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Bryophyte diversity hotspot: the Marmore Waterfalls Regional Park (Umbria, central Italy)

Silvia Poponessi[1], Michele Aleffi[2], Marko S. Sabovljević[3], Roberto Venanzoni[1]

1 *Dipartimento di Chimica, Biologia e Biotecnologie, Università di Perugia, via del Giochetto 6, 06126 Perugia, Italy* **2** *Scuola di Bioscienze e Medicina veterinaria, Università di Camerino, via Pontoni 5, 62032 Camerino (MC), Italy* **3** *Institute of Botany and Botanical Garden, Faculty of Biology, University of Belgrade Takovska 43, 11000 Belgrade, Serbia*

Corresponding author: Silvia Poponessi (Silvia.poponessi@hotmail.it)

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Abstract

A study of the bryophyte of Marmore Waterfall Natural Park a very peculiar territory for its geological, biogeographical and bioclimatic traits, was carried out. The reported data were collected in the valley area of 'Parco Fluviale del Nera' Regional Park, where the waters are flowing and the humidity of the rocks is oozing. Research led to the identification of 101 taxa of bryophytes (21 liverworts and 80 mosses), among which two liverwort and 10 moss species are new records for the Umbria region, while four are confirmed. The study offers new outcomes on neglected aspects of the flora of central Italy and represents a considerable improvement of the floristic, biogeographical and ecological understanding of its bryophytic component. Additionally, the area turn out to be significant from the conservation point of view both nationally and internationally considering that it harbours high diversity of bryophytes species among which many rare, threatened and interesting species occur. Eighteen species of conservation interest in Italy are recorded during the latest investigation (all in category NT – near threatened). Additionally two species that are considered data deficient in Italy are present in the researched area (*Conocephalum salebrosum* and *Fissidens curvatus*). Also, there is a small populations of a species vulnerable (*Marchantia paleacea*), endangered (*Bryum calophyllum*) and data deficient (*Fissidens curvatus* and *Barbula bolleana*) in European scale.

Keywords

Bryophyte, ecology, Habitats Directive 92/43/EEC, liverworts, mosses, Petrifying springs, Umbria

Introduction

The Regional Park Marmore waterfalls are man-made waterfalls, built by ancient Romans at 271 BC for tried to solve the problem of the Velino River and Valnerina weatlands and, at the same time, to use the water resource both for the agriculture and as a source of power. With a total height of 165 m, it is one of the highest man-made waterfalls in Italy and worldwide.

The Marmore Falls is located in the Umbrian Region (42°33'23"N, 12°42'73"E) near the Terni city at 218 m above sea level, within the Valnerina valley in the 'Parco Fluviale del Nera' Regional Park (Fig. 1). It is a Site of Community Importance (SCI) IT5220017 and a Special Area of Conservation (SAC) of the Natura 2000 EU-wide network due to the presence of the 72.20* 'Petrifying springs with tufa formation (Cratoneurion)' Annexe I priority habitat (http://vnr.unipg.it/habitat/) Biondi et al. (2009). An important stipulation within the habitats directive manual is that 'in order to preserve this habitat of very limited expanse in the field, it is essential to preserve its surroundings and the whole hydrological system concerned'. Petrifying springs fall under the remit of the Water Framework Directive (Directive 2000/60/EC) as groundwater-dependent terrestrial ecosystems (Pedley 1990; Pentecost 1995; Ford and Pedley 1996; Curtis et al. 2009; Kimberley et al. 2013); their ecological significance is recognised under this legislation and there is a legal requirement to maintain or improve the status of the ground waters with which they are fed.

The vegetation type "Cratoneurion commutati" was first described by Walo Koch in his 1928 monograph 'Die höhere Vegetation der subalpinen Seen und Moorgebiete des Val Piora'. This alliance (sometimes shortening the name to Cratoneurion) as freshwater, lime-rich spring communities with frequent tufa formation, is found especially

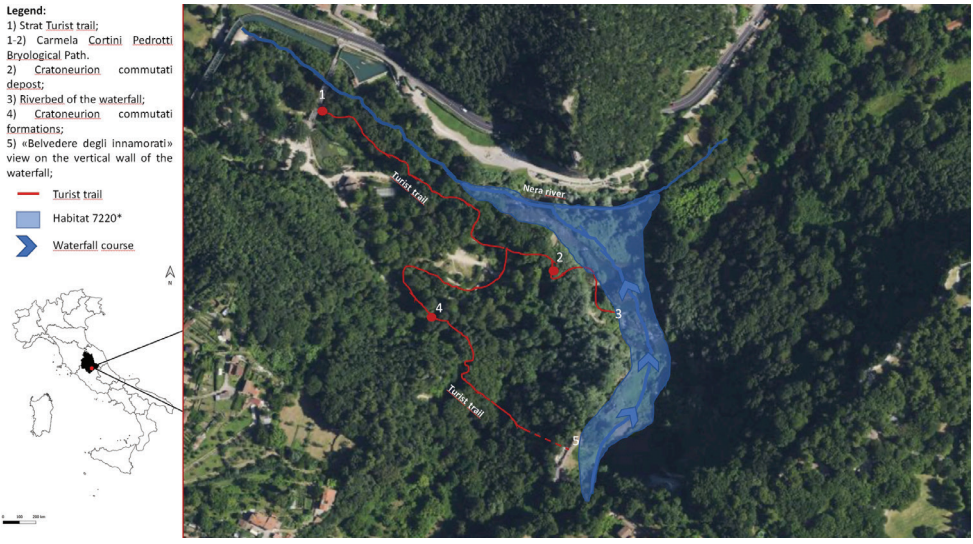

Figure 1. Schematic Map of the study area.

in the montane and sub-Alpine zone, in which the ground layer consisted of mosses (Lyons and Kelly 2016).

The first bryological explorations made at the Marmore Falls date back to 1869 where author recorded for the first time in the Umbria Region of the tufa moss *Cratoneuron commutatum* (Hedw.) Roth, currently *Palustriella commutata* (Hedw.) Ochyra (Fiorini Mazzanti 1869).

The particular environment, with a gorge and waterfall (Fig 2.), created a very special microclimate that allowed the establishment of interesting liverworts and moss flora which have been studied in recent years (Ellis et al. 2014; Poponessi et al. 2014; Ellis et al. 2016, 2017, 2018). In this study we present the first catalogue of species recorded within the protected area.

Material and method

The site of the park, has been examined from a bryological point of view in the year 2008 during a single inspection and in the years 2012–2018 with repeatedly investigation (especially from October to March, even twice a month). Collectors have inspected

Figure 2. Tufa morphologies Marmore waterfalls: **A** vertical slope seepage with *Palustriella commutata* **B** rock outcrops with tufa **C** banks Nera river **D** tuff steps (closed waterfall view) **E** complex tufa block **F** block of fossil tufa.

the area almost always on the same day or alternatively. The transect methodology was applied with aim to cover as much as possible habitat and microhabitat types, with special emphasis on wet habitats. We also investigated in a less hydrophilic context, poor in cormophytic vegetation and with a more mineral substrate. The *exsiccata* were stored in the Herbarium PERU of the Department of Chemistry, Biology and Biotechnologies, University of Perugia and labels will be available soon on web http://www.anarchive.it (Panfili et al. 2004). Additionally, small collection is deposited in bryophyte collection of Belgrade University Herbarium – BEOU. The nomenclature of taxa follows Söderström et al. (2016) for the liverworts and Ros et al. (2013) for the mosses and the novelties in bryological nomenclature follows Hodgetts et al. (2019a).

Results

The research conducted resulted in identification of 101 bryophytes taxa: 21 liverworts and 80 mosses. According to Aleffi et al. (2008), 2 liverworts and 11 mosses are new records for the Umbria region and additionally 3 liverworts and one moss are newly confirmed. The complete list of the identified bryophytes is reported hereafter. The taxa are listed in alphabetical order. The new taxa for the Umbria region are marked with an asterisk (*), while the symbol "#" indicates a confirmation of the old and doubtful records in the region.

List of taxa

Liverworts

Aneura pinguis (L.) Dumort.: on the bank of the Velino river.
Apopellia endiviifolia (Dicks.) Nebel & D. Quandt: very abundant in the study area. Grows on wet rock.
* *Cephaloziella baumgartneri* Schiffn.: on dry rock at the entrance to damp cavities.
Cololejeunea rossettiana (C.Massal.) Schiffn.: abundant on base rich substrate.
Conocephalum conicum (L.) Dumort.: very abundant near the waterfall and in the study area.
Conocephalum salebrosum Szweyk., Buczk. & Odrzyk.: locally abundant at entrance to "Grotta degli Innamorati".
Jungermannia atrovirens Dumort.: abundant on damp limestone.
Lejeunea cavifolia (Ehrh.) Lindb.: on rocks and trees in shaded and humid places.
Lophocolea bidentata (L.) Dumort.: abundant in damp places.
Lunularia cruciata (L.) Dumort. ex Lindb.: particularly in damp, shady places.
Marchantia paleacea Bertol.: on damp limestone.
Marchantia polymorpha L. subsp. *polymorpha*: very abundant in damp and shady places.
* *Marchantia polymorpha* subsp. *montivagans* Bischl. & Boissel.-Dub.: only presence on lightly shaded and base-rich soil.

Marchantia polymorpha subsp. *ruderalis* Bischl. & Boissel.-Dub.: on disturbed habitats, at the edges of the tourist trails.
Marchantia quadrata Scop.: grows on dry rock.
Mesoptychia turbinata (Raddi) L.Söderstr. & Váňa : on calcareous substrates.
Pellia epiphylla (L.) Corda: on shaded banks.
Porella platyphylla (L.) Pfeiff.: on bark of *Alnus glutinosa* (L.) Gaertn.
Radula complanata (L.) Dumort.: on bark of *Alnus glutinosa* and *Fraxinus excelsior* L.
Reboulia hemisphaerica (L.) : on limestone pavement and on earthy.
Solenostoma gracillimum (Sm.) R.M.Schust.: on soft rock.
Southbya tophacea (Spruce) Spruce: on limestone rock.

Mosses

Barbula unguiculata Hedw.: disturbed and open habitats.
Brachytheciastrum velutinum (Hedw.) Ignatov & Huttunen var. *velutinum*: on stones and compacted soil.
Brachythecium rivulare Schimp.: on runnels and wet ledges.
Brachythecium rutabulum (Hedw.) Schimp. var. *rutabulum*: very abundant on rock and walls.
Bryum calophyllum R.Br.: on soil along waterways.
**Bryum gemmiparum* De Not.: on dry walls.
Calliergonella cuspidata (Hedw.) Loeske: on dry walls, rock and soil.
Cratoneuron filicinum (Hedw.) Spruce: near the cascade.
Ctenidium molluscum (Hedw.) Mitt.: on dry rock.
Didymodon fallax (Hedw.) R.H.Zander: on wet soil and rock.
Didymodon ferrugineus (Schimp. ex Besch.) M.O.Hill: on dry soil.
Didymodon insulanus (De Not.) M.O.Hill: on walls.
**Didymodon spadiceus* (Mitt.) Limpr.: on soil and limestone rock.
Didymodon tophaceus (Brid.) Lisa: on limestone rock.
Encalypta streptocarpa Hedw.: on limestone rock.
Eucladium verticillatum (With.) Bruch & Schimp.: on wet limestone rock.
Exsertotheca crispa (Hedw.) S.Olsson, Enroth & D.Quandt: on limestone rock and walls in lightly shaded sites.
Fissidens bryoides Hedw. var. *bryoides*: on streamsides.
Fissidens crassipes subsp. *warnstorfii* (M.Fleisch.) Brugg.-Nann.:
Fissidens crassipes Wilson ex Bruch & Schimp. subsp. *crassipes*: on wet rock.
Fissidens crispus Mont.: on soil.
Fissidens curvatus Hornsch.: on soil.
Fissidens exilis Hedw.: on soil.
Fissidens osmundoides Hedw.: on limestone rock and walls in lightly shaded sites.
Fissidens rufulus Bruch & Schimp.: immersed in the water.
Fissidens serrulatus Brid.: on limestone rock and walls in lightly shaded sites.
Fissidens taxifolius Hedw. subsp. *taxifolius*: is common on soil or in cracks and crevices in rock.

#*Gymnostomum calcareum* Nees & Hornsch.: on limestone rock.
Homalothecium sericeum (Hedw.) Schimp.: on dry places.
Hydrogonium bolleanum (Müll. Hal.) A. Jaeger: on dripping stone wall.
Hygroamblystegium fluviatile (Hedw.) Loeske: on fast-flowing streams.
Hygroamblystegium tenax (Hedw.) Jenn.: on wet substrate.
Hygroamblystegium varium (Hedw.) Mönk. *subsp. varium*: on wet substrate.
**Hymenostylium recurvirostrum* (Hedw.) Dixon var. *recurvirostrum*: on soil with high-humidity.
Hypnum cupressiforme Hedw. var. *cupressiforme*: on the bark of *Ostrya carpinifolia* Scop.
Hypnum cupressiforme Hedw. var. *filiforme* Brid.: on the bark of *Ostrya carpinifolia*.
Imbribryum mildeanum (Jur.) J.R.Spence: on wet rock.
Isothecium alopecuroides (Lam. ex Dubois) Isov.: on limestone rock.
Kindbergia praelonga (Hedw.) Ochyra: on wet rock.
Leptodon smithii (Hedw.) F.Weber & D.Mohr: on the bark of *Ostrya carpinifolia*.
Leucodon sciuroides (Hedw.) Schwägr.: on the bark of *Ostrya carpinifolia*.
* *Mnium hornum* Hedw.: on wet rock and soil.
Mnium stellare Hedw.: on wet soil.
Orthotrichum diaphanum Schrad. ex Brid.: on the bark of *Ostrya carpinifolia*.
Oxyrrhynchium hians (Hedw.) Loeske: on the wet soil and rock.
Oxyrrhynchium speciosum (Brid.) Warnst.: on the wet soil and rock.
Palustriella commutata (Hedw.) Ochyra: present along the vertical walls to waterfall.
**Palustriella falcata* (Brid.) Hedenäs: present along the vertical walls to waterfall.
Plagiomnium affine (Blandow ex Funck) T.J.Kop.: on the wet soil.
Plagiomnium cuspidatum (Hedw.) T.J.Kop.: on the wet soil.
**Plagiomnium elatum* (Bruch & Schimp.) T.J.Kop.: on the wet soil.
Plagiomnium ellipticum (Brid.) T.J.Kop.: on the wet soil.
Plagiomnium undulatum (Hedw.) T.J.Kop.: on the wet soil.
Plasteurhynchium meridionale (Schimp.) M.Fleisch.: on soil.
Pleurozium schrebei (Willd. ex Brid.) Mitt.: on limestone soil.
**Pohlia annotina* (Hedw.) Lindb.: on wet soil.
**Polia melanodon* (Brid.) A.J.Shaw: on wet soil.
Pohlia wahlenbergii (F.Weber & D.Mohr) A.L.Andrews var. *wahlenbergii*: on limestone soil near the cascade.
Pseudoscleropodium purum (Hedw.) M.Fleisch.: among rocks and on rock ledges.
Ptychostomum archangelicum (Bruch & Schimp.) J.R.Spence: among rocks and on rock ledges.
Ptychostomum capillare (Hedw.) Holyoak & N.Pedersen: among rocks and on rock ledges.
Ptychostomum donianum (Grev.) Holyoak & N.Pedersen: on soil.
Ptychostomum imbricatulum (Müll.Hal.) Holyoak & N.Pedersen: on soil.
Ptychostomum torquescens (Bruch & Schimp.) Ros & Mazimpaka: on limenstone soil and rock.
Rhizomnium punctatum (Hedw.) T.J.Kop.: on soil.: on damp or wet soil.
Rhynchostegiella tenella (Dicks.) Limpr. var. *tenella*: on limestone rock.
Rhynchostegium confertum (Dicks.) Schimp.: on rock and walls.

Rhynchostegium megapolitanum (Blandow ex F.Weber & D.Mohr) Schimp.: accumulated soil on walls.
Rhynchostegium riparioides (Hedw.) Cardot: on along the banks of rivers.
Scorpiurium circinatum (Bruch) M.Fleisch. & Loeske: on rocks and the base of trees.
Syntrichia leavipila Brid.: on walls and rocks.
Tortella inflexa (Bruch) Broth.: on limestone rock.
Tortella tortuosa (Hedw.) Limpr. var. *tortuosa*: on moist, often shaded or sheltered rocks and walls.
**Tortula marginata* (Bruch & Schimp.) Spruce: on moist, often shaded or sheltered rocks and walls.
Trichostomum crispulum Bruch: on shaded calcareous.
**Weissia brachycarpa* (Nees & Hornsch.) Jur.: On wet soil.
Weissia controversa Hedw. var. *controversa*: on damp, bare soil.
**Weissia rutilans* (Hedw.) Lindb.: on damp, bare soil.
Zygodon rupestris Schimp. ex Lorentz: on the bark of old trees.

Discussion

The results of this survey bring undoubtly the idea of significance of this area as one of the region of high bryophytes diversity. Though, the hydrogeology of the investigated area is so peculiar *per se*, it offers so many microhabitat types that also this aspect should be taken into consideration when estimated this zone natural peculiarities.

The bryophytic flora and its role in the deposition of active travertines has been well documented over time (Charrier 1952; Pavletić 1955; Weijermars et al. 1986; Pentecost 1987; Zhang 1996). The sponge-like nature of travertine is no doubt important in the retention of water, often resulting in luxuriant bryophytes growth and the maintenance of the high water humidity in nearby sites. Therefore petrifying springs are lime-rich water sources which deposit tuff (or tufa). The water is rich in carbon dioxide and dissolved calcium carbonate. By contacting the atmosphere, carbon dioxide is outgassed and calcium carbonate is deposited as tufa. The resulting ecological conditions, with high pH and constant inundation by water and deposition of precipitated calcium carbonate, constitute a challenging environment for bryophytes to colonise.

The reported bryophytic survey shows a high level of floristic and biogeographical diversity for a Priority Habitat 7220 and gorge of the Marmore waterfall. It significantly improves the knowledge of a territory, which was already known for providing peculiar habitats for rare and endangered bryophytes taxa (Ellis et al. 2014; Poponessi et al. 2014; Ellis et al. 2016, 2017, 2018).

Additionaly, ecologically contrasting species like mesophilic *Rhynchostegiella tenella*, and more xerophilic (*Ctenidium molluscum*, *Leucodon sciuroides*) are often recorded in short distance one from another suggesting transitional gradient of habitat condition in very small scale. Some species are rather plastic from the point of view of their water requirements and habitat water regime (*Barbula unguiculata*,

Brachythecium rutabulum), and can be recorded in range of microhabitat type suggesting wider ecological valences, and genetic plasticity.

In the sence of biomass and abudance *Palustriella commutata* (syn. *Cratoneuron commutatum* (Hedw.) G. Roth), is the species characteristic to Priority Habitat 7220, and it is well presented along the vertical walls to Marmore waterfall. It forms almost monospecific pillows which constitute the portion of active deposition to travertines. In other portions of the waterfall, where the formation of travertine remains active, generally we observed the repetitive composition of the following species: *Brachythecium rivulare*, *Barbula bolleana*, *Bryum gemmiparum*, *Conocephalum conicum*, *Cratoneuron filicinum*, *Didymodon tophaceus*, *Eucladium verticillatum*, *Hymenostylium recurvirostrum*, *Jungermannia atrovirens*, *Palustriella commutata*, *Pellia endiviifolia*, *Rhynchostegium riparioides* which is in accordance with the similar sites reported elsewhere (e.g. Hugonnot et al. 2017). High flows impose considerable stresses on bryophytes, and the pleurocarp, with long, and somewhat flexible stems, partly buried in the travertine have a clear advantage in survival of such environmental conditions.

The taxa that repeatedly and most frequently occurred in the limestone portion with dripping and/or oozing rock were: *Eucladium verticillatum*, *Conocephalum conicum*, *Pellia endiviifolia*, *Barbula bolleana*, *Gymnostomum calcareum* and *Didymodon tophaceus*

Eucladium verticillatum, tended to grow on steeper, more sheltered terrain. This acrocarp moss was absent from sites with high water flow and it gained moisture mainly from spray or capillarity. Unlike *P. commutata* which forms almost monospecific pillows and is definitely the moss significant in tufa formation as considered its biomass, *E. verticillatum* was often intermixed with other species also not of great biomass. Among others *Didymodon tophaceus* and *Gymnostomum calcareum* were mostly recorded as associate species.

Three species among bryophytes recorded were categorized as Potentially Negative Indicator Species, depend on the circumstances in which they occurred. *Cratoneuron filicinum*, *Brachythecium rivulare* and *Platyhypnidium riparioides* can be indicative of nutrient enrichment, especially elevated phosphate levels. However, these species (especially *C. filicinum*) can occur individually at low levels of abundance in springs with Good water quality, where they form part of a mixed bryophytes assemblages along with other characteristic petrifying spring species (Lyons and Kelly 2016).

Cephaloziella baumgartneri and *Marchantia polymorpha* subsp. *montivagans* are newly recorded liverworts taxa for the Umbria Region. Additionally, *M. polymorpha* subsp. *montivagans* is rare in central and southern Italy. They are localized along the Nera river where the banks flow into the tourist route of the Marmore Didactic Centre. *M. polymorpha* subsp. *ruderalis* is confirmed for the flora of Region and it is localized along antropogenic pathway. The most abundant liverworts in the investigated area were *C. conicum* and *P. endiviifolia*. They occur in moist, shaded positions and seems to be strongly restricted to calcareous substrates. Indeed they grow frequently along streams, bases of moist rocks and cliffs, and especially near the waterfalls.

All liverworts recorded at the Marmore waterfall are very interesting from biodiversity point of view of this park. The region is also very significant in harbouring such a lot liverwort species that are Near Threatened (NT) nationally. According to IUCN criteria they are likely to qualify for a threatened category in the near future. *Conocephalum salebrosum*

is evalutated Data Deficient (DD) in Italy, since it was recently reported for Umrbia and Italy in the Marmore waterfall area (Poponessi et al. 2014).

Marchantia paleacea is a rare liverwort in central and southern Italy (Aleffi et al. 2008). This taxon has been assigned to the tropical montane-submeridional geographical element (Dierßen 2001). Sabovljevic et al. (2019) and Hodgetts et al. (2019a) considered this taxon Vulnerable in Europeean level. Thus, the population in Marmore waterfall area gives the region internationally significance from the conservation aspect and even higher national responsibility in protecting it. *Bryum gemmiparum* have a localized distribution on open limestone pavement where it grows in small damp crevices amongst other mosses like *Rizomnium punctatum*. It is firstly reported for the Umbria Region and it is very rare in Italy (Aleffi et al. 2008). In Europe, it is considered stable (Hodgetts et al. 2019c), but it is nationally threatened in Great Britain, Ireland, Malta, Germany, Switzerland, Bulgaria and Romania (Hodgetts 2015). In Portugal and Greece, it seems to be quite abundant and overall population in Europe is stable but it is under constant threat due to habitat damage and destruction (Hodgetts et al. 2019c).

Weissia rutilans is a rare moss in Italy (Aleffi et al. 2008). Hodgetts (2015) considered it as a candidate for the European Bryophyte Red list due to its presence in many national red lists. However, the number of known population is rather high and the overall European population seems to be stable thus it is not assessed as threatened in Europe (Hällingback et al. 2019d). Nationally, it is CR in Romania and Switzerland, EN in Austria and Czechia, VU in Sweden, Ireland and Spain, and threatened also in Germany and Poland (Hodgetts 2015). Elsewhere it is data deficient or simply not threat-assessed.

Other taxa recorded for the first time in the Umbria Region are: *Didymodon spadiceus*, *Hymenostylium recurvirostrum* var. *recurvirostrum*, *Mnium hornum*, *Palustriella falcata*, *Plagiomnium elatum*, *Pohliaannotina*, *P. melanodon*, *Tortula marginata* and *Weissia brachycarpa*. These are all significant bryophytes representatives of high-humidity stands, habitat types that in time of severe climate changes undergo strong decrease especially in southern Europe.

Barbula bolleana is very rare in Italy but very abundant in this habitat in the investigated area, which consists of a dripping stone wall, with chalky incrustations at its base, suggesting it takes an active part in the formation of tufa. *B. bolleana* is a hygrophilous and calcareous moss for the first time reported on the Marmore Falls site according to Ellis et al. (2016). It is CR in Portugal and possibly extinct in Switzerland, rare and data deficient elsewhere in Europe (Schröck et al. 2019). According to Hodgetts et al. (2019a) this species is rather under recorded in Europe. It is considered as DD over European continent and overall European population trend is unknown (Schröck et al. 2019). The makes the report and presence of this species even more valuable within this regional natural park.

An interesting acrocarp moss found in Marmore Waterfall is *Fissidens rufulus* and it has been firstly reported for Umbria Region recently (Ellis et al. 2016). It was abundant in the area where it was discovered, colonizing intermittently submerged limestone rocks. In the Marmore Waterfall site, a very special microclimate allowed the establishment of *F. rufulus* assemblages. According to Hodgetts (2015), it was a candidate species for European bryophyte red list. *F. rufulus* is an uncommon plant,

listed as Nationally Scarce in Britain (Lockhart et al. 2012), RE in Sweden and the Netherlands, CR in Romania, EN in Switzerland, Luxembourg, Ireland and Northern Ireland, VU in Austria and Slovakia, Near Threatened in the Czech Republic, Data Deficient in Poland, and Spain, rare in Ukraine and seldom recorded elsewhere in Europe: France, Croatia, Greece and Russia (Hodgetts 2015). Hodgetts et al. (2019a, b) assessed it at European level as least concern but since the overall European population decreasing they suggest species monitoring.

Ecologically significant species of petrifying springs which serve as positive indicators of habitat status consist largely of mosses and liverworts, with a smaller number of vascular plants. Rather high diversity of bryophytes is not proportional to small surface of studied areas. This is a consequence of the high portion of microhabitat types and quick gradient changes from ecological humid situations to shaded humid and irradiated dry sites. Also, from the bryological point of view protected area of Parco Fluviale del Nera' Regional Park is a habitat of many regionally, nationally threatened and scarce species and harbour a good population of species of European conservation interest. Further studies and monitoring programs are welcomed in future with aim to maintain survival of national and European significant bryophytes species. During these years of study, Carmela Cortini Pedrotti Bryological Path was established. Entitled to Professor Cortini, who spent her life studying bryophytes (1931–2007). She is forever remembered for her work with, and great knowledge of Bryophyte. The path runs along the tourist trail number 2 of the waterfall site and has been enriched with information boards concerning the bryophytes that have been found in the site and along the path.

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