

## The bryophyte flora of the geothermal field of Sasso Pisano (Pisa, Italy)

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**Résumé** – La bryoflore de la zone géothermique de Sasso Pisano (Pisa) est étudiée. 19 taxons (16 mousses et 3 hépatiques) sont recensés. Deux mousses, *Campylopus pyriformis* (Schultz) Brid. et *Leucobryum juniperideum* (Brid.) Müll. Hal., et une hépatique, *Odontoschisma denudatum* (Mart.) Dumort., sont nouvelles pour la Toscane. La bryoflore enregistrée n'est pas riche en espèces mais comprend quelques taxons rares et écologiquement intéressants.

**Abstract** – The results of a study on the bryophyte flora of the Sasso Pisano geothermal area (Pisa) are reported in this paper. A total of 16 mosses and 3 liverworts were found. Two moss species, *Campylopus pyriformis* (Schultz) Brid. and *Leucobryum juniperideum* (Brid.) Müll. Hal. and one liverwort species, *Odontoschisma denudatum* (Mart.) Dumort., are new for Tuscany. The recorded bryoflora is not rich in species but includes some rare and ecologically interesting taxa.

**Bryophytes / Geothermal area / Fumaroles / Chorology / Tuscany / Italy**

**Riassunto** – Viene riportato lo studio sulla brioflora dell'area geotermale di Sasso Pisano (Pisa). In questo particolare ambiente sono state rilevate 19 specie di briofite (16 muschi e 3 epatiche). Due specie di muschi, *Campylopus pyriformis* (Schultz) Brid. e *Leucobryum juniperideum* (Brid.) Müll. Hal., e una specie di epatica, *Odontoschisma denudatum* (Mart.) Dumort., sono risultate nuove per la Toscana. La brioflora rinvenuta è risultata non ricca in specie, ma include alcune specie rare e ecologicamente interessanti.

### INTRODUCTION

Geothermal fields are habitats with special environmental conditions, such as high temperature, low pH and presence of toxic gases (e.g. HCl, SO<sub>2</sub>, CO<sub>2</sub>). Plant and bryophyte species living in these environments often show spe-

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cial adaptations to withstand these habitat conditions (Merola, 1957; Verona, 1960; Poli, 1970; Grime, 1979; Given, 1980; Brock, 1985; Glime & Hong, 1997; Rothschild & Mancinelli, 2001).

Many geothermal fields, related to residual volcanic activity or highly radioactive solidified magma, are present in the Italian peninsula and islands (Duchi *et al.* 1985). The geothermal sites in southern Italy have been subjected to bryological approaches (Privitera & Puglisi, 1989; Brullo *et al.* 2001), while those of Tuscany have been described almost exclusively for vascular plants (Bargagli-Petrucci, 1916; Fiori, 1920). In a study on *Campylopus polytrichoides* De Not. (= *Campylopus pilifer* Brid.), Giacomini (1955) reported four varieties within the subspecies *polytrichoides*, two of which were linked to different geothermal areas of Italy: var. *vaporarius* (Bolle) De Not. and var. *boracicola* De Not. The former was reported to grow in the vicinity of hot vapours from the fumaroles and vents of Pozzuoli, Ischia, Pantelleria and Vietri, while the latter was indicated for Tuscany at Calboli near Castelnuovo Val di Cecina. Brullo *et al.* (2001) retained the variety *vaporarius* as a good *taxon* and reported it as *Campylopus pilifer* Brid. subsp. *vaporarius* (De Not.) Brullo, Privitera & Puglisi (Cortini Pedrotti, 2001).

The present study aims to list the bryoflora of a geothermal field in Tuscany. This site, known as “Monterotondo Marittimo and Sasso Pisano geothermal fields”, has been indicated as a Site of Regional Interest (SIR B12, IT 5160103) with two types of natural habitats listed in the Natura 2000 EU directive: “forests of *Castanea sativa* Miller (cod. 9260)” and “lava fields and natural cavities (cod. 8320)” (European Communities, 1991; Codice Regionale dell’Ambiente, 1999).

## STUDY AREA

The investigated geothermal field, named Sasso Pisano, is located in the upper Cornia valley, north-western part of Colline Metallifere, Tuscany (Fig. 1). The field is bordered to the west by the stream Milia, to the east by the stream Pavone and to the north by the river Cecina. The nearest village is Sasso Pisano, on the north-eastern slope of Poggio il Monte. The whole area, the Larderello region, is characterised by natural geothermal emissions known in Tuscany as *soffioni boraciferi*. They are similar to the volcanic solfataras of the Campi Flegrei and Aeolian islands of Italy and the volcanic regions of Iceland and Rocky Mountains of north America. This habitat is characterised by emissions of steam vents containing H<sub>2</sub>S, CO<sub>2</sub>, boric acid and water vapour and by the surface of soil often reaching temperatures above 50-60°C. The steam vents emerge from small fissures or cavities on the ground. Sometimes the vapour condenses on the ground to form puddles of hot water, known as *lagoni* (Poli, 1970; Duchi *et al.*, 1991).

The geology of the area is a complex mosaic, consisting largely of Eocene sandstones known as *Macigno toscano* (Lazarotto, 1967; 1993). Table 1 shows climatic data from Sasso Pisano (years 1951-80, Barazzuoli *et al.* 1993). Mean annual temperature is 13.3°C; the coldest and warmest months are January and July (mean temperature 5.4°C and 22.3°C respectively). Mean annual rainfall is 1107.2 mm; the wettest and driest months are November and July (mean rainfall 136.7 mm and 42.7 mm respectively). According to Thornthwaite (1948), the climate is humid mesothermic with moderate hydrologic deficit and concentration of thermal efficiency in summer (type B1.B1'.s.b4'; Bigi & Rustici, 1984; Barazzuoli *et al.*, 1993).

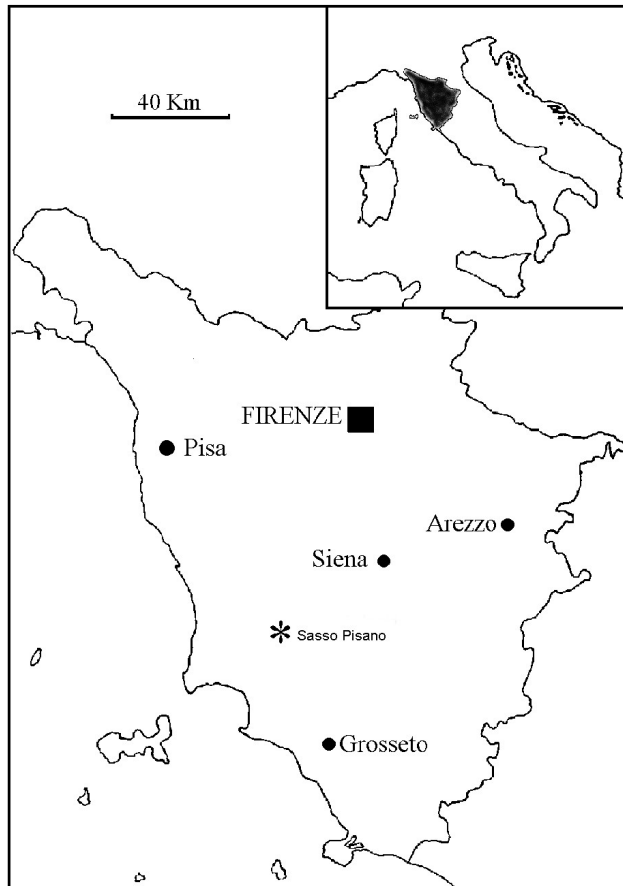


Fig. 1. Geographic location of the study area

The vegetation of the geothermal field is characterised by the prevalence of herbaceous species with a few shrubs and trees occurring at some distance. The most abundant shrub species is *Calluna vulgaris* (L.) Hull; *Erica arborea* L. is also relatively common, as well as *Agrostis castellana* Boiss. et Reuter, reported by Fiori (1920) as “the only species linked to the site” and “abundant around the fumaroles”. This species is indicated as tolerant of high temperatures and very acid soil (Selvi & Bettarini, 1999).

### COLLECTION OF BRYOLOGICAL DATA

Moss and liverwort samples were collected at Sasso Pisano fumaroles in four habitat types along a gradient of closeness to the steam vents (Table 2): under *Calluna vulgaris* shrubs (A); grasslands (B); mineral soil (C); rock surfaces and fis-

Table 1. Mean monthly and annual rainfall (mm) and temperatures (°C) at Sasso Pisano estimated for the period 1951-1980 (Barazzuoli *et al.*, 1993).

<i>Sasso Pisano</i>	<i>Rainfall</i>	<i>Temperature</i>
Alt. (m)	440	440
Years	1951-1958	1951-1958
J	111.8	5.4
F	101.4	6.1
M	97.2	8.2
A	92.1	11.4
M	80.3	15.4
J	61.5	19.3
J	42.7	22.3
A	65.6	22.2
S	98.9	18.9
O	121.3	14.4
N	136.7	9.8
D	116.3	6.6
Year	1 107.2	13.3

tures (D). Nomenclature of mosses and liverworts follows Cortini Pedrotti (2001) and Aleffi & Schumacker (1995) respectively. Chorological types are from Düll (1983, 1984, 1985, 1992), grouped according to Sérgio *et al.* (1994). The voucher specimens are preserved in the *Herbarium Universitatis Senensis* (SIENA).

## RESULTS AND DISCUSSION

### Floristic records

Nineteen bryophyte *taxa* (16 mosses and 3 liverworts) were found (Table 2). The families with the highest species richness were *Dicranaceae* and *Pottiaceae*. Acrocarpous species, typical of xeric environments (Richardson, 1981), dominated the studied flora, with 84.3% and were collected in all the habitat types. Pleurocarpous species were only found under the *Calluna* shrubs and in the grasslands.

Four species of *Campylopus*, often reported as dominant in geothermal habitats (Smith, 1981; Brullo *et al.*, 2001; Grandstein & Sipman, 1978), were recorded: *C. flexuosus* (Hedw.) Brid., *C. introflexus* (Hedw.) Brid., *C. pilifer* Brid. and *C. pyriformis* (Schultz) Brid.

According to the check-list of Italian mosses (Cortini Pedrotti, 2001), two species of mosses were not previously known for Tuscany: *Campylopus pyriformis*

Table 2. Bryological flora of Sasso Pisano, with the indication of Chorotypes, growth form and habitats of each species. Chorotypes of bryophyte: **Temp** = Temperate; **Suboc** = Suboceanic; **Suboc (mont)** = Suboceanic (mountain); **Oc-submed** = Oceanic-Submediterranean, Subkont = Subcontinental; **Oc-med** = Oceanic-mediterranean; **Submed** = Submediterranean. Growth form: *a*= acrocarpous; *p*= pleurocarpous. Habitats: **A**: under *Calluna vulgaris* shrubs; **B**: grasslands; **C**: mineral soil; **D**: rock surfaces and fissures.

Growth form	Chorotypes	Species	Habitat			
			A	B	C	D
Total number of species			11	6	6	5
<b>Bryaceae</b>						
a	Temp	<i>Bryum capillare</i> Hedw.	x			
<b>Dicranaceae</b>						
a	Suboc	<i>Campylopus flexuosus</i> (Hedw.) Brid.		x		
a	Suboc	<i>Campylopus introflexus</i> (Hedw.) Brid.		x	x	
a	Oc-submed	<i>Campylopus pilifer</i> Brid.	x	x	x	
a	Suboc	<i>Campylopus pyriformis</i> (Schultz) Brid.	x	x	x	
a	Temp	<i>Dicranella heteromalla</i> (Hedw.) Schimp.			x	x
a	Suboc	<i>Leucobryum glaucum</i> (Hedw.) Ångstr.	x		x	
a	Suboc (-mont)	<i>Leucobryum juniperideum</i> (Brid.) Müll. Hal.	x			
<b>Hypnaceae</b>						
p	Temp	<i>Hypnum cupressiforme</i> Hedw.	x	x		
p	Suboc	<i>Hypnum jutlandicum</i> Holmen & Warncke		x		
p	Subkont	<i>Platygyrium repens</i> (Brid.) Bruch, Schimp. & Gümbe	x			
<b>Pottiaceae</b>						
a	Temp	<i>Barbula convoluta</i> Hedw.				x
a	Submed	<i>Pleurochaete squarrosa</i> (Brid.) Lindb.	x			
a	Temp	<i>Pottia lanceolata</i> (Hedw.) Müll. Hal.				x
a	Oc-med	<i>Tortella nitida</i> (Lindb.) Broth.				x
a	Temp	<i>Tortula muralis</i> Hedw.				x
<b>Cephaloziaceae</b>						
a	Suboc-mont	<i>Odontoschisma denudatum</i> (Mart.) Dumort.	x			
a	Temp	<i>Cephaloziella divaricata</i> (Sm.) Schiffn.	x	x		
<b>Jungermanniaceae</b>						
a	Temp-mont	<i>Jungermannia hyalina</i> Lyell	x			

(Schultz) Brid. and *Leucobryum juniperideum* (Brid.) Müll. Hal. *Campylopus pyri-formis* (Schultz) Brid. was known for northern Italy (Emilia, Friuli, Trentino, Lombardy and Piedmont) and Sicily. It was found on mineral soil, grasslands and under *Calluna* shrubs. *Leucobryum juniperideum* (Brid.) Müll. Hal. was previously known only for Piedmont, Friuli and Lombardy and it is included in the Red List of Italian Bryophytes (Cortini Pedrotti & Aleffi, 1992) as an endangered species. It was only found under *Calluna* shrubs associated with *L. glaucum* (Hedw.) Ångstr.

Liverworts were recorded almost exclusively under *Calluna* shrubs; only *Cephaloziella divaricata* (Sm.) Schiffn. was also found on bare soil. According to the Italian check-list of liverworts (Aleffi & Schumacker, 1995), *Odontoschisma denudatum* (Mart.) Dumort. was not previously reported for Tuscany, being only known for northern Italy (Emilia, Friuli, Trentino and Piedmont); this species is also included in the Red List of Italian Liverworts as endangered species (Aleffi & Schumacker, 1995).

### Ecological and phytogeographic considerations

In the habitat types closest to the geothermal vents, where vascular plants did not occur, 5 and 6 species of bryophytes were respectively found. The *Agrostis* grasslands hosted a total of 6 bryophyte species, while the *Calluna* shrubs, the less influenced habitat, had 11 bryophyte species. The total number of bryophyte species reduced with increasing vicinity to the geothermal steams (Table 2). Total species richness of bryophyte flora of Sasso Pisano was very low, but comparable to those found in other geothermal areas of Italy and Canary Islands (Table 3). Only the bryoflora of the Pantelleria geothermal area was richer. The vegetation of geothermal areas is known to be characterised, or even dominated, by bryophytes, but with a low species richness (Given, 1980; Glime & Iwatsuki, 1990; Glime & Hong, 1997; Convery *et al.*, 2000).

The proportion of liverworts at Sasso Pisano (Table 3) was intermediate (15.8%) with those reported for the other geothermal sites (0 – 36.4%). Only foliose species were found among liverworts. The photosynthesizing parts of thallose liverworts are irreversibly damaged by the high temperatures (Weis *et al.*, 1986). *Cephaloziella divaricata* was the only liverwort species found in two habitats, in agreement with the fact that many *Cephaloziella* species are known to occur in several geothermal areas (Sheppard, 1971; Glime & Hong, 1997).

The genus *Campylopus*, which is dominant in the studied flora, is widespread in tropical regions and the Mediterranean area, with a distribution connected to acid substrates and secondary volcanic phenomena (Gradstein & Sipman, 1978; Frahm, 1999). In particular, *Campylopus pilifer* Brid. and *C. introflexus* (Hedw.) Brid. have been found near fumaroles on the islands of Pantelleria, Linosa, Ischia and Vulcano, at Pozzuoli (Naples), in the Canary Islands and in southern Tuscan geothermal fields (Selvi & Bettarini, 1999; Brullo *et al.*, 2001). These species are both rare in Italy (Cortini Pedrotti, 2001).

The bryoflora of Sasso Pisano shows a prevalence of Temperate and Suboceanic species (Table 4), with a low proportions of Oceanic-Mediterranean, Continental and Submediterranean species. As shown by Brullo *et al.* (2001), the geothermal areas of Tenerife and Vulcano islands are dominated by Oceanic-Mediterranean species (44.5% and 63.5% respectively, while those of Pantelleria and Ischia islands are dominated by Temperate species (41% and 35.5% respectively), similarly to Sasso Pisano.

Table 3. Number of species recorded in the geothermal field of Sasso Pisano in comparison to other geothermal fields of southern Italy and Tenerife, Canary Islands (data from Brullo *et al.*, 2001).

	<i>Sasso Pisano</i>	<i>Tenerife</i>	<i>Vulcano</i>	<i>Pantelleria</i>	<i>Linosa</i>	<i>Ischia</i>	<i>Pozzuoli</i>
Liverwort	3	2	4	3	0	0	0
Mosses	16	7	7	43	8	17	5
Total bryophytes	19	9	11	46	8	17	5

Table 4. Number and percentage of bryophyte species belonging to the Chorological groups according to Sérgio *et al.* (1994): Suboceanic (including Suboceanic-Mountane); Oceanic-Mediterranean (including Oceanic-Submediterranean); Temperate (including Temperate-Montane); Continental (including Subcontinental); Submediterranean.

<i>Chorological groups</i>	<i>Bryophytes Species</i>	
	<i>Number</i>	<i>%</i>
Temperate	8	42.1
Suboceanic	7	36.8
Oceanic-Mediterranean	2	10.5
Continental	1	5.3
Submediterranean	1	5.3

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## REFERENCES

- ALEFFI M. & SCHUMACKER R., 1995 — Check-list and red list of the liverworts (marchantiophyta) and hornworts (Anthocerotophyta) of Italy. *Flora Mediterranea* 5: 73-161.
- BARGAGLI-PETRUCCI G., 1916 — Studi sulla Flora Microscopica della Regione Boracifera Toscana. *Nuovo Giornale Botanico Italiano*, n.s., 23: 171-184.
- BARAZZUOLI P., GUASPARRI G. & SALLEOLINI M., 1993 — Il clima. In: A. Pizzi (Ed.), *La Storia Naturale delle Toscana Meridionale*. Cinisello Balsamo, pp. 114-171.
- BIGI L. & RUSTICI L., 1984 — *Regime idrico dei suoli e tipi climatici in Toscana*. Regione Toscana, Dipartimento Agricoltura e Foreste, pp. 1-129.
- BROCK T.D., 1985 — Life at high temperature. *Science* 230: 132-138.
- BRULLO S., PRIVITERA M. & PUGLISI M., 2001 — Phytogeographical considerations on the fumarole bryoflora from Mediterranean and Macaronesian areas. *Bocconea* 13: 329-336.
- CODICE REGIONALE DELL'AMBIENTE, 1999 — Giunta Regionale, Regione Toscana. Firenze.
- CONVERY P., LEWIS SMITH R.I., HODGSON D.A. & PEAT H.J., 2000 — The flora of the South Sandwich Islands, with particular reference to the influence of geothermal heating. *Journal of Biogeography* 27: 1279-1295.

- CORTINI PEDROTTI C. & ALEFFI M., 1992 — Lista rossa delle Briofite d'Italia. In : Conti F., Manzi A., Pedrotti F. *Libro rosso delle Piante d'Italia*. WWF, SBI, pp. 559-637.
- CORTINI PEDROTTI C., 2001 — New Check-list of Mosses of Italy. *Flora Mediterranea* 11: 23-107.
- DUCHI V., MINISALE A. & ROMANI L., 1985 — Studio geochimico su acque e gas dell'area geotermica lago di Vico-M. Cimino (Viterbo). *Atti Società Toscana di Scienze Naturali, Serie A*, 92: 237-254.
- DUCHI V., MANGANELLI M. & MINISALE A., 1991 — Composizione chimica delle fasi fluide naturali superficiali del campo geotermico di Larderello. *Bollettino della Società Geologica Italiana* 110: 41-46.
- DÜLL R., 1983 — Distribution of European and Macaronesian liverworts (Hepaticophytina). *Bryologische Beiträge* 2: 1-115.
- DÜLL R., 1984 — Distribution of European and Macaronesian mosses (Bryophytina) Part I. *Bryologische Beiträge* 4: 1-113.
- DÜLL R., 1985 — Distribution of European and Macaronesian mosses (Bryophytina) Part II. *Bryologische Beiträge* 5: 110-232.
- DÜLL R., 1992 — Distribution of European and Macaronesian mosses (Bryophytina) Part I, Annotations and Progress. *Bryologische Beiträge* 8/9: 1-223.
- EUROPEAN COMMUNITIES 1991 — CORINE BIOTOPES MANUAL. A method to identify and describe consistently sites of major importance for nature conservation. Habitat of the European Community. Luxembourg. 1-3 Vol, 300 p.
- FIORI A., 1920 — Rilievi geografici e forestali sulla flora del bacino della Cecina e località finitime. *Annali del Regio Istituto Superiore Forestale Nazionale* 5: 151-186.
- FRAHM J. P., 1999 — A survey of the *Campylopus* species from the Azores. *Cryptogamie, Bryologie* 20: 145-152.
- GIACOMINI V., 1955 — Sull'autonomia specifica e sul ciclo di forme di *Campylopus polytrichoides* De Not. *Atti dell'Istituto Botanico dell'Università e Laboratorio Crittogamico di Pavia* 13:45-83.
- GIVEN D. R., 1980 — Vegetation on heated soils at Karapiti, central North Island, New Zealand, and its relation to ground temperature. *New Zealand Journal of Botany* 18: 1-13.
- GLIME J.M. & IWATSUKI Z., 1990 — Niche characteristics of *Cladonia* lichens associate with geothermal vents in Japan. *Ecological Research* 5: 131-141.
- GLIME J.M. & HONG W.S., 1997 — Relationships of Geothermal bryophyte communities to soil characteristics at Thermal Meadow, Hotsprings Island, Queen Charlotte Islands, Canada. *Journal of Bryology* 19: 435-448.
- GRADSTEIN S.R. & SIPMAN H.J.M., 1978 — Taxonomy and world distribution of *Campylopus introflexus* and *C. pilifer* (= *C. polytrichoides*): a new synthesis. *The Bryologist* 81: 114-121.
- GRIME J.P., 1979 — *Plant strategies and vegetation processes*. Chichester, John Wiley & Sons, 222 p.
- LAZZAROTTO A., 1967 — Geologia della zona compresa tra l'alta valle del fiume Cornia ed il Torrente Pavone (Prov. di Pisa e Grosseto). *Memorie della Società Geologica Italiana* 6: 151-197.
- LAZZAROTTO A., 1993 — Elementi di Geologia. In: Pizzi A. (Eds) Giusti F., *La Storia Naturale delle Toscana Meridionale*. Cinisello Balsamo, pp. 19-87.
- MEROLA A. 1957 — Osservazioni sull'ecologia e sulla biologia dei vegetali viventi presso le fumarole. Nota I — Termotropismo radicale e riscaldamento del terreno in *Erica arborea* L. *Delpinoa* 10: 5-20.
- POLI E., 1970 — Aspetti della vita vegetale in ambienti vulcanici. *Annali di Botanica* 30: 47-86.
- PRIVITERA M. & PUGLISI M., 1989 — Osservazioni sulla flora e vegetazione Briofitica dell'Isola di Pantelleria. *Bollettino Accademia Gioenia Scienze Naturali* 22 (n° 335): 67-104.
- RICHARDSON P.H.S., 1981 — *The biology of mosses*. London, Boston, Blackwell Scientific Publications.



- ROTHSCHILD L.J. & MANCINELLI R.L., 2001 — Life at extreme environments. *Nature*, 409: 1092-1101.
- SELVI F. & BETTARINI I., 1999 — Geothermal biotopes in central-western Italy from a botanical view point. In: Raschi A., Vaccai F. P., Maglietta F., *Ecosystem response to CO<sub>2</sub>: the maple project results*. European Commission: 1-12.
- SÉRGIO C., CASAS C., BRUGUÉS M. & CROS R.M., 1994 — *Red List of Bryophytes of the Iberian Peninsula*. Lisboa, ICN, 45p.
- SHEPPARD J.S., 1971 — *The influence of geothermal temperature gradients upon vegetation patterns in Yellowstone National Park*. PhD Thesis, Colorado State University.
- SMITH C.W., 1981 — Bryophytes and lichens of the Puhimau geothermal area, Hawaii Volcanoes National Park. *The Bryologist* 84: 457-466.
- THORNTHWAITE C.W., 1948 - An approach toward a rational classification of climate. *Geographical Review* 38: 55-94.
- VERONA O., 1960 — Il particolare ambiente ecologico prossimo alle centrali boracifere di Larderello e la boro-tolleranza di alcune specie vegetali. *Nuovo Giornale Botanico Italiano*, n.s., 67: 226-237.
- WEIS E., WAMPER D. & SANTARIUS K.A., 1986 — Heat sensitivity and thermal adaptation of photosynthesis in liverwort thalli. *Oecologia* 69: 134-139.