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Bryophytes of Alpine and Apennine mountain streams: floristic features and ecological notes

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Abstract – Floristic and ecological features of aquatic bryophytes, and main abiotic factors, were studied in 23 mountain streams located in the Western Alps and Central Apennines (Italy). At 46 stations, a total of 36 taxa were collected. Most species showed both low occurrence (≤ 2 records) and low cover respect to sampled area (< 4%). However, in over 50% of stations, bryophyte communities with at least three species and cover over 10% were recorded. *Platyhypnidium riparioides*, *Fontinalis antipyretica* subsp. *antipyretica* and *Hygrohypnum luridum* were the most common and abundant species. Other species, more rarely recorded, have limited distribution in the Mediterranean region (*Blindia caespiticia*) and Italy (*Hygrohypnum duriusculum*). Some species show specific ecological preferences. In particular, *Hygrohypnum luridum* and *Palustriella falcata* are mostly linked to turbulent and cold waters (11.0-16.0°C), neutro-alkaline (7.3-8.4), with low conductivity (< 160 µS) and phosphates (< 0.01 mg/l) values. *Brachythecium rivulare*, *Platyhypnidium riparioides* and *Fontinalis antipyretica* subsp. *antipyretica* occur abundantly in less turbulent and less cold (15.3-18.2°C) waters, shaded, alkaline (8.3-8.6), with moderate conductivity (330-440 µS), and higher values of phosphates (0.06-0.09 mg/l). This study provides new floristic and ecological data on bryophyte communities occurring in mountain streams. It can also represent a useful contribution for biomonitoring activities of these habitats, often understudied floristically, where bryophytes are a significant part of the aquatic macroflora.

Running water / bryoflora / macrophyte / Western Alps and Central Apennines

Résumé – Les caractéristiques floristiques et écologiques de bryophytes aquatiques, et les principaux facteurs abiotiques, ont été étudiés dans 23 ruisseaux de montagne situés dans l'ouest des Alpes et des Apennins Centrale (Italie). Dans les 46 stations, un total de 36 taxa ont été recueillis. La plupart des espèces ont montré une faible occurrence (≤ 2) et une faible abondance (< 4 %). Cependant, dans plus de 50 % des stations, les communautés de bryophytes avec au moins trois espèces et une couverture de plus de 10 % ont été enregistrées. *Platyhypnidium riparioides*, *Fontinalis antipyretica* subsp. *antipyretica* et *Hygrohypnum luridum* étaient les espèces les plus communes et les plus abondantes. D'autres espèces, rarement enregistrées, ont leur limite de distribution dans la région méditerranéenne (*Blindia caespiticia*) et l'Italie (*Hygrohypnum duriusculum*). Certaines espèces présentent des préférences écologiques spécifiques. En particulier *Hygrohypnum luridum* et *Palustriella*

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falcata sont fréquents dans les eaux turbulentes et froides (11.0-16.0°C), neutre-alcaline (7.3-8.4), avec une faible conductivité (< 160 µS) et des valeurs basses de phosphates (< 0.01 mg/l). *Brachythecium rivulare*, *Platyhypnidium riparioides* et *Fontinalis antipyretica* subsp. *antipyretica*, sont en abondance dans des eaux moins turbulentes et moins froides (15.3-18.2°C), ombragées, alcalines (8.3-8.6), avec une conductivité modérée (330-440 µS) et des valeurs plus élevées de phosphates (0.06-0.09 mg/l). Cette étude fournit de nouvelles données floristiques et écologiques sur les communautés de bryophytes des ruisseaux de montagne. Ceci représente un outil utile pour la surveillance de ces habitats, dont la macroflore aquatique, dominée par les bryophytes, est peu étudiée.

Eau courante / bryoflore / macrophyte / Alpes occidentales et Apennin central

INTRODUCTION

Aquatic bryophytes, including both mosses and liverworts, are a dominant part of the macrophyte community occurring in mountain streams. Other macrophyte groups, especially vascular plants, are almost completely absent in these habitats due to environmental conditions greatly limiting their growth (e.g., turbulent and intense water flow, constant low water temperature, rocky substrates, steep slopes) (Suren, 1996; Tremp, 1999; Gecheva *et al*., 2010). Since the macrophyte community is often identified primarily with vascular plants, it has been long thought that macrophytes are not present in mountain streams, thus neglecting the bryophytes that indeed occur in these habitats. Probably also for this reason, in Europe, during the implementation phase of the Water Framework Directive (WFD; European Council, 2000) – the intercalibration exercise – the European Commission established that the macrophytes should not be considered as a relevant biological element to be monitored in the Alpine streams (European Commission, 2013).

Thus, a better knowledge of bryophytes, both from a floristic and an ecological viewpoint, could contribute to an improved characterization of the macrophyte community in mountain streams, and to a better evaluation of the conservation state of these aquatic ecosystems.

Despite the floristic and ecological importance of the aquatic bryophytes, few bryologists have focused their attention on these communities in mountain streams (Slack & Glime, 1985; Cattaneo & Fortin, 2000; Vieira *et al*., 2005, 2007). In Italy, in particular, they are poorly investigated and the few relative data are reported within comprehensive studies about bryophyte flora and vegetation of some rivers in Central-Southern Italy (Cortini Pedrotti, 1970, 1982; Lo Giudice & Privitera, 1984; Laschin, 1990; Privitera, 1990; Allegrini & Vitali, 1996; Allegrini, 2000; Mezzotero *et al*., 2009; Ceschin *et al*., 2010, 2012a, 2012b) or spring habitats in Southern-Eastern Alps (Tomaselli *et al*., 2011; Spitale, 2012).

Within this background, the present study aims to contribute to the knowledge of the aquatic bryophytes occurring in mountain streams of the Apennines and the Alps in Italy, providing data on floristic and ecological features. This type of information can improve macrophyte characterization and biomonitoring activities of the mountain stream ecosystems, where the aquatic flora is mainly composed of bryophytes.

STUDY AREA

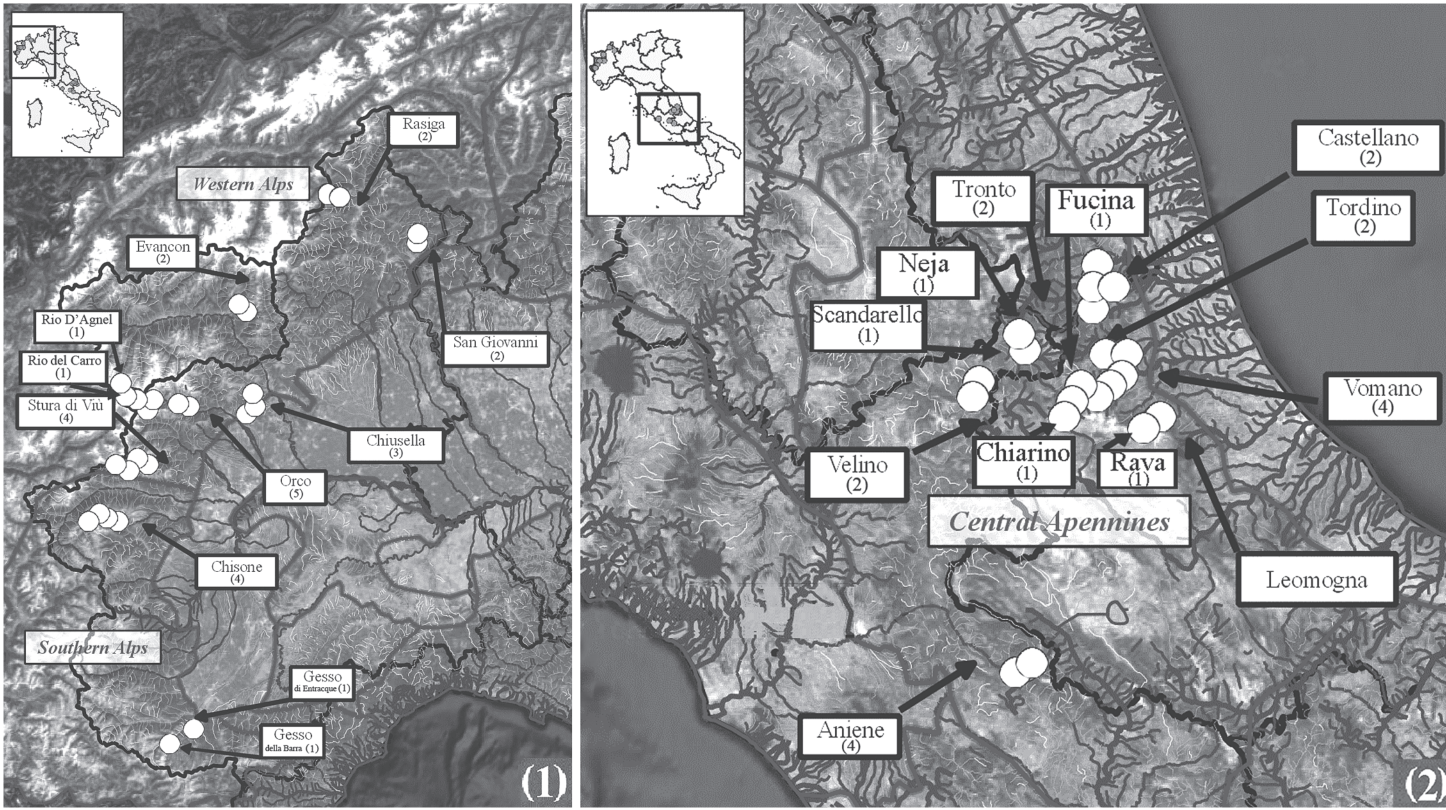
In this study, 23 mountain or piedmont streams located in the Italian Western Alps and in the Central Apennines were investigated (Figs 1 and 2). According to Wasson *et al.* (2001) and Buffagni *et al*. (2006), these streams fall into three hydro-ecoregions: Western Alps (HER 1, 20 sampling stations), Southern Alps (HER 4, 6) and Central Apennines (HER 13, 20). In Italy, the division into hydro-ecoregions was adopted for the application of the WFD and it divides the country on the basis of the main abiotic characteristics. HER 1 refers to geographic areas with Alpine mountain climate, geological substrate characterized by crystalline rock complexes and aquifers in igneous and metamorphic rocks; HER 4 is similar to HER 1 but with a larger occurrence of carbonate outcrops; HER 13 refers to areas with temperate mountain climate and geological substrate characterized mainly by flysch complex with aquifers hosted in silicate rocks and secondarily in carbonate rocks (Wasson *et al.*, 2001).

Forty-six sampling stations were selected along the considered mountain streams. Twenty-six were in the Western and Southern Alps (Fig. 1) and twenty in the Central Apennines (Fig. 2). The selection criteria were: accessibility to the site, bryophyte community predominance in terms of total coverage respect to the other macrophyte communities, homogeneous morphological features at macro-scale (confined watercourses, floodplain absent or greatly reduced), prevalence of natural and few disturbed habitats (e.g. pastures, mowed meadows) in the catchment area and scarce presence of settlements.

Most of the selected stations were located less than 30 km from the stream source and showed a riverbed width varying from 3 up to 16 m. The sites displayed medium to high stretch slope ranging from 1.2% to 18.4%. The altitude ranged from 300 to 1900 m a.s.l., with the 54% of the stations located above 800 m a.s.l. The distance between stations selected along the same stream was at least 2 km.

MATERIALS AND METHODS

In 2011 and 2012, between June and September, floristic surveys were carried out once for each station. Surveys were performed according to the national protocol for macrophyte sampling in running waters (Minciardi *et al*., 2014). At each station, all bryophyte taxa observed in riverbed within a 100 m long river stretch were recorded. This length of river stretch is considered optimal for taking into account all proper habitats occurring in that river segment and for characterizing the whole bryophyte community (Holmes *et al.*, 1999). The river stretch was forded twice, back and forth, and with zigzag modality (from bank to bank), to estimate the bryophyte coverage. The coverage was assigned at each taxon utilizing percent values respect to all sampled area. Bryophytes were collected from submerged aquatic habitats and from boulders, cobbles (or tree stumps) submerged at the time of the survey. In laboratory, the bryophyte samples were examined under stereoscope (Olympus SZX16) and optical microscope (Leica DM RB) for taxonomical determination purposes. For the determination of mosses, primarily Smith (2004) and Cortini Pedrotti (2001, 2005), and secondly Atherton *et al.* (2010) and Lüth (2004-2011) were consulted.



Figs 1-2. Study areas and location of the sampling stations along the mountain streams investigated. **1.** Alpine study area including stations belonging to the hydro-ecoregions Western and Southern Alps. **2.** Apennine study area including stations belonging to the hydro-ecoregion Central Apennines.

To identify liverworts, Smith (1990), Paton (1999) and Casas *et al.* (2009) were used. The species nomenclature was updated according to Aleffi *et al.* (2008). For the species distribution, we referred to Cortini Pedrotti (2001, 2005) at national level, Aleffi *et al.* (2008) at regional level, and Ros *et al.* (2007, 2013) for the Mediterranean region. The bryophyte specimens were stored as herbarium *exsiccata* and deposited at the Herbarium of Roma Tre University (URT) and at the Laboratory of Ecology of the "Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile" (ENEA), at the Research Center of Saluggia (Italy).

In order to describe the environmental features of the sampling stations, the main physico-chemical factors of the water were analysed at each station, twice a year. Specifically, temperature (°C), conductivity (µS/cm), pH and dissolved oxygen (mg/l) were measured using a multi-parameter probe (Hach-Lange-HQ40d). COD, ammonium, nitrate and phosphate concentration (mg/l) were measured in laboratory through spectrophotometric analysis (Hach-Lange – DR2800). Moreover, shading (percentage of shaded riverbed), water turbulence (percentage in multiples of 10 of wet surface characterized by flow types as cascades, broken waves, unbroken standing waves), and granulometry composition (percentage of abundance of size classes), were estimated in the field according to Minciardi *et al*. (2014).

The whole set of collected biotic and abiotic data was drawn up through statistical analyses. A hierarchical cluster analysis, based on Euclidean distance and Ward algorithm, was performed on abiotic dataset in order to identify groups of stations united by the similarity in their environmental conditions. For this analysis, the abiotic variables were standardized to z-scores (to zero mean and unit variance) to eliminate the difference in scale between them. A Principal Component Analysis (PCA) was used to display the stations according to the abiotic factors across the ordination space. The PCA was performed on the correlation matrix and the physico-chemical variables were log transformed $[\log_{10}(x+1)]$ to tend to a normal distribution of the variables and a linear relationship between them. The variables expressed in percentage (i.e., turbulence, shading, substrate sizes) were not transformed. For each considered factor, a characterization of the station groups emerging from the cluster analysis was displayed through box-plots and tested by Mann-Whitney test. This test was chosen to avoid violating the assumptions required for parametric tests, such as the normal distribution of variables.

On the same station groups, the non-parametric ANOSIM test (Bray Curtis distance, 9999 permutations) was applied for testing whether there is a significant difference between the emerging groups based on bryophyte species composition.

The SIMPER analysis applied to the bryophyte dataset has allowed identifying the species that mostly contribute to floristically differentiate the station groups, on the basis of their occurrence and cover. The SIMPER analysis calculates the average Bray-Curtis dissimilarity between all pairs of inter-group samples. The obtained average dissimilarity between sites of emerging groups can be expressed in terms of average contribution from each species and gives a measure of how consistently a species will contribute to the dissimilarity between groups.

All statistical analyses were performed utilizing PAST package vers. 1.94b.

RESULTS

Abiotic data

Values of the abiotic factors analysed in each station are reported in Table 1. From an abiotic point of view, the sampling stations can be divided into two main

Table 1. Average values of the abiotic factors measured in each station. Acronyms: HER: hydro-ecoregion. Spring dist: distance from spring. Turb: turbulence. T: temperature. Cond: conductivity. NH4: ammonium ions. NO3: nitrates. PO4: phosphates. COD: Chemical Oxygen Demand.

Stream	*Station acronym*	*River basin/region*	*HER*	*Cluster group*	*Altitude (m)*	*Spring dist (km)*	*Shading (%)*	*Turb (%)*
Evancon	Eva1	Dora Baltea/Val D'Aosta	1	A	1402	24	35	50
Evancon	Eva2	Dora Baltea/Val D'Aosta	1	A	1278	26	50	40
Chisone	Chis1	Chisone/Piedmont	4	A	1480	19	30	40
Chisone	Chis2	Chisone/Piedmont	4	A	1402	23	20	20
Chisone	Chis3	Chisone/Piedmont	4	A	1109	27	20	30
Chisone	Chis4	Chisone/Piedmont	4	A	1005	30	20	30
Chiusella	Chiu1	Chiusella/Piedmont	1	A	537	21	20	20
Chiusella	Chiu2	Chiusella/Piedmont	1	A	330	27	20	10
Chiusella	Chiu3	Chiusella/Piedmont	1	A	305	28	40	30
Gesso della Barra	GesB	Gesso/Piedmont	4	A	984	11	40	30
Gesso di Entracque	GesE	Gesso/Piedmont	4	A	989	11	50	30
Orco	Orc1	Orco/Piedmont	1	A	1712	10	30	20
Orco	Orc2	Orco/Piedmont	1	A	1505	18	20	10
Orco	Orc3	Orco/Piedmont	1	A	1485	19	40	20
Orco	Orc4	Orco/Piedmont	1	A	735	33	10	20
Orco	Orc5	Orco/Piedmont	1	A	654	36	10	20
Rio d'Agnel	D'Ag	Orco/Piedmont	1	A	1891	7	30	40
Rio del Carro	Car	Orco/Piedmont	1	A	1904	5	20	30
Rasiga	Ras1	Toce/Piedmont	1	A	1618	5	40	60
Rasiga	Ras2	Toce/Piedmont	1	A	1604	5	20	30
San Giovanni	SGio1	Ticino/Piedmont	1	A	484	8	70	40

groups: A and B (Fig. 3). Group A includes Alpine stations exclusively and is composed of stations belonging to HER 1 (Western Alps) and HER 4 (Southern Alps), while Group B is formed by all Apennine stations belonging to HER 13 (Central Apennines).

The two groups differ primarily on the basis of some abiotic factors, such as temperature, pH, conductivity, COD, nutrients, turbulence, shading and percent values of boulders in riverbed, whose differences are statistically significant. Conversely, the observed differences for the other abiotic factors, were not significant (Fig. 4). Specifically, group A is formed by stations that are generally at high altitude (> 1100 m a.s.l.), with cold (14.0°C), turbulent, sub-alkaline (7.9) waters, with moderate levels of COD (8.0 mg/l) and low values of phosphates (0.01 mg/l) and conductivity (140 μS/cm). Boulders and secondarily pebbles mainly constitute the

Table 1. Average values of the abiotic factors measured in each station. Acronyms: HER: hydro-ecoregion. Spring dist: distance from spring. Turb: turbulence. T: temperature. Cond: conductivity. NH4: ammonium ions. NO3: nitrates. PO4: phosphates. COD: Chemical Oxygen Demand. *(continued)*

Bedrock (%)	*Boulders (%)*	*Pebbles (%)*	*Gravel (%)*	*Sand (%)*	*T (°C)*	*pH*	*Oxygen (mg/l)*	*Cond (µS/cm)*	*NH4 (mg/l)*	*N03 (mg/l)*	*P04 (mg/l)*	*COD (mg/l)*
1	60	20	5	0	7,2	8,3	10,5	163	0,06	0,27	0,01	8,44
5	50	35	5	0	8,0	7,9	9,9	154	0,03	0,36	0,00	6,29
5	50	30	5	5	9,7	8,4	9,4	293	0,16	0,38	0,01	11,20
5	35	20	5	15	13,6	8,5	9,1	295	0,06	0,37	0,00	12,30
20	45	30	10	10	13,1	8,7	9,1	306	0,10	0,42	0,00	13,12
10	45	30	10	10	14,2	8,7	9,2	287	0,07	0,58	0,00	13,10
10	45	25	5	5	21,6	7,6	8,3	72	0,04	0,83	0,02	14,38
0	60	30	1	0	22,7	8,5	8,6	81	0,04	0,67	0,01	14,07
20	65	25	5	5	21,3	7,3	9,0	71	0,06	0,57	0,00	16,33
20	45	25	5	5	11,0	7,3	9,1	280	0,04	0,47	0,01	5,57
10	30	40	20	1	11,0	7,3	9,1	280	0,04	0,23	0,01	5,70
20	40	35	5	1	11,2	8,4	9,0	53	0,04	0,10	0,01	5,00
5	50	30	5	5	14,0	7,3	8,9	55	0,04	0,27	0,01	5,15
10	60	15	10	5	16,8	7,8	8,2	59	0,17	0,37	0,03	6,05
10	55	30	5	0	17,6	7,2	8,9	55	0,03	0,41	0,01	5,54
5	50	30	5	5	17,1	7,3	8,9	51	0,04	0,44	0,01	5,01
10	45	25	10	10	14,3	8,7	8,3	156	0,03	0,06	0,01	5,05
20	35	30	10	5	11,0	7,4	8,9	36	0,04	0,14	0,01	4,92
20	40	30	5	5	10,4	7,6	9,1	59	0,04	0,28	0,01	5,15
10	45	35	5	5	10,6	7,5	9,0	58	0,03	0,28	0,01	3,96
10	40	35	10	5	14,4	7,5	8,3	42	0,03	0,82	0,00	9,50

substrate. Overall, compared to those of group A, group B stations are more shaded and at lower altitude (630 m); the waters are less turbulent and less cold (16.0°C), alkaline (8.4), with values slightly higher of phosphates (0.08 mg/l) and conductivity (410 µS/cm), but lower of COD (1.3 mg/l). Substrate is mainly composed of boulders and pebbles but with a not-negligible presence of gravel and sand (Fig. 4).

The PCA confirms the grouping of the stations into these two main groups A and B (Fig. 5). Indeed, the two groups are significantly separated across the ordination space according to the analysed abiotic factors. Abiotic factors, such as conductivity, COD, phosphates concentration, boulders, and secondarily shading, pH and turbulence, are confirmed as these mainly distinguishing the two groups of stations (Fig. 5).

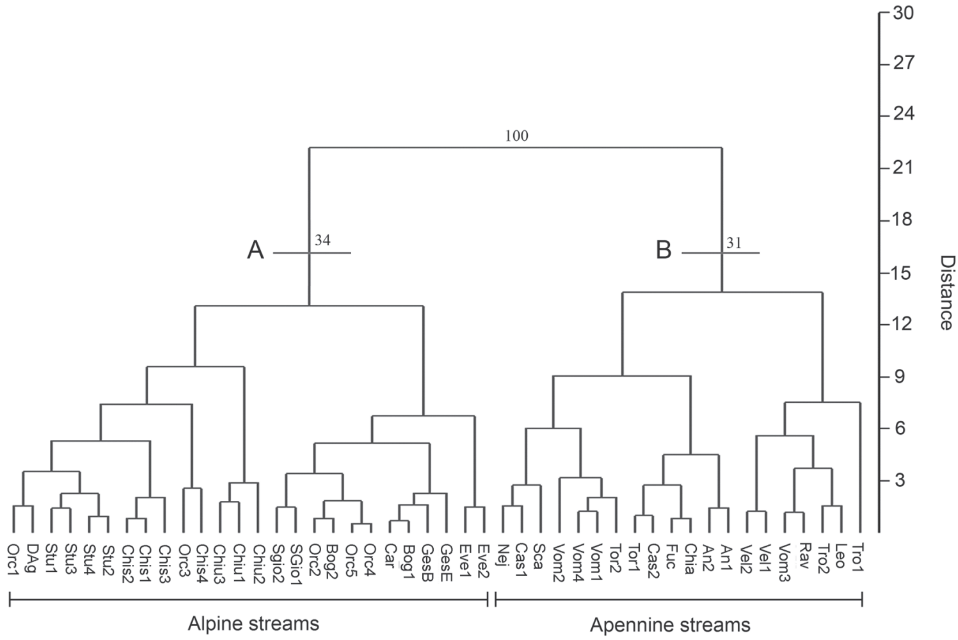


Fig. 3. Cluster analysis dendrogram of the stations selected along the mountain streams investigated (cophenetic correlation: 0.58). Grouping of the stations into two main clusters: A and B. The percentage of replicates where the selected nodes are supported in a bootstrap procedure is given (4999 replicates). For the station acronyms, see Table 1.

Bryophyte data

A total of 36 bryophyte taxa were identified. The collected species include 5 liverworts and 31 mosses, belonging to 7 orders and 14 families (Table 2). The most represented families are Amblystegiaceae (8 species, 5 genera), Brachytheciaceae (6, 4) and Pottiaceae (5, 3).

Many species show low occurrence (from 1 to 2), records (from 1 to 2 records) including all liverworts and 36% of mosses. Less than 1/3 of the collected species were found more than three times, and among these the most common were *Platyhypnidium riparioides* with a frequency of the 66%, *Fontinalis antipyretica* subsp. *antipyretica* (34%), *Hygrohypnum luridum* (26%) and *Fissidens* sp. (20%) (Fig. 6). So, most of species display low frequency, but also low cover percentage respect to sampled area in each station; indeed, 70% of the species showed a cover always under 4% of the sampled area (Fig. 6). However, considering the total number of species and the total cover of the bryophyte community in the investigated streams, it emerges that over 60% of the streams host a bryophyte community of at least 3 species, and that over 50% are formed by communities with total cover values over 10%.

In the stations belonging to group A (i.e. Alpine stations) and B (i.e. Apennine stations) 26 and 19 species were collected, respectively. Based on species occurrence, only few of the sampled species are shared by the two groups (22%) (e.g., *Cinclidotus riparius*, *Cratoneuron filicinum, Fontinalis antipyretica* subsp.

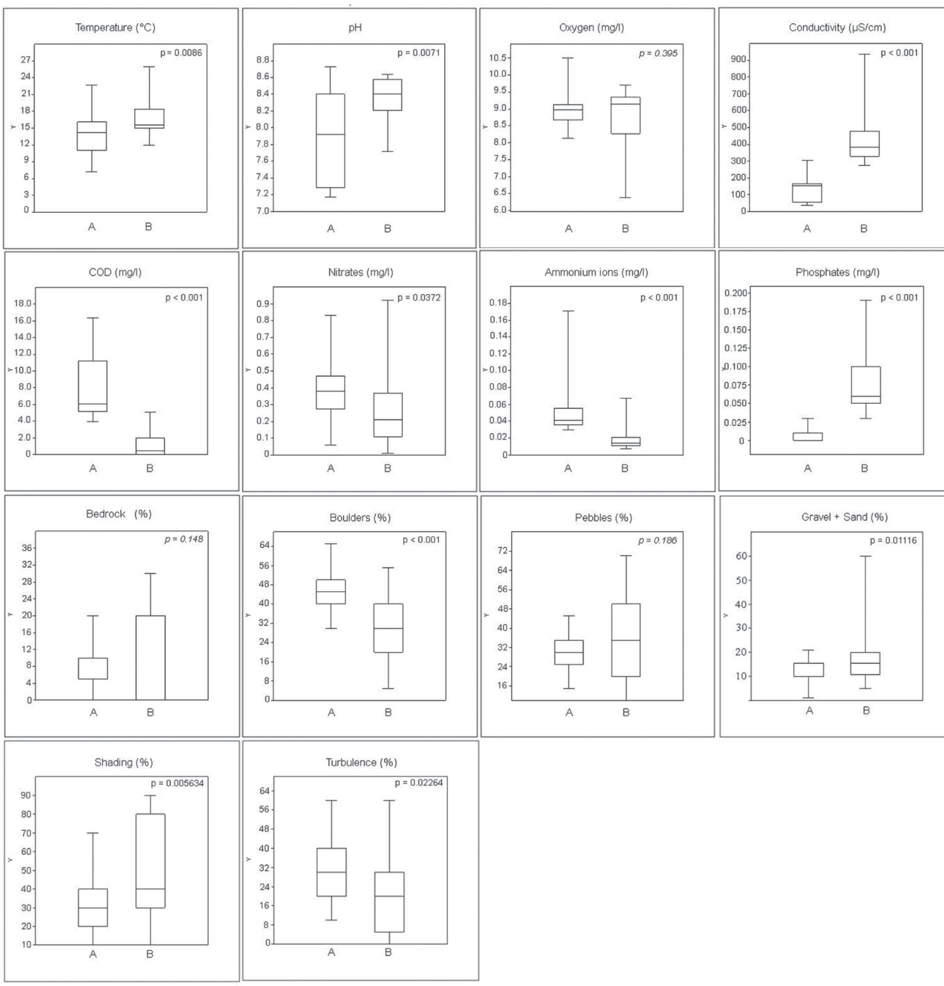


Fig. 4. Box-plots of the abiotic factors measured at Alpine stations grouped in group A and at Apennine stations grouped in group B. For each box-plot, the 25 and 75 percent quartiles are depicted by a box. The median is indicated by a horizontal line inside the box. Whiskers indicate minimal and maximal values. The p values based on Mann-Whitney test are reported, and in italic $p > 0.05$.

antipyretica, Palustriella commutata, *Platyhypnidium riparioides*), while the majority was found either in group A (48%) (e.g., *Blindia caespiticia*, *Hygrohypnum duriusculum*, *H. luridum*, *Palustriella falcata*, *Schistidium* sp. 1) or in group B (30%) (e.g., *Brachythecium rutabulum*, *Eucladium verticillatum*, *Fontinalis squamosa*, *Leptodictyum riparium*). Most likely, a high number of unshared species is linked to their low frequency (within the dataset).

The comparison through the ANOSIM test of the bryophyte community occurring in the two groups A and B highlighted a significant difference between the two groups in terms of composition and abundance ($R = 0.1035$; $p = 0.0139$).

On the basis of their different occurrence and cover, some species contribute more than others to differentiate the bryophyte composition of the communities

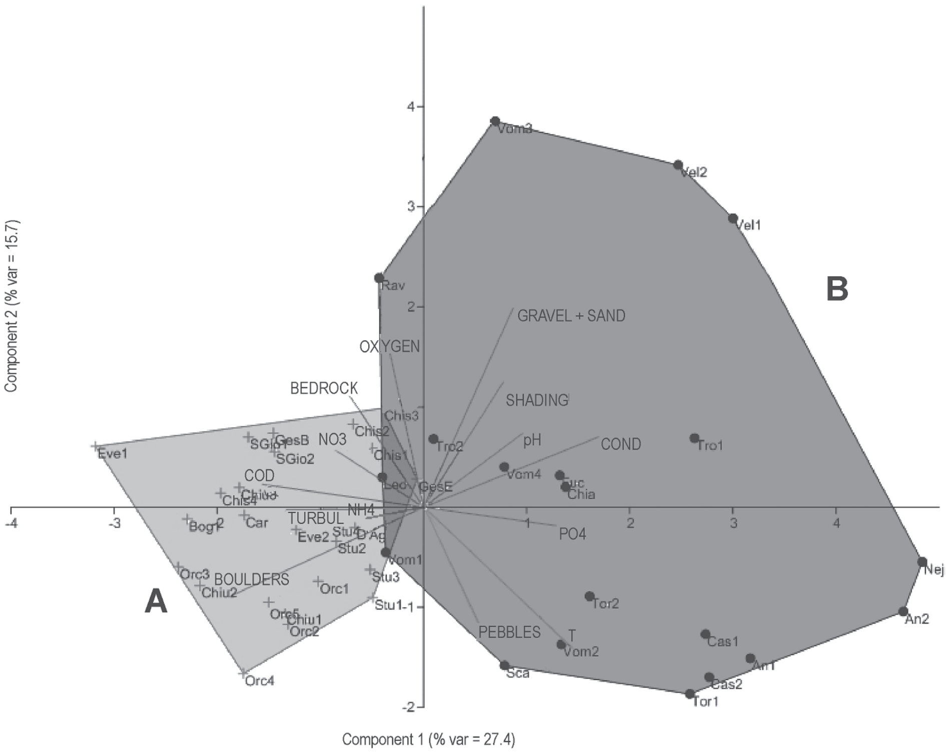


Fig. 5. PCA biplot showing the sampling stations according to abiotic factors across the ordination space. A and B station groups emerging from the cluster analysis are displayed. For the acronyms of stations and abiotic factors, see Table 1.

collected in stations included in the two groups, i.e. explain the floristic dissimilarity between group A and B. In particular, *Brachythecium rivulare*, *Fontinalis antipyretica* subsp. *antipyretica* and *Platyhypnidium riparioides* show a greater degree of belonging to group B, especially for their major coverage in stations of the group B than those of the group A. By contrast, species such as *Hygrohypnum luridum* and *Palustriella falcata* are mostly associated to group A, especially considering their occurrence more than cover values (Table 3).

DISCUSSION

The dominance of bryophyte communities in mountain stream stations, as well as the finding of bryophyte species known as taxa with limited distribution in the Mediterranean region and/or in Italy, underlines the importance of investigating this type of flora further. Indeed, the aquatic bryophyte communities are generally little studied, although interesting naturalistically and strongly characterizing the macroflora of the mountain running waters, where they prevail over other

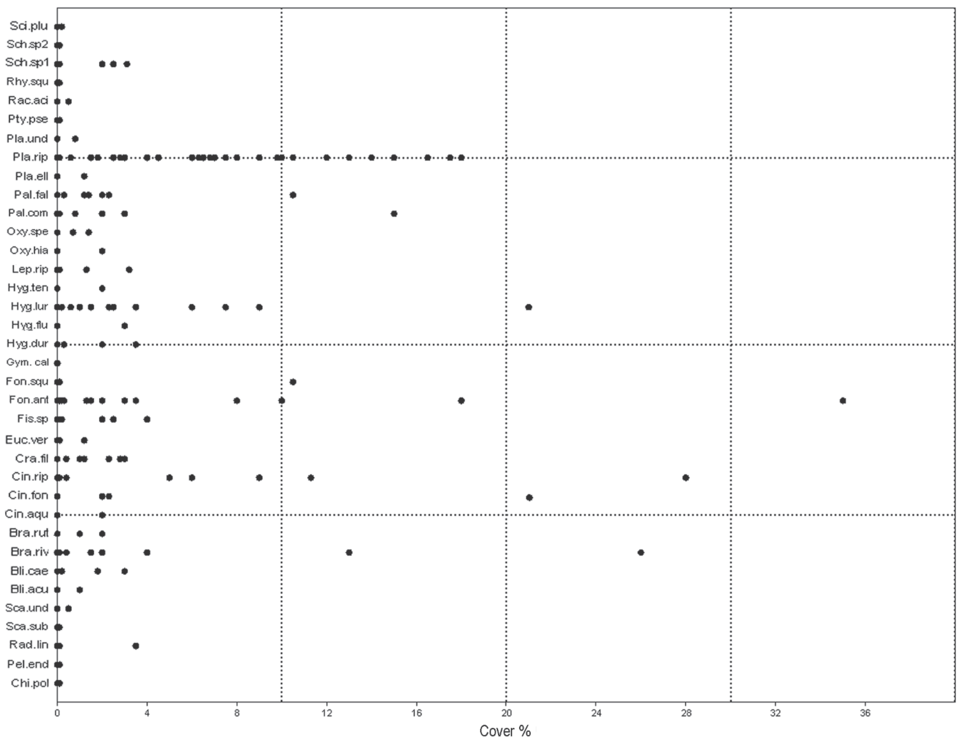


Fig. 6. Occurrence of the bryophyte species collected. Each point indicates one occurrence of each species in a sampling station. Cover value (%) for each species is also reported. For the species acronyms see Table 2.

macrophyte groups (Slack & Glime, 1985; Haury & Muller, 1991; Tremp, 1999). Therefore, the floristic knowledge deriving from this type of studies may be useful to assess the status of the bryophyte diversity which, due to its peculiarities, should be the object of investigations and consideration within protection and management policies.

Particular attention should be paid, for example, to those species collected in the study area that, on the basis of the reference checklists of mosses and liverworts of the Mediterranean region (Ros *et al*., 2007, 2013) and Italy (Cortini Pedrotti, 2001, 2005; Aleffi *et al*., 2008), show a rather limited distribution. In particular, the moss *Blindia caespiticia* is a species with limited distribution within the Mediterranean region, since it was recorded only in Bulgaria, France, Italy, Turkey and some of the ex-Yugoslavia countries (Bosnia-Herzegovina, Croatia, Montenegro and Slovenia (Ros *et al.,* 2013). At national level, *Hygrohypnum duriusculum* and *Blindia caespiticia* are very uncommon species, and *Blindia acuta*, *Cinclidotus aquaticus*, *Fontinalis squamosa*, *Hygroamblystegium fluviatile* and *Scapania subalpina*, are uncommon. Some species are also new interesting reports at regional level or updates of reports published before 1950 (Aleffi *et al*., 2008). In particular, the finding of *Cinclidotus riparius* along the Evancon stream is the first report for Valle D'Aosta, while the finding of *Plagiomnium ellipticum* in the Scandarello stream is the first

Table 2. List of the bryophytes collected in this study. For each species, sampling station(s) are reported. For the station acronyms, see Table 1.

Taxon acronym	*Bryophyte taxon*	*Station*
	MARCHANTIOPSIDA	
	JUNGERMANNIALES	
	GEOCALYCACEAE	
Chi.pol	*Chiloscyphus polyanthos* (L.) Corda	Chiu2
	RADULACEAE	
Rad.lin	*Radula lindenbergiana* Gottsche *ex* Hartm.	SGio1, SGio2
	SCAPANIACEAE	
Sca.sub	*Scapania subalpina* (Nees *ex* Lindenb.) Dumort.	Car
Sca.und	*Scapania undulata* (L.) Dumort.	Car
	METZGERIALES	
	PELLIACEAE	
Pel.end	*Pellia endiviifolia* (Dicks.) Dumort.	Vom1, Sca
	BRYOPSIDA	
	BRYALES	
	BRYACEAE	
Pty.pse	*Ptychostomum pseudotriquetrum* (Hedw.) Spence & Ramsay	Orc2, Ras2
	PLAGIOMNIACEAE	
Pla.ell	*Plagiomnium ellipticum* (Brid.) T.J. Kop.	Sca
Pla.und	*Plagiomnium undulatum* (Hedw.) T J. Kop.	Sca
	DICRANALES	
	FISSIDENTACEAE	
Fis.sp	*Fissidens* sp.	Vom1, Vom2, Tor1, Vel1, Sca, Tro1, Tro2, Stu4, Chiu1
	GRIMMIALES	
	GRIMMIACEAE	
Rac.aci	*Racomitrium aciculare* (Hedw.) Brid.	Ras1
Sch.sp1	*Schistidium* sp. 1	Car, Orc1, Orc2, Orc3
Sch.sp2	*Schistidium* sp. 2	Orc2
	SELIGERIACEAE	
Bli.acu	*Blindia acuta* (Hedw.) Bruch & Schimp.	Stu2
Bli.cae	*Blindia caespiticia* (F. Weber & D. Mohr) Müll. Hal	Car, D'Ag, Orc2

Table 2. List of the bryophytes collected in this study. For each species, sampling station(s) are reported. For the station acronyms, see Table 1. *(continued)*

Taxon acronym	*Bryophyte taxon*	*Station*
	HYPNALES	
	AMBLYSTEGIACEAE	
Cra.fil	*Cratoneuron filicinum* (Hedw.) Spruce	Chia, Cas2, Stu3, Stu4, Ras2, GesB
Hyg.flu	*Hygroamblystegium fluviatile* (Hedw.) Loeske	Chiu3
Hyg.ten	*Hygroamblystegium tenax* (Hedw.) Jenn.	Tro1
Hyg.dur	*Hygrohypnum duriusculum* (De Not.) D.W. Jamieson	Chiu2, Car, Ras1, Eve2
Hyg.lur	*Hygrohypnum luridum* (Hedw.) Jenn.	Stu1, Stu2, Stu3, Stu4, Chis4, D'Ag, Orc1, Orc2, Orc3, Orc4, GesB, Eve1, Eve2
Lep.rip	*Leptodictyum riparium* (Hedw.) Warnst.	Tro1, Tro2
Pal.com	*Palustriella commutata* (Hedw.) Ochyra	Fuc, Vom2, Chia, Cas2, Tor2, Stu1, Stu3
Pal.fal	*Palustriella falcata* (Brid.) Hedenäs	Stu2, Chis3, D'Ag, Orc2, Ras1, Ras2
	BRACHYTHECIACEAE	
Bra.riv	*Brachythecium rivulare* Schimp.	Chia, Tor2, Ani1, Sca, Stu3, Ras2, GesE
Bra.rut	*Brachythecium rutabulum* (Hedw.) Schimp.	Vom4
Oxy.hia	*Oxyrrhynchium hians* (Hedw.) Loeske	Sca
Oxy.spe	*Oxyrrhynchium speciosum* (Brid.) Warnst.	SGio1, SGio2
Pla.rip	*Platyhypnidium riparioides* (Hedw.) Dixon	Leo, Fuc, Vom1, Vom2, Vom3, Vom4, Chia, Cas1, Tor1, Tor2, Vel1, Vel2, Nej, Tro1, Stu3, Stu4, Chis1, Chis2, Chiu1, Chiu2, Chiu3, Orc4, Orc5, SGio1, SGio2, GesB, GesE, Eve1, Eve2
Sci.plu	*Sciuro-hypnum plumosum* (Hedw.) Ignatov & Huttunen	Car
	FONTINALACEAE	
Fon.ant	*Fontinalis antipyretica* (Hedw.) subsp. *antipyretica*	Fuc, Vom2, Vom3, Vom4, Ani2, Vel1, Chis1, Chiu3, Orc2, Orc3, Orc4, Orc5, SGio2, Eve2
Fon.squ	*Fontinalis squamosa* Hedw.	Tro1, Tro2
	HYLOCOMIACEAE	
Rhy.squ	*Rhytidiadelphus squarrosus* (Hedw.) Warnst.	Ras2
	POTTIALES	
	POTTIACEAE	
Cin.aqu	*Cinclidotus aquaticus* (Hedw.) Bruch & Schimp	Ani2
Cin.fon	*Cinclidotus fontinaloides* (Hedw.) P. Beauv.	Tro2, Stu4, Eve2
Cin.rip	*Cinclidotus riparius* (Host *ex* Brid.) Arn.	Ani1, Ani2, Tro2, Stu4, Chiu3, Eve2
Euc.ver	*Eucladium verticillatum* (With.) Bruch & Schimp.	Vom1, Cas2
Gym.cal	*Gymnostomum calcareum* Nees & Hornsch.	Stu2

Table 3. Contribution of each bryophyte species (dissimilarity) to differentiate floristically the two station groups (A, B) on the basis of their occurrence (n) and cover (%) is shown. Species are listed in order of increasing dissimilarity value.

Species	*Main reference group*	*Occurrence in A group*	*Occurrence in B group*	*Dissimilarity (%)*
Platyhypnidium riparioides	B	15	17	40.18
Fontinalis antipyretica subsp. *antipyretica*	B	9	6	11.14
Hygrohypnum luridum	A	13	0	9.17
Brachythecium rivulare	B	3	5	7.76
Palustriella falcata	A	6	0	4.45
Cinclidotus riparius	B	3	1	3.66
Palustriella commutata	A	2	5	3.34
Cratoneuron filicinum	A	4	2	2.90
Fissidens sp.	B	2	7	2.50
Cinclidotus fontinaloides	B	2	1	2.37
Hygrohypnum duriusculum	A	4	0	1.93
Schistidium sp.1	A	4	0	1.36
Radula lindenbergiana	A	2	0	1.00
Fontinalis squamosa	B	0	2	0.97
Leptodictyum riparium	B	0	2	0.90
Blindia caespiticia	A	3	0	0.89
Hygroamblystegium fluviatile	A	1	0	0.88
Oxyrrhynchium speciosum	A	2	0	0.84
Eucladium verticillatum	B	0	2	0.75
Brachythecium rutabulum	B	0	2	0.60
Hygroamblystegium tenax	B	0	1	0.56
Cinclidotus aquaticus	B	0	1	0.43
Blindia acuta	A	1	0	0.34
Racomitrium aciculare	A	1	0	0.29
Oxyrrhynchium hians	B	0	1	0.29
Plagiomnium ellipticum	B	0	1	0.17
Scapania undulata	A	1	0	0.14
Chiloscyphus polyanthos	A	2	0	0.13
Plagiomnium undulatum	B	0	1	0.11
Pellia endiviifolia	B	0	2	0.06
Ptychostomum pseudotriquetrum	A	2	0	0.06
Sciuro-hypnum plumosum	A	1	0	0.05
Rhytidiadelphus squarrosus	A	1	0	0.04
Scapania subalpina	A	1	0	0.03
Schistidium sp. 2	A	1	0	0.02
Gymnostomum calcareum	A	1	0	0.02

report for Latium. The samples of *Fontinalis squamosa* and *Cinclidotus fontinaloides*, found respectively along the Tronto stream (Marche) and the Stura Viù stream (Piedmont), confirm regional reports published before 1950 as well as the findings of *Cinclidotus riparius* along the Aniene River (Latium). The occurrence of *Cinclidotus aquaticus* along the Aniene confirms a recent report of this species for Latium (Ceschin *et al.*, 2012b).

The species *Hygrohypnum luridum* and *Palustriella falcata*, being mostly associated to the Alpine stations (group A), taking into account their grater coverage and occurrence there, show an ecological preference for stations characterized by substrate composed mainly of boulders, and by turbulent and cold (11.0-16.0°C) waters, neutro-alkaline (7.3-8.4), with low values of conductivity (< 160 µS/cm) and phosphates (< 0.01 mg/l), but moderate values of COD (5.0-11.0 mg/l).

Other species, among which *Brachythecium rivulare*, *Fontinalis antipyretica* subsp. *antipyretica* and *Platyhypnidium riparioides*, are very abundant in the Apennine stations (group B), and so they tend to show preferences for waters which are less turbulent and less cold (15.3-18.2°C), more shaded, as well as alkaline waters (8.3-8.6), with moderate conductivity (330-440 µS/cm) and lower values of ammonium ions (<0.02 mg/l) and COD (< 2.0 mg/l), but higher values of phosphates (0.06-0.09 mg/l). However, it is noted that *Fontinalis antipyretica* subsp. *antipyretica* and *Platyhypnidium riparioides* were recorded frequently, and sometimes abundantly, also in the Alpine stations (group A), showing therefore a wider distribution, and consequently a wide ecology.

For descriptive purposes of the mountain aquatic bryoflora, another important feature must be considered: the percentage of the total bryophyte cover recorded in stations. In fact, it should be noted that over 50% of the stations showed a total bryophyte cover over 10% of the sampled area and about 13% of the stations showed a cover over 30%. This finding is relevant because it emphasizes that, even in mountain stations, the occurrence of macrophytes (although almost exclusively as bryophytes and macroalgae) is not negligible, as it is often thought. Indeed, such last consideration is linked to the fact that the macrophyte component is commonly identified only with the vascular plants, which are almost completely missing in the mountain streams. For this reason, macrophyte biomonitoring activities and, in particular, application of macrophyte indices (e.g. EQR-IBMR: Ecological Quality Ratio-Indice Biologique Macrophytique en Rivière) for evaluating aquatic ecosystem ecological status, could be considered unreliable, placing a minimum cover threshold of 5%, as defined by Minciardi *et al*. (2003, 2014). In this study, over the 70% of the investigated stream stations exceed this threshold (considering *inter alia* exclusively the bryophyte component). This demonstrates that in mountain habitat, the macrophyte community, represented mainly by bryophytes, is not negligible. Thus, in mountain streams, the macrophyte communities should be monitored and considered among the biological elements contributing to description of these habitats and definition of the water ecological status, as well as being required for the other running water habitats (WFD 2000/60/CE).

In conclusion, this study provides data on floristic composition, distribution and main ecological features of bryophytes occurring in several streams of the Italian Alps and Apennines. It contributes to a better knowledge of the macrophyte community of these mountain aquatic habitats, generally understudied from this viewpoint. Thus, it can be also useful for monitoring and conservation activities of mountain streams where bryophytes, together with macroalgae communities, are the prevalent component of the aquatic macroflora.

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