.

The identification and classification of the species were done on the basis of the *Flora dei Muschi d'Italia* (Cortini Pedrotti 2001, 2005), while the *Check-list of the Hornworts, Liverworts and Mosses of Italy* by Aleffi et al. (2008) was the reference for nomenclature and species distribution, recently available online as a database (Martellos et al. 2013). For the identification and attribution of the ecological parameters of the individual species, we took as reference the indices of Hellenberg, modified and adapted to bryophytes by Düll (1991). Finally, further observations on the life strategies and the ecology of each species were drawn from Dierβen (2001).

Results

Table I summarizes the results of the explorations conducted in the six sites. Specimens were collected between the spring of 2010 and the summer of 2012, and principally concerned the gypsum outcrops and the areas with the priority habitats listed above.

During the explorations, a total of 137 bryophyte *taxa* were noted (23 liverworts and 114 mosses), of which 9 species (3 liverworts and 6 mosses) are new for the Emilia-Romagna Region: *Cephaloziella calyculata, Leiocolea bantriensis, Riccia sorocarpa, Crossidium crassinerve, Didymodon asperifolius, Mnium spinulosum*, *Rhynchostegium rotundifolium*, *Scorpidium scorpioides*, *Tortula cuneifolia* (Aleffi et al. 2008). These species, as well as other mosses recently found (Puglisi et al. 2013), contribute to increase the knowledge on the Italian bryophyte flora. The contingent of *taxa* noted represents over 10% of the Italian bryophyte flora, a fairly significant fact, considering the limited extension of the area explored and the particular ecological and edaphic conditions of the territory. The asterisk (*) indicates the new species for Emilia-Romagna.

Alongside the list of species and their distribution in the six sites explored, Table I indicates the values of the ecological parameters examined and the chorological elements.

Before moving on to overall ecological and chorological considerations, we offer here some observations about the individual sites.

Gessi Triassici (SIC IT4030009)

The site covers a section of about 10 km of the high Val Secchia along which the river has cut deeply into a vast formation of Triassic gypsums that currently form the steep white sides of the valley bottom. Due to the high solubility of the gypseous rock, widespread superficial karstic phenomena (dolines, gorges, and other forms of erosion) and underground phenomena (caves, sink-holes, and resurgences) geomorphologically characterize vast sectors of the site.

Among the outcrops studied, the triassic gypsums are the furthest west, in the shelter of a series of mountain ranges of the Tuscan–Romagnan Apennines, and these two aspects significantly condition the bryophyte flora of this site.

The soil pH ($R = 6$) is the lowest of the sites explored. In fact, next to the species with strong basophilous needs such as *Trichostomum crispulum, Tortella densa, Scorpidium scorpioides, Gymnostomum calcareum,* and *Distichium inclinatum*, species were found that grow on very acidic substrata, such as *Scapania nemorea, Bartramia pomiformis,* and *Lophozia ventricosa*. Probably this is related to the thick stratum of humus that covers the gypseous rocks, giving the superficial strata a more acidic pH that influences the colonization of the bryophytes. It is important to note the values of light ($L = 5$), temperature ($T = 4$), and moisture ($M = 5$) that indicate the presence of prevalently sciophilous species, indicators of climatic conditions ranging from cool to cold in the upper montane or the temperate-boreal belts. In terms of chorology, temperate species prevail, with 46% of the total of the *taxa* reported. The sub-Mediterranean component is entirely absent, while there is a significant presence of a group of species of oceanic tendency, with 24% of the total, to which should be added the information on the species of boreal tendency, which in the area reach the considerable 30%.

Cà del Vento, Cà del Lupo, Gessi di Borzano (SIC IT4030017)

The site is located at altitudes between 160 and 525 m, around the gypseous outcrops of Messiniano, known as Gessi Reggiani.

The light index ($L = 6$) of the site indicates characteristics of full but indirect light, only rarely with conditions of full shadow. The species that grow here respond to characteristics that are intermediate between these two conditions. The temperature, in consideration of the low altitude, has a value of 4.5, which indicates conditions of moderate heat. Moisture as well has average values ($M = 4.5$), which characterize cool sites that are also subject to long periods of summer aridity. Concerning how the species react to the soil pH, there are no markedly basophile species, except for the one exclusively gypsophilous species, *Tortula revolvens*, which was found on the sunlit spurs of Castello di Borzano. Regarding the chorological aspect, alongside the percentage of temperate species (43%), it is noteworthy that the sub-Mediterranean–suboceanic component presents the significant percentage of 37%, which in any case indicates ecological and climatic conditions typical of the area. In addition to these values, there is a contingent of species with boreal tendency that have values around 18.5% and that in any case indicate the presence of sciophilous environments in which cold currents from the subterranean karstic system significantly influence the flora of the area.

Gessi di Monte Rocca, Monte Capra, and Tizzano (SIC IT4050027)

The area is located near Bologna, between the Lavino Torrent and the Reno River. The gypseous outcrops in the site are very important because of an extremely diversified flora and fauna, strictly linked

Table I. List of species and their distribution in the six sites explored, values of the ecological parameters examined, and the chorological elements.

Taxa	IT4030009	IT4030017	IT4050001	IT4050027	IT4070011	IT4090001	*L*	*T*	*M*	*R*	Chorological elements
Hepatics											
Cephaloziella baumgartneri Schiffn.	x	x	x	x		x	8	5	2	4	Oc-med-mont
**Cephaloziella calyculata* (Durieu & Mont.) Müll. Frib.	x						8	5	3	5	Oc-med
Cephaloziella divaricata (Sm.) Schiffn.			x				9	3	2	4	Temp
Cephaloziella hampeana (Nees) Schiffn.			x				8	4	3	3	N.suboc
Cephaloziella rubella (Nees) Warnst.			x				8	3	3	3	N.temp
Conocephalum conicum (L.) Dumort.	x		x				7	3	7	7	Subbor-mont
Fossombronia caespitiformis (De Not.) ex. Rabenh.			x				7	9	5	8	Oc-med
Jungermannia atrovirens Dumort.			x				5	2	7	8	w. temp-mont/dealp
Jungermannia gracillima Sm.			x				8	4	7	3	w. temp
**Leiocolea bantriensis* (Hook.) Jörg.		x	x				5	2	8	8	Bor-dealp
Lophocolea bidentata (L.) Dumort.			x				7	3	6	5	w. temp
Lophocolea heterophylla (Schrad.) Dumort.	x		x				4	3	4	3	Temp
Lophozia sudetica (Nees ex Huebener) Grolle			x				9	3	7	2	Bor-mont
Lophozia ventricosa (Dicks.) Dumort.	x		x				5	3	6	3	Bor
Pellia endiviifolia (Dicks.) Dumort.			x	x			6	4	8	9	s. temp
Pellia epiphylla (L.) Corda	x		x				6	4	8	3	w. temp
Plagiochila porelloides (Torrey ex Nees) Lindenb.	x		x				6	3	4	7	Subbor-mont
Porella platyphylla (L.) Pfeiff.		x	x	x		x	7	7	2	7	w. temp
Radula complanata (L.) Dumort.			x			x	7	3	5	7	w. temp
Reboulia hemisphaerica (L.) Raddi	x		x		x		7	4	7	7	Submed-suboc-mont
**Riccia sorocarpa* Bisch.					x		9	8	5	5	Temp
Scapania aequiloba (Schwägr.) Dumort.			x				5	2	6	8	Bor-mont/dealp
Scapania nemorea (L.) Grolle	x						4	4	5	2	w. temp-mont
Mosses											
Acaulon muticum (Hedw.) Müll. Hal.					x		9	5	7	5	Temp
Aloina aloides (Koch ex Schultz) Kindb.		x					7	6	4	9	Submed
Amblystegium serpens (Hedw.) Schimp.					x		5	5	4	6	Temp
Anomodon viticulosus (Hedw.) Hook. & Taylor	x	x	x			x	4	3	4	8	Temp
Atrichum undulatum (Hedw.) P.Beauv.	x						6	2	6	4	Temp
Barbula convoluta Hedw.			x				8	6	3	6	Temp
Barbula unguiculata Hedw.	x	x	x		x	x	7	6	2	7	Temp
Bartramia pomiformis Hedw.	x						5	3	5	4	bor (-mont)
Brachytheciastrum velutinum (Hedw.) Ignatov & Huttunen			x				5	3	4	6	Temp
Brachythecium rutabulum (Hedw.) Schimp.			x				5	4	4	6	Temp
Brachythecium salebrosum (Hoffm. ex F.Weber & D.Mohr) Schimp.					x		6	4	4	5	Subbor
Bryum argenteum Hedw.			x	x	x		7	5	4	6	Temp
Bryum ruderale Crundw. & Nyholm			x				7	8	3	7	suboc
Campyliadelphus chrysophyllus (Brid.) R.S.Chopra	x						9	2	2	8	Bor
Campylophyllum calcareum (Crundw. & Nyholm) Hedenäs			x				4	5	4	8	Suboc
Campylophyllum halleri (Hedw.) M.Fleisch			x				7	2	6	9	bor-mont/dealp
Cirriphyllum crassinervium (Taylor) Loeske & M.Fleisch.			x				4	5	5	8	subarc-subalp
**Crossidium crassinerve* (De Not.) Jur.					x		9	8	2	8	submed

Crossidium squamiferum (Viv.) Jur.					x		9	8	1	8	submed
Ctenidium molluscum (Hedw.) Mitt.	x	x	x	x	x	x	6	4	4	8	temp
Dichodontium pellucidum (Hedw.) Schimp.					x		5	3	7	7	bor-mont
Dicranella varia (Hedw.) Schimp.					x		8	7	7	8	temp
Didymodon acutus (Brid.) K. Saito			x		x		9	5	1	8	submed
**Didymodon asperifolius* (Mitt.) H.A. Crum, Steere & L.E. Anderson		x	x	x			9	1	7	9	arc-alp
Didymodon fallax (Hedw.) R.H. Zander			x	x	x		9	8	2	7	temp
Didymodon luridus Hornsch.		x	x		x	x	9	6	2	8	submed
Didymodon tophaceus (Brid.) Lisa			x				7	3	7	7	temp
Didymodon vinealis (Brid.) R.H. Zander		x	x		x	x	9	6	2	7	submed
Distichium capillaceum (Hedw.) Bruch & Schimp.			x				4	3	5	8	bor-mont
Distichium inclinatum (Hedw.) Bruch & Schimp.	x						5	1	6	9	subarc-subalp
Encalypta rhaptocarpa Schwägr.			x				6	2	6	9	subarc-subalp
Encalypta streptocarpa Hedw.	x	x	x	x	x		5	2	5	8	subbor (-mont)
Encalypta vulgaris Hedw.					x		9	5	4	8	submed
Eucladium verticillatum (With.) Bruch & Schimp.			x		x		5	7	7	9	submed (-mont)
Eurhynchiastrum pulchellum (Hedw.) Ignatov & Huttunen			x				6	4	4	6	subbor-mont
Eurhynchium striatum (Hedw.) Schimp.	x	x					5	6	5	6	suboc
Fissidens adianthoides Hedw.			x				4	3	8	7	subbor
Fissidens crassipes Wilson ex Bruch & Schimp.			x				4	6	8	8	suboc-submed
Fissidens dubius P.Beauv			x		x		4	4	4	8	temp-mont
Fissidens exilis Hedw.			x	x			4	5	6	5	temp
Fissidens osmundoides Hedw.			x				4	2	8	5	subarc-subalp
Fissidens serrulatus Brid.	x		x	x	x		4	4	4	8	oc-submed
Fissidens taxifolius Hedw.			x				5	4	6	7	temp
Funaria hygrometrica Hedw.		x			x		8	6	6	6	temp
Gymnostomum calcareum Nees & Hornsch.	x		x		x		4	7	5	9	submed-mont
Homalothecium lutescens (Hedw.) H. Rob.					x		9	4	2	8	temp
Homalothecium sericeum (Hedw.) Schimp.	x	x			x	x	8	3	2	7	temp
Hypnum cupressiforme Hedw. var. *cupressiforme*	x	x	x	x	x		5	4	4	4	temp
Hypnum cupressiforme Hedw. var. *lacunosum* Brid.	x	x	x	x	x	x	9	4	2	6	temp
Hypnum vaucheri Lesq.					x		8	1	3	8	bor-mont
Isothecium alopecuroides (Lam. ex Dubois) Isov.			x				5	4	5	6	temp
Kindbergia praelonga (Hedw.) Ochyra				x	x		6	4	6	5	temp
Lescuraea mutabilis (Brid.) Lindb. ex I.Hagen					x		8	2	5	3	temp-mont
Leskea polycarpa Hedw.			x				7	5	4	7	temp
Microbryum davallianum (Sm.) R.H. Zander					x		8	5	6	6	submed
Microeurhynchium pumilum (Wilson) Ignatov & Vanderp.		x	x		x		3	7	5	8	suboc-submed
Mnium hornum Hedw.			x				5	3	6	3	n.suboc
**Mnium spinulosum* Bruch & Schimp.	x						5	7	5	6	subkont-mont
Mnium stellare Hedw.					x		4	3	5	7	bor-mont
Neckera complanata (Hedw.) Huebener	x		x				4	3	4	7	temp
Neckera crispa Hedw.	x		x	x			3	3	4	7	temp-mont
Orthotrichum rupestre Schleich. ex Schwägr.						x	8	2	3	6	n.suboc-mont
Oxyrrhynchium hians (Hedw.) Loeske			x				7	4	5	7	temp
Oxystegus tenuirostris (Hook. & Taylor) A.J.E. Sm.					x		8	7	6	6	suboc-mont
Plagiomnium ellipticum (Brid.) T.J. Kop.	x	x					3	2	7	3	bor

Table I. *(continued)*

Taxa	IT4030009	IT4030017	IT4050001	IT4050027	IT4070011	IT4090001	*L*	*T*	*M*	*R*	Chorological elements
Plagiomnium rostratum (Schrad.) T.J. Kop.			x				4	3	6	8	Temp
Plagiomnium undulatum (Hedw.) T.J. Kop.			x				4	3	6	6	temp
Plasteurhynchium striatulum (Spruce) M.Fleisch.					x		7	8	4	6	Suboc
Pottiopsis caespitosa (Bruch ex Brid.) Blockeel & A.J.E.Sm.					x		8	8	2	9	oc-med
Pseudocrossidum revolutum (Brid.) R.H. Zander					x		7	6	3	8	oc-submed
Pseudoleskeella nervosa (Brid.) Nyholm						x	7	4	5	6	bor-mont
Pseudoscleropodium purum (Hedw.) M.Fleisch.	x		x		x		6	4	4	5	temp
Ptychostomum capillare (Hedw.) D.T.Holyoak & N.Pedersen	x		x	x	x		5	6	5	6	Temp
Ptychostomum creberrimum (Taylor) J.R.Spence & H.P.Ramsay					x		6	2	6	7	bor
Ptychostomum donianum (Grev.) D.T.Holyoak & N.Pedersen			x				4	6	4	6	oc-med
Ptychostomum imbricatulum (Müll. Hal) D.T.Holyoak & N.Pedersen		x	x		x		8	3	5	6	temp
Ptychostomum pallens (Sw.) J.R.Spence			x		x		7	3	7	7	bor
Ptychostomum pallescens (Schleich. ex Schwägr.) J.R.Spence					x		7	4	4	7	temp
Ptychostomum torquescens (Bruch & Schimp.) Ros & Mazimpaka					x		8	6	3	7	submed-suboc
Rhizomnium punctatum (Hedw.) T.J.Kop.			x				3	3	6	4	n.suboc
Rhynchostegiella tenella (Dicks.) Limpr.		x	x			x	4	5	3	8	submed-suboc
Rhynchostegium megapolitanum (Blandow ex F.Weber & D.Mohr) Schimp.		x		x		x	8	6	2	6	submed
**Rhynchostegium rotundifolium* (Scop. ex Brid.) Schimp.				x			4	4	5	7	submed-suboc
Rhytidiadelphus triquetrus (Hedw.) Warnst.		x					7	3	4	5	subbor
Schistidium apocarpum (Hedw.) Bruch & Schimp.					x		4	2	3	7	temp
**Scorpidium scorpioides* (Hedw.) Limpr.	x						9	2	8	9	bor
Scorpiurium circinatum (Bruch) M.Fleisch. & Loeske			x		x	x	7	6	4	6	oc-med
Seligeria pusilla (Hedw.) Bruch & Schimp.					x		3	4	5	9	temp-mont
Syntrichia montana Nees					x		9	6	1	8	submed-mont
Syntrichia princeps (De Not.) Mitt.					x		9	6	2	6	oc-submed
Syntrichia ruralis (Hedw) F.Weber & D.Mohr var. *ruralis*		x	x	x	x	x	9	6	2	6	temp
Syntrichia ruralis (Hedw) F.Weber & D.Mohr var. *ruraliformis* (Besch.) Delogne			x		x		1	5	1	7	suboc-submed
Thamnobryum alopecurum (Hedw.) Gangulee	x		x	x		x	4	4	6	7	suboc-submed
Thuidium recognitum (Hedw.) Lindb.	x						5	3	6	6	n.suboc-mont
Timmiella anomala (Bruch & Schimp.) Limpr.					x		5	9	5	5	med
Tortella flavovirens (Bruch) Broth.			x		x		8	5	2	8	suboc-submed
Tortella inclinata (R.Hedw.) Limpr. var. *inclinata*			x		x		9	3	2	8	temp
Tortella inclinata (R.Hedw.) Limpr. var. *densa* (Lorentz & Molendo) Limpr.	x		x				9	2	3	8	bor-mont
Tortella inflexa (Bruch) Broth.			x	x			4	8	3	9	oc-med
Tortella nitida (Lindb.) Broth.			x				8	8	2	7	oc-med
Tortella squarrosa (Brid.) Limpr.		x	x	x	x	x	9	8	2	6	submed
Tortella tortuosa (Hedw.) Limpr.	x			x	x		5	6	4	8	bor-mont
Tortula atrovirens (Sm.) Lindb.			x		x		9	7	1	6	submed
**Tortula cuneifolia* (Dicks.) Turner		x	x				5	8	5	6	suboc-submed
Tortula lindbergii Broth.			x		x		8	5	6	7	temp
Tortula muralis Hedw.	x		x		x	x	8	5	1	7	temp
Tortula muralis Hedw. subsp. *obtusifolia* (Schwägr.) Culm.					x		5	3	5	7	temp-mont
Tortula revolvens (Schimp.) G.Roth		x	x		x		9	8	1	5	submed

Tortula vahliana (Schultz) Mont.					x		5	4	6	7	oc-med
Trichostomum brachydontium Bruch			x		x		8	6	2	8	submed-mont
Trichostomum crispulum Bruch	x	x	x	x	x	x	6	4	6	9	temp-mont
Weissia condensa (Voit) Lindb.					x		9	6	1	9	submed-mont
Weissia controversa Hedw.	x		x		x		7	4	4	6	temp
Weissia rostellata (Brid.) Lindb.					x		7	6	7	5	suboc

to the characteristic microclimates and habitats shaped by the karstic phenomena.

The light ($L = 5$) and the temperature ($T = 4$) values indicate the presence of sciaphilous species that are frequently found in the montane belt and that evidently find here the ecological and climatic conditions favorable for their establishment, even at lower altitudes. The moisture values ($M = 4.5$) mirror those found previously for the Cà del Vento site and indicate the presence of species that grow preferably on moist soils. The data regarding soil pH demonstrate that the species found are more basophilous, probably in relation to the fact that the outcrops in this area are more exposed to sunlight. In terms of chorology, temperate species predominate (56.5%), while about 30% of the species have sub-Mediterranean–oceanic tendencies.

Gessi Bolognesi and Calanchi dell'Abbadessa (SIC IT4050001)

This area extends over the first hillsides south-east of Bologna, between the Savena, Zena, Idice, and Quaderna Torrents, and encloses a composite territory marked by spectacular outcrops of messinian gypsums and the characteristic ravines of the Passo dell'Abbadessa.

Because of the karstic nature of the gypsum, there are numerous dolines, sink-holes, and candle-erosions in these areas. The gypsums are crisscrossed by complex systems of subterranean waters. The gypseous cliffs are covered by reduced and discontinuous vegetation characterized by small herbaceous and aromatic plants adapted to life on rocks. Here and there the plant cover is also composed of thick woods, shrubwoods, and bushes that merge with the outcrops, bounding the areas that are still cultivated (Bertolani Marchetti 1960, 1961). The areas prevalently explored were those of dolines, less exposed and more shaded and the more exposed areas in which the Alysso-Sedion albi association grows, such as in Miserazzano, Novella, and Palestrina (Ferrari 1974).

The site of the Gessi Bolognesi is surely the richest and most interesting from the floristic point of view, because of the extreme diversity of the environments, which conditions a corresponding diversity of microhabitats (Aleffi & Silenzi 2000).

The parameters of light and temperature mirror this extreme diversity of environments that favors the growth of prevalently sciaphilous species ($L = 5$), normally distributed in the montane belt ($T = 4$), but which find in this hilly area not far from the city of Bologna excellent ecological conditions for their development. Concerning moisture, the value $M = 4$ indicates species that prefer locations that are fairly moist but are also subject to long periods of aridity.

Of note in this site are some species that do not grow in the other sites, and which are indicators of a strongly basic substratum, united with conditions of very pronounced moisture, namely *Didymodon tophaceus*, *Gymnostomum calcareum*, and *Eucladium verticillatum* and some species belonging to the *Fissidens* genus that are characteristic of stillicidious environments that are strongly basic and normally present as active components in the travertinous formations of the central-southern Apennines. In this area as well, the one species that strongly characterizes the gypseous outcrops is *Tortula revolvens*.

From the chorological point of view, we must first of all note that this area as well has a strong contingent of temperate species (46%). Species of (sub)-Mediterranean tendency present a relatively low percentage (13.5%), while the contingent of (sub)oceanic species is much more substantial and significant, reaching 19.5%, even more so the (sub) boreal species, at 21% of the species noted in the census. The last two observations are extremely significant and indicative of the markedly mesophilous character of the area of the Gessi Bolognesi. The growth forms of the species are also affected by this environmental variety: alongside a substantial group of chamaephytes, there are also numerous hemicriptophytes, species whose vegetative reproduction relies on over-wintering buds at soil level that are partly covered by surface debris.

Vena del Gesso Romagnola (SIC IT4070011)

After the site of the Gessi Bolognesi, the Vena del Gesso has the greatest number of species. Its particular bulwark-like conformation from NW to SE generates climatic differences in the two slopes. In fact, while the slope exposed to the south-west has subvertical walls with reduced vegetation, a dryer microclimate and greater insolation even in winter, the slope exposed to the north-west has a cooler, more moist, and shaded climate, also because of greater forest cover (Corbetta & Zanotti 1983), which causes modifications and adaptations in the bryophyte cover as well.

In fact, alongside the prevalently sciaphilous plants, there is a substantial group of heliophilous species that have adapted to living in full light and that grow on the more exposed and sunlit slopes. In addition to *Tortula revolvens*, of particular note are *Acaulon muticum, Crossidium crassinerve, C. squamiferum, Didymodon acutus, D. fallax, Syntrichia montana, S. princeps, Tortula squarrosa, Tortella flavovirens, Trichostomum triumphans*, and *Weissia condensa.*

The temperature value ($T = 5$) is also determined by the presence of indicator plants of moderate heat, present in the montane belt, alongside the presence of species adapted to living in xeric environments. The moisture value ($M = 4$) indicates the presence of numerous xeric species.

The data on the chorology of the species, better than others, confirm how the different exposures of the slopes have influenced the distribution and colonization of the species observed. In fact, alongside the substantial number of temperate species (42%), we find a substantial group of species with (sub)-Mediterranean tendency (26%). Also of note is the presence of a discrete number of species with (sub) oceanic tendency (20%) and boreal species (12%).

Onferno (SIC IT4090001)

The Onferno Oriented Nature Reserve, located inland in the Rimini Province, occupies an area of 274 ha. The zone is characterized by a limited strip of messinian evaporites with karstic phenomena and surrounding relict woodland. The vegetation cover is composed of strips of forest vegetation and secondary meadows.

In contrast to observations in the area of the Gessi Bolognesi, the Onferno site has the fewest number of species. This aspect is undoubtedly due to the reduced extension of the area and of the gypseous outcropping in particular. In addition, there is significant anthropic impact here, as the Onferno Cave and the castle attract many tourists.

Notwithstanding the reduced dimensions and the consequently small number of species, the ecological and chorological information provided us by the species examined is very interesting. First of all, the light value $L = 7$, the highest found, is due to the presence of markedly heliophilous species that live and develop in sites with full light. The data on temperature ($T = 7$) and moisture ($M = 3.5$) indicate on the one hand species that rarely grow at altitudes over those of the hilly belt, and on the other hand species that are indicators of xericity, developing on arid soils and dry sites. These elements contribute to delineating a territory that is much more arid than the other sites studied, because of the closeness to the coast, which has an immediate repercussion on the colonization of bryophytes. The confirmation of this marked xericity of the area comes from analyzing the chorological data of the species examined. In this area, the temperate contingent reaches 50% of the species, as does the contingent of species with (sub)-Mediterranean tendency. There is a complete lack of species of oceanic tendency and boreal species.

Discussion

Ecological aspects

Moving on to analyze the behavior of each species in the light of the various ecological parameters

observed, the first datum that emerges evidently is the substantial homogeneity in how the species react to the gypseous substratum. In fact, the *R* values in all six sites are in the range from 6 to 7.

Comparing the bryological flora observed with that studied on calcareous substrata, one can also note that, at the same latitude and altitude, there are numerous affinities and analogies. The gypseous substratum does not make it possible to select a clearly distinct gypsicolous flora compared to calcareous substrata (Zangheri 1959). The one species that is exclusive to gypsicolous environments is *Tortula revolvens*, rare in Europe, with typically circum-Mediterranean areal distribution. In Italy it has only been reported for the gypseous–calcareous strip of the Romagna Apennines and for the gypseous substrata of Agrigento (Privitera 1989a, 1989b; Privitera & Puglisi 2004). In our study, the species was reported only in the sites of Cà del Vento, of the Gessi Bolognesi and of the Vena del Gesso, a demonstration that the gypseous substratum alone does not suffice to determine the colonization of this species, but that its growth and distribution influence the particular ecological and microenvironmental conditions that the species finds within these formations, true sites of refuge for the species. This would explain the existence of sites that are so isolated and far from each other.

However, it must be noted that while there are no exclusively gypsicolous species other than *Tortula revolvens,* a broad suite of strongly calcicolous species was found in the sites studied, including *Aloina aloides, Crossidium squamiferum, Crossidium crassinerve, Didymodon asperifolius, Encalypta rhaptocarpa, Trichostomum cripulum, Tortella inflexa, Trichostomum triumphans,* and *Weissia controversa,* which characterize the more arid and exposed environments, as well as *Pellia endiviifolia, Gymnostomum calcareum, Eucladium verticillatum*, and *Seligeria pusilla*, which colonize the outcrops characterized by greater moisture and shade.

This distinction leads to some considerations on the temperature, light, and moisture values that characterize the study areas and in turn are strictly related to the different exposure of the slopes and the Mediterranean or continental characteristics of the six sites studied.

Figure 2 compares the light, temperature, moisture and pH values of the six sites, ordered from east to west. To the right of the black line are the analogous values calculated for the sites of the habitat 6110*.

This layout highlights the substantial homogeneity of the *R* values (soil pH) which, as noted before, do not characterize and determine significant species differences in the sites explored.

The values of light and temperature tend to diminish as one gradually moves from the easternmost and more Mediterranean sites such as Onferno and Vena del Gesso toward the more continental and montane sites, in particular that of the Gessi Triassici. At the same time, the moisture values tend constantly and progressively to increase.

Light, temperature, and moisture are therefore strictly correlated and inversely proportional factors. Greater exposure of the substrata, most of all for the rocky ones, determines increasingly higher values of light and temperature, but this greater exposure at the same time determines a strong reduction of the gradient of moisture, determining the presence of heliophilous and xerophilous species able to survive long periods of aridity.

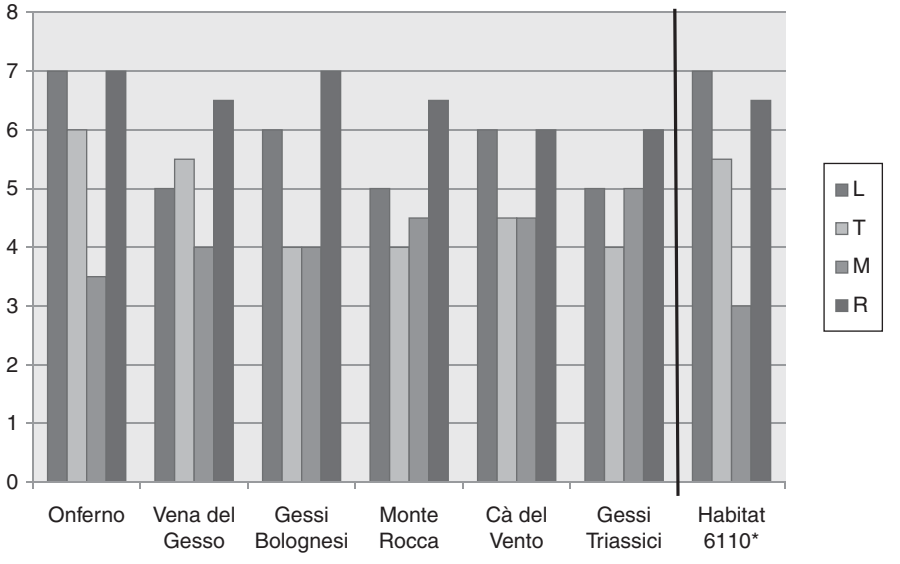

Figure 2. Average values of the ecological parameters examined in the six sites explored and in habitat 6110*.

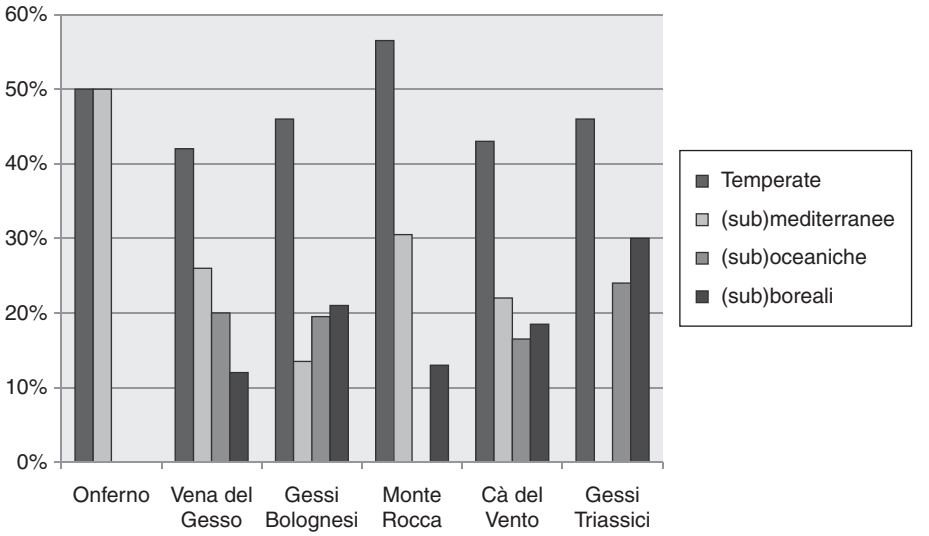

Figure 3. Chorological elements (in percentage) in the six sites explored.

The histogram of the habitat 6110* sites sampled facilitates comparison of its values and those of the other sites analyzed. There emerges a striking similarity between the 6110* values and those of the sites closest to the coast, in particular the Onferno site. Thus it is possible to see how the set of environmental variables, in particular substratum, geomorphology, and exposure, plays a fundamental role in the selection of species adapted to climatic or microclimatic conditions that are more typically Mediterranean. These results agree with Ferrari's conclusion about the vascular vegetation of the Vena del Gesso, according to which the vegetation of the gypseous cliffs with southern exposure should be included among the "splashes of the great Mediterranean wave" (Bassi 2010).

Chorological considerations

Our considerations on the ecological characteristics of the species find confirmation in the analysis of their chorological aspects.

The various chorological elements were united according to their affinity into four major groups: temperate, (sub)-Mediterranean, (sub)oceanic, and (sub)boreal. These values were translated into terms of percentages in the histogram of Figure 3, in order to highlight the substantial differences between the different areas.

The first point that emerges plainly is the clear predominance in all six areas of temperate species, regardless of the absolute number of species, which varies according to the extension of the area and consequently also by the different floristic richness.

In fact, these species demonstrate notable ecological plasticity; they are adapted to live in different types of environment both in terms of climatic condition of temperature, light, and moisture, and in terms of the characteristics of the substratum.

In addition to the group of temperate species, another that stands out is that of (sub)-Mediterranean species, and this, too, is in agreement with the climatic characteristics of the areas studied. However, it is interesting to note how the massive presence of this group of species on Onferno (50% of the species) tends to diminish drastically in the remaining areas, to the point of disappearing entirely in the most continental site, that of the Gessi Triassici, where the Mediterranean currents have a reduced, almost null influence on the composition of the bryophyte flora.

Contemporaneous with the progressive disappearance of the Mediterranean element, the oceanic element appears and strengthens. It is entirely absent in Onferno and Monte Rocca, but grows progressively in the other sites to the point of reaching its greatest percentage (about 25%) in Gessi Triassici. The same pattern is visible for the group of (sub) boreal species that increases progressively from the Vena del Gesso to the Gessi Triassici, to the point of reaching in the latter area the considerable percentage of 30%. The size of this group is unquestionably determined by the increasingly marked boreal–continental influx, with the gradual distancing from the influx of Mediterranean currents. The numerous dolines and other karstic elements also determine increases in the relative moisture and reductions in the temperature within these formations, thus contributing to the creation of refuges for numerous boreal and continental species even in markedly Mediterranean contexts. In this way, one sees how exposure and moisture are decisive factors for the distribution of species in the territories studied.

It is clear that in the various sites, the microclimatic factors, more than the macroclimatic factors, determine the substantial diversification of the bryophyte flora.

Species that are indicators of naturality or anthropization

On the basis of the floristic, ecological, and chorological aspects, it is possible to identify the species that indicate conditions of naturality or anthropization in the areas explored, in order to obtain criteria and indications for organizing direct and indirect actions to protect and restore the habitats.

A first important consideration concerns identification of species characteristic of gypseous formations. As we noted earlier, the one clearly gypsicolous species is *Tortula revolvens*, which forms, in the areas in which it was found, the association *Tortuletum revolventis* Marstaller 1980, characteristic of very arid and exposed environments. This species and its association are always found in sites in which *Alysso alyssoidis-Sedion albi* Oberdorfer & Müller in Müller 1961 was reported. Thus these two elements indicate without doubt the characters of marked naturality in the gypseous outcrops of Cà del Vento, in some sites within the Gessi Bolognesi and the Vena del Gesso. Alongside this species, one always finds *Trichostomum crispulum*, a markedly calciphile species that forms the association *Tortello flavovirentis-Trichostometum crispuli* Brullo, Lo Giudice & Privitera 1991, often associated with *Aloina aloides*, which forms *Trichostomo crispuli-Aloinetum aloidis* Guerra & Varo 1981 association, as in the site of Cà del Vento, or associated with *Crossidium crassinerve* and *C. squamiferum* as in the Vena del Gesso site; the occurrence of *Tortello flavovirentis-Trichostometum crispuli* indicates a character of naturality too (Puglisi et al. 2012).

Instead, in the sites where anthropic impact is felt, *Tortula revolvens* and the species that accompany it are substituted by more nitrophilous species that are indicators of anthropization, such as *Didymodon vinealis* and *D. luridus*, present with the *Trichostomo brachydontii-Didymodontetum vinealis* Privitera & Puglisi 1989 association. In the sites most subject to anthropic impact such as Castello di Onferno, these two species form almost mono-specific carpets.

Regarding the cooler and more shaded environments of gorges and dolines, the characterization of the conditions of naturality is entrusted to more markedly sciaphilous species that take the place of the xerophilous species of the more exposed and sunlit outcrops. Here species belonging to the Class Adiantetea Br.-Bl. 1942 dominate, among them are *Cephaloziella baumgartneri, Eucladium verticillatum* (which forms the *Eucladietum verticillati* Braun 1968 association), *Gymnostomum calcareum, Fissidens exilis, F. dubius, F. serrulatus*, and *F. osmundoides*. In these cooler environments, such as the entrance of caves or dolines visited by a steady stream of tourists, we see a passage from conditions of naturality to conditions of seminaturality or anthropization; here, these species are substituted by nitrophilous one such as *Anomodon viticulosus*, belonging to the *Anomodonto viticulosi-Leucodontetum sciuroidis* Wisniewski 1930 association, *Neckera complanata* of the Neckerion complanatae, and *Hypnum cupressiforme*, which form mono-specific carpets on the surfaces of the rocks.

The indispensable condition for the growth of these species, be it on the more exposed rocks or on those near dolines, sink-holes, or caves, is the lack of herbaceous and shrub cover.

*Habitat 6110**

The ecological parameters of the bryophyte flora of the areas analyzed mirror the environmental characteristics of the habitat as defined in the Habitat Identification Manual of the European Community (European Commission DG Environment 2013). The sites sampled in this study have outcropping rock with south-eastern exposure, in full light with heliophile ($L = 7$) and thermophile ($T = 6$) and bryoflora adapted to situations of xericity ($M = 3$). The values for soil pH do not differ from those described for all the sites covered in this article.

In the sites sampled in our study, it was possible to observe that the moss carpet serves many of the vascular plants as a preferential substratum for growth and colonization. The strongest link was observed for the vascular species that are characteristic of the habitat in question, namely *Sedum rupestre* and *S. sexangulare*. These results seem to fit with those reported by Czarnecka (2004), according to whom in xeric environments such as the habitat in question, the bryophytes can act as water reserves for the vascular plants, holding a quantity of water sufficient for their survival.

In this regard, the relationships between bryophytes and vascular plants should be studied further to correctly evaluate whether the bryophytes play a role in supporting plant biodiversity. The results obtained in this study show that in extreme habitats, the bryophyte component, too often ignored, should be taken into consideration in policies for management and conservation of our naturalistic heritage.

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