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**Distribution, ecology and conservation of bryoflora in the
Mediterranean temporary ponds**

Settore/i scientifico disciplinari di afferenza

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Abstract

Mediterranean temporary ponds are small, shallow water bodies, isolated from permanent water bodies, which undergo a periodic cycle of flooding and drought. These ephemeral environments are considered to be amongst the most biologically and biogeographically interesting habitats; in Europe, they are recognised as habitats of Community Interest. Despite their important ecological functions, bryophytes are neglected or underrated in most projects addressing the management of fragile environments, such as damp habitats. The main outcome for this study is to bridge the gap of information on bryophytes in the Mediterranean temporary ponds regarding i) the floristic, biogeographic and ecological knowledge of the bryophytic component in these ephemeral habitats and their distribution in the Mediterranean basin ii) the local distribution of bryophytes within the ponds (outer, central, inner) according to their tolerance to floods iii) the first analysis on the diasporic banks dynamics in wet environments that are driven by species traits and microhabitat characteristics, that can give information on the fast (re)establishment of species when natural conditions are favourable.

Introduction

Mediterranean temporary ponds are small, shallow water bodies, isolated from permanent water bodies, which undergo a periodic cycle of flooding and drought. They host a peculiar and specialized flora and fauna well adapted to this water oscillation. In the Mediterranean region are considered to be amongst the most biologically and biogeographically interesting habitats (Grillas et al., 2004; Zacharias et al., 2007) and in Europe, they are recognised as habitats of Community Interest (European Commission, 1992). These ponds occupy depressions, often endorheic, which are annually subjected to extreme and unstable ecological conditions (Pinto-Cruz et al., 2009; Rhazi et al., 2009; Ghons et al., 2010).

The vegetation in these ponds is mainly represented by the classes of Littorelletea Br.-Bl. et Tx. 1943 and Isoeto-Nanojuncetea Br.-Bl. et Tx. 1943 (Mossa et al., 1989; Lorenzoni & Paradis, 1997; Bagella et al., 2007, 2012). Temporary ponds are extremely vulnerable habitats due to their natural characteristics such as the small size, the shallow depth of water, their typical scattered and isolated distribution at a regional level and also because of the anthropogenic pressure such as the proximity to expanding urban areas, intensive agriculture, industrialisation and the increasing development of tourism. For example, for thousands of years temporary ponds have been compatible with and even favoured by traditional farming regimes, but modern agriculture obliterates them (Rhazi et al., 2001; Beja & Alcazar, 2003).

Despite their small size, temporary ponds present a large variability, which is mainly attributed to a typical trait: a fine-scale zonation, depending on the water depth and the flooding period (Florencio et al., 2009; Bagella et al., 2009; 2010; Caria et al., 2013).

The damp habitats with a seasonal presence of surface water are potential bryophyte habitats. This is especially true in the Mediterranean areas where water availability is a key factor for those plant groups, requiring it for the completion of their life cycle at the reproductive stage.

The success of bryophytes in these habitat is the ability to tolerate long periods of dehydration without undergoing physiological damage at cell level. The physiology of bryophytes differs in major respects from that of vascular plants by virtue of their smaller size; unlike vascular plants, the leafy shoots of bryophytes equilibrate rapidly with the water potential in their surroundings and tend to be either fully hydrated or desiccated and metabolically inactive. Bryophytes posses no real vascular tissues and, consequently, they are very dependent on their local environment, hence their ability to survive cold and dry conditions is unparalleled in other principal plant groups (Glime, 2007). Since desiccation tolerance and other ecophysiological traits also vary among bryophytes, different species exhibit a broad range of physiological optima and ecological amplitudes.

Bryophytes have evolved several characters to limit water loss that include hair points, papillae, lamellae, dead hyaline leaves to protect the photosynthetic leaves, thick cell walls, and the ability to change the orientation of their leaves. These adaptations produce substantial variations in each species ability to withstand desiccation and also affect the time necessary to metabolically recover from drought conditions after rewetting (Gignac, 2001). Bryophytes have a dominating role in the ecosystem by influencing factors a dominating role in such ecosystem by subsequently influencing factors viz., soil temperature, nutrient input, etc. Generally, the soil under bryophytes mats become cool and moist, which affect nutrient cycling of ecosystem by catching atmospheric deposition and leaching from dripping above ground. Bryophytes play an efficient role to filter the nutrients reaching to soil by absorbing them directly from the atmosphere in liquid phase. Bryophytes protect the soil against erosion due to their netted and webbed protonemata and gametophores to cover the exposed substrata and help in increasing water-holding capacity of the soil. The role of bryophytes in an ecosystem is governed by four properties, their ability to establish soils, to trap and hold moisture, to exchange cations and, to tolerate desiccation (Bahuguna et al., 2014).

Despite their important ecological functions, bryophytes are neglected or undervalued in most projects addressing the management of fragile environments, such as damp habitats (Rhazi et al., 2006; Ferchichi-Ben Jamaa et al., 2010; Bagella et al., 2009, 2012).

The objectives of the research project to conduct during the PhD program will follow a multiscale approach:

Macroscale - The Mediterranean basin context

- i) compile the first bryoflora of Mediterranean temporary ponds (**Chapter 1, 2**).
- ii) to define a list of bryophyte species typical of the habitat “3170* Mediterranean temporary pond” to be used as a reference list to complete the habitat description (**Chapter 1, 2**).

Regional Scale – The island context

iii)to determine the impacts of the main environmental factors on bryophyte richness in Mediterranean temporary ponds (**Chapter 2**).

Local Scale – Spatial distribution and spore bank

iv) study the spatial distribution of bryophytes within the temporary ponds (**Chapter 2**).

i) analysis of bryophyte's spores in Mediterranean temporary ponds to identify what are the species that show a better fitness for survival and adaptation to these environments (**Chapter 3**).

The main expected outcome for this project is to bridge the gap of information on bryophytes in the Mediterranean temporary ponds. Those information are useful to build up a scientifically sound knowledge useful for future effective conservation actions. The results were presented at national and international congresses and symposia and published in peer-reviewed journals.

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Chapter 1

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Bryoflora of the Mediterranean temporary ponds: a tentative reference list for the Mediterranean basin

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Abstract

The "Mediterranean Temporary pond" are important habitat for biodiversity in the Mediterranean region, classified as a priority natural habitat (3170*) under the Habitats Directive 92/43/EEC. To describe the bryoflora of Mediterranean temporary ponds we compared the available bibliographical data on temporary ponds in the Mediterranean basin and created a georeferenced database of 224 bryophyte species, defined as the most common species surveyed in 95 ponds located in 9 study area, ranging from Spain to Sicily. We analized the bryoflora in terms of species richness and composition, chorological and ecological elements. Particularly interesting is the presence of bryophytes species considered, according to the European Committee for Conservation of Bryophytes (ECCB), under threat at different levels in Europe. We propose a tentative bryoflora

of Mediterranean temporary ponds in the Mediterranean basin that is propaedeutic to define a list of bryophyte species typical of the habitat “3170* Mediterranean temporary pond” to be used as a reference list to complete the habitat description and propose effective conservation actions to preserve all its biotic components.

Keywords:

Database; ephemeral habitats; mosses; liverworts

Introduction

Mediterranean temporary ponds are present in the five regions of the world with Mediterranean climate (Rhazi et al., 2009). They occur in Europe (Grillas et al., 2004; Zacharias et al., 2007); Australia (Warwick & Brock, 2003); Western USA (Kneitel & Lessin, 2010), South Africa (Rhazi et al., 2006), and North Africa (Rhazi et al., 2009). Mediterranean temporary ponds are shallow water bodies, which are flooded in winter or in the end of spring for a sufficiently long period, to allow the development of (semi-) aquatic vegetation and animal communities. In Europe, they are listed as priority habitat according to the Natura 2000 network of the European Union (Natura code 3170, Habitats Directive 92/43/EEC). In the Mediterranean basin there are many types of temporary ponds. They vary from small copular ponds ($<1\text{ m}^2 <50\text{ cm}$ deep), hollowed out in rocks (e.g. Colle du Rouet, France) to almost permanent lakes, which sometimes cover an area of more than several hectares (e.g. Teppe Rosse, Corsica, France; Zacharias et al., 2010). They are usually inundated for at least a few months every year, drying out during the March–June period. Some temporary ponds may hold water for more than one year, whereas others may remain dry for more than one season, depending on the amount of rainfall. Thus, they present a significant variability in size, shape,

depth, diversity among organisms (flora and fauna) and duration of flooding (Fahd et al., 2000; Lahr et al., 2000; Boix et al., 2001, 2004; Rhazi et al., 2001, 2004; Beja & Alcazar, 2003; European Commission DG Environment 2003; Jakob et al., 2003; Grillas et al., 2004; Zacharias et al., 2007). Mediterranean temporary ponds are of major conservation importance because, despite their small size, they shelter many rare and endangered species. Fauna and flora of Mediterranean temporary ponds, have been the subject of scientific interest (e.g., Murray, 1911; Mozley, 1932; Rzóska, 1961; Stout, 1964). However, the number of scientific publications on Mediterranean Temporary Ponds is not proportional to their ecological importance (Grillas et al., 2010) and only in recent years for vegetation and fauna it increased significantly (Boix et al., 2012).

Despite their important ecological functions, the studies addressing bryophytes are very scarce, with a local exceptions (Casas et al., 1998; Hugonnot, 2002; Cogoni et al., 2009, 2016; Pericàs et al., 2010; Puglisi et al., 2015; Poponessi et al., 2016).

Thus, Mediterranean temporary ponds should be a target habitat for the study and knowledge of bryophytes.

Aims of this study were to i) compile the first bryoflora of Mediterranean temporary ponds in the Mediterranean basin ii) to define a list of bryophyte species typical of the habitat “3170* Mediterranean temporary pond” to be used as a reference list to complete the habitat description.

Materials and methods

Study area

We analyzed bryophyte species in the Mediterranean temporary ponds, ranging from Spain to Sicily. According to the Ramsar Convention (2002), temporary ponds are small, shallow water bodies (less than 10 ha), isolated from permanent water sources, which undergo a periodic cycle of flooding and drought.

The Interpretation Manual of European Union Habitats (EC, 2007) defines Mediterranean temporary ponds as “very shallow temporary ponds (a few centimetres deep) which exist only in winter or in late spring, with a flora mainly composed of Mediterranean therophytic and geophytic species belonging to the alliances *Isoetion*, *Nanocyperion flavescentis*, *Preslion cervinae*, *Agrostion salmanticae*, *Heleochnloion* and *Lythrion tribracteati*.

They occur in substrate depressions. These depressions may have been created by various geomorphological processes such as subsidence or erosion by wind on dry plains, and dissolution of limestone in karstic areas. Alternatively, they might be of artificial origin, e.g. in abandoned quarries or watering holes for cattle or sheep (Ramsar Convention Secretariat, 2002).

Water originates from a variety of sources: rainfall, runoff from the surrounding catchment area (usually an endorheic basin) and/or from groundwater. Temporary ponds that depend on groundwater are typically those of karstic origin or in sandy substrates. Those that depend strictly on rainfall and runoff are usually on impermeable substrates, such as rock or clay.

Site selection and data gathering

We surveyed the existing bryological literature on the composition of temporary ponds in the Mediterranean using the following keywords “bryophytes, Mediterranean, temporary ponds” and the literature cited in those papers (updated December 2016). We collected published material on ponds in northern Spain, Southern France and main Mediterranean islands such as Menorca (Balearic Islands), Corsica and in Italy (Sicily, Sardinia, Latium, Campania and Umbria; Casas et al., 1998; Hugonnot, 2002; Cogoni et al., 2009; Pericàs et al., 2010; Puglisi et al., 2015; Cogoni et al., 2016; Poponessi et al., 2016). All data were analysed to provide taxonomic harmonization of information; hence they were inserted in a georeferenced database.

Data analysis

To describe the bryoflora of Mediterranean temporary ponds we analyzed the flora in terms of species richness and composition, chorological and ecological elements (life form, life strategy and humidity). The life form term refers to the general appearance of a colony of bryophytes arising from the growth model, the branching pattern and general assemblage of individuals, influenced by environment (Puglisi et al., 2016). Life strategy, based on the reproduction and dispersal strategies, reflects the ecological site conditions and gives knowledge on the mechanisms of habitat maintenance, establishment and re-establishment of species and communities (Puglisi et al., 2016). Bryophyte communities are highly sensitive to humidity levels.

We followed Ros et al. (2007, 2013) for nomenclature, for chorological elements Sérgio et al. (2014), for life forms Hill (2007) and Mägdefrau (1982), and for life strategy Kürschner & Frey (2012). The life form mat include species mat-rough, mat-smooth and mat-thalloid. The life strategy

shuttle include species annual shuttle, short-lived shuttle and perrennial shuttle. Humidity, the main limiting factor of this environment, has been assigned according to the categories proposed by Dierssen, (2001).

To investigate the differences in species composition among sites, we performed a cluster analysis. Analysis were performed with Modified TWINSPAN (Roleček et al., 2009) using Juice (Tichý, 2002).

Results

We collected data on 224 bryophyte species distributed in 95 ponds, located in 9 study area in northern Spain, Southern France and main Mediterranean islands such as Menorca (Balearic Islands), Corsica and in Italy (Sicily, Sardinia, Latium, Campania and Umbria; Casas et al., 1998; Hugonnot, 2002; Cogoni et al., 2009; Pericàs et al., 2010; Puglisi et al., 2015; Cogoni et al., 2016; Poponessi et al., 2016) (Fig. 1) (Table 1). The 224 taxa surveyed are 176 mosses and 48 liverworts (for a complete list of species see Supplementary Material 1 and for species distribution see Supplementary Material 2).

Four out of 42 reported families (Pottiaceae, Brachytheciaceae, Bryaceae and Ricciaceae) include 53% of the total species.

We can define a group of bryophytes with ponds frequency higher than 20%: *Archidium alternifolium* (Hedw.) Mitt., *Trichostomum brachydontium* Bruch., *Imbribryum alpinum* (Huds. ex Wiyh.) N.Pedersen, *Tortella flavovirens* (Bruch) Broth., *Ptychostomum pseudotriquetrum* (Hedw.) J.R. Spence & H.P. Ramsay, *Fossombronia caespitiformis* subsp. *caespitiformis* De Not. ex Rabenh., and *Riccia sorocarpa* Bisch.

In particular, *Archidium alternifolium* is the most common species found in temporary ponds.

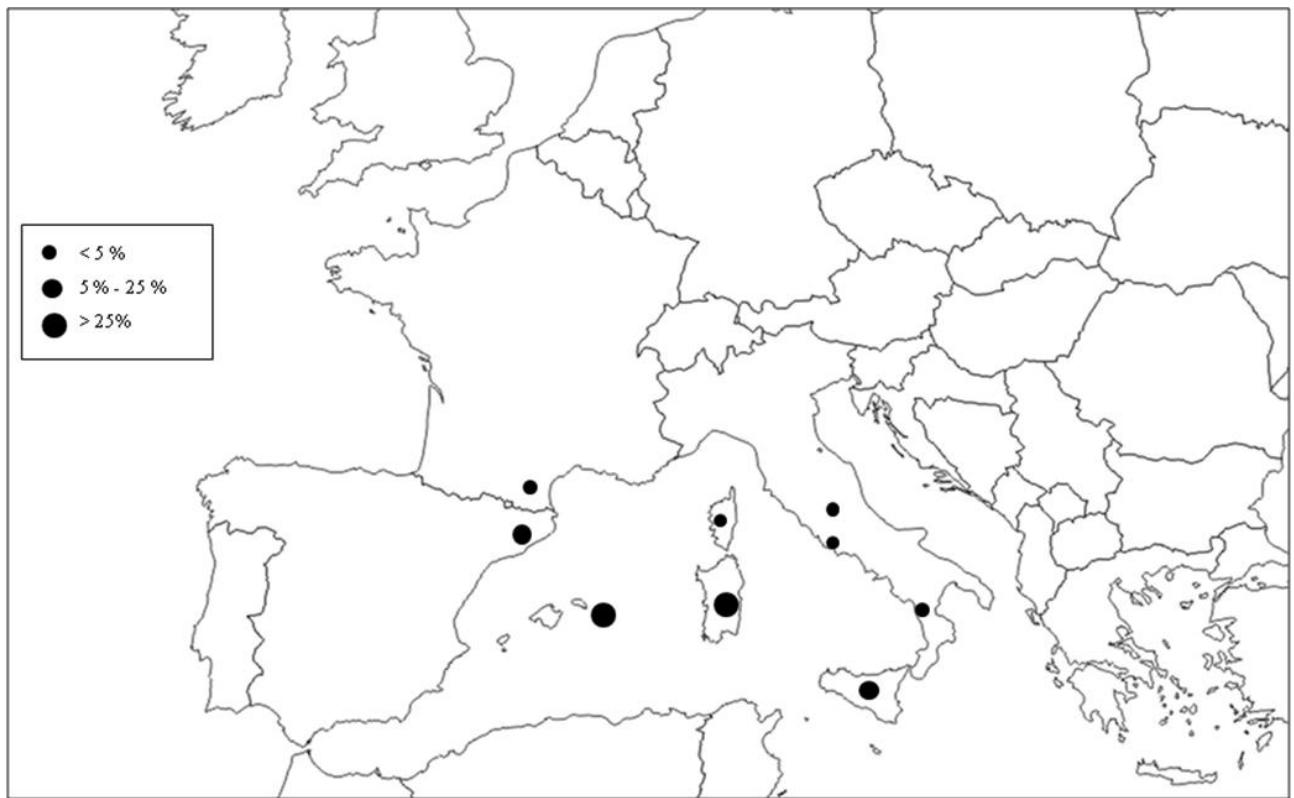


Fig. 1 - Percentage distribution of the ponds in the investigated countries.

PONDS	SITES
Palinuro al Faro	Campania
Bassa del Serrat de les Garrigues	Catalonia
Estany del Serrat de les Garrigues	Catalonia
Bassa dels Tòrlits	Catalonia
Estany d'en Parù	Catalonia
Depressió a prop del menhir de Santa Fe dels Solers	Catalonia
Riu Anyet, a prop del mas dels Solers	Catalonia
Bassa dels Castellars	Catalonia
Bassa del mas d'en Faig	Catalonia
Eestany del mas Baleta	Catalonia
Estany d'en Martí	Catalonia
Padule 1	Corsica
Padule 2	Corsica
Padule 3	Corsica
Padule maggiore	Corsica
Bosco della Cerasella	Latium
Castel Porziano	Latium

Bosco di Foligno	Latium
Piscina della Verdesca	Latium
Castellet de Sanitja	Menorca
Son Morell	Menorca
El Clot des Guix	Menorca
Bassa Verda	Menorca
Bassa de Torrellafud	Menorca
Bassa de Son Morro	Menorca
Basses de Corniola	Menorca
Bassa de Binigaful	Menorca
Ses Penyes d'Egipte	Menorca
Bassa des Molinet	Menorca
Bassa de Biniguardò	Menorca
Les Planes de Son Arro	Menorca
Basses de Biniatrum	Menorca
Bassa de Son Gornes	Menorca
Bassa de ses Palisses	Menorca
Pla de sa Vinyeta	Menorca
Bassa des Mal Lloc	Menorca
Bassa Verda d'Algaiarens	Menorca
Cocons de Daia	Menorca
Cocons de Binicodrell	Menorca
Cocons de Binissaid	Menorca
Cocons d'Algendar	Menorca
Bassa des Cap Negre	Menorca
Bassa de sa Mesquida	Menorca
Bassa Plana	Menorca
Còs des Sòndic	Menorca
Es Armaris	Menorca
Bassa des Banyuls	Menorca
Paule Santa Lucia	Sardinia
Pranu Mallu	Sardinia
Paule Bartili	Sardinia
Paule Pardu Longu de Joso	Sardinia
Paule Maricca	Sardinia
Paule Perdosu	Sardinia
Paule Camisa	Sardinia
Paule Majori	Sardinia
Paule de Fenu	Sardinia
Paule Tramatzu	Sardinia
Paule Cerrobica	Sardinia
Paule Piccia	Sardinia
Paule Salamessi	Sardinia
Paule M1	Sardinia

Paule M2	Sardinia
Paule M3	Sardinia
Paule S1	Sardinia
Paule S2	Sardinia
Paule S3	Sardinia
Paule Medrogu	Sardinia
Pischina e Paule	Sardinia
Paule 1	Sardinia
Paule 2	Sardinia
Paule 3	Sardinia
Paule Loelle	Sardinia
Paule Olzale	Sardinia
Paule Monte Minerva	Sardinia
Paule 1	Sardinia
Paule 3	Sardinia
Paule Punta Palai	Sardinia
Paule B	Sardinia
Paule D	Sardinia
Paule E	Sardinia
Gorgo del Drago	Sicily
Coda di Riccio	Sicily
Gorgo Lungo	Sicily
Contrada Montagnola	Sicily
S. Maria la Stella	Sicily
Capo Mulini	Sicily
Mt S. Angelo	Sicily
Cave di Caolino	Sicily
Mt Illice	Sicily
Rauque Haute	France
Podere Coccoargo	Umbria
Podere Marella	Umbria
Monelli	Umbria
Le 7 Strade	Umbria

Table 1 - Sites studied

Chorological and ecological features

Chorological data show that the element Oceanic (35%) prevails on the others chorological elements (Temperate 29%, Mediterranean 25% and Boreal-Alpine 10%).

Most of the species are xerophytic (20%), hygro-mesophytic (19%) and meso-xerophytic (18%) closely linked to the hydroperiod of the temporary ponds. Entities that are strictly hygrophytic (18%) such as *Rhyncostegium ripariooides* (Hedw.) Cardot, *Dalytrichia mucronata* (Brid.) Broth. and *Leptodictyum riparium* (Hedw.) Warnst. undergo periods of submersion during the spring. *Leptodictyum riparium* is also capable of tolerating the summer drought by taking refuge at the base of boulders with niches that form a microclimate with residual humidity.

Regarding life-form analysis, there is a predominance of turf (36%) followed by mat rough (23%) and tuft (11%). Concerning life strategy, most species are colonist (37%) such as the pioneer species *Bryum dichotomum* Hedw. and *Tortella squarrosa* (Brid.) Limpr. and shuttle (38%) represented especially by liverworts belonging to genus *Riccia* that do not tolerate water stress in the driest season (During, 1979).

Conservation concern taxa

Several species of conservation concern are linked to these environment. *Petalophyllum ralfsii* Nees et Gottsche (Sardinia and Menorca sites) is included in the Habitats Directive 92/43/EEC and assessed as Critically Endangered in the Italian Flora Red List (Rossi et al., 2013, 2014). The species *Cephaloziella calyculata* (Durieu & Mont.) Mull. Frib. (Sardinia site) and *Fossombronia pusilla* (L.) Nees (Sardinia, Spain and Menorca sites) are assessed as Critically Endangered in Sardinia (Hodgetts, 2015). *Riccia crozalsii* Levier (Sardinia, Spain, Corsica and France) is a

common species in much of the Mediterranean area, but it is recognized as Endangered in Italy, Sardinia and Sicily (Hodgetts, 2015). The liverworts *Fossombronia caespitiformis* subsp. *multispira* (Schiffn.) J.R.Bray & D.C.Cargill and *F. wondraczekii* (Corda) Dumort. ex Lindb. are considered Critically Endangered for Italy (Hodgetts, 2015). *Riccia canaliculata* Hoffm. are considered Endangered in Italy, very rare in the Italian territory, reported in Latium and Sardinia on the basis of new records (Hodgetts, 2015; Aleffi et al., 2008).

Riccia perennis Steph. is a liverwort included in the Red List of European Bryophytes (ECCB, 1995) and is considered to be a Rare species (Schumacker & Váña, 2005; Sotiaux et al., 2007).

The *Riccia huebeneriana* Lindenb. (Sardinia site) is Vulnerable in Spain and Italy (Hodgetts, 2015). In Sardinia the finding of *Hypnum revolutum* (Mitt.) Lindb. var. *revolutum* is also important (Hodgetts, 2015), since it was reported in Italy only in the northern regions and thus represents the first discovery in the central-southern part of the country (Cogoni et al., 2016).

The species of *Riella*, in particular *Riella helicophylla* Mont., (Menorca site), are Rare and/or Underrecorded due to their specific habitat types, ecology and biology (Hodgetts, 2015).

The occurrence of *Riccia beyrichiana* Hampe ex Lehm. (Sardinia, Spain, Corsica, France, Campania sites) is to highlight since it is Rare in Italy and in other Mediterranean countries (Hodgetts, 2015; Puglisi et al., 2015) and reported as Critically Endangered in the Red list of the Italian bryophytes (Cortini Pedrotti et al., 1992).

Riccardia chamedryfolia (With.) Grolle is considered Vulnerable in Italy, according to Hodgetts (2015). Other species considered Near Threatened according to Hodgetts (2015) are: *Riccia subbifurca* Warnst. ex Croz., *Phaeoceros laevis* (L.) Prosk., *Riccia gougetiana* var. *gougetiana* Durieu & Mont., *R. sorocarpa* var. *sorocarpa* Bisch., *Cephalozziella rubella* (Nees) Warnst., and *Gongylanthus ericetorum* (Raddi) Nees.

Bryophytes composition in the Mediterranean temporary ponds

The results of the cluster analysis show 7 bryophytes groups (Fig. 2). The groups 1 and 2 are isolated and separated from other groups. The group 1 assembles the bryophytes found in the ponds Estany d'en Martí (Spain) and "Piscina della Verdesca" (Latium). These ponds are characterized by few species, such as the hygro-hydrophytic pleurocarpous mosses *Drepanocladus aduncus* (Hedw.) Warnst. and *Dalytrichia mucronata* (Brid.) Broth. The pool "Piscina della Verdesca", a seasonally flooded depression within the Circeo National Park (Latium) is floristically very poor, being constituted only by *Ricciocarpos natans* (L.) Corda, a small liverwort floating on still waters, accompanied by two species of *Lemna*, free-floating aquatic flowering plants, and the hygro-hydrophytic pleurocarpous mosses *Drepanocladus aduncus* and *Dalytrichia mucronata* (Puglisi et al., 2016).

The group 2 assembles the bryophytes found mostly in the Menorca ponds: in the ponds Còs des Sìndic and Bassa des Cap Negre it was found the rare *Riella helicophylla* species. Other species found only in the Menorca ponds are: *Aloina aloides* (J.Koch ex Schulz) Kindb., *Leptobarbula berica* (De Not.) Schimp. *Rhynchostegiella tenella* (Dicks.), Limpr. and *Microbryum rectum* (With.) R.H.Zander.

The groups 3 and 4 are heterogeneous and assemble species belonging to ponds of Corsica, Sicily, Spain and France. In the group 3, in the Corsica ponds, was found the rare liverwort *Riccia perennis*. The group 4 assembles the bryophytes found mostly in the Spain ponds, such as *Pleuridium subulatum* (Hedw.) Rabenh., *Aschisma carniolicum* var. *speciosum* (Limpr.) Mönk., *Ceratodon purpureus* (Hedw.) Brid., *Ptychostomum bornholmense* (Wink. & R.Ruthe) Holyoak & N.Pedersen and *Pohlia melanodon* (Brid.) A.J.Shaw.

The others groups are most closely joined in particular the groups 6 and 7. In these groups there are more species found in Sardinia. In the groups 5 and 7 there are few species found in Sicily ponds, such as *Lunularia cruciata* (L.) Dumort. ex Lindb and in the group 6 there are bryophytes found in Sardinia.

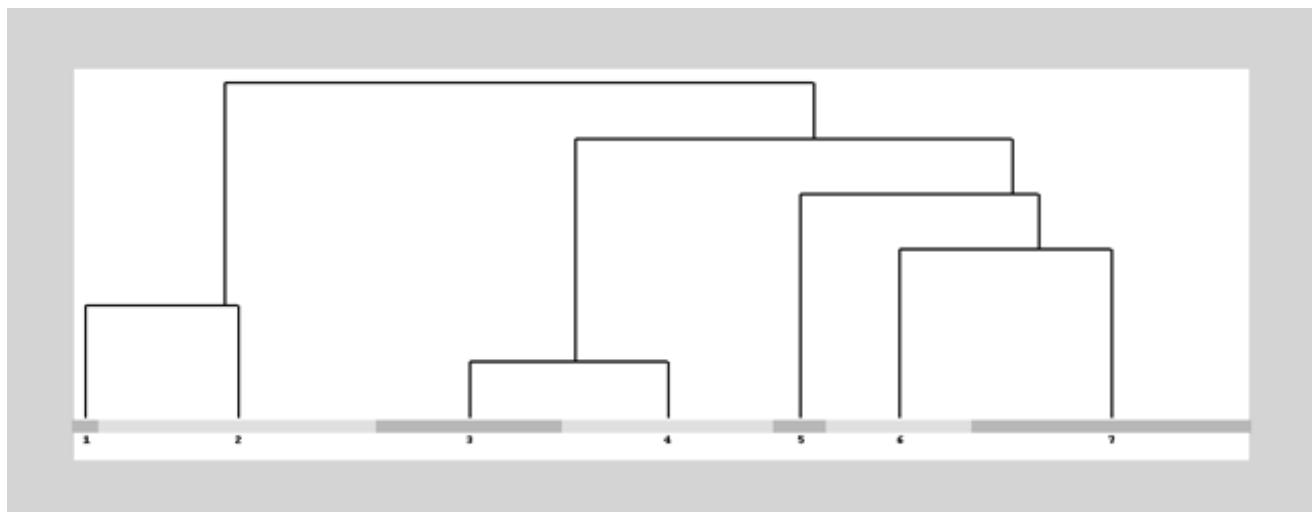


Fig. 2 – Dendograms derived from the cluster analysis

Discussion

The bryoflora of Mediterranean temporary ponds is a substantial component of biodiversity of these ephemeral habitats. They are ephemeral communities, occurring in substrate depressions subject to different periodic cycles of flooding and drought. They depend on the type of substrate beneath the pond, the depth of water, the duration of flooding and tolerate a more or less strong anthropic disturbance (Puglisi et al., 2016). Our results give the first contribution to the knowledge of bryodiversity at Mediterranean basin level and provide a helpful benchmark to plan future conservation actions in those fragile environments.

We can define a group of bryophytes typically present in Mediterranean temporary ponds: *Archidium alternifolium*, *Trichostomum brachydontium*, *Imbribryum alpinum*, *Tortella flavovirens*, *Ptychostomum pseudotriquetrum*, *Fossombronia caespitiformis* subsp. *caespitiformis* and *Riccia sorocarpa*. The rich group of taxa belonging to the genus *Riccia*, mainly distributed in the Mediterranean region, is common in the habitat types “Mediterranean temporary ponds” (3170*) (Grillas et al., 2004; Cogoni et al., 2009). The most frequent species *Archidium alternifolium* is an acrocarpic moss that shows a high ecological plasticity, growing on open, moist and for long periods submerged soils (Hill et al., 2007).

The chorological data with mostly Oceanic species confirm the presence of species associated with humid environmental conditions. The abundant presence of xerophytic and hygro-mesophytic bryophytes is indicative of the elevated diversity found in temporary ponds caused by a typical small-scale zonation. The predominance of turf life form is linked to the ability of the species to tolerate extreme aridity during the most critical period. The presence of species with colonist life strategy is important for the habitat conservation because these species prevent high substrate desiccation and encourage the establishment of other species (During & Van Tooren, 1990). These

species are characterized by a moderately short lifespan of only few years (pauciannual), a high sexual reproduction effort with the production of numerous, small spores which often allow long-range dispersal. The asexual reproduction is frequent by rhizoid gemmae, leaf gemmae, tubers, allowing a rapid establishment of the populations. *Cephaloziella stellulifera* (Taylor) Schiffn., *C. turneri* (Hook.) K. Müller, *Bryum dichotomum* Hedw. and *B. radiculosum* Brid. are typical examples of colonist species. The analysis of the life strategies emphasized a very high occurrence of the shuttle species, largely due to the dominance of the *Riccia* spp. and other liverworts, such as *Corsinia coriandrina* (Spreng.) Lindb., *Fossombronia caespitiformis* subsp. *caespitiformis* De Not. ex Rabenh and *F. caespitiformis* De Not. ex Rabenh subsp. *multispira* Schiffn. The life cycle of the shuttle species is strongly determined in the temporary ponds by seasonal fluctuations, strong alternation between dry and moist seasons and a severe stress period which is avoided by the bryophytes being present in the spore stage. In these species, the vegetation period is short, cyclic and starts predictably. The shuttle species produce large spores (>25 µm in diameter), strongly increasing shortrange dispersion (engychory), and the capsules are often cleistocarpous, such as in *Archidium alternifolium* and *Pleuridium acuminatum*, or enclosed in the thallus, as in *Riccia* spp. (spores released by decay of thallus tissue), suggesting, in both cases, an achorous dispersal strategy (Kürschner & Parolly, 1999). For species of conservation importance such as *Riella helicophylla*, the presence of large spore banks serve as “insurance” against local extinction. Such strategy may take on special importance in Mediterranean temporary ponds where environmental conditions vary in unpredictable ways from year to year.

Although ephemeral, limited to peculiar and scattered conditions and quantitatively small in area, this habitat host several species of high conservation interest such as *Petalophyllum ralfsii*: this thallose liverwort develops during the spring and disappears during the summer when the plant survives the dryness by producing spores that remain quiescent in the soil until the following

spring. The species grows on damp substrates, sandy ponds in conjunction with periods of rain, at altitudes between sea level and 200 m. Due to the fragility of the habitat and its unique ecology, *P. ralfsii* is potentially threatened by a number of factors including pressure from tourism, removal, or drying of the thallus due to water withdrawals or reforestation (Aleffi & Cogoni, 2008). *Fossombronia pusilla* is at risk in several countries (Hodgetts, 2015). Among the Brachytheciaceae, *Scleropodium cespitans* is a taxon with few mentions in the Mediterranean (Aleffi et al., 2008; Cogoni et al., 2009).

Some significant papers on the Menorca and Sardinia are reported (Pericàs et al., 2009; Cogoni et al., 2004, 2006, 2009, 2016), but for other Mediterranean countries, more data are needed to optimize the cluster analysis performance, the information on the bryophyte vegetation is very scarce and fragmentary despite its important application in the environmental field. In the Menorca site 95 taxa were recorded, a large variability of moist microhabitats in the ponds, contribute in a positive way to the richness and diversity of bryoflora. The different composition and morphology of the substrate, favor the presence of different types of microhabitats (Pericàs et al., 2009). In the Sardinia site 139 taxa were recorded, these species are a homogeneous group which is repeated in the island's ponds, mainly characterized by the same type of substrate. Temporary ponds are mainly located in the large tablelands that divide the reliefs and in the lowlands, where they occupy depressions characterized by soils with a clay texture and slow drainage along a broad altitudinal range of 10–1100 m a.s.l.

Conclusions

The Mediterranean temporary ponds show a high degree of floristic bryodiversity, such as reported in other papers (see Puglisi et al., 2015), offering peculiar habitats for the survival and conservation

of rare and endangered species. The information gathered on the bryophyte component is very scarce and fragmentary despite its important applications: some significant papers on the island of Menorca and Sardinia are reported (Pericàs et al., 2009; Cogoni et al., 2004, 2006, 2016), but for other Mediterranean countries, more data are needed.

Nevertheless, we propose a tentative first bryoflora of Mediterranean temporary ponds in the Mediterranean basin that is propaedeutic to define a list of bryophyte species typical of the habitat “3170* Mediterranean temporary pond” to be used as a reference list to complete the habitat description and propose effective conservation actions to preserve all its biotic components.

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Bryoflora of the Mediterranean temporary ponds: a tentative reference list for the Mediterranean basin

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Complete species list of bryoflora surveyed in Mediterranean temporary ponds.

Species	Corology	Humidity	Life strategy	Life forms
<i>Acaulon mediterraneum</i> Limpr.	Oceanic	meso-xerophytic	Shuttle	Turf, scattered
<i>Acaulon triquetrum</i> (Spruce) Müller Hal.	Mediterranean	xerophytic	Shuttle	Turf, scattered
<i>Aloina aloides</i> (J.Koch ex Schulz) Kindb.	Mediterranean	xerophytic	Colonist	Turf, scattered
<i>Archidium alternifolium</i> (Hedw.) Mitt.	Oceanic	hygro-xerophytic	Shuttle	Turf
<i>Aschisma carniolicum</i> var. <i>speciosum</i> (Limpr.) Mönk.	Mediterranean	meso-xerophytic	Shuttle	Turf
<i>Atrichum undulatum</i> (Hedw.) P.Beauv.	Temperate	hygro-mesophytic	Shuttle	Turf
<i>Barbula convoluta</i> Hedw.	Mediterranean	meso-xerophytic	Colonist	Turf
<i>Barbula unguiculata</i> Hedw.	Temperate	hygro-xerophytic	Colonist	Turf
<i>Bartramia pomiformis</i> Hedw.	Boreal and Alpine	hygro-mesophytic	Shuttle	Tuft
<i>Bartramia stricta</i> Brid.	Oceanic	xerophytic	Shuttle	Tuft
<i>Brachythecium rutabulum</i> (Hedw.) Schimp.	Temperate	hygro-mesophytic	Perennial	Mat
<i>Brachytheciastrum velutinum</i> (Hedw.) Ignatov & Huttunen	Temperate	hygro-mesophytic	Colonist	Mat
<i>Brachythecium glareosum</i> (Bruch ex Spruce) Schimp.	Boreal and Alpine	meso-xerophytic	Perennial	Mat
<i>Brachythecium rivulare</i> Schimp.	Boreal and Alpine	hygrophytic	Perennial	Mat
<i>Brachythecium salebrosum</i> (Hoffm. ex F.Weber & D.Mohr) Schimp.	Boreal and Alpine	hygro-mesophytic	Colonist	Mat
<i>Bryum argenteum</i> Hedw.	Temperate	meso-xerophytic	Colonist	Turf
<i>Bryum dichotomum</i> Hedw.	Mediterranean	meso-xerophytic	Colonist	Turf
<i>Bryum elegans</i> Nees	Boreal and Alpine	xerophytic	Colonist	Tuft
<i>Bryum gemmiferum</i> R. Wilczek & Demaret	Mediterranean	hygrophytic	Colonist	Turf
<i>Bryum gemmilucens</i> Wilcz. & Dem.	Mediterranean	meso-xerophytic	Colonist	Tuft
<i>Bryum gemmiparum</i> De Not.	Oceanic	hygrophytic	Colonist	Turf
<i>Bryum klinggraeffii</i> Schimp.	Boreal and Alpine	hygrophytic	Perennial	Turf
<i>Bryum kunzei</i> Hornsch.	Temperate	meso-xerophytic	Colonist	Tuft
<i>Bryum radiculosum</i> Brid.	Oceanic	xerophytic	Colonist	Cushion
<i>Bryum turbinatum</i> (Hedw.) Turner	Temperate	hygrophytic	Shuttle	Turf

Supplementary Material 1

<i>Calliergonella cuspidata</i> (Hedw.) Loeske	Temperate	hygro-mesophytic/amphiphytic	Perennial	Weft
<i>Campylopus atrovirens</i> De Not.	Oceanic	hygro-mesophytic	Perennial	Tuft
<i>Campylopus brevipilus</i> Bruch & Schimp.	Oceanic	hygro-xerophytic	Colonist/Perennial	Tuft
<i>Campylopus introflexus</i> (Hedw.) Brid.	Oceanic	hygro-xerophytic	Perennial/Shuttle	Tuft
<i>Campylopus pilifer</i> Brid.	Oceanic	xerophytic	Shuttle	Tuft
<i>Cephaloziella calyculata</i> (Durieu & Mont.) Mull. Frib.	Oceanic	hygro-xerophytic	Colonist	Solitary creeping
<i>Cephaloziella divaricata</i> (Sm.) Schiffn.	Temperate	meso-xerophytic	Colonist	Mat
<i>Cephaloziella hampeana</i> (Nees) Schiffn.	Oceanic	hygro-xerophytic	Colonist	Thread
<i>Cephaloziella rubella</i> (Nees) Warnst.	Temperate	meso-xerophytic	Colonist	Mat
<i>Cephaloziella stellulifera</i> (Taylor) Schiffner	Oceanic	meso-xerophytic	Colonist	Mat
<i>Cephaloziella turneri</i> (Hook.) K. Müller Frib.	Oceanic	hygro-xerophytic	Colonist	Mat
<i>Ceratodon purpureus</i> (Hedw.) Brid.	Oceanic	meso-xerophytic	Colonist	Turf
<i>Cheilotrichia chloropus</i> (Brid.) Broth.	Oceanic	xerophytic	Colonist	Turf
<i>Conocephalum conicum</i> (L.) Dumort.	Boreal and Alpine	hygrophytic	Shuttle	Mat
<i>Corsinia coriandrina</i> (Spreng.) Lindb.	Oceanic	xerophytic	Shuttle	Mat
<i>Dalytrichia mucronata</i> (Brid.) Broth.	Mediterranean	hygro-mesophytic	Colonist	Tuft
<i>Dicranella heteromalla</i> (Hedw.) Schimp.	Temperate	mesophytic	Colonist	Turf
<i>Dicranella howei</i> Renaud & Cardot	Oceanic	xerophytic	Colonist	Turf
<i>Dicranella humilis</i> R.Ruthe	Temperate	hygro-mesophytic	Colonist	Turf
<i>Dicranella staphylina</i> H.Whitehouse	Temperate	hygrophytic	Colonist	Turf
<i>Dicranella varia</i> (Hedw.) Schimp.	Temperate	hygrophytic	Colonist	Turf
<i>Dicranum majus</i> Sm.	Temperate	mesophytic	Perennial	Tuft
<i>Dicranum polysetum</i> Sw. ex anon.	Temperate	mesophytic	Perennial	Tuft
<i>Didymodon fallax</i> (Hedw.) R.H. Zander	Mediterranean	hygro-xerophytic	Colonist	Turf
<i>Didymodon insulanus</i> (De Not.) M.O. Hill	Mediterranean	hygro-mesophytic	Colonist	Turf
<i>Didymodon luridus</i> Hornsch.	Mediterranean	xerophytic	Colonist	Turf
<i>Didymodon rigidulus</i> Hedw.	Temperate	xerophytic	Colonist	Tuft
<i>Didymodon spadiceus</i> (Mitt.) Limpr.	Temperate	hygrophytic	Colonist	Turf
<i>Didymodon tophaceus</i> (Bridel) Lisa	Temperate	hygrophytic	Colonist	Turf
<i>Didymodon vinealis</i> (Brid.) R.H.Zander	Mediterranean	xerophytic	Colonist	Tuft
<i>Distichium capillaceum</i> (Hedw.) Bruch & Schimp	Boreal and Alpine	mesophytic	Colonist	Tuft
<i>Drepanocladus aduncus</i> (Hedw.) Warnst.	Temperate	hydro-hygrophytic	Perennial	Weft
<i>Dydimodon luridus</i> Hornsch.	mediterranean	hygro-xerophytic	Colonist	Turf
<i>Encalypta ciliata</i> Hedw.	Boreal and Alpine	meso-xerophytic	Shuttle	Tuft
<i>Enthostodon convexus</i> (Spruce) Brugués	Mediterranean	xerophytic	Shuttle	Turf
<i>Enthostodon fascicularis</i> (Hedw.) C. Müll	Oceanic	hygro-mesophytic	Shuttle	Turf
<i>Entosthodon attenuatus</i> (Dicks.) Bryhn	Mediterranean	hygro-mesophytic	Shuttle	Turf, scattered
<i>Entosthodon mouretii</i> (Corb.) Jelenc	Mediterranean	hygrophytic	Shuttle	Turf
<i>Entosthodon obtusus</i> (Hedw.) Lindb.	Oceanic	hygro-xerophytic	Shuttle	Turf, scattered
<i>Entosthodon pulchellus</i> (H. Philib.)	Oceanic	hygro-mesophytic	Shuttle	Turf
<i>Ephemerum crassinervium</i> sbsp <i>sessile</i>	Oceanic	hygro-xerophytic	Shuttle	Turf, protonemal
<i>Ephemerum minutissimum</i> Lindb.	Oceanic	hygro-mesophytic	Shuttle	Turf, protonemal
<i>Ephemerum recurvifolium</i> (Dicks.)	Mediterranean	hygro-mesophytic	Shuttle	Turf, protonemal

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<i>Ephemerum serratum</i> Hedw.) Hampe	Oceanic	hygro-mesophytic	Shuttle	Turf, protonemal
<i>Epipterygium tozeri</i> (Grev.) Lindb.	Oceanic	hygro-mesophytic	Colonist	Turf, scattered
<i>Eurhynchiastrum pulchellum</i> (Hedw.) Ignatov & Huttunen	Boreal and Alpine	meso-xerophytic	Perennial	Mat
<i>Fissidens bryoides</i> Hedw. var. <i>bryoides</i>	Temperate	hygro-xerophytic	Colonist	Turf
<i>Fissidens crispus</i> Mont.	Oceanic	meso-xerophytic	Colonist	Turf
<i>Fissidens dubius</i> P.Beauv.	Temperate	mesophytic	Perennial	Turf
<i>Fissidens ovatifolius</i> R.Ruthe	Mediterranean	hygro-mesophytic	Shuttle	Turf
<i>Fissidens taxifolius</i> Hedw.	Temperate	mesophytic	Colonist	Turf
<i>Fissidens viridulus</i> var. <i>incurvus</i> (Starke ex Röhl.) Waldh.	Mediterranean	xerophytic	Colonist	Turf
<i>Fissidens viridulus</i> var. <i>viridulus</i> (Sw. ex anon) Wahlenb.	Mediterranean	hygro-mesophytic	Colonist	Turf
<i>Fossombronia angulosa</i> (Dicks.) Raddi	Oceanic	hygro-mesophytic	Shuttle	Mat
<i>Fossombronia caespitiformis</i> subsp. <i>caespitiformis</i> De Not. ex Rabenh.	Oceanic	meso-xerophytic	Shuttle	Solitary creeping
<i>Fossombronia caespitiformis</i> subsp. <i>multispira</i> (Schiffn.) J.R.Bray & D.C.Cargill	Oceanic	hygro-xerophytic	Shuttle	Solitary creeping
<i>Fossombronia pusilla</i> (L.) Nees	Oceanic	hygro-mesophytic	Shuttle	Solitary creeping
<i>Fossombronia wondraczekii</i> (Corda) Dumort. ex Lindb.	Temperate	hygro-mesophytic	Shuttle	Solitary creeping
<i>Frullania dilatata</i> (L.) Dumort.	Temperate	hygro-xerophytic	Shuttle	Mat
<i>Frullania tamarisci</i> (L.) Dumort.	Temperate	meso-xerophytic	Shuttle	Mat
<i>Funaria hygrometrica</i> Hedw.	Temperate	hygro-mesophytic	Fugitives	Tuft
<i>Gongylanthus ericetorum</i> (Raddi) Nees	Oceanic	hygro-xerophytic	Shuttle	Solitary creeping
<i>Grimmia anodon</i> Bruch & Schimp.	Oceanic	xerophytic	Perennial	Cushion
<i>Grimmia laevigata</i> (Brid.) Brid.	Mediterranean	xerophytic	Colonist	Cushion
<i>Grimmia lisae</i> De Not.	Mediterranean	hygro-mesophytic	Colonist	Turf
<i>Grimmia orbicularis</i> Bruch ex Wilson	Mediterranean	xerophytic	Colonist	Cushion
<i>Grimmia pulvinata</i> (Hedw.) Sm.	Temperate	xerophytic	Colonist	Cushion
<i>Grimmia trichophylla</i> Grev.	Temperate	hygro-xerophytic	Colonist	Cushion
<i>Gymnostomum calcareum</i> Nees & Hornsch.	Mediterranean	hygrophytic	Colonist	Turf
<i>Hedwigia stellata</i> Hedenäs	Boreal and Alpine	xerophytic	Shuttle	Mat
<i>Homalothecium aureum</i> (Spruce) H.Rob.	Mediterranean	xerophytic	Perennial	Mat
<i>Homalothecium lutescens</i> Hedw. H.Rob.	Temperate	meso-xerophytic	Perennial	Weft
<i>Homalothecium sericeum</i> (Hedw.) Scimp.	Temperate	xerophytic	Perennial	Mat
<i>Hygroamblystegium tenax</i> (Hedw.) Jenn.	Temperate	hygrophytic	Perennial	Mat
<i>Hypnum andoi</i> A.J.E.Sm.	Oceanic	mesophytic	Perennial	Mat
<i>Hypnum cupressiforme</i> var. <i>cupressiforme</i> Hedw.	Temperate	meso-xerophytic	Perennial	Mat
<i>Hypnum cupressiforme</i> var. <i>resupinatum</i> (Taylor) Schimp.	Oceanic	mesophytic	Perennial	Weft
<i>Hypnum jutlandicum</i> Holmen & E.Warncke	Oceanic	hygro-mesophytic	Perennial	Mat
<i>Hypnum revolutum</i> (Mitt.) Lindb. var. <i>revolutum</i>	Boreal and Alpine	meso-xerophytic	Perennial	Mat
<i>Imbribryum alpinum</i> (Huds. ex With.) N.Pedersen	Oceanic	hygro-mesophytic	Colonist/Perennial	Turf
<i>Imbribryum mildeanum</i> (Jur.) J.R.Spence	Oceanic	hygro-mesophytic	Perennial	Cushion
<i>Isothecium alopecuroides</i> (Lam. ex Dubois) Isov.	Temperate	mesophytic	Perennial	Dendroid
<i>Isothecium myusuroides</i> Brid.	Oceanic	hygro-mesophytic	Perennial	Dendroid
<i>Kindbergia praelonga</i> (Hedw.) Ochyra	Temperate	hygrophytic	Perennial	Mat
<i>Leptobarbula berica</i> (De Not.) Schimp.	Mediterranean	xerophytic	Colonist	Turf
<i>Leptodictyum riparium</i> (Hedw.) Warnst.	Temperate	hygrophytic-t submerged	Perennial	Mat

Supplementary Material 1

<i>Leptophascum leptophyllum</i> (Müll.Hal.) J.Guerra & M.J.Cano	Oceanic	xerophytic	Shuttle	Turf, scattered
<i>Lophocolea bidentata</i> (L.) Dumort.	Temperate	hygrophytic	Perennial	Weft
<i>Lophocolea minor</i> Nees	Continental	meso-xerophytic	Colonist	Mat
<i>Lunularia cruciata</i> (L.) Dumort. ex Lindb.	Oceanic	meso-xerophytic	Perennial	Mat
<i>Metzgeria coniugata</i> Lindb.	Oceanic	hygro-mesophytic	Shuttle	Weft
<i>Microbryum davallianum</i> (Sm.) R.H.Zander	Mediterranean	hygrophytic	Shuttle	Turf, scattered
<i>Microbryum rectum</i> (With.) R.H.Zander	Oceanic	meso-xerophytic	Shuttle	Turf, scattered
<i>Microbryum starkeanum</i> (Hedw.) R.H.Zander	Mediterranean	meso-xerophytic	Shuttle	Turf, scattered
<i>Microeurhynchium pumilum</i> (Wilson) Ignatov & Vanderp.	Oceanic	xerophytic	Perennial	Mat
<i>Nogopterium gracile</i> (Hedw.) Crosby & W.R.Buck	Oceanic	hygro-xerophytic	Shuttle	Tail
<i>Oncophorus virens</i> (Hedw.) Brid.	Boreal and Alpine	hygrophytic	Shuttle	Turf
<i>Orthotrichum tenellum</i> Bruch ex Brid.	Mediterranean	xerophytic	Colonist	Cushion
<i>Oxymitra incrassata</i> (Brot.) Sérgio & Sim-Sim	Mediterranean	xerophytic	Shuttle	Mat
<i>Oxyrrhynchium speciosum</i> (Brid.) Warnst.	Temperate	hygro-mesophytic	Shuttle	Mat
<i>Petalophyllum ralfsii</i> (Wilson) Nees et Gottsche.	Oceanic	hygrophytic	Shuttle	Solitary thalloid
<i>Phaeoceros laevis</i> (L.) Prosk.	Oceanic	hygro-mesophytic	Shuttle	Mat
<i>Philonotis caespitosa</i> Jur.	Boreal and Alpine	hygrophytic	Shuttle	Turf
<i>Philonotis capillaris</i> Lindb.	Oceanic	hygrophytic	Shuttle	Turf
<i>Philonotis marchica</i> (Hedw.) Brid.	Mediterranean	hygrophytic	Shuttle	Turf
<i>Phymatoceros bulbiculosus</i> (Brot.) Stotler, W.T.Doyle & Crand.-Stotl.	Mediterranean	hygrophytic	Shuttle	Mat
<i>Physcomitrella patens</i> (Hedw.) Bruch & Schimp.	Temperate	hygrophytic	Shuttle	Turf
<i>Plagiomnium elatum</i> (Bruch & Schimp.) T.J.Kop.	Boreal and Alpine	hygrophytic	Perennial	Turf
<i>Plagiomnium ellipticum</i> (Brid.) T.J.Kop.	boreal and alpine	hygrophytic	Perennial	Turf
<i>Plagiothecium denticulatum</i> (Hedw.) Schimp	Boreal and Alpine	hygro-mesophytic	Perennial	Mat
<i>Pleuridium acuminatum</i> Lindb.	Oceanic	hygro-mesophytic	Shuttle	Turf
<i>Pleuridium subulatum</i> (Hedw.) Rabenh.	Oceanic	hygrophytic	Shuttle	Turf
<i>Polygonatum nanum</i> (Hedw.) P.Beauv.	Oceanic	meso-xerophytic	Colonist	Turf, protonemal
<i>Pohlia elongata</i> Hedw.	Boreal and Alpine	mesophytic	Colonist	Tuft
<i>Pohlia melanodon</i> (Brid.) A.J.Shaw	Temperate	hygrophytic	Colonist/Shuttle	Turf
<i>Pohlia nutans</i> (Hedw.) Lindb.	boreal and alpine	hygro-xerophytic	Colonist	Tuft
<i>Polytrichum juniperinum</i> Hedw.	Temperate	xerophytic	Perennial	Turf
<i>Pottiopsis caespitosa</i> (Brid.) Blockeel & A.J.E.Sm.	Mediterranean	xerophytic	Colonist	Turf, scattered
<i>Pseudephemerum nitidum</i> (Hedw.) Loeske	Oceanic	hygrophytic	Shuttle	Turf, scattered
<i>Pseudocrossidium hornschuchianum</i> (Schultz) R.H.Zander	Mediterranean	meso-xerophytic	Colonist	Turf
<i>Pseudoscleropodium purum</i> (Hedw.) M Fleisch.	Temperate	mesophytic	Perennial	Weft
<i>Pseudotaxiphyllum elegans</i> (Brid.) Z.Iwats.	Oceanic	mesophytic	Colonist	Mat
<i>Ptychosporium boreale</i> (F.Weber & D.Mohr) Ochyra & Bednarek-Ochyra	Temperate	hygro-xerophytic	Colonist	Turf
<i>Ptychosporium bornholmense</i> (Wink. & R.Ruthe) Holyoak & N.Pedersen	Temperate	mesophytic	Colonist	Turf
<i>Ptychosporium capillare</i> (Hedw.) Holyoak & N.Pedersen	Temperate	meso-xerophytic	Colonist	Turf
<i>Ptychosporium compactum</i> Hornsch.	Temperate	hygro-xerophytic	Shuttle	Turf
<i>Ptychosporium donianum</i> (Grev.) Holyoak & N.Pedersen	Oceanic	xerophytic	Colonist	Turf
<i>Ptychosporium imbricatulum</i> (Müll. Hal.) Holyoak & N. Pedersen	Temperate	meso-xerophytic	Colonist	Turf

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<i>Ptychostomum pallens</i> (Sw.) J.R.Spence	Boreal and Alpine	hygrophytic	Shuttle	Turf, scattered
<i>Ptychostomum pseudotriquetrum</i> (Hedw.) J.R. Spence & H.P. Ramsay	Temperate	hygrophytic	Perennial	Tuft
<i>Ptychostomum rubens</i> (Mitt.) Holyoak & N. Pedersen	Temperate	mesophytic	Colonist	Turf
<i>Ptychostomum torquescens</i> (Bruch & Schimp.) Ros & Mazimpaka	Mediterranean	hygro-xerophytic	Shuttle	Turf
<i>Racomitrium ericoides</i> (Brid.) Brid.	Oceanic	hygro-mesophytic	Colonist	Turf
<i>Reboulia hemisphaerica</i> (L.) Raddi	Mediterranean	hygro-xerophytic	Shuttle	Mat
<i>Rhynchostegiella curviseta</i> (Brid.) Lindb.	Mediterranean	hygro-xerophytic	Perennial	Mat
<i>Rhynchostegiella litorea</i> (De Not.) Limpr.	Oceanic	hygrophytic	Perennial	Mat
<i>Rhynchostegiella tenella</i> (Dicks.) Limpr.	Mediterranean	hygro-mesophytic	Perennial	Mat
<i>Rhynchostegium confertum</i> (Dicks.) Schimp.	Mediterranean	hygro-mesophytic	Perennial	Mat
<i>Rhynchostegium megapolitanum</i> (Blandow ex F. Weber & D. Mohr) Schimp.	Mediterranean	hygro-xerophytic	Perennial	Mat
<i>Rhynchostegium riparioides</i> (Hedw.) Cardot	Temperate	hygrophytic	Perennial	Mat
<i>Riccardia chamedryfolia</i> (With.) Grolle.	Temperate	hygrophytic	Colonist	Mat
<i>Riccia beyrichiana</i> Hampe ex Lehm.	Oceanic	hygro-mesophytic	Shuttle	Solitary thalloid
<i>Riccia bifurca</i> Hoffm.	Mediterranean	hygro-xerophytic	Shuttle	Solitary thalloid
<i>Riccia canaliculata</i> Hoffm.	Temperate	hygro-mesophytic	Shuttle	Solitary thalloid
<i>Riccia ciliata</i> Hoffm.	Mediterranean	hygro-xerophytic	Shuttle	Solitary thalloid
<i>Riccia crinita</i> Taylor	Mediterranean	xerophytic	Shuttle	Solitary thalloid
<i>Riccia crozalsii</i> Levier	Oceanic	hygro-xerophytic	Shuttle	Solitary thalloid
<i>Riccia crystallina</i> L.	Mediterranean	hygrophytic	Shuttle	Solitary thalloid
<i>Riccia fluitans</i> Mill.	Temperate	hydro-hygrophytic	Shuttle	Lemnoid
<i>Riccia glauca</i> L.	Mediterranean	hygro-mesophytic	Shuttle	Solitary thalloid
<i>Riccia gougetiana</i> Durieu & Mont.	Mediterranean	hygro-xerophytic	Shuttle	Solitary thalloid
<i>Riccia huebeneriana</i> Lindenb.	Temperate	hygrophytic	Shuttle	Solitary thalloid
<i>Riccia macrocarpa</i> Levier	Oceanic	hygro-xerophytic	Shuttle	Solitary thalloid
<i>Riccia michelii</i> Raddi	Mediterranean	meso-xerophytic	Shuttle	Solitary thalloid
<i>Riccia nigrella</i> DC.	Oceanic	hygro-xerophytic	Shuttle	Solitary thalloid
<i>Riccia perennis</i> Steph.	Oceanic	hygro-xerophytic	Shuttle	Solitary thalloid
<i>Riccia sorocarpa</i> Bisch.	Temperate	meso-xerophytic	Shuttle	Solitary thalloid
<i>Riccia subbifurca</i> Warnst. ex Croz.	Mediterranean	meso-xerophytic	Shuttle	Solitary thalloid
<i>Riccia warnstorffii</i> Limpr. ex Warnst.	Oceanic	hygro-mesophytic	Shuttle	Solitary thalloid
<i>Ricciocarpus natans</i> (L.) Corda	Temperate	hydrophyte	Shuttle	Lemnoid
<i>Riella helicophylla</i> (Bory & Mont.) Mont.	Mediterranean	hydrophyte	Shuttle	Mat
<i>Scapania compacta</i> (Roth) Dumort.	Mediterranean	meso-xerophytic	Shuttle	Mat
<i>Sciuro-hypnum populeum</i> (Hedw.) Ignatov & Huttunen	Temperate	meso-xerophytic	Perennial	Mat
<i>Scleropodium cespitans</i> (Wilson ex Müll. Hal.) L.F.Koch	Oceanic	hygrophytic	Perennial	Mat
<i>Scleropodium touretii</i> (Brid.) L.F.Koch	Oceanic	xerophytic	Perennial	Mat
<i>Scorpidium revolvens</i> (Sw. ex anon.) Rubers	Boreal and Alpine	hygrophytic	Perennial	Weft
<i>Scorpiurium circinatum</i> (Bruch) M.Fleisch. & Loeske	Oceanic	xerophytic	Perennial	Mat
<i>Scorpiurium reflexifolium</i> (Solms) M.Fleisch & Loeske	Mediterranean	seasonally hygrophytic	Perennial	Mat
<i>Sematophyllum substrumulosum</i> (Hampe) E. Britton	Oceanic	hygrophytic	Colonist/Perennial	Mat
<i>Soutbya nigrella</i> (De Not.) Henriq.	Oceanic	hygro-mesophytic	Shuttle	Mat
<i>Sphaerocarpos michelii</i> Bellardi	Oceanic	hygro-mesophytic	Shuttle	Solitary thalloid

Supplementary Material 1

<i>Syntrichia laevipila</i> (Brid.)	Oceanic	xerophytic	Colonist	Turf
<i>Syntrichia princeps</i> (De Not.) Mitt.	Oceanic	meso-xerophytic	Colonist	Turf
<i>Syntrichia ruralis</i> var. <i>ruraliformis</i> (Besch.) Delogne	Oceanic	xerophytic	Colonist	Turf
<i>Syntrichia virescens</i> (De Not.) Ochyra	Temperate	xerophytic	Colonist	Turf
<i>Thamnobryum alopecurum</i> (Hedw.) Gangulee	Oceanic	hygro-mesophytic	Perennial	Dendroid
<i>Timmiella barbuloides</i> (Brid.) Mönk.	Mediterranean	xerophytic	Shuttle	Turf
<i>Tortella flavovirens</i> (Bruch) Broth.	Oceanic	xerophytic	Colonist	Tuft
<i>Tortella humilis</i> (Hedw.) Jenn.	Mediterranean	xerophytic	Colonist	Tuft
<i>Tortella inflexa</i> (Bruch) Broth.	Oceanic	meso-xerophytic	Colonist	Turf, protonemal
<i>Tortella nitida</i> (Lindb.) Broth.	Oceanic	xerophytic	Perennial	Cushion
<i>Tortella squarrosa</i> (Brid.) Limpr.	Mediterranean	xerophytic	Colonist	Turf
<i>Tortella tortuosa</i> (Hedw.) Limpr.	Boreal and Alpine	meso-xerophytic	Perennial	Tuft
<i>Tortula acaulon</i> (Withering) R. H. Zander	Temperate	mesophytic	Shuttle	Turf, scattered
<i>Tortula canescens</i> Mont.	Oceanic	xerophytic	Colonist	Turf
<i>Tortula caucasica</i> Broth.	Temperate	mesophytic	Shuttle	Turf
<i>Tortula freibergii</i> Dixon & Loeske	Oceanic	mesophytic	Colonist	Turf
<i>Tortula marginata</i> (Bruch & Schimp.) Spruce	Oceanic	hygro-mesophytic	Colonist	Turf
<i>Tortula muralis</i> Hedw.	Temperate	meso-xerophytic	Colonist	Turf
<i>Tortula solmsii</i> (Schimp.) Limpr.	Oceanic	hygro-xerophytic	Colonist	Turf
<i>Tortula subulata</i> Hedw.	Boreal and Alpine	meso-xerophytic	Colonist	Tuft
<i>Tortula truncata</i> (Hedw.) Mitt.	Temperate	meso-xerophytic	Colonist	Turf
<i>Trichostomum brachydontium</i> Bruch	Mediterranean	meso-xerophytic	Perennial	Turf
<i>Trichostomum crispulum</i> Bruch	Temperate	meso-xerophytic	Colonist	Turf
<i>Weissia brachycarpa</i> (Nees & Hornsch.) Jur.	Temperate	xerophytic	Shuttle	Turf
<i>Weissia condensa</i> (Voit) Lindb.	Mediterranean	xerophytic	Colonist	Turf
<i>Weissia controversa</i> Hedwig	Temperate	xerophytic	Colonist	Turf
<i>Weissia longifolia</i> Mitt.	Temperate	xerophytic	Shuttle	Turf
<i>Weissia squarrosa</i> (Nees & Hornsch.) Müll.	Oceanic	hygrophytic	Shuttle	Turf

Bryoflora of the Mediterranean temporary ponds: a tentative reference list for the Mediterranean basin

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Bryophytes distribution for sites (Italy includes Latium, Campania and Umbria).

Species	Sardinia	Les basses de l'Albera - Alt Embordà - Spain	Sicily	Italy	Suartone - Corsica	Rauque- Haute - France	Menorca
<i>Acaulon mediterraneum</i> Limpr.	-	-	-	-	-	-	+
<i>Acaulon triquetrum</i> (Spruce) Müller Hal.	-	-	-	-	-	-	+
<i>Aloina aloides</i> (J.Koch ex Schulz) Kindb.	-	-	-	-	-	-	+
<i>Archidium alternifolium</i> (Hedw.) Mitt.	+	+	+	+	+	+	+
<i>Aschisma carniolicum</i> var. <i>speciosum</i> (Limpr.) Mönk.	-	+	-	-	-	-	-
<i>Atrichum undulatum</i> (Hedw.) P.Beauv.	-	-	-	+	-	-	-
<i>Barbula convoluta</i> Hedw.	+	-	-	-	-	+	+
<i>Barbula unguiculata</i> Hedw.	+	-	+	+	-	+	+
<i>Bartramia pomiformis</i> Hedw.	+	-	-	-	-	-	-
<i>Bartramia stricta</i> Brid.	+	-	-	-	-	-	-
<i>Brachythecium rutabulum</i> (Hedw.) Schimp.	+	-	+	-	+	-	-
<i>Brachytheciastrum velutinum</i> (Hedw.) Ignatov & Huttunen	+	-	-	-	-	-	-
<i>Brachythecium glareosum</i> (Bruch ex Spruce) Schimp.	+	-	-	-	-	-	-
<i>Brachythecium rivulare</i> Schimp.	+	-	+	-	-	-	-
<i>Brachythecium salebrosum</i> (Hoffm. ex F.Weber & D.Mohr) Schimp.	+	-	-	-	-	-	-
<i>Bryum argenteum</i> Hedw.	+	-	-	-	-	-	-
<i>Bryum dichotomum</i> Hedw.	+	+	+	+	+	+	+
<i>Bryum elegans</i> Nees	+	-	+	-	-	-	-
<i>Bryum gemmiferum</i> R. Wilczek & Demaret	-	+	-	-	-	-	+
<i>Bryum gemmilucens</i> Wilcz. & Dem.	-	+	-	-	-	+	-
<i>Bryum gemmiparum</i> De Not.	+	+	-	-	-	-	+
<i>Bryum klingraeffii</i> Schimp.	-	-	+	-	-	-	-
<i>Bryum kunzei</i> Hornsch.	+	-	-	-	-	-	-

Supplementary Material 2

<i>Bryum radiculosum</i> Brid.	+	+	+	+	-	-	+
<i>Bryum turbinatum</i> (Hedw.) Turner	+	-	-	-	-	-	-
<i>Calliergonella cuspidata</i> (Hedw.) Loeske	+	-	-	+	-	-	-
<i>Campylopus atrovirens</i> De Not.	-	-	-	+	-	-	-
<i>Campylopus brevipilus</i> Bruch & Schimp.	-	-	-	+	+	-	+
<i>Campylopus introflexus</i> (Hedw.) Brid.	-	-	-	+	+	-	-
<i>Campylopus pilifer</i> Brid.	+	-	-	+	-	-	+
<i>Cephaloziella calyculata</i> (Durieu & Mont.) Mull. Frib.	+	-	-	-	-	-	-
<i>Cephaloziella divaricata</i> (Sm.) Schiffn.	-	+	-	-	-	-	-
<i>Cephaloziella hampeana</i> (Nees) Schiffn.	-	-	-	-	-	-	+
<i>Cephaloziella rubella</i> (Nees) Warnst.	-	-	-	+	-	-	-
<i>Cephaloziella stellulifera</i> (Taylor) Schiffner	-	+	+	-	+	-	+
<i>Cephaloziella turneri</i> (Hook.) K. Müller Frib.	-	-	+	+	-	-	-
<i>Ceratodon purpureus</i> (Hedw.) Brid.	-	+	-	-	-	-	-
<i>Cheilotrichia chloropus</i> (Brid.) Broth.	+	-	-	-	-	-	+
<i>Conocephalum conicum</i> (L.) Dumort.	+	-	-	-	-	-	-
<i>Corsinia coriandrina</i> (Spreng.) Lindb.	+	-	+	+	+	-	+
<i>Dalytrichia mucronata</i> (Brid.) Broth.	+	-	-	+	-	-	-
<i>Dicranella heteromalla</i> (Hedw.) Schimp.	-	+	-	-	-	-	-
<i>Dicranella howei</i> Renauld & Cardot	+	-	-	-	-	-	+
<i>Dicranella humilis</i> R.Ruthe	+	-	-	-	-	-	-
<i>Dicranella staphylina</i> H.Whitehouse	-	-	-	+	-	-	-
<i>Dicranella varia</i> (Hedw.) Schimp.	+	-	-	-	-	-	-
<i>Dicranum majus</i> Sm.	+	-	-	-	-	-	-
<i>Dicranum polysetum</i> Sw. ex anon.	+	-	-	-	-	-	-
<i>Didymodon fallax</i> (Hedw.) R.H. Zander	+	-	-	-	-	-	+
<i>Didymodon insulanus</i> (De Not.) M.O. Hill	+	-	+	-	-	-	-
<i>Didymodon luridus</i> Hornsch.	+	-	-	+	-	-	+
<i>Didymodon rigidulus</i> Hedw.	+	-	-	-	-	-	-
<i>Didymodon spadiceus</i> (Mitt.) Limpr.	+	-	-	-	-	-	-
<i>Didymodon tophaceus</i> (Bridel) Lisa	-	-	+	+	-	-	+
<i>Didymodon vinealis</i> (Brid.) R.H.Zander	+	-	+	+	-	-	-
<i>Distichium capillaceum</i> (Hedw.) Bruch & Schimp	+	-	-	-	-	-	-
<i>Drepanocladus aduncus</i> (Hedw.) Warnst.	-	+	-	+	-	-	+
<i>Dydimodon luridus</i> Hornsch.	-	-	-	+	-	-	-
<i>Encalypta ciliata</i> Hedw.	+	-	-	-	-	-	-
<i>Enthostodon convexus</i> (Spruce) Brugués	-	+	-	-	-	-	+
<i>Enthostodon fascicularis</i> (Hedw.) C. Müll	-	-	+	+	-	+	+
<i>Entosthodon attenuatus</i> (Dicks.) Bryhn	-	-	+	+	+	-	-
<i>Entosthodon mouretii</i> (Corb.) Jelenc	-	+	-	-	-	-	-
<i>Entosthodon obtusus</i> (Hedw.) Lindb.	-	-	-	-	+	-	+
<i>Entosthodon pulchellus</i> (H. Philib.)	-	-	-	-	-	-	+
<i>Ephemerum crassinervium</i> sbsp <i>sessile</i>	-	+	-	-	-	-	+
<i>Ephemerum minutissimum</i> Lindb.	+	+	-	-	-	-	+

Supplementary Material 2

<i>Ephemerum recurvifolium</i> (Dicks.)	-	-	-	+	-	-	+
<i>Ephemerum serratum</i> Hedw.) Hampe	+	+	-	-	-	-	-
<i>Epipterygium tozeri</i> (Grev.) Lindb.	+	+	+	+	-	-	-
<i>Eurhynchiastrum pulchellum</i> (Hedw.) Ignatov & Huttunen	+	-	-	-	-	-	-
<i>Fissidens bryoides</i> Hedw. var. <i>bryoides</i>	-	-	-	+	-	-	-
<i>Fissidens crispus</i> Mont.	+	-	-	-	+	-	-
<i>Fissidens dubius</i> P.Beauv.	-	-	-	+	-	-	-
<i>Fissidens ovatifolius</i> R.Ruthe	+	-	-	-	-	-	-
<i>Fissidens taxifolius</i> Hedw.	+	-	+	-	-	-	+
<i>Fissidens viridulus</i> var. <i>incurvus</i> (Starke ex Röhl.) Waldh.	-	+	+	-	-	+	+
<i>Fissidens viridulus</i> var. <i>viridulus</i> (Sw. ex anon) Wahlenb.	+	+	-	-	+	-	+
<i>Fossombronia angulosa</i> (Dicks.) Raddi	+	-	+	+	+	-	+
<i>Fossombronia caespitiformis</i> subsp. <i>caespitiformis</i> De Not. ex Rabenh.	+	-	+	+	+	+	+
<i>Fossombronia caespitiformis</i> subsp. <i>multispira</i> (Schiffn.) J.R.Bray & D.C.Cargill	-	+	+	+	-	+	-
<i>Fossombronia pusilla</i> (L.) Nees	+	+	+	+	-	-	+
<i>Fossombronia wondracekii</i> (Corda) Dumort. ex Lindb.	-	-	-	+	-	-	-
<i>Frullania dilatata</i> (L.) Dumort.	+	-	-	-	-	-	+
<i>Frullania tamarisci</i> (L.) Dumort.	-	-	-	-	-	-	+
<i>Funaria hygrometrica</i> Hedw.	+	-	+	+	-	-	+
<i>Gongylanthus ericetorum</i> (Raddi) Nees	+	-	-	+	-	-	+
<i>Grimmia anodon</i> Bruch & Schimp.	+	-	-	-	-	-	-
<i>Grimmia laevigata</i> (Brid.) Brid.	+	-	-	-	+	+	+
<i>Grimmia lisae</i> De Not.	+	-	+	-	-	-	+
<i>Grimmia orbicularis</i> Bruch ex Wilson	+	-	-	-	-	-	-
<i>Grimmia pulvinata</i> (Hedw.) Sm.	+	-	+	+	-	-	-
<i>Grimmia trichophylla</i> Grev.	+	-	-	-	-	+	-
<i>Gymnostomum calcareum</i> Nees & Hornsch.	-	-	-	-	-	-	+
<i>Hedwigia stellata</i> Hedenäs	-	-	-	+	-	-	-
<i>Homalothecium aureum</i> (Spruce) H.Rob.	+	-	-	-	-	-	-
<i>Homalothecium lutescens</i> Hedw. H.Rob.	+	-	-	-	-	-	-
<i>Homalothecium sericeum</i> (Hedw.) Scimp.	+	-	+	-	-	-	-
<i>Hygroamblystegium tenax</i> (Hedw.) Jenn.	+	-	-	-	-	-	-
<i>Hypnum andoi</i> A.J.E.Sm.	+	-	-	-	-	-	-
<i>Hypnum cupressiforme</i> var. <i>cupressiforme</i> Hedw.	+	+	-	+	+	-	+
<i>Hypnum cupressiforme</i> var. <i>resupinatum</i> (Taylor) Schimp.	+	-	-	-	+	-	-
<i>Hypnum jutlandicum</i> Holmen & E.Warncke	+	-	-	-	-	-	-
<i>Hypnum revolutum</i> (Mitt.) Lindb. var. <i>revolutum</i>	+	-	-	-	-	-	-
<i>Imbribryum alpinum</i> (Huds. ex With.) N.Pedersen	+	+	-	+	+	+	+
<i>Imbribryum mildeanum</i> (Jur.) J.R.Spence	+	-	-	-	-	-	-
<i>Isothecium alopecuroides</i> (Lam. ex Dubois) Isov.	+	-	-	-	-	-	-
<i>Isothecium myusuroides</i> Brid.	+	-	-	-	-	-	-
<i>Kindbergia praelonga</i> (Hedw.) Ochyra	+	-	+	-	+	-	+
<i>Leptobarbula berica</i> (De Not.) Schimp.	-	-	-	-	-	-	+
<i>Leptodictyum riparium</i> (Hedw.) Warnst.	+	+	+	-	+	-	-

Supplementary Material 2

<i>Leptophascum leptophyllum</i> (Müll.Hal.) J.Guerra & M.J.Cano	-	+	-	-	-	-	+
<i>Lophocolea bidentata</i> (L.) Dumort.	-	-	+	-	-	-	-
<i>Lophocolea minor</i> Nees	-	-	-	-	-	-	+
<i>Lunularia cruciata</i> (L.) Dumort. ex Lindb.	-	-	+	-	-	-	+
<i>Metzgeria coniugata</i> Lindb.	+	-	-	-	-	-	-
<i>Microbryum davallianum</i> (Sm.) R.H.Zander	+	-	-	-	-	-	+
<i>Microbryum rectum</i> (With.) R.H.Zander	-	-	-	-	-	-	+
<i>Microbryum starkeanum</i> (Hedw.) R.H.Zander	-	+	-	-	-	-	+
<i>Microeurhynchium pumilum</i> (Wilson) Ignatov & Vanderp.	+	-	+	-	-	-	-
<i>Nogopterium gracile</i> (Hedw.) Crosby & W.R.Buck	+	-	-	-	-	-	-
<i>Oncophorus virens</i> (Hedw.) Brid.	+	-	-	-	-	-	-
<i>Orthotrichum tenellum</i> Bruch ex Brid.	+	-	-	-	-	-	-
<i>Oxymitra incrassata</i> (Brot.) Sérgio & Sim-Sim	-	+	+	-	-	-	-
<i>Oxyrrhynchium speciosum</i> (Brid.) Warnst.	+	-	-	-	-	-	-
<i>Petalophyllum ralfsii</i> (Wilson) Nees et Gottsche.	+	-	-	-	-	-	+
<i>Phaeoceros laevis</i> (L.) Prosk.	+	+	+	+	-	-	+
<i>Philonotis caespitosa</i> Jur.	+	+	-	-	-	-	-
<i>Philonotis capillaris</i> Lindb.	+	-	-	-	-	-	-
<i>Philonotis marchica</i> (Hedw.) Brid.	-	+	-	-	-	-	-
<i>Phymatoceros bulbiculosus</i> (Brot.) Stotler, W.T.Doyle & Crand.-Stoll.	-	+	-	-	-	-	-
<i>Physcomitrella patens</i> (Hedw.) Bruch & Schimp.	-	-	+	-	-	-	-
<i>Plagiomnium elatum</i> (Bruch & Schimp.) T.J.Kop.	-	-	-	+	-	-	-
<i>Plagiomnium ellipticum</i> (Brid.) T.J.Kop.	-	-	-	+	-	-	-
<i>Plagiothecium denticulatum</i> (Hedw.) Schimp	+	-	-	-	-	-	-
<i>Pleuridium acuminatum</i> Lindb.	-	+	+	+	-	-	-
<i>Pleuridium subulatum</i> (Hedw.) Rabenh.	-	+	-	-	-	-	-
<i>Pogonatum nanum</i> (Hedw.) P.Beauv.	+	-	-	-	-	-	-
<i>Pohlia elongata</i> Hedw.	+	-	-	-	-	-	-
<i>Pohlia melanodon</i> (Brid.) A.J.Shaw	-	+	-	-	-	-	-
<i>Pohlia nutans</i> (Hedw.) Lindb.	-	-	-	+	-	-	-
<i>Polytrichum juniperinum</i> Hedw.	-	-	-	-	+	-	-
<i>Pottiopsis caespitosa</i> (Brid.) Blockeel & A.J.E.Sm.	+	-	-	-	-	-	-
<i>Pseudephemerum nitidum</i> (Hedw.) Loeske	-	+	-	-	-	-	-
<i>Pseudocrossidium hornschuchianum</i> (Schultz) R.H.Zander	+	+	-	-	-	-	+
<i>Pseudoscleropodium purum</i> (Hedw.) M Fleisch.	+	-	-	+	-	-	+
<i>Pseudotaxiphyllum elegans</i> (Brid.) Z.Iwats.	+	-	-	-	-	-	-
<i>Ptychostomum boreale</i> (F.Weber & D.Mohr) Ochyra & Bednarek-Ochyra	+	-	-	-	-	-	-
<i>Ptychostomum bornholmense</i> (Wink. & R.Ruthe) Holyoak & N.Pedersen	-	+	-	-	-	-	-
<i>Ptychostomum capillare</i> (Hedw.) Holyoak & N.Pedersen	+	+	+	+	+	-	+
<i>Ptychostomum compactum</i> Hornsch.	+	-	-	-	-	-	-
<i>Ptychostomum donianum</i> (Grev.) Holyoak & N.Pedersen	+	+	-	-	-	-	+
<i>Ptychostomum imbricatulum</i> (Müll. Hal.) Holyoak & N. Pedersen	+	+	-	-	-	+	-
<i>Ptychostomum pallens</i> (Sw.) J.R.Spence	+	-	-	-	-	-	-

Supplementary Material 2

<i>Ptychostomum pseudotriquetrum</i> (Hedw.) J.R. Spence & H.P. Ramsay	+	+	-	+	+	+	+
<i>Ptychostomum rubens</i> (Mitt.) Holyoak & N. Pedersen	+	-	-	-	-	-	+
<i>Ptychostomum torquescens</i> (Bruch & Schimp.) Ros & Mazimpaka	+	+	-	-	-	-	+
<i>Racomitrium ericoides</i> (Brid.) Brid.	-	-	-	+	-	-	-
<i>Reboulia hemisphaerica</i> (L.) Raddi	-	-	+	-	-	-	-
<i>Rhynchostegiella curviseta</i> (Brid.) Lindb.	+	-	-	-	-	-	-
<i>Rhynchostegiella litorea</i> (De Not.) Limpr.	+	-	-	-	-	-	+
<i>Rhynchostegiella tenella</i> (Dicks.) Limpr.	-	-	-	-	-	-	+
<i>Rhynchostegium confertum</i> (Dicks.) Schimp.	+	-	-	-	-	-	-
<i>Rhynchostegium megapolitanum</i> (Blandow ex F. Weber & D. Mohr) Schimp.	+	+	-	-	-	-	+
<i>Rhynchostegium riparioides</i> (Hedw.) Cardot	+	-	-	-	-	-	-
<i>Riccardia chamedryfolia</i> (With.) Grolle	-	-	-	+	-	-	-
<i>Riccia beyrichiana</i> Hampe ex Lehm.	+	+	-	+	+	+	+
<i>Riccia bifurca</i> Hoffm.	+	+	-	-	-	-	-
<i>Riccia canaliculata</i> Hoffm.	+	-	-	+	-	-	-
<i>Riccia ciliata</i> Hoffm.	-	-	-	-	-	+	-
<i>Riccia crinita</i> Taylor	-	-	-	-	-	+	-
<i>Riccia crozalsii</i> Levier	+	+	-	+	+	+	-
<i>Riccia crystallina</i> L.	-	-	-	-	-	-	+
<i>Riccia fluitans</i> Mill.	-	+	-	-	-	-	-
<i>Riccia glauca</i> L.	+	-	+	+	+	+	-
<i>Riccia gougetiana</i> Durieu & Mont.	-	+	+	+	-	-	+
<i>Riccia huebeneriana</i> Lindenb.	+	-	-	-	-	-	-
<i>Riccia macrocarpa</i> Levier	-	-	-	-	-	-	+
<i>Riccia michelii</i> Raddi	+	-	+	-	-	+	-
<i>Riccia nigrella</i> DC.	+	+	-	-	-	+	+
<i>Riccia perennis</i> Steph.	-	-	-	-	+	-	-
<i>Riccia sorocarpa</i> Bisch.	+	+	+	+	+	+	-
<i>Riccia subbifurca</i> Warnst. ex Croz.	-	+	-	+	-	+	+
<i>Riccia warnstorffii</i> Limpr. ex Warnst.	-	+	-	-	-	-	+
<i>Ricciocarpus natans</i> (L.) Corda	-	-	-	+	-	-	-
<i>Riella helicophylla</i> (Bory & Mont.) Mont.	-	-	-	-	-	-	+
<i>Scapania compacta</i> (Roth) Dumort.	-	-	+	+	-	-	-
<i>Sciuro-hypnum populeum</i> (Hedw.) Ignatov & Huttunen	+	-	-	-	-	-	-
<i>Scleropodium cespitans</i> (Wilson ex Müll. Hal.) L.F.Koch	+	-	-	-	+	-	-
<i>Scleropodium touretii</i> (Brid.) L.F.Koch	+	+	-	-	-	+	+
<i>Scorpidium revolvens</i> (Sw. ex anon.) Rubers	+	-	-	-	-	-	-
<i>Scorpiurium circinatum</i> (Bruch) M.Fleisch. & Loeske	+	-	-	-	-	+	+
<i>Scorpiurium deflexifolium</i> (Solms) M.Fleisch & Loeske	+	-	-	-	-	-	-
<i>Sematophyllum substrumulosum</i> (Hampe) E. Britton	-	-	-	+	-	-	+
<i>Southbya nigrella</i> (De Not.) Henriq.	-	-	-	-	-	-	+
<i>Sphaecarpos michelii</i> Bellardi	-	-	+	-	-	-	-
<i>Syntrichia laevipila</i> (Brid.)	+	-	-	-	-	-	-
<i>Syntrichia princeps</i> (De Not.) Mitt.	+	-	-	-	-	-	-

Supplementary Material 2

<i>Syntrichia ruralis</i> var. <i>ruraliformis</i> (Besch.) Delogne	+	-	-	-	-	-	-
<i>Syntrichia virescens</i> (De Not.) Ochyra	+	-	-	-	-	-	-
<i>Thamnobryum alopecurum</i> (Hedw.) Gangulee	+	-	-	-	-	-	-
<i>Timmiella barbuloides</i> (Brid.) Mönk.	+	-	-	-	-	-	+
<i>Tortella flavovirens</i> (Bruch) Broth.	+	-	-	-	+	-	+
<i>Tortella humilis</i> (Hedw.) Jenn.	+	-	-	-	-	-	-
<i>Tortella inflexa</i> (Bruch) Broth.	+	-	-	-	-	-	-
<i>Tortella nitida</i> (Lindb.) Broth.	+	-	-	-	-	-	-
<i>Tortella squarrosa</i> (Brid.) Limpr.	+	+	+	+	-	+	+
<i>Tortella tortuosa</i> (Hedw.) Limpr.	+	-	-	-	-	-	-
<i>Tortula acaulon</i> (Withering) R. H. Zander	-	-	-	-	-	+	+
<i>Tortula canescens</i> Mont.	-	+	-	-	-	-	-
<i>Tortula caucasica</i> Broth.	+	-	+	-	-	+	+
<i>Tortula freibergii</i> Dixon & Loeske	-	-	-	-	-	-	+
<i>Tortula marginata</i> (Bruch & Schimp.) Spruce	+	-	-	-	-	-	+
<i>Tortula muralis</i> Hedw.	+	-	-	+	-	-	+
<i>Tortula solmsii</i> (Schimp.) Limpr.	+	-	-	-	-	-	-
<i>Tortula subulata</i> Hedw.	+	-	-	-	-	-	-
<i>Tortula truncata</i> (Hedw.) Mitt.	+	+	-	+	-	+	+
<i>Trichostomum brachydontium</i> Bruch	+	+	+	+	+	+	+
<i>Trichostomum crispulum</i> Bruch	+	-	-	-	-	-	+
<i>Weissia brachycarpa</i> (Nees & Hornsch.) Jur.	-	-	-	-	-	-	+
<i>Weissia condensa</i> (Voit) Lindb.	-	-	-	-	-	-	+
<i>Weissia controversa</i> Hedwig	-	+	+	-	-	+	+
<i>Weissia longifolia</i> Mitt.	-	+	-	-	-	+	+
<i>Weissia squarrosa</i> (Nees & Hornsch.) Müll.	-	+	-	-	-	-	+

Chapter 2

Small-scale pattern of bryoflora in Mediterranean temporary ponds: hints for monitoring

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Abstract In the Mediterranean region temporary ponds are classified among the most biologically and biogeographically interesting ecosystems. Despite their important ecological functions in those environments, bryophytes are neglected or undervalued in most monitoring and conservation actions. We analyzed the data to understand if (i) environmental variables had an influence on the composition of bryophytes in temporary ponds (dbRDA); (ii) there are differences among sites and ponds, in terms of species composition (PERMANOVA); (iii) bryophytes respond to the water table fluctuation, showing a typical small-scale spatial zonation and comprehend if there are species or life form/strategies typical of those belts (PCoA). Bryophytes are distributed in concentric belts (outer, central, inner) according to their tolerance to floods: we observed a gradient from the outer belt, mainly composed by colonist and

perennial such as Pottiaceae and Brachytheciaceae, to the more humid inner one where annual shuttle such as Ricciaceae dominates. We found significant species associated with belts, such as *Tortella squarrosa* in the outer belt, *Fossumbronia caespitiformis* in the central belt, and *Riccia canaliculata* in the inner belt. The presence of indicator species and the distribution of dominant life form/strategies in the belts allow to monitor over time the changes in the flood level.

Keywords Sardinia · Indicator species · Taxonomic impediment · Hydroperiod · Tolerance to floods · Principal coordinates analysis

Introduction

Temporary ponds (vernal pools) are unusual habitats, neither truly aquatic nor truly terrestrial: they are seasonal wetlands with annually alternating phases of flooding and drying in shallow depressions. In Europe the “Mediterranean Temporary pond” is classified as a priority natural habitat (3170*) under the Habitats Directive 92/43/EEC (European Commission, 1992). Regardless of that, these habitats remain vulnerable to destruction (Rhazi et al., 2001; Bagella & Caria, 2013). The main threats result from inadequate management, or even from partial or total destruction, which might be unintentional, owing to the intrinsic characteristics of an ephemeral habitat that occupies

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small areas (Snodgrass et al., 2000; Grillas et al., 2004; Bagella et al., 2007; Ruiz 2008; Bouahim et al., 2010; Van den Broeck et al., 2015).

In the Mediterranean region, temporary ponds are classified among the most biologically and biogeographically interesting ecosystems (Grillas et al., 2004; Zacharias et al., 2007). Their elevated biodiversity has been attributed to their high spatiotemporal variability (i.e., hydroperiod or length of inundation, Florencio et al., 2009; Van den Broeck et al., 2015) and to a typical small-scale zonation (Casas et al., 1998; Rhazi et al., 2001; Bagella et al., 2009b; Caria et al., 2013). In each pond, three belts can usually be identified: an inner belt in the toe slope, a central belt in the foot/back slope, and an outer belt in the upper slope position (Casas et al., 1998; Rhazi et al., 2001). Each belt is characterized by species assemblages largely diversified in their composition for vascular plants (Rhazi et al., 2006; Bagella et al., 2009b, 2010b), macroinvertebrates, and zooplankton (Boix et al., 2004; Florencio et al., 2009; Rouissi et al., 2014), but the zonation of bryophytes has never been investigated. This lack of knowledge confirms that, despite their important ecological functions, bryophytes are neglected or undervalued in most projects addressing the management of temporary ponds (Casas et al., 1998; Rhazi et al., 2006; Ferchichi-Ben Jamaa et al., 2010; Bagella et al., 2009a; Bagella & Caria, 2012) with few local exceptions (Hugonnot, 2002; Grillas et al., 2004; Cogoni et al., 2006, 2009; Pericàs et al., 2010; Ernandes et al., 2010). This missing information appears particularly significant since several studies showed that the pattern of richness and distribution of bryophytes cannot be surrogated using vascular plants (Pharo et al., 2000; Chiarucci et al., 2007; Bacaro et al., 2008; Bagella, 2014), but then see also Maccherini et al. (2013). The scarce interest in the bryophyte component in the study and conservation of Mediterranean damp habitats looks incongruous: the success of bryophytes in these ephemeral habitat is largely due to their unique and very effective physiological water relation system that allows species to tolerate long periods of dehydration without undergoing physiological damage at cell level (Gignac, 2001; Glime, 2007). Bryophytes are poikilohydric (state of hydration closely resembling local environment), possessing no real vascular tissues and, consequently, they are very dependent on their local environment. When exposed to severe

environmental stressors, bryophyte populations can be very unstable in time and space and abruptly change from year to year (Grillas et al., 2004). For these reasons, they are particularly sensitive to climatic variation and therefore are appropriate candidates to detect the biological effects of global change (Shaw, 2001; Pharo & Zartman, 2007; Désamoré et al., 2012; Ellis, 2013) especially in the Mediterranean areas (Sérgio et al., 2014). Accordingly, the value of bryophytes as indicator species is recognized in several environments (Brunialti et al., 2010; Ceschin et al., 2012; Vieira et al., 2012; Debén et al., 2015).

In this study we were interested in understanding the spatial pattern of bryophytes in Mediterranean temporary ponds addressing the following questions (i) is the composition of Mediterranean temporary ponds influenced by environmental variables? (ii) Do bryophytes respond to the water table fluctuation, showing a typical small-scale spatial zonation, as other taxa? (iii) If the distribution of bryophytes within the ponds follow a concentric zonation, are there species or life form/strategies typical of those belts?

Those information are necessary to build up a scientifically sound knowledge useful for future effective conservation actions, in particular to characterize the observed spatiotemporal variability of Mediterranean temporary ponds and suggest elements to carry out a simple monitoring strategy. As case study we selected the island of Sardinia (Italy), the second largest island in the Mediterranean basin.

Materials and methods

Study area

Sardinia is home of a rich and peculiar flora, shaped by a long geological history (Médail & Quézel, 1997, 1999; Fenu et al., 2014). The island is included in the biodiversity hotspot of the Tyrrhenian islands (Médail & Quézel, 1999; Grillas et al., 2004). Its vascular flora includes 2408 taxa, 180 of which are endemic to Sardinia and about 4% to Sardinia, Corsica, and other small areas in the Tyrrhenian area (Conti et al., 2005, 2007; Arrigoni, 2006; Bacchetta et al., 2011; Peruzzi et al., 2014). Bryoflora amounts to 498 entity (399 Bryophyta, 95 Marchantiophyta, and 4 Anthocerotophyta, Ros et al., 2007, 2013).

The climate is typically Mediterranean, with dry and hot summers and relatively rainy and mild winters: rainfall ranges from 411 mm to more than 1215 mm in the inner mountainous regions. Measured mean annual temperature ranges from 11.68 to 18.08°C. Two macrobioclimates (Mediterranean pluviseasonal oceanic and Temperate oceanic), one variant of Temperate (Submediterranean), four classes of continentality (from weak semihyperoceanic to weak subcontinental), eight thermotypic horizons (from lower thermomediterranean to upper supratemperate), and seven ombrothermic horizons (from lower dry to lower hyperhumid) describe the bioclimatic variability of the island. Mediterranean types are widespread and occupy an area of about 99.1% (Canu et al., 2014). Sardinia is extremely heterogeneous in terms of lithology and geomorphology: Smiraglia et al. (2013) recognized 23 land systems and 94 land facets, while Blasi et al. (2014) recognized 4 different ecoregion subsection.

Temporary ponds are mainly located in the large tablelands that divide the reliefs and in the lowlands, where they occupy depressions characterized by soils with a clay texture and slow drainage along a broad altitudinal range of 10–1100 m a.s.l. Tableland landscape is characterized by neutroacidophilic cork oak (*Quercus suber* L.) woods, subjected to pastoral use and often converted to wooded pastures (*dehesa* landscape) and by deciduous oak woods, dominated by *Quercus ichnusae* Mossa, Bacchetta et Brullo, widely distributed in central-northern Sardinia on noncarbonatic substrata. Lowland landscape is characterized by edaphomesophilous holm oak (*Quercus ilex* L.) and cork oak (*Q. suber*) vegetation in the alluvial plains of a mixed clay-sand matrix, on soils that are moderately hydromorphic (Bacchetta et al., 2009).

The main vernacular names in use for temporary pools in the island are *paule* or *pischina*. As testified by the widespread use of these names, temporary pools occupied large areas in the past, but during the past centuries, they were reclaimed for agricultural activities (Bagella & Caria, 2012).

Site selection and data gathering

To obtain an even distribution of representative sites on the island, we selected nine sites from the existing literature (Cogoni et al., 2006; Desfayes, 2008; Bagella et al., 2009a, b, c; Bagella & Caria, 2013),

choosing ponds meeting the Habitats Directive's criteria for "Mediterranean temporary ponds, 3170*" (Williams, 1987, 2006; Keeley & Zedler, 1998; Yaverkovski et al., 2004). In the selected sites, we surveyed a total of 33 temporary ponds of natural origin (Fig. 1).

For the bryophyte sampling we utilized the method adopted for the vascular flora surveys of the Mediterranean temporary ponds (Bagella et al., 2009b). To record the presence of bryophytes in the ponds, we visited every pond several times a year (from October 2008 to October 2014) and listed all present taxa; we recorded presence/absence data.

To study the small-scale spatial zonation distribution of bryophytes within the temporary ponds, we followed the scheme proposed for Iberian and Moroccan ponds (Casas et al., 1998; Rhazi et al., 2006) which is based on water depth at the beginning of the dry season, morphology of the pond, and type of vegetation present. Accordingly, three belts were recognized in the temporary ponds: an inner belt (I), a central belt (C), and an outer belt (O).

We followed Ros et al. (2007, 2013) for nomenclature, for chorological elements Sérgio et al. (2014), for life forms Hill (2007) and Magdefrau (1982), and for life strategy Kürschner & Frey (2012). Humidity, the main limiting factor of this environment, has been assigned according to the categories proposed by Dierssen (2001).

For environmental variables we used available information existing in Bagella et al. (2010a, b) and original data (Table 1).

Data analysis

To test if there are differences among sites and ponds, in terms of species composition, we performed a PERMANOVA (non-parametric multivariate analysis of variance, Anderson, 2001), using a nested design (factors: belts are nested within pond, within Sites, 999 permutation, Unrestricted permutation of raw data, Jaccard resemblance). A test of the homogeneity of multivariate dispersions within groups (PERMDISP) was performed, as PERMANOVA makes the implicit assumption that dispersions are roughly constant across groups (Anderson, 2001). The differences among belts cannot be analyzed because there are no replicates for every pond (some belts in some ponds have no species).

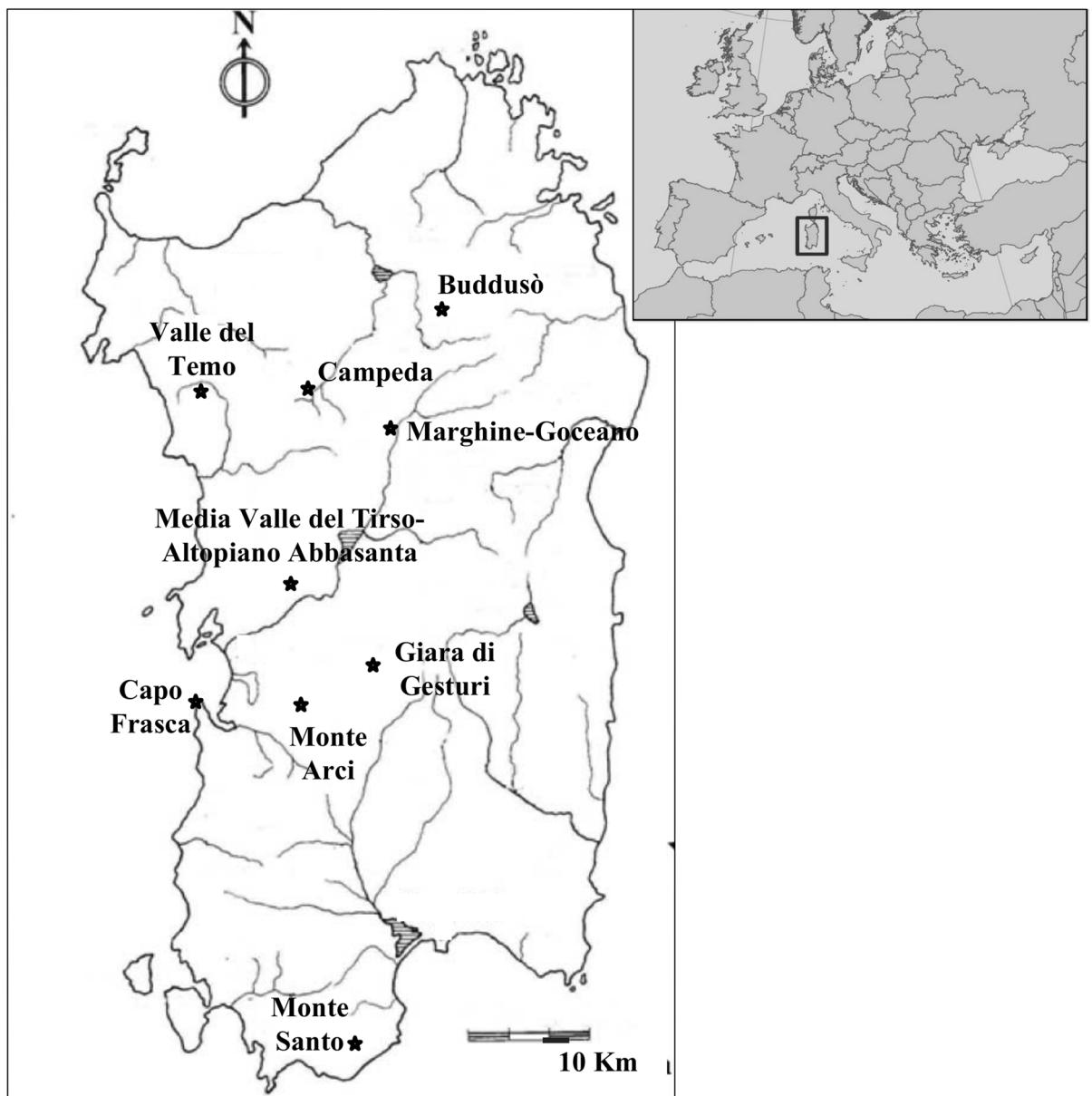


Fig. 1 Location of the study sites in Sardinia, Italy

To understand if the environmental variables have an influence on the composition of bryophytes in temporary ponds in Sardinia and quantify the proportion of variance that can be explained by these variables, we performed a distance-based redundancy analysis (dbRDA), using Jaccard similarity, using a set of environmental predictors (Table 1). Distance-based RDA is a constrained ordination technique that, contrary to classical RDA, do not require multivariate

normality and the use of Euclidean distance (Mc Ardle & Anderson, 2001; Roberts, 2009).

As environmental variables we considered data on altitude, latitude, longitude (Datum WGS84, UTM 32 N), and the bioclimatic classification of Sardinia according to Canu et al. (2014) reclassifying the selected bioclimate types from the wettest and coldest (lower supramediterranean, lower humid, semicontinental weak, coded as 1) to the driest and warmest

Table 1 Characteristics of the nine sites studied (Datum WGS84, UTM 32N)

Site	Number of ponds	Species richness (mean)	Latitude	Longitude	Altitude (mean, m)	Pond max depth (mean, m)	Pond area (mean, sqm)	Grazing type code	Bioclimate code (mean)
Monte Arci	2	37.00	39.848897	8.796849	371.50	0.15	6026.50	1.00	5.50
Buddusò	1	27.00	40.569214	9.318745	798.00	0.15	928.00	5.00	3.00
Campeda	1	11.00	40.387191	8.859391	755.00	0.15	7975.00	3.00	2.00
Capo Frasca	2	15.50	39.730937	8.457577	83.00	0.23	6712.00	4.00	6.00
Giara	19	12.33	39.784275	8.955465	572.22	0.30	23739.78	5.00	4.44
Margh-Goceano	1	26.00	40.343583	8.918293	1120.00	0.15	740.00	4.00	1.00
MValle Tirso	3	16.33	40.025857	8.845838	214.00	0.20	2108.67	4.00	6.67
Monte Santo	3	6.33	39.010325	8.570648	68.00	0.20	100.00	1.00	8.00
Valle del Temo	1	14.00	40.442835	8.538762	625.00	0.15	620.00	2.00	3.00

(upper thermomediterranean, lower dry, euoceanic strong, coded as 8). We also considered the maximum pond depth and the pond area, both assessed during the wet season.

All sites are grazed, but the main grazers are not the same in every site (Table 1): we transformed the information on the presence of different grazing animals according to the weight of the animals (sheep = 1; wild boars = 2; horses = 3; cattle = 4; mixed = 5).

To test if bryophytes respond to the water table fluctuation, showing a typical small-scale spatial zonation and understanding if there are species or life form/strategies typical of those belts, we performed a Principal Coordinates Analysis (PCoA) on the composition of the three belts in the different sites using species, chorotypes, life form, life strategy, and the ecological character “humidity” (for a complete list—see Supplementary Material 1). Like Principal Component Analysis, PCoA returns a set of orthogonal axes whose importance is measured by eigenvalues; the difference is that PCoA provides Euclidean representation of a set of objects whose relationship is measured by any similarity or distance measure chosen by the user. We transformed the abundance of chorotypes, life form, life strategy, and the ecological character “humidity” in relative frequency. We used Jaccard’s index of similarity for species composition (presence/absence data) and Bray–Curtis as index of similarity for frequency data. To facilitate the PCoA interpretation, on the biplot we represented the vectors of the variables and their relative correlation to the ordination using Spearman correlation.

The contribution of a particular species as indicator of a specific belt was assessed by performing an indicator species analysis (Dufrêne & Legendre, 1997). This analysis combines information on the frequency of species, defined as the frequency of the species in the sampled temporary ponds, in two or more groups defined a priori (in our case, belts), considering the constancy of occurrence of a species in a particular group. This comparison produces an indicator value (IV) for each species in each belt, ranging from zero (no indication) to 1 (perfect indication). The results were tested for statistical significance using a Monte Carlo technique: the null hypothesis is that the indicator value observed is no higher than that expected by chance (i.e., that the species has no indicator value, since its presence is the same as that expected by chance).

Analyses were performed using PRIMER v.6.1.11, PERMANOVA + v.1.0.1 (Primer-E Ltd., Luton, UK), and the R-package indicspecies version 1.7.4 (De Cáceres & Legendre, 2009; De Cáceres et al., 2010; De Cáceres, 2013).

Results

In 33 ponds, 139 taxa were surveyed: 119 Bryophyta, 19 Marchantiophyta, and 1 Anthocerotophyta. The 139 taxa surveyed represent approximately 28% of Sardinia’s total stock of bryophytes (for a complete list of species—see Supplementary Material 1).

Four out of 30 reported families (Pottiaceae, Brachytheciaceae, Bryaceae, and Ricciaceae) include

Table 2 Significance of the Indicator Value analysis carried out between bryophytes and belts

Species	Belts	Ind. Value
<i>Microeurhynchium pumilum</i>	O	0.551***
<i>Hypnum cupressiforme</i> var. <i>cupressiforme</i>	O	0.492***
<i>Fissidens crispus</i>	O	0.461**
<i>Dicranella varia</i>	O	0.389**
<i>Scleropodium touretii</i>	O	0.389**
<i>Sciuro-hypnum populeum</i>	O	0.422*
<i>Rhynchosstegium confertum</i>	O	0.416*
<i>Ptychostomum capillare</i>	O	0.403*
<i>Isothecium myosuroides</i>	O	0.393*
<i>Tortula solmsii</i>	O	0.393*
<i>Tortella squarrosa</i>	O	0.389*
<i>Didymodon insulanus</i>	O	0.353*
<i>Bryum gemmiparum</i>	O	0.348*
<i>Didymodon fallax</i>	O	0.348*
<i>Rhynchosstegiella curviseta</i>	O	0.348*
<i>Tortula caucasica</i>	O	0.348*
<i>Tortula muralis</i>	O	0.348*
<i>Fossombronia caespitiformis</i>	C	0.459*
<i>Riccia canaliculata</i>	I	0.490**
<i>Riccia glauca</i>	I	0.435**
<i>Riccia sorocarpa</i>	I	0.435**
<i>Riccia crozalsii</i>	I	0.417**
<i>Conocephalum conicum</i>	I	0.440*

Only significant species are reported (* $P < 0.05$;

** $P < 0.01$;

*** $P < 0.001$)

58% of the total species; 19 families are only represented by one or two species.

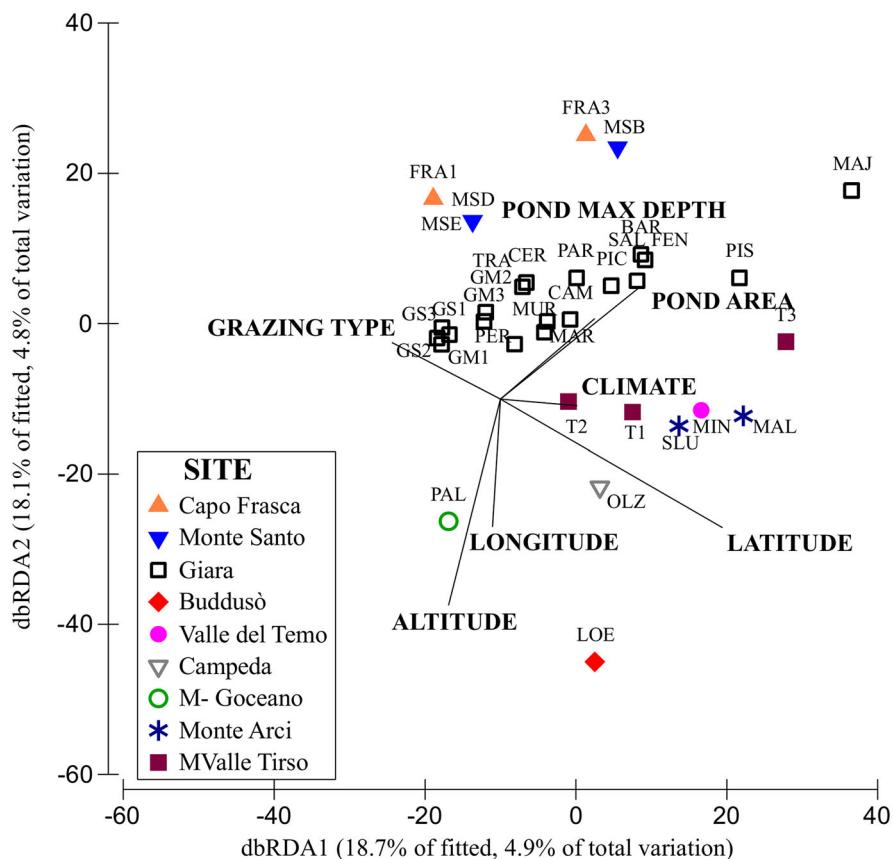
The most frequent species in the Mediterranean temporary ponds, showing a frequency higher than 30% are: *Archidium alternifolium* (Hedw.) Mitt., *Bryum turbinatum* (Hedw.) Turner, *Imbrybryum alpinum* (Huds. ex With.) N.Pedersen, *Conocephalum conicum* (L.) Dumort., *Fossombronia caespitiformis* De Not. ex Rabenb., *Kindbergia praelonga* (Hedw.) Ochyra, *Microeurhynchium pumilum* Ignatov & Vanderp., *Ptychostomum compactum* Hornsch., and *Ptychostomum pallens* J.R.Spence. In particular, *Archidium alternifolium* is the most common species found in temporary ponds in Sardinia, being surveyed in more than 55% of the investigated ponds.

Chorological data show that the element Oceanic (35%) prevails on the others chorological elements (Temperate 31%, Mediterranean 21%, and Boreal-Alpine 13%).

Most of the species are xerophytic (22%), hygro-mesophytic (22%) and meso-xerophytic (19%)

closely linked to the hydroperiod of the temporary ponds. Entities that are strictly hygrophyt (16%) such as *Rhynchosstegium ripariooides* (Hedw.) Cardot and *Leptodictyum riparium* (Hedw.) Warnst. undergo periods of submersion during the spring. This species is also capable of tolerating the summer drought by taking refuge at the base of boulders with niches that form a microclimate with residual humidity. Regarding life-form analysis, there is a predominance of turf (33%) followed by mat rough (14%) and tuft (13%). Concerning life strategy, most species are colonist (41%) such as the pioneer species *Bryum dichotomum* Hedw. and *Tortella squarrosa* (Brid.) Limpr. and perennial (29%) represented by species that tolerate fluctuations that characterize these environments (*Scorpiurium reflexifolium* (Solms) M. Fleisch & Loeske, *Scleropodium cespitans* (Wilson ex Müll. Hal.) L.F.Koch, *Rhynchosstegium ripariooides*, *Leptodictyum riparium*). Species with annual life strategy (12%) are represented especially by liverworts belonging to

Fig. 2 The distance-based redundancy analysis (dbRDA) show that environmental variables have a little influence on the composition of bryophytes in temporary ponds in Sardinia, explaining a small proportion of variation. For site distribution, refer to Fig. 1 and Table 1



genus *Riccia* that do not tolerate water stress in the driest season (During, 1979).

Differences among sites and environmental variables

Results of PERMANOVA analyses showed that the composition of bryophyte species do not variate in a significant way among sites (Site $P = 0.189$; PERMDISP $P < 0.001$) and ponds ((Pond nested within Sites) $P = 0.919$; PERMDISP $P < 0.001$).

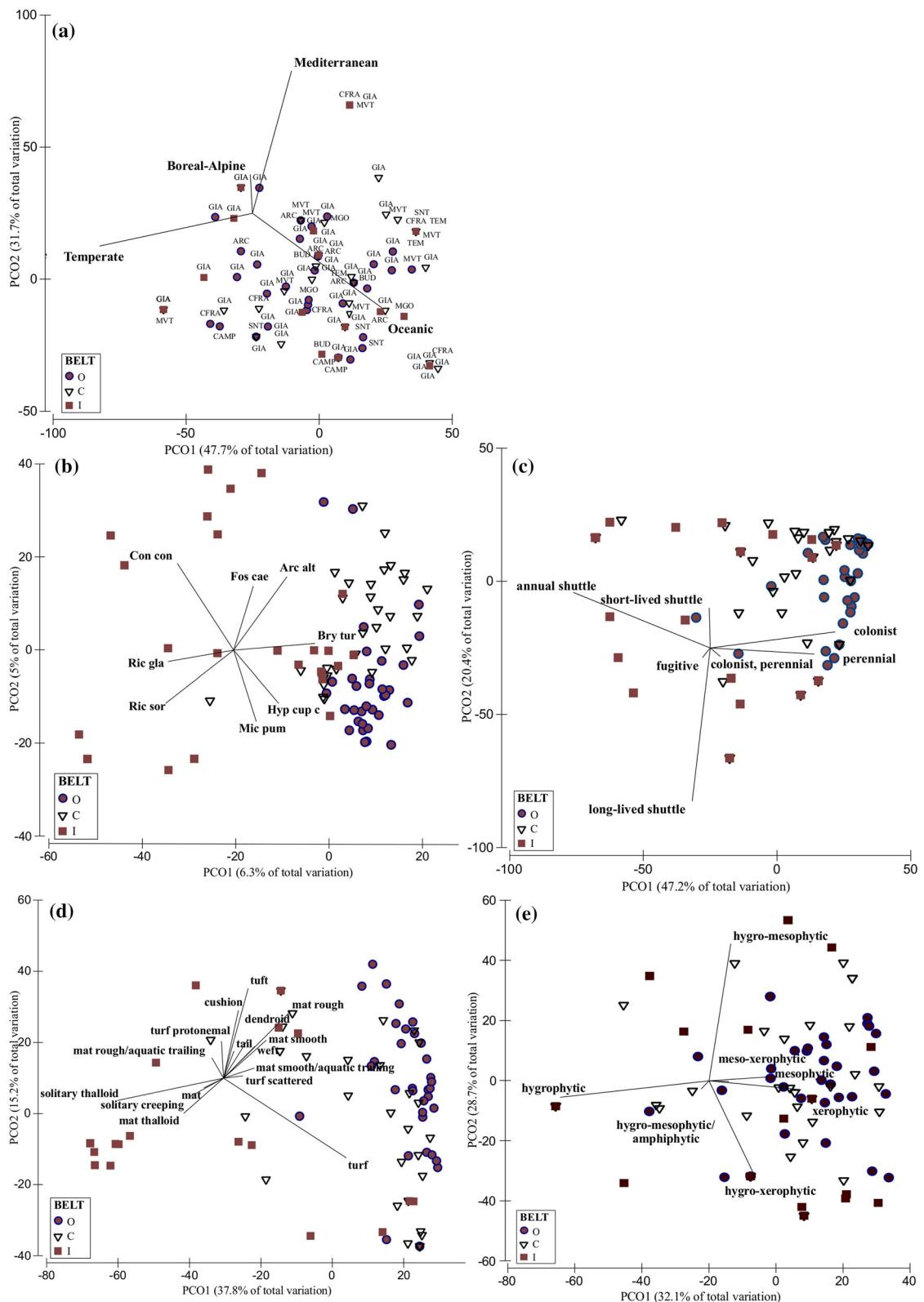
The dbRDA of the floristic data set with the environmental variables showed that no environmental variables clearly explained the variability among sites: axis 1 only explained 18.7% of fitted model variation, with a positive correlation with latitude and pond area; axis 2 explained 18.1% of fitted model variation, with a negative correlation with altitude and longitude (Fig. 2). However, only latitude ($P = 0.024$) and altitude ($P = 0.018$) were found statistically significant.

Species and ecological features distribution within the ponds

PCoA performed on chorotypes showed that Oceanic type is dominant and there is not a clear distinction following the distribution of sites on the island (Fig. 3a).

The results obtained with PCoA using species and life/form/humidity strategies (Fig. 3b–e) are confirmed by the results for Indicator Value analysis of species in the belts (Table 2).

The outer belt (O) hosts the majority of the species (56) with 17 species with significative values for indications and 10 species exclusively found in the belt (for a complete list of species and relative frequency associated with the belts—see Supplementary Material 2). Most of these species are xerophytic with colonist and perennial life strategy and turf life form (Fig. 3c, e). Species with perennial life strategy are represented by pleurocarpic mosses. Among



◀ Fig. 3 PCoA performed on the composition of the three belts in the different sites using chorotypes (a), species (b), life strategy (c), life form (d), and the ecological character “humidity” (e). In a sites are abbreviated as follow: ARC Monte Arci; BUD Buddusò; CAMP Campeda; CFRA Capo Frasca; GIA Giara; MGO M Goceano; MVT MValle Tirso; SNT Monte Santo; TEM Valle del Temo (see Fig. 1 for sites distribution)

acrocars, the turf life form dominates, since it allows species to survive during the dry periods (Fig. 3d).

The central belt (C) is often submerged during the winter: we found 13 species that are limited to this belt only because are strictly linked to water oscillation. Most of these species are hygro-mesophytic and meso-xerophytic with colonist life strategy (Fig. 3c, e). The most abundant life form is the turf. *Fossombronia caespitiformis*, a meso-xerophytic species with an annual shuttle life strategy and solitary creeping life form, is the only indicator species for this belt (Fig. 3b; Table 2).

The inner belt (I) is the most humid one, since it can be flooded even during springtime; we recognized 6 specialized species, with the *Riccia* as the most common genus (Fig. 3b; Table 2). In this belt we found a majority of hygro-mesophytic hepatic, with annual shuttle life strategy and solitary thalloid life form.

We also found 42 species that indifferently live in the outer and in the central belt, such as *Archidium alternifolium* and *Bryum turbinatum* (Fig. 3b). *A. alternifolium* frequently is in the outer belt in the margins of temporary ponds but it is also a species that tolerates the typical hydroperiod of this habitat. This ecological feature can explain its presence in two belts characterized by diverse ecological conditions. *Bryum turbinatum* is a typical species of wet habitat, it was found on damp soil and on rocks in the outer and central belts.

A group of species (6) occurred in the outer and the inner belts, such as *Grimmia trichophylla*, that is predominantly an upland species, which was found on exposed rocks and boulders in the outer belt and in the internal belt during the most critical period. A group of species (10) occurred in the three belts: they mainly are *Bryaceae*, and the most common species is *Ptychostomum pallens*, hygrophytic, with short-lived shuttle life strategy and turf-scattered life form (see Supplementary Material 2).

Conservation concern taxa

We sampled several species of conservation concern linked to these environment: we collected *Petalophyllum*

ralfsii Nees et Gottsche. (Capo Frasca site), that is included in the Habitats Directive 92/43/EEC and assessed as *Critically Endangered* in the Italian Flora Red List (Rossi et al., 2013, 2014), and *Cephalozia calyculata* (Durieu & Mont.) Müll. Frib. (Giara and Monte Santo sites) and *Fossombronia pusilla* (L.) Nees (Tirso, Buddusò and Monte Santo sites) assessed as *Critically Endangered* in Sardinia (Hodgetts, 2015).

Two species are new for Sardinia (Martellos et al., 2013): *Riccia huebeneriana* Lindenb. at the Buddusò site, in the inner belt on clayey substrate with emerging rockiness and *Hypnum revolutum* (Mitt.) Lindb. var. *revolutum* at the Marghine-Goceano site, in the outer belt on volcanic substrate (Fig. 1).

Discussion

The bryoflora of Mediterranean temporary ponds is a substantial component of biodiversity of these ephemeral habitats. Our results give the first contribution to the knowledge of bryodiversity and small-scale spatial pattern of temporary wetland ecosystem and provide a helpful benchmark to plan future conservation actions in those fragile environments.

The floristic component of temporary ponds

In agreement with the findings on temporary ponds in the Mediterranean (Casas et al., 1998; Hugonnot, 2002; Cogoni et al., 2009; Pericàs et al., 2010) we can define a group of bryophytes typically present in Mediterranean temporary ponds: *Archidium alternifolium*, *Imbribryum alpinum*, *Bryum dichotomum*, *Ptychostomum pseudotriquetrum* (Hedw.) J.R. Spence & H.P. Ramsay, *Riccia beyrichiana* Hampe ex Lehm, and *Trichostomum brachydontium* Bruch. The genus *Riccia* is the most common taxa (Grillas et al., 2004). The most frequent species *Archidium alternifolium* is an acrocarpic moss that shows a high ecological plasticity, growing on open, moist, and for long periods submerged soils (Hill et al., 2007).

In terms of species composition there are no significant differences among the investigated sites: this confirms the strong selection that the Mediterranean temporary pond environment exerts on the bryoflora, creating a species assemblage mainly influenced by local factors, namely water table oscillation and microhabitat type, as suggested also by Hespanhol

et al. (2011), than by other environmental factors such as climate or altitude. In fact, in our analyses the type of grazing animals did not appear to be a very informative environmental variable, even if we observed in the field that at local scale the action of animals caused an alteration in substrate morphology and in the dynamism of the vascular vegetation favoring, for example, the settlement of entities of the genus *Riccia* (Grillas et al., 2004). The presence of grazers, instead of reducing the moss cover and contrarily to what observed for vascular plants (Bouahim et al., 2010), seems to contribute in a positive way to the richness and diversity of bryoflora of the *pauli* (see also Van den Broeck et al., 2015). In particular, the footprints left by the trampling of the cattle favor the survival of the some bryophytes during the dry period, since they can take advantage of the continuous creation of those moist microhabitats (Cogoni et al., 2009). According to our results and field observations, to better understand and quantitatively assess the impact of grazing animals on bryophyte diversity, in the future we should collect more detailed and quantitative information on their action on the substrate morphology, microhabitats creation, and on the removal of possible competitors, namely vascular plants (see Bouahim et al., 2010).

At the scale of the entire island, chorotype composition was not influenced by the distribution of ponds in the territory: the high percentage of Oceanic species suggested the dominance of species associated with humid environmental conditions. The abundant presence of xerophytic and hygro-mesophytic bryophytes is indicative of the diversity found in temporary ponds caused by the typical small-scale zonation. The predominance of turf life form is linked to the ability of the species to tolerate extreme aridity during the most critical period, i.e., the dry season. The major presence of species with colonist life strategy is important for the habitat conservation because these species prevent high substrate desiccation and encourage the establishment of other species (During & Van Tooren, 1990).

Although ephemeral, limited to peculiar and scattered conditions and quantitatively small in area, this habitat hosts several species of high conservation interest such as *Riccia huebeneriana* (Hodgetts, 2015). This plant survives, potentially for many years, as a spore bank in the mud, only developing when the mud is exposed, whether by drought or by artificial lowering of water levels (Lockhart et al., 2012). The

finding of *Hypnum revolutum* is also important (Hodgetts, 2015), since it was reported in Italy only in the northern regions and thus represents the first discovery in the central-southern part of the country. *R. huebeneriana* and *H. revolutum* were surveyed in two sites (Buddusò and Marghine-Goceano) that have already been identified as Important Plant Areas for conservation of vascular plants (Blasi et al., 2011; Marignani et al., 2014), confirming the value of those areas.

The presence of the species included in Habitats Directive *Petalophyllum ralfsii* is particularly interesting: this thallose liverwort develops during the spring and disappears during the summer when the plant survives the dryness by producing spores that remain quiescent in the soil until the following spring. The species grows on damp substrates, sandy ponds in conjunction with periods of rain, at altitudes between sea level and 200 m. Due to the fragility of the habitat and its unique ecology, *P. ralfsii* is potentially threatened by a number of factors including pressure from tourism, removal, or drying of the thallus due to water withdrawals or reforestation (Aleffi & Cogoni, 2008). *Cephaloziella calyculata*, previously reported by Bischler & Jovet-Ast (1971, 1972), was found for the second time in Sardinia and, as *Fossumbronia pusilla* (Hodgetts, 2015), it is at risk in several countries. Among the Brachytheciaceae, *Scleropodium cespitans* is a taxon with few mentions in the Mediterranean (Aleffi et al., 2008; Cogoni et al., 2009).

Spatial pattern of bryophytes within the pond and monitoring implications

Results obtained with the analyses of species distribution within the defined belts showed a pattern characterized by typical species, life strategy, life forms, and humidity: we synthesized a pattern dynamic in time and space, that changes seasonally and according to water availability and related humidity gradients (Fig. 4).

Bryophytes are adapted morphologically, physiologically, and reproductively to wetland hydroperiods. Flood frequency and water-level fluctuations exert a controlling influence on bryophyte' species composition and life strategies. The distribution of the species in the belts mirrors their tolerance to floods (Brewer et al., 1997; Lenssen et al., 1999). Most of the species were found in the outer belt, confirming what already reported for the vascular flora (Rhazi et al., 2006). The

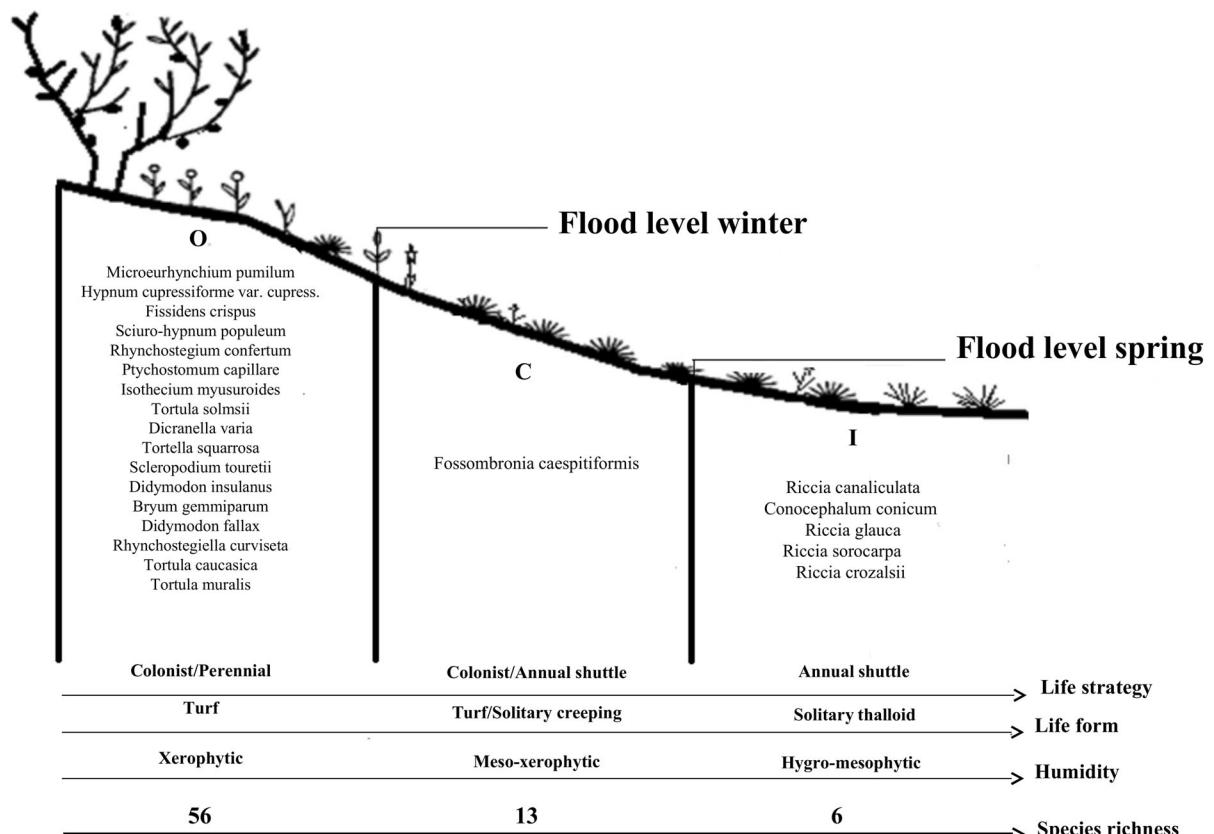


Fig. 4 Graphical scheme of main results on the distribution of the most frequent life strategy, life form, and ecological character “humidity” of bryophytes within a Mediterranean

temporary pond. The belts are: O outer belt; C central belt; I inner belt (modified from Casas et al., 1998)

outer belt is the one less influenced by hydroperiods and water-level fluctuation; hence, it is the most stable and richest in species (Gough & Grace, 1998). Several species of this belt, such as *Hypnum cupressiforme* var. *cupressiforme* Hedw., can be found in the surrounding environments. The surrounding species find suitable habitats in the outer belt taking advantage of the low frequency of flooding. The central and inner belts host fewer species and their presence is strictly linked to water-level oscillation.

Life strategies are used to categorize bryophytes in terms of their ability to occupy, reproduce, and persist in a particular environment. Since Mediterranean temporary habitats are ephemeral, life strategies inherently represent trade-offs in a variety of characteristics, such as avoidance or tolerance of stressful environments, dominance of sexual or asexual reproduction, short or long life span, and large or small spore size. The life strategies employed by bryophyte

species result in differential responses to disturbance along a gradient from avoidance to tolerance.

Analyzing the pattern of species distribution among the defined belts (Fig. 4, Table 2), it is interesting to note the gradient from the outer belt (O), mainly composed by colonist and perennial such as Pottiaceae and Brachytheciaceae, to the inner one (I) where annual shuttle such as Ricciaceae dominates.

In the outer belt, the mats formed by some colonist species such as Pottiaceae *Tortella squarrosa*, prevent high desiccation of the substrate during the most critical period and encourage the establishment of other species, especially vascular plants, creating a favorable environment where spores and plant seeds can germinate.

The presence of perennial species can be used as an efficient bioindicator to monitor the state of conservation of temporary ponds, since they persist in habitats for relatively long periods of time (During,

1992). For example, the reduction of the temporary pond and/or a change in the hydroperiod fluctuation could be early detected observing the spreading in the flooded (inner) belt of pleurocarpic perennial species typical of the surrounding environments, while the absence of typical species in the outer belt might suggest the presence of a disturb.

Classifying the bryoflora using life strategy/form is simpler than classifying species: this approach can be more easily followed by non-expert bryologist to monitor the yearly ponds' fluctuations. Species characterized by shuttle life strategy, such as *Riccia canaliculata*, typical of the inner belt (I), achieve their establishment and survival by the large spores which are present in the diaspore bank. The presence of large numbers of viable spores in deeper soils could serve as "insurance" against local extirpation: it might be a winning strategy in Mediterranean temporary habitats. At the same time, it lowers the risk of local extinction of the species, populations, and communities (Kürschner & Frey, 2012).

Conclusions

The bryoflora of Sardinian Mediterranean temporary ponds is rich and diversified, including groups of species with different chorological and ecological features with a presence of endangered species. This bryoflora contributes to the biodiversity at a regional scale, and it is particularly important as a benchmark for future monitoring actions of freshwater biodiversity.

The distribution analysis of bryophytes in the belts within the ponds allows us to suggest the bryophytes as useful bioindicators of the state of conservation of Mediterranean temporary ponds, since the presence of indicator species in the different belts enables us to monitor over time the changes in the flood level.

Even if they are one of the main elements in the ecology of wet and temporary ecosystems, bryophytes are difficult to classify, specialists are few, and the Wallacean shortfall is still a problem (but see Aranda et al., 2011, 2015); this can limit the use of this taxa for monitoring activities (Debén et al., 2015). Nevertheless, the use of life forms and life strategy to characterize the belts addresses this problem, suggesting a relatively easy solution for a quick survey to monitor the condition of temporary ponds. The quick survey based on life strategy/forms will never

substitute a comprehensive survey (see e.g., Marignani et al., 2008); nevertheless, it is important to recognize that a simple classification of species in the field can help non-professional botanists, such as rangers or local people, in conducting a monitoring survey, gathering data that can be completed and improved by specialists.

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Annex I

Small-scale pattern of bryoflora in Mediterranean temporary ponds – hints for monitoring (Hydrobiologia)

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Annex I.

Complete species list of bryoflora surveyed in Mediterranean temporary ponds in Sardinia.

Species	Corology	Humidity	Life strategy	Life form
<i>Archidium alternifolium</i> (Hedw.) Mitt.	oceanic	hygro-xerophytic	short-lived shuttle	turf
<i>Barbula convoluta</i> Hedw.	mediterranean	meso-xerophytic	colonist	turf
<i>Barbula unguiculata</i> Hedw.	temperate	hygro-xerophytic	colonist	turf
<i>Bartramia pomiformis</i> Hedw.	boreal-alpine	hygro-mesophytic	long-lived shuttle	tuft
<i>Bartramia stricta</i> Brid.	oceanic	xerophytic	long-lived shuttle	tuft
<i>Brachythecium rutabulum</i> (Hedw.) Schimp.	temperate	hygro-mesophytic	perennial	mat rough
<i>Brachytheciastrum velutinum</i> (Hedw.) Ignatov & Huttunen	temperate	hygro-mesophytic	colonist	mat rough
<i>Brachythecium glareosum</i> (Bruch ex Spruce) Schimp.	boreal-alpine	meso-xerophytic	perennial	mat rough
<i>Brachythecium rivulare</i> Schimp.	boreal-alpine	hygrophytic	perennial	mat rough
<i>Brachythecium salebrosum</i> (Hoffm. ex F.Weber & D.Mohr) Schimp.	boreal-alpine	hygro-mesophytic	colonist	mat rough
<i>Bryum argenteum</i> Hedw.	mediterranean	meso-xerophytic	colonist	turf
<i>Bryum dichotomum</i> Hedw.	temperate	meso-xerophytic	colonist	turf
<i>Bryum elegans</i> Nees	boreal-alpine	xerophytic	colonist	tuft
<i>Bryum gemmiparum</i> De Not.	oceanic	hygrophytic	colonist	turf
<i>Bryum kunzei</i> Hornsch.	temperate	meso-xerophytic	colonist	tuft
<i>Bryum radiculosum</i> Brid.	oceanic	xerophytic	colonist	cushion
<i>Bryum turbinatum</i> (Hedw.) Turner	temperate	hygrophytic	long-lived shuttle	turf
<i>Calliergonella cuspidata</i> (Hedw.) Loeske	temperate	hygro-mesophytic/amphiphytic	perennial	weft
<i>Campylopus pilifer</i> Brid.	oceanic	xerophytic	long-lived shuttle	tuft
<i>Cephaloziella calyculata</i> (Durieu & Mont.) Mull. Frib.	oceanic	hygro-xerophytic	colonist	solitary creeping
<i>Cheilotrichia chloropus</i> (Brid.) Broth.	oceanic	xerophytic	colonist	turf
<i>Conocephalum conicum</i> (L.) Dumort.	boreal-alpine	hygrophytic	long-lived shuttle	mat thalloid
<i>Corsinia coriandrina</i> (Spreng.) Lindb.	oceanic	xerophytic	short-lived shuttle	mat
<i>Dalytrichia mucronata</i> (Brid.) Broth.	mediterranean	hygro-mesophytic	colonist	tuft
<i>Dicranella howei</i> Renaud & Cardot	oceanic	xerophytic	colonist	turf
<i>Dicranella humilis</i> R.Ruthe	temperate	hygro-mesophytic	colonist	turf
<i>Dicranella varia</i> (Hedw.) Schimp.	temperate	hygrophytic	colonist	turf
<i>Dicranum majus</i> Sm.	temperate	mesophytic	perennial	tuft
<i>Dicranum polysetum</i> Sw. ex anon.	temperate	mesophytic	perennial	tuft
<i>Didymodon fallax</i> (Hedw.) R.H. Zander	mediterranean	hygro-xerophytic	colonist	turf
<i>Didymodon insulanus</i> (De Not.) M.O. Hill	mediterranean	hygro-mesophytic	colonist	turf
<i>Didymodon luridus</i> Hornsch.	mediterranean	xerophytic	colonist	turf
<i>Didymodon rigidulus</i> Hedw.	temperate	xerophytic	colonist	turf
<i>Didymodon spadiceus</i> (Mitt.) Limpr.	temperate	hygrophytic	colonist	turf
<i>Didymodon vinealis</i> (Brid.) R.H.Zander	mediterranean	xerophytic	colonist	tuft
<i>Distichium capillaceum</i> (Hedw.) Bruch & Schimp	boreal-alpine	mesophytic	colonist	tuft
<i>Encalypta ciliata</i> Hedw.	boreal-alpine	meso-xerophytic	long-lived shuttle	tuft
<i>Ephemerum minutissimum</i> Lindb.	oceanic	hygro-mesophytic	annual shuttle	turf protonemal
<i>Ephemerum serratum</i> (Hedw.) Hampe	oceanic	hygro-mesophytic	annual shuttle	turf protonemal
<i>Epipterygium tozeri</i> (Grev.) Lindb.	oceanic	hygro-mesophytic	colonist	turf scattered
<i>Eurhynchiastrum pulchellum</i> (Hedw.) Ignatov & Huttunen	boreal-alpine	meso-xerophytic	perennial	mat rough
<i>Fissidens crispus</i> Mont.	oceanic	meso-xerophytic	colonist	turf
<i>Fissidens ovatifolius</i> R.Ruthe	mediterranean	hygro-mesophytic	long-lived shuttle	turf
<i>Fissidens taxifolius</i> Hedw.	temperate	mesophytic	colonist	turf
<i>Fissidens viridulus</i> (Sw. ex anon) Wahlenb.	mediterranean	hygro-mesophytic	colonist	turf

Annex I

<i>Fossombronia angulosa</i> (Dicks.) Raddi	oceanic	hygro-mesophytic	annual shuttle	mat
<i>Fossombronia caespitiformis</i> De Not. ex Rabenh.	oceanic	meso-xerophytic	annual shuttle	solitary creeping
<i>Fossombronia pusilla</i> (L.) Nees	oceanic	hygro-mesophytic	annual shuttle	solitary creeping
<i>Frullania dilatata</i> (L.) Dumort.	temperate	hygro-xerophytic	long-lived shuttle	mat smooth
<i>Funaria hygrometrica</i> Hedw.	temperate	hygro-mesophytic	fugitive	tuft
<i>Gongylanthus ericetorum</i> (Raddi) Nees	oceanic	hygro-xerophytic	long-lived shuttle	solitary creeping
<i>Grimmia anodon</i> Bruch & Schimp.	oceanic	xerophytic	perennial	cushion
<i>Grimmia laevigata</i> (Brid.) Brid.	mediterranean	xerophytic	colonist	cushion
<i>Grimmia lisae</i> De Not.	mediterranean	hygro-mesophytic	colonist	turf
<i>Grimmia orbicularis</i> Bruch ex Wilson	mediterranean	xerophytic	colonist	cushion
<i>Grimmia pulvinata</i> (Hedw.) Sm.	temperate	xerophytic	colonist	cushion
<i>Grimmia trichophylla</i> Grev.	temperate	hygro-xerophytic	colonist	cushion
<i>Homalothecium aureum</i> (Spruce) H.Rob.	mediterranean	xerophytic	perennial	tail
<i>Homalothecium lutescens</i> Hedw. H.Rob.	temperate	meso-xerophytic	perennial	weft
<i>Homalothecium sericeum</i> (Hedw.) Scimp.	temperate	xerophytic	perennial	mat rough
<i>Hygroamblystegium tenax</i> (Hedw.) Jenn.	temperate	hygrophytic	perennial	mat rough
<i>Hypnum andoi</i> A.J.E.Sm.	oceanic	mesophytic	perennial	mat smooth
<i>Hypnum cupressiforme</i> var. <i>cupressiforme</i> Hedw.	temperate	meso-xerophytic	perennial	weft
<i>Hypnum cupressiforme</i> var. <i>resupinatum</i> (Taylor) Schimp.	oceanic	mesophytic	perennial	mat smooth
<i>Hypnum jutlandicum</i> Holmen & E.Warncke	oceanic	hygro-mesophytic	perennial	mat smooth
<i>Hypnum revolutum</i> (Mitt.) Lindb. var. <i>revolutum</i>	boreal-alpine	meso-xerophytic	perennial	mat rough
<i>Imbribryum mildeanum</i> (Jur.) J.R.Spence	oceanic	hygro-mesophytic	perennial	cushion
<i>Imbribryum alpinum</i> (Huds. ex With.) N.Pedersen	oceanic	hygro-mesophytic	colonist, perennial	turf
<i>Isothecium alopecuroides</i> (Lam. ex Dubois) Isov.	temperate	mesophytic	perennial	dendroid
<i>Isothecium myrsuroides</i> Brid.	oceanic	hygro-mesophytic	perennial	dendroid
<i>Kindbergia praelonga</i> (Hedw.) Ochyra	temperate	hygro-mesophytic	perennial	mat rough
<i>Leptodictyum riparium</i> (Hedw.) Warnst.	temperate	hygrophytic	perennial	mat rough/aquatic trailing
<i>Metzgeria coniugata</i> Lindb.	oceanic	hygrophytic	long-lived shuttle	weft
<i>Microbryum davallianum</i> (Sm.) R.H.Zander	mediterranean	hygrophytic	annual shuttle	turf scattered
<i>Microeurhynchium pumilum</i> (Wilson) Ignatov & Vanderp.	oceanic	xerophytic	perennial	mat rough
<i>Nogopterium gracile</i> (Hedw.) Crosby & W.R.Buck	oceanic	hygro-xerophytic	long-lived shuttle	tail
<i>Oncophorus virens</i> (Hedw.) Brid.	boreal-alpine	hygrophytic	long-lived shuttle	turf
<i>Orthotrichum tenellum</i> Bruch ex Brid.	mediterranean	xerophytic	colonist	cushion
<i>Oxyrrhynchium speciosum</i> (Brid.) Warnst.	temperate	hygro-mesophytic	short-lived shuttle	mat rough
<i>Petalophyllum ralfsii</i> (Wilson) Nees et Gottsche.	oceanic	hygrophytic	short-lived shuttle	solitary thalloid
<i>Phaeoceros laevis</i> (L.) Prosk.	oceanic	hygro-mesophytic	annual shuttle	mat thalloid
<i>Philonotis capillaris</i> Lindb.	oceanic	hygrophytic	long-lived shuttle	turf
<i>Philonotis caespitosa</i> Jur.	boreal-alpine	hygrophytic	long-lived shuttle	turf
<i>Plagiothecium denticulatum</i> (Hedw.) Schimp.	boreal-alpine	hygro-mesophytic	perennial	mat smooth
<i>Pogonatum nanum</i> (Hedw.) P.Beauv.	boreal-alpine	meso-xerophytic	colonist	turf protonemal
<i>Pohlia elongata</i> Hedw.	oceanic	mesophytic	colonist	tuft
<i>Pottiopsis caespitosa</i> (Brid.) Blockeel & A.J.E.Sm.	mediterranean	hygrophytic	colonist	turf scattered
<i>Pseudocrossidium hornschuchianum</i> (Schultz) R.H.Zander	mediterranean	xerophytic	colonist	turf
<i>Pseudoscleropodium purum</i> (Hedw.) M Fleisch.	mediterranean	meso-xerophytic	colonist	weft
<i>Pseudotaxiphyllum elegans</i> (Brid.) Z.Iwats.	temperate	mesophytic	colonist	mat smooth
<i>Ptychosporium boreale</i> (F.Weber & D.Mohr) Ochyra & Bednarek-Ochyra	oceanic	mesophytic	colonist	turf
<i>Ptychosporium capillare</i> (Hedw.) Holyoak & N.Pedersen	temperate	hygro-xerophytic	colonist	turf
<i>Ptychosporium compactum</i> Hornsch.	temperate	meso-xerophytic	short-lived shuttle	turf
<i>Ptychosporium donianum</i> (Grev.) Holyoak & N.Pedersen	oceanic	hygro-xerophytic	colonist	turf
<i>Ptychosporium imbricatum</i> (Muill. Hal.) Holyoak & N. Pedersen	temperate	hygro-xerophytic	colonist	turf
<i>Ptychosporium pallens</i> (Sw.) J.R.Spence	boreal-alpine	hygrophytic	short-lived shuttle	turf scattered
<i>Ptychosporium pseudotriquetrum</i> (Hedw.) J.R. Spence & H.P. Ramsay	temperate	hygrophytic	perennial	tuft
<i>Ptychosporium rubens</i> (Mitt.) Holyoak & N. Pedersen	temperate	mesophytic	colonist	turf
<i>Ptychosporium torquescens</i> (Bruch & Schimp.) Ros & Mazimpaka	mediterranean	hygro-xerophytic	long-lived shuttle	turf
<i>Rhynchostegiella curviseta</i> (Brid.) Lindb.	mediterranean	hygro-xerophytic	perennial	mat smooth
<i>Rhynchostegiella litorea</i> (De Not.) Limpr.	oceanic	hygrophytic	perennial	mat rough
<i>Rhynchostegium confertum</i> (Dicks.) Schimp.	mediterranean	hygro-mesophytic	perennial	mat rough
<i>Rhynchostegium megapolitanum</i> (Blandow ex F. Weber & D. Mohr) Schimp.	mediterranean	hygro-xerophytic	perennial	mat rough
<i>Rhynchostegium ripariooides</i> (Hedw.) Cardot	temperate	hygrophytic	perennial	mat smooth/aquatic trailing
<i>Riccia beyrichiana</i> Hampe ex Lehm.	oceanic	hygro-mesophytic	annual shuttle	solitary thalloid
<i>Riccia bifurca</i> Hoffm.	mediterranean	hygro-xerophytic	annual shuttle	solitary thalloid
<i>Riccia canaliculata</i> Hoffm.	temperate	hygro-mesophytic	annual shuttle	solitary thalloid
<i>Riccia crozalsii</i> Levier	oceanic	hygro-xerophytic	annual shuttle	solitary thalloid
<i>Riccia glauca</i> L.	mediterranean	hygrophytic	annual shuttle	solitary thalloid
<i>Riccia huebeneriana</i> Lindenb.	temperate	hygrophytic	annual shuttle	solitary thalloid
<i>Riccia michelii</i> Raddi	mediterranean	meso-xerophytic	annual shuttle	solitary thalloid
<i>Riccia nigrella</i> DC.	oceanic	hygro-xerophytic	annual shuttle	solitary thalloid
<i>Riccia sorocarpa</i> Bisch.	temperate	meso-xerophytic	annual shuttle	solitary thalloid
<i>Sciuro-hypnum populeum</i> (Hedw.) Ignatov & Huttunen	temperate	meso-xerophytic	perennial	mat rough

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<i>Scleropodium cespitans</i> (Wilson ex Müll. Hal.) L.F.Koch	oceanic	hygrophytic	perennial	mat smooth
<i>Scleropodium touretii</i> (Brid.) L.F.Koch	oceanic	xerophytic	perennial	mat rough
<i>Scorpidium revolvens</i> (Sw. ex anon.) Rubers	boreal-alpine	hygrophytic	perennial	weft
<i>Scorpiurium circinatum</i> (Bruch) M.Fleisch. & Loeske	oceanic	xerophytic	perennial	mat rough
<i>Scorpiurium deflexifolium</i> (Solms) M.Fleisch & Loeske	mediterranean	hygrophytic	perennial	mat rough
<i>Syntrichia laevipila</i> (Brid.)	oceanic	xerophytic	colonist	turf
<i>Syntrichia princeps</i> (De Not.) Mitt.	oceanic	meso-xerophytic	colonist	turf
<i>Syntrichia ruralis</i> var. <i>ruraliformis</i> (Besch.) Delogne	oceanic	xerophytic	colonist	turf
<i>Syntrichia virescens</i> (De Not.) Ochyra	temperate	xerophytic	colonist	turf
<i>Thamnobryum alopecurum</i> (Hedw.) Gangulee	oceanic	hygro-mesophytic	perennial	dendroid
<i>Timmiella barbuloides</i> (Brid.) Mönk.	mediterranean	xerophytic	short-lived shuttle	turf
<i>Tortella flavovirens</i> (Bruch) Broth.	oceanic	xerophytic	colonist	turf
<i>Tortella humilis</i> (Hedw.) Jenn.	mediterranean	xerophytic	colonist	tuft
<i>Tortella inflexa</i> (Bruch) Broth.	oceanic	meso-xerophytic	colonist	turf protonemal
<i>Tortella nitida</i> (Lindb.) Broth.	oceanic	xerophytic	perennial	cushion
<i>Tortella squarrosa</i> (Brid.) Limpr.	mediterranean	xerophytic	colonist	turf
<i>Tortella tortuosa</i> (Hedw.) Limpr.	boreal-alpine	meso-xerophytic	perennial	tuft
<i>Tortula caucasica</i> Broth.	temperate	mesophytic	annual shuttle	turf
<i>Tortula marginata</i> (Bruch & Schimp.) Spruce	oceanic	hygro-mesophytic	colonist	turf
<i>Tortula muralis</i> Hedw.	temperate	meso-xerophytic	colonist	turf
<i>Tortula solmsii</i> (Schimp.) Limpr.	oceanic	hygro-xerophytic	colonist	turf
<i>Tortula subulata</i> Hedw.	boreal-alpine	meso-xerophytic	colonist	tuft
<i>Tortula truncata</i> (Hedw.) Mitt.	temperate	meso-xerophytic	colonist	turf
<i>Trichostomum brachydontium</i> Bruch	mediterranean	meso-xerophytic	perennial	turf
<i>Trichostomum crispulum</i> Bruch	temperate	meso-xerophytic	colonist	turf

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**Small-scale pattern of bryoflora in Mediterranean temporary ponds – hints for monitoring
(Hydrobiologia)**

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Annex II

Frequency of the species in the three belts are expressed as percentage

Taxa	Outer	Central	Inner
Archidium alternifolium	39	61	0
Barbula convoluta	50	50	0
Barbula unguiculata	100	0	0
Bartramia pomiformis	100	0	0
Bartramia stricta	100	0	0
Brachythecium rutabulum	80	20	0
Brachytheciastrum velutinum	50	50	0
Brachythecium glareosum	100	0	0
Brachythecium rivulare	100	0	0
Brachythecium salebrosum	100	0	0
Bryum argenteum	50	50	0
Bryum elegans	33	67	0

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Taxa	Outer	Central	Inner
<i>Bryum dichotomum</i>	100	0	0
<i>Bryum gemmiparum</i>	100	0	0
<i>Bryum kunzei</i>	0	100	0
<i>Bryum radiculosum</i>	100	0	0
<i>Bryum turbinatum</i>	60	40	0
<i>Calliergonella cuspidata</i>	0	50	50
<i>Campylophorus pilifer</i>	100	0	0
<i>Cephaloziella calyculata</i>	33	67	0
<i>Cheilotrichia chloropus</i>	0	100	0
<i>Conocephalum conicum</i>	18	18	64
<i>Corsinia coriandrina</i>	0	0	100
<i>Dalytrichia mucronata</i>	67	33	0
<i>Dicranella howei</i>	100	0	0
<i>Dicranella humilis</i>	0	50	50
<i>Dicranella varia</i>	100	0	0
<i>Dicranum majus</i>	100	0	0
<i>Dicranum polysetum</i>	100	0	0
<i>Didymodon fallax</i>	100	0	0
<i>Didymodon insulanus</i>	83	17	0
<i>Didymodon luridus</i>	100	0	0

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Taxa	Outer	Central	Inner
<i>Didymodon rigidulus</i>	100	0	0
<i>Didymodon spadiceus</i>	100	0	0
<i>Didymodon vinealis</i>	40	60	0
<i>Distichium capillaceum</i>	100	0	0
<i>Encalypta ciliata</i>	100	0	0
<i>Ephemerum minutissimum</i>	100	0	0
<i>Ephemerum serratum</i>	0	100	0
<i>Epipterygium tozeri</i>	0	100	0
<i>Eurhynchiastrum pulchellum</i> var. <i>pulchellum</i>	50	50	0
<i>Fissidens crispus</i>	100	0	0
<i>Fissidens ovatifolius</i>	25	50	25
<i>Fissidens taxifolius</i>	33	33	33
<i>Fissidens viridulus</i>	50	0	50
<i>Fossombronia angulosa</i>	0	0	100
<i>Fossombronia caespitiformis</i>	8	75	17
<i>Fossombronia pusilla</i>	75	25	0
<i>Frullania dilatata</i>	100	0	0
<i>Funaria hygrometrica</i>	50	50	0
<i>Gongylanthus ericetorum</i>	33	0	67
<i>Grimmia anodon</i>	50	50	0

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Taxa	Outer	Central	Inner
<i>Grimmia laevigata</i>	44	44	11
<i>Grimmia lisae</i>	67	33	0
<i>Grimmia orbicularis</i>	33	67	0
<i>Grimmia pulvinata</i>	71	29	0
<i>Grimmia trichophylla</i>	67	0	33
<i>Homalothecium aureum</i>	100	0	0
<i>Homalothecium lutescens</i>	67	33	0
<i>Homalothecium sericeum</i>	67	33	0
<i>Hygroamblystegium tenax</i>	100	0	0
<i>Hypnum andoi</i>	100	0	0
<i>Hypnum cupressiforme</i> var. <i>resupinatum</i>	100	0	0
<i>Hypnum cupressiforme</i> var. <i>cupressiforme</i>	100	0	0
<i>Hypnum jutlandicum</i>	75	25	0
<i>Hypnum revolutum</i> var. <i>revolutum</i>	100	0	0
<i>Imbribryum mildeanum</i>	25	75	0
<i>Imbrybryum alpinum</i>	60	40	0
<i>Isothecium alopecuroides</i>	100	0	0
<i>Isothecium myusuroides</i>	86	14	0
<i>Kindbergia praelonga</i>	60	40	0
<i>Leptodictyum riparium</i>	0	100	0

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Taxa	Outer	Central	Inner
<i>Metzgeria coniugata</i>	100	0	0
<i>Microbryum davallianum</i>	0	0	100
<i>Microeurhynchium pumilum</i>	86	7	7
<i>Nogopterium gracile</i>	75	25	0
<i>Oncophorus virens</i>	0	100	0
<i>Orthotrichum tenellum</i>	100	0	0
<i>Oxyrrhynchium speciosum</i>	67	33	0
<i>Petalophyllum ralfsii</i>	0	0	100
<i>Phaeoceros laevis</i>	0	100	0
<i>Phytonotis arnelii</i>	33	67	0
<i>Phytonotis caespitosa</i>	100	0	0
<i>Plagiothecium denticulatum</i>	100	0	0
<i>Pogonatum nanum</i>	100	0	0
<i>Pohlia elongata</i>	100	0	0
<i>Pottiopsis caespitosa</i>	100	0	0
<i>Pseudocrossidium hornschuchianum</i>	100	0	0
<i>Pseudoscleropodium purum</i>	100	0	0
<i>Pseudotaxiphyllum elegans</i>	100	0	0
<i>Ptychostomum boreale</i>	33	67	0
<i>Ptychostomum capillare</i>	78	22	0

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Taxa	Outer	Central	Inner
<i>Ptychostomum compactum</i>	27	64	9
<i>Ptychostomum donianum</i>	67	33	0
<i>Ptychostomum imbricatulum</i>	100	0	0
<i>Ptychostomum pallens</i>	36	57	7
<i>Ptychostomum pseudotriquetrum</i>	33	44	22
<i>Ptychostomum rubens</i>	0	100	0
<i>Ptychostomum torquescens</i>	0	100	0
<i>Rhynchostegiella curviseta</i>	100	0	0
<i>Rhynchostegiella litorea</i>	50	50	0
<i>Rhynchostegium confertum</i>	73	27	0
<i>Rhynchostegium megapolitanum</i>	100	0	0
<i>Rhynchostegium riparioides</i>	67	33	0
<i>Riccia beyrichiana</i>	33	0	67
<i>Riccia bifurca</i>	0	50	50
<i>Riccia canaliculata</i>	0	0	100
<i>Riccia crozalsii</i>	17	0	83
<i>Riccia glauca</i>	0	25	75
<i>Riccia huebeneriana</i>	0	100	0
<i>Riccia micheli</i>	0	50	50
<i>Riccia nigrella</i>	0	0	100

Small-scale pattern of bryoflora in Mediterranean temporary ponds – hints for monitoring - Cogoni, Filippino, Marignani - Hydrobiologia - Annex II

Taxa	Outer	Central	Inner
<i>Riccia sorocarpa</i>	0	25	75
<i>Sciuro-hypnum populeum</i>	88	0	13
<i>Scleropodium cespitans</i>	33	33	33
<i>Scleropodium touretii</i>	100	0	0
<i>Scorpidium revolvens</i>	0	100	0
<i>Scorpiurium circinatum</i>	50	50	0
<i>Scorpiurium deflexifolium</i>	100	0	0
<i>Syntrichia laevipila</i>	67	33	0
<i>Syntrichia princeps</i>	50	50	0
<i>Syntrichia ruralis</i> var. <i>ruraliformis</i>	100	0	0
<i>Syntrichia virescens</i>	100	0	0
<i>Thamnobryum alopecurum</i>	100	0	0
<i>Timmiella barbuloides</i>	100	0	0
<i>Tortella flavovirens</i>	50	50	0
<i>Tortella humilis</i>	100	0	0
<i>Tortella inflexa</i>	50	50	0
<i>Tortella nitida</i>	100	0	0
<i>Tortella squarrosa</i>	100	0	0
<i>Tortella tortuosa</i>	100	0	0
<i>Tortula caucasica</i>	100	0	0

Small-scale pattern of bryoflora in Mediterranean temporary ponds – hints for monitoring - Cogoni, Filippino, Marignani - Hydrobiologia - Annex II

Taxa	Outer	Central	Inner
<i>Tortula marginata</i>	60	40	0
<i>Tortula muralis</i>	100	0	0
<i>Tortula solmsii</i>	86	14	0
<i>Tortula subulata</i>	80	20	0
<i>Tortula truncata</i>	100	0	0
<i>Trichostomum brachydontium</i>	0	100	0
<i>Trichostomum crispulum</i>	0	100	0

Chapter 3

Manuscript to be submitted

Diaspore bank of bryophytes in Mediterranean temporary ponds mirrors the aboveground bryodiversity

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Abstract

Bryophyte species in temporary ponds overcome periods of unfavorable weather conditions by building up a large diasporic bank. With this strategy, the species diversity of ponds is preserved and information on their dynamics and structure is retained. Little is known about the characteristics, spatial patterns and role of diasporic banks in the Mediterranean temporary ponds, which are regarded as priority habitats under protection. We analyzed the diasporic bank of selected ponds to i) identify which are the species that show a better fitness for survival and adaptation to these environments ii) investigate the relationship existing between the diasporic bank and the surface populations iii) understand if the distribution of bryophytes in the diasporic banks within the ponds follow a concentric zonation, as observed for the aboveground composition.

Results show that the diasporic bank is characterized by typically taxa present in Mediterranean temporary ponds, such as *Archidium alternifolium* and *Riccia* sp.

Diaspore banks in these ecosystems indicated a spatial heterogeneity that mirrored the aboveground population distribution, sorted along the moisture gradient by their tolerance to flooding. Diaspore banks play a key role in the vegetation recovery after summer drought. The acts of preserving the diaspore bank and ensuring a transient flooding regime are essential to protect the unique bryophyte communities of Mediterranean temporary ponds.

Keywords:

Sardinia; transient wetland; zonation; species composition; species richness

Introduction

The diaspore bank, defined as an aggregation of non germinated spore and/or asexual propagules (rhizoidal or protonemal gemmae, tubers, and resting buds on stem fragments), potentially capable of replacing aboveground bryoflora (Bakker, 1989), represents a fundamental component in the structure, succession and development of bryophyte communities in wetlands (Valk, 1981). Hence, the diaspore bank is a good starting point for studying the ecological condition of any water-linked ecosystem (Bisang, 1996, During & Lloret, 2001, Hébrard, 2001, Milberg & Persson, 1994, Sundberg & Rydin, 2000, Trabaud et al., 1997), like the temporary ponds.

Temporary ponds (or vernal pools) are ephemeral habitats, neither truly aquatic nor truly terrestrial: they are seasonal wetlands with annually alternating phases of flooding and drying in shallow depressions. In the Mediterranean region, temporary ponds show an elevated biodiversity due to a high spatio-temporal variability (i.e hydroperiod) accompanied by a small-scale zonation (Florencio et al., 2009; Van den Broeck et al., 2015; Casas et al., 1998; Rhazi et al., 2001; Bagella et al., 2009b; Caria et al., 2013; Cogoni et al., 2016; Carta, 2016; Lumbreras et al., 2016; Rodríguez-

Rodríguez et al., 2016) for these characteristics they are classified in Europe as a priority natural habitat (3170* Mediterranean temporary ponds) under the Habitats Directive 92/43/EEC (European Commission 1992).

In seed plants, seed dispersal is not always immediately followed by germination, leading to the development of soil propagule banks (Thompson et al., 1997). Although very little is known about dormancy in bryophytes to date (During, 1979; Miles & Longton, 1992), some species rely on large and persistent diaspore banks. In fact, the success of bryophytes in ephemeral habitat is largely due to their peculiar capacity to tolerate long periods of dehydration without undergoing physiological damage at cell level (Gignac, 2001; Glime, 2007) and, if exposed to severe environmental stressors, to their capacity to survive using the spores present in the diaspore bank. These banks are understood to play a particularly important role in the dynamics of populations of species adapted to habitats with great environmental fluctuations (During, 1997, 2001), being crucial for the maintenance and resilience of bryophytes species. Diaspore banks also have a significant impact on surface populations (Levin, 1990; McCue & Holtsford, 1998). They may function as a memory accumulating and storing propagules formed during different years and under potentially different environmental conditions (Cabin, 1996; Cabin et al., 1998). As dynamic systems, diaspore banks are coupled with surface populations and respond to environmental variations and changes in population parameters (Koch et al., 2003).

Compared to seed banks, the dynamics and role of the bryophyte diaspore bank have received less attention (During, 1997, 2001) and existing studies concentrate on forests (e.g. Kövendi-Jakó et al., 2016; Iglesias et al., 2015). This is the first study to focus on the role of diaspore banks of bryophytes in Mediterranean temporary ponds.

Aims of this study were to i) study the composition of diaspore bank of bryophytes in Mediterranean temporary ponds ii) develop a better understanding of the role of bryophyte diaspore banks in influencing the evolutionary potential of surface populations iii) identify in the diaspore

banks indicator species useful to confirm the small-scale spatial zonation, as observed in the surface populations.

Material and methods

Study area

The island of Sardinia (Italy) is included in the biodiversity hotspot of the Tyrrhenian islands (Médail & Quézel, 1999; Grillas et al., 2004) because of its rich and peculiar biodiversity, shaped by a long geological history (Médail & Quézel, 1997, 1999; Fenu et al., 2014) (Fig. 1). The territory of the island is mainly mountainous, with an average altitude of 334 m a.s.l. and a typical Mediterranean climate, with dry and hot summers and relatively rainy and mild winters (Canu et al., 2014). Bryoflora of Sardinia amounts to 498 entity (399 Bryophyta, 95 Marchantiophyta and 4 Anthocerophyta (Ros et al., 2007, 2013).

Temporary ponds are mainly spread on impermeable substrate in the large tablelands which divide the reliefs (Cogoni et al., 2016); the dominant vegetation of the tablelands is composed by neutro-acidophilic cork-oak (*Quercus suber* L.) woods mainly subjected to pastoral use and often converted to wooded pastures (*dehesa* landscape) and by edaphomesophilous holm oak (*Quercus ilex* L.) and cork oak (*Q. suber*) vegetation in the alluvial plains (Bacchetta et al., 2009).

In the past, temporary pools (*paule* or *pischina*) occupied large areas of the island, but during the last centuries, they were reclaimed for agricultural activities (Bagella & Caria, 2012).

In each pond, three belts can usually be identified: an inner belt (I) in the toe slope, a central belt (C) in the foot/back slope and an outer belt (O) in the upper slope position (Casas et al., 1998; Rhazi et al., 2001; Cogoni et al., 2016); the biodiversity of each belt is clearly diversified in terms of composition for vascular plants (Rhazi et al., 2006; Bagella et al., 2009b, 2010a),

macroinvertebrates, zooplankton (Boix et al., 2004; Florencio et al., 2009; Rouissi et al., 2014) and bryophytes (Cogoni et al., 2016).

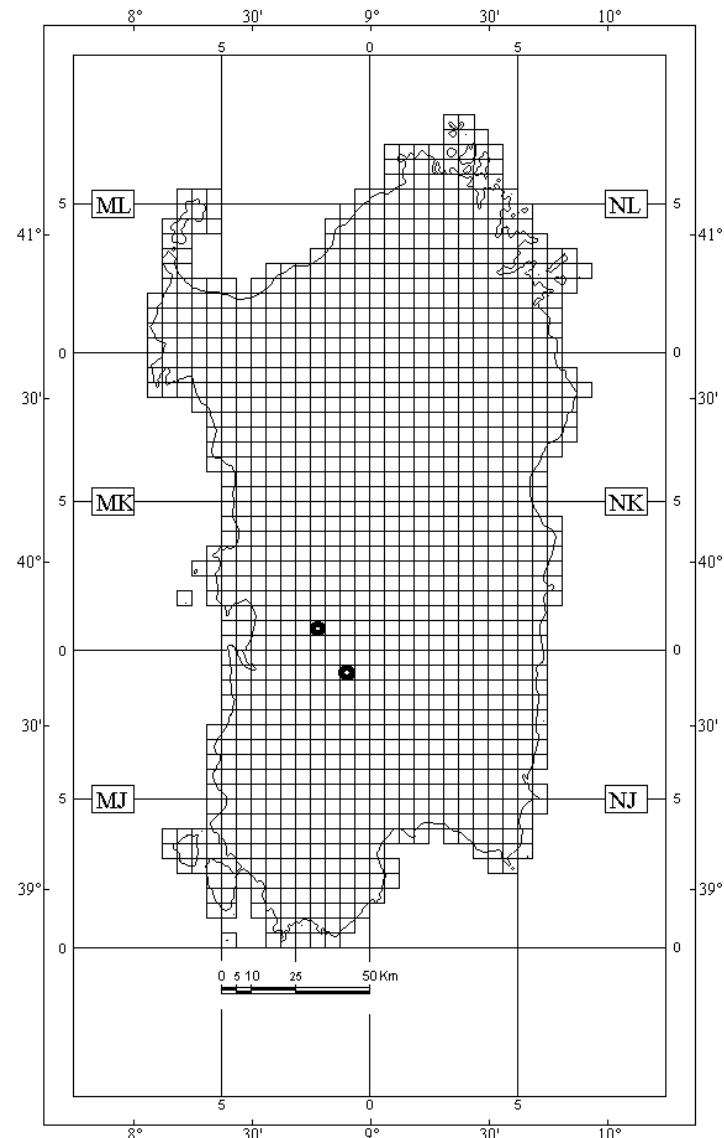


Fig 1. Location of the study sites in Sardinia, Italy.

Site selection and data gathering

The sites selected for this study are located in Southern Sardinia (Fig. 1), Italy (Usellus, OR) and Giara of Gesturi (VS). In the selected sites, we surveyed two ponds meeting the Habitats Directive's criteria for "Mediterranean temporary ponds, 3170*": *Paule S3* at the Giara of Gesturi site (Lat: 39,743588 Long: 8,986787, Datum WGS84, UTM 32N) covering 1300 sqm and *Paule Su Quaddu*

at the Usellus site (Lat: 39,492299 Long: 8,490425, Datum WGS84, UTM 32N) covering 2211 sqm. (Fig. 1).

The Giara of Gesturi is an elongated basaltic tableland whose the main axis is oriented NW-SE; it covers about 42 sqkm at an average altitude of 550 m asl. Its origin is connected with the last Miocene volcanic phenomena, with M.te Zeppara Manna (580 m) to the NW and M.te Zepparedda (609 m) to the SE representing the centres from which lava erupted. The water regime is determined by springs (*mitzas*), torrential water corse (*spendulas*) and, in the depressed areas, by numerous endorheic basins of varying size, known as “*pauli*”. Such pools of water, which in winter reach a depth of 30 to 40 cm, are favoured by the presence of clays deriving from *in situ* alteration (weathering) of the basaltic lithotypes (Cogoni et al., 2016).

Usellus, belonging to the Regional Park of M.te Arci, is located in a mainly hilly and mountainous area on the borders between the Giara of Gesturi and M.te Arci. M.te Arci is an isolated massif of volcanic origin, reaching a maximum height of 812 m. The mantle of M.te Arci stretches out on a skeleton of trachyte, constituted by basaltic lava castings, with the ancient lava vents of the Pliocene-Quaternary that rise up in the two necks (the Trebini). From the historical viewpoint, M.te Arci has always been considered of invaluable importance for its rich deposits of obsidian. Most of the surface of M.te Arci is covered by holm oak woods, but there are also cork oaks, downy oaks and large areas of Mediterranean brush.

Due to the fact that no previous studies were available, the two temporary ponds were sampled according to different sampling strategies: at *Paule Su Quaddu* (PSQ hereafter) we sampled four samples for each of the three belt (see Cogoni et al., 2006) according to the four cardinal points (4 sample x 3 belts = 12 samples). For *Paule S3* (PS3 hereafter), we decided to perform a simple random sampling, increasing the sampling effort (52 samples).

During the autumn (October 2013 for PSQ and October 2015 PS3) when the ponds were damp but not flooded, we sampled the ponds' surface with soil samples of 7 cm depth and 5 cm wide.

The samples were spread in the plates, for PSQ, preliminarily the samples were subdivided in seven portions, one for each centimeter of the sample (7 portions X 12 samples=84 plates). PS3 samples were not subdivided in portions (52 samples=52 plates).

These plates were arranged in an unheated greenhouse with natural light and samples were watered regularly from above with tap water, keeping them moist but free from standing water.

The samples were observed for 6 months and the emerged vascular plants were removed. During the spores germination the emerged bryophyte were identified and presence and absence data were recorded weekly. Bryophytes that could not be identified for the absence of spores were recorded as genus. When no new germination was observed for some weeks, all bryophytes were removed and the soil was then stirred in order to encourage germination of the remaining spores (Roberts, 1981). No more spores emerged after the six month period of observation.

For each pond we recorded the bryoflora on the surface, using the method adopted for the vascular flora surveys of Mediterranean temporary ponds (Bagella et al., 2009a, 2009b; Cogoni et al., 2016).

To record the presence of bryophytes in the ponds, we visited every pond several times a year (from October 2008 to October 2015) and listed all present taxa; we recorded presence/absence data.

For environmental variables we used available information existing in Bagella et al. (2010a; 2010b) and original data (Table 1).

We followed Ros et al. (2007, 2013) for nomenclature, for chorological elements Sérgio et al. (2014), for life forms Hill (2007) and Mägdefrau (1982), for life strategy and spore size Kürschner & Frey (2012). Humidity, the main limiting factor of this environment, has been assigned according to the categories proposed by Dierssen (2001).

Data analysis

Surface populations and diaspore bank species were classified into functional groups according to their chorology, life form, life strategy, humidity and spore size.

To compare the similarity among the aboveground and belowground flora, we used the Sørensen coefficient of similarity (Sørensen, 1948), calculated using the presence/absence data; we use the same approach to analyze the similarity between the two diaspore banks (Van der Valk & Davis, 1976; Kent & Coker, 1992). Results of the similarity are reported in percent.

To understand the pattern of distribution of bryophytes within the diaspore bank, we analyzed the distribution of the flora according to the zonation scheme proposed in Casas et al. (1998) and Rhazi et al. (2006).

In ecology an important quantitative criterion in identifying different communities is the presence and abundance of species in sampling units. However, not every species contributes equally to the identification of groups and key indicator species are usually used for community classification.

The most widely used techniques to determine indicator species rank is Dufrêne & Legendre (1997) Indicator Value Method (IVM). The IVM provides an explicit method to detect indicator species by identifying similarities (groups) in sample compositions (sites) (McGeoch and Chown, 1998). The method produces Indicator Values (IV) by combining species abundance in a particular group and the faithfulness of occurrence of a species in a particular group, in our case belts (McCune and Grace, 2002); Indicator Values (IV) ranges between 0 (no indication) and 1 (strong indication).

Analysis was performed using the R package *indicspecies* version 1.7.4 (De Cáceres & Legendre, 2009; De Cáceres et al., 2010, 2013).

Results

Aboveground bryoflora composition

In the aboveground bryoflora we collected 45 taxa at the PSQ and 15 at the PS3, for a total of surveyed 56 taxa (Table 1).

Regarding families among acrocarps, Pottiaceae and Bryaceae make up more than 20%. Among pleurocarps Brachytheciaceae (14%) prevail.

Chorological data show that the element Oceanic (38%) and Temperate (38%) prevails on the others chorological elements (Mediterranean 14% and Boreal-Alpine 11%).

Most of the species are meso-xerophytic (25%) xerophytic (21%), hygro-mesophytic (21%) and closely linked to the hydroperiod of the temporary ponds. A certain percentage of entities are strictly hygrophyt (16%). Regarding life-form analysis, there is a predominance of turf (39%). Concerning life strategy, most species are colonist (52%) such as the pioneer species *Bryum dichotomum* Hedw. and *Tortella squarrosa* (Brid.) Limpr. and perennial (21%) represented by species that tolerate fluctuations that characterize these environments (*Scleropodium cespitans* (Wilson ex Müll. Hal.) L.F.Koch and *Leptodictyum riparium* (Hedw.) Warnst.). Species with annual life strategy (11%) are represented especially by liverworts belonging to genus *Riccia* that do not tolerate water stress in the driest season (During, 1979).

Bryophytes are distributed in concentric belts according to their tolerance to floods (Cogoni et al., 2016).

Species	Usellus Paule Su Quaddu Latitude: 39,492299 Longitude: 8,490425 Altitude (m): 370 Substrate: basaltic Pond max depth (m): 0,30	Giara di Gesturi - Paule S3 Latitude: 39,784275 Longitude: 8,955465 Altitude (m): 590 Substrate: basaltic Pond max depth (m): 0,30	Corology	Humidity	Life strategy	Life form
<i>Archidium alternifolium</i> (Hedw.) Mitt.	+	-	oceanic	hygro-xerophytic	short-lived shuttle	turf
<i>Barbula convoluta</i> Hedw.	-	+	mediterranean	meso-xerophytic	colonist	turf
<i>Barbula unguiculata</i> Hedw.	-	-	temperate	hygro-xerophytic	colonist	turf
<i>Brachythecium rutabulum</i> (Hedw.) Schimp.	+	-	temperate	hygro-mesophytic	perennial	mat rough
<i>Brachytheciastrum velutinum</i> (Hedw.) Ignatov & Huttunen	+	-	temperate	hygro-mesophytic	colonist	mat rough
<i>Brachythecium glareosum</i> (Bruch ex Spruce) Schimp.	+	-	boreal-alpine	meso-xerophytic	perennial	mat rough
<i>Brachythecium rivulare</i> Schimp.	+	-	boreal-alpine	hygrophytic	perennial	mat rough
<i>Bryum dichotomum</i> Hedw.	+	-	temperate	meso-xerophytic	colonist	turf
<i>Bryum kunzei</i> Hornsch.	+	-	temperate	meso-xerophytic	colonist	tuft
<i>Bryum radiculosum</i> Brid.	+	-	oceanic	xerophytic	colonist	cushion
<i>Bryum turbinatum</i> (Hedw.) Turner	+	-	temperate	hygrophytic	long-lived shuttle	turf
<i>Cephaloziella calyculata</i> (Durieu & Mont.) Mull. Frib.	+	-	oceanic	hygro-xerophytic	colonist	solitary creeping
<i>Conocephalum conicum</i> (L.) Dumort.	-	+	boreal-alpine	hygrophytic	long-lived shuttle	mat thalloid
<i>Corsinia coriandrina</i> (Spreng.) Lindb.	+	-	oceanic	xerophytic	short-lived shuttle	mat
<i>Dicranella humilis</i> R.Ruthe	+	-	temperate	hygro-mesophytic	colonist	turf
<i>Dicranella varia</i> (Hedw.) Schimp	+	-	temperate	hygrophytic	colonist	turf
<i>Didymodon fallax</i> (Hedw.) R.H. Zander	+	-	mediterranean	hygro-xerophytic	colonist	turf
<i>Epipterygium tozeri</i> (Grev.) Lindb.	+	-	oceanic	hygro-mesophytic	colonist	turf scattered
<i>Fissidens crispus</i> Mont.	-	+	oceanic	meso-xerophytic	colonist	turf
<i>Fossombronia caespitiformis</i> De Not. ex Rabenh	+	-	oceanic	meso-xerophytic	annual shuttle	solitary creeping
<i>Fossombronia pusilla</i> (L.) Nees	+	-	oceanic	hygro-mesophytic	annual shuttle	solitary creeping
<i>Grimmia laevigata</i> (Brid.) Brid.	+	-	mediterranean	xerophytic	colonist	cushion
<i>Grimmia lisae</i> De Not.	+	-	mediterranean	hygro-mesophytic	colonist	turf
<i>Grimmia orbicularis</i> Bruch ex Wilson	+	-	mediterranean	xerophytic	colonist	cushion
<i>Grimmia pulvinata</i> (Hedw.) Sm.	+	-	temperate	xerophytic	colonist	cushion
<i>Grimmia trichophylla</i> Grev.	+	-	temperate	hygro-xerophytic	colonist	cushion
<i>Hypnum cupressiforme</i> var. <i>cupressiforme</i> Hedw.	+	-	temperate	meso-xerophytic	perennial	mat smooth
<i>Imbribryum mildeanum</i> (Jur.) J.R.Spence	+	+	oceanic	hygro-mesophytic	perennial	cushion

<i>Imbribryum alpinum</i> (Huds. ex With.) N.Pedersen	+	+	oceanic	hygro-mesophytic	colonist, perennial	turf
<i>Leptodictyum riparium</i> (Hedw.) Warnst.	+	-	temperate	hygrophytic	perennial	mat
<i>Microeurhynchium pumilum</i> (Wilson) Ignatov & Vanderp	-	+	oceanic	xerophytic	perennial	rough/aquatic trailing
<i>Oxyrrhynchium speciosum</i> (Brid.) Warnst.	-	+	temperate	hygro-mesophytic	short-lived shuttle	mat rough
<i>Ptychostomum boreale</i> (F.Weber & D.Mohr) Ochyra & Bednarek-Ochyra	-	+	temperate	hygro-xerophytic	colonist	turf
<i>Ptychostomum capillare</i> (Hedw.) Holyoak & N.Pedersen	+	-	temperate	meso-xerophytic	colonist	turf
<i>Ptychostomum compactum</i> Hornsch.	-	+	temperate	hygro-xerophytic	short-lived shuttle	turf
<i>Ptychostomum pallens</i> (Sw.) J.R.Spence	-	+	boreal-alpine	hygrophytic	short-lived shuttle	turf scattered
<i>Ptychostomum pseudotriquetrum</i> (Hedw.) J.R. Spence & H.P. Ramsay	+	-	temperate	hygrophytic	perennial	tuft
<i>Ptychostomum torquescens</i> (Bruch & Schimp.) Ros & Mazimpaka	+	-	mediterranean	hygro-xerophytic	long-lived shuttle	turf
<i>Riccia beyrichiana</i> Hampe ex Lehm.	+	-	oceanic	hygro-mesophytic	annual shuttle	solitary thalloid
<i>Riccia canaliculata</i> Hoffm.	+	-	temperate	hygro-mesophytic	annual shuttle	solitary thalloid
<i>Riccia crozalsii</i> Levier	+	-	oceanic	hygro-xerophytic	annual shuttle	solitary thalloid
<i>Riccia sorocarpa</i> Bisch.	+	-	temperate	meso-xerophytic	annual shuttle	solitary thalloid
<i>Scleropodium cespitans</i> (Wilson ex Müll. Hal.) L.F.Koch	+	-	oceanic	hygrophytic	perennial	mat smooth
<i>Scleropodium tourrettii</i> (Brid.) L.F.Koch	-	+	oceanic	xerophytic	perennial	mat rough
<i>Scorpidium revolvens</i> (Sw. ex anon.) Rubers	+	-	boreal-alpine	hygrophytic	perennial	weft
<i>Syntrichia laevipila</i> (Brid.)	+	-	oceanic	xerophytic	colonist	turf
<i>Syntrichia princeps</i> (De Not.) Mitt	+	-	oceanic	meso-xerophytic	colonist	turf
<i>Tortella flavovirens</i> (Bruch) Broth.	+	+	oceanic	xerophytic	colonist	turf
<i>Tortella humilis</i> (Hedw.) Jenn.	+	-	mediterranean	xerophytic	colonist	tuft
<i>Tortella inflexa</i> (Bruch) Broth.	+	-	oceanic	meso-xerophytic	colonist	turf protonemal
<i>Tortella nitida</i> (Lindb.) Broth.	+	-	oceanic	xerophytic	perennial	cushion
<i>Tortella squarrosa</i> (Brid.) Limpr.	+	-	mediterranean	xerophytic	colonist	turf
<i>Tortula marginata</i> (Bruch & Schimp.) Spruce	-	+	oceanic	hygro-mesophytic	colonist	turf
<i>Tortula muralis</i> Hedw.	+	-	temperate	meso-xerophytic	colonist	turf
<i>Tortula subulata</i> Hedw.	+	-	boreal-alpine	meso-xerophytic	colonist	tuft
<i>Tortula truncata</i> (Hedw.) Mitt.	+	-	temperate	meso-xerophytic	colonist	turf

Table 1. Characteristics and aboveground bryoflora of sites studied (Datum WGS84, UTM 32N); + presence - absence

Diaspore bank

In the 64 plates, the *ex situ* germination test of spores produced a total of 10 taxa: 8 at the PS3 and 9 at the PSQ; for some taxa, it was impossible to determine the species for sporophyte absence and, accordingly, attribute the chorological, ecological elements and spore size (Table 2). In the PSQ we observed the presence of diaspore in all seven levels, we found species at the sides of the sample portion, hence for the PS3, we decided not to divide the sediment in portions but homogenize the sample, in order to germination facilitate. For data processing, we have not considered the levels. The germination was high in both sites: for the PSQ reached 100% (12 out of 12 plates) while for PS3 was 96% (50 out of 52 plates). Taxa composition were similar between the two sites (Sørensen index = 45%).

The collected species belong to 10 different families. The most represented family is Bryaceae (38%). The most frequent taxa in the diaspore bank, showing a frequency higher than 20% in the samples are *Bryum* sp. and *Archidium alternifolium* (Hedw.) Mitt.

Chorological data show that the element Oceanic (58%) prevails on the others chorological elements. Most of the taxa germinated from sampled diaspore bank are hygro-mesophytic (50%) closely linked to the hydroperiod of the temporary ponds. Regarding life-form analysis, there is a predominance of turf (64%). Concerning life strategy, most species are colonist (39%). Species with annual life strategy (22%) are represented especially by liverworts belonging to genus *Riccia* that do not tolerate water stress in the driest season (During, 1979). For the spore size there is a predominance of > 25 µm spore diameter, such as *Archidium alternifolium* and *Riccia* sp.

The outer belt (O) shows the highest taxa frequency (62), the most abundant are hygro-mesophytic with colonist life strategy and turf life form.

The central belt (C) showing a frequency of 46 taxa. Abundant taxa identified as species are hygro-mesophytic and meso-xerophytic with colonist and short-lived annual shuttle life strategy. The major life form are turf.

No significative species were found for the outer and central belt, but *Archidium alternifolium* was found as a indicative species of a macrogroup which includes the outer and central belts (O+C) (indicator value = 0.659 p<0.01). The inner belt (I) is the most humid one, since it can be flooded even during springtime; we recognized a frequency of 30 taxa, with the *Riccia* as only taxa with significative values (indicator value = 0.707 p<0.001). In this belt we found a majority of annual shuttle life strategy, solitary thalloid life form and hygro-mesophytic.

We also found 8 taxa that indifferently live in the outer and in the central belt, such as *Archidium alternifolium*. *A. alternifolium* frequently is in the outer belt in the margins of temporary ponds but it is also a species that tolerates the typical hydroperiod of this habitat. This ecological feature can explain its presence in two belts characterized by diverse ecological conditions.

We found 5 taxa that indifferently live in the central and in the inner belt. A group of taxa (4) occurred in the outer and the inner belts, such as *Bryum* sp., that is predominantly an upland species, which was found on exposed rocks and boulders in the outer belt and in the internal belt during the most critical period.

A group of species (3) occurred in the three belts: they mainly are *Bryaceae*.

Species	<i>Paule Su Quaddu</i> (Usellus)	<i>Paule S3</i> (Giara of Gesturi)	Family	Corology	Humidity	Life strategy	Life forms	Spore diameter
<i>Archidium alternifolium</i>	+	+	Archidiaceae	Oceanic	hygro-xerophytic	short-lived shuttle	turf	125-260 µm
<i>Dicranella humilis</i>	+	+	Dicranaceae	Temperate	hygro-mesophytic	colonist	turf	< 25 µm
<i>Epipterygium tozeri</i>	+	-	Mielichhoferiaceae	Oceanic	hygro-mesophytic	colonist	turf scattered	< 25 µm
<i>Brachythecium rivulare</i>	+	-	Brachytheciaceae	Boreal-Alpine	hygrophytic	perennial	mat rough	< 25 µm
<i>Riccia</i> sp.	+	+	Ricciaceae	-	-	annual shuttle	solitary thalloid	> 25-200 µm
<i>Bryum</i> sp.	+	+	Bryaceae	-	-	-	-	-
<i>Fossombronia</i> sp.	+	+	Fossombroniaceae	Oceanic	-	annual shuttle	-	> 25-200 µm
<i>Ptychostomum</i> sp.	-	+	Bryaceae	-	-	-	-	-
<i>Tortula</i> sp.	+	+	Pottiaceae	-	-	-	-	-
<i>Tortella</i> sp.	+	+	Pottiaceae	-	-	-	-	-

Table 2. Species found in the diaspore bank; + presence - absence

Aboveground vegetation composition and comparison with diaspore banks

The similarity between species composition of the diaspore bank and the aboveground bryoflora is 25% for PSQ and 30% for PS3, a large percentage of species recorded in the aboveground bryoflora are absent in the diaspore bank, contrary almost all species present in the diaspore bank are present in the aboveground bryoflora (Table 3). In the case of PS3, the species present in diaspore bank, *Archidium alternifolium*, *Riccia* sp. and *Fossombronia* sp. are absent in the aboveground bryoflora. Contrary in the PSQ all the species present in the diaspore bank are present in the aboveground vegetation.

	PSQ	PS3
Species in spore bank	9	8
Aboveground species	45	15
Common species	9	5
Spore bank species not present in vegetation (%)	0	3
Vegetation species not present in spore bank (%)	80	66,6
Sørensen similarity value	25	30

Table 3. Comparison between the number of species composition in spore bank and the aboveground vegetation and Sørensen similarity values.

Discussion

This study aims to develop a better understanding of the role of bryophyte diaspore banks in the Mediterranean temporary ponds. The results of the current study support the hypothesis that the diaspore bank of bryophytes plays an important role in conserving typical bryophytes of these fragile environments. This role is an important new aspect of bryophyte population biology that has been neglected to date, probably because of technical difficulties and a general image of bryophyte spores being short-lived (Hock et al., 2008). The presence of a diaspore bank acting as a long-term reservoir of species has crucial implications for the evolution of populations because it has the

potential to buffer the effects linked to water-oscillation. The diaspore bank suggest what species will colonize after a disturbance or when environmental conditions become adequate for germination (Valk, 2006). The diaspore bank primarily provides a safeguard for years with particularly unfavourable site conditions and bridge gaps between favourable ad infrequent periods. At the same time, it lowers the risk of local extinction of the species, populations and communities (During, 1997). The presence of grazers, in the sampled ponds, in particular, the footprints left by the trampling of the cattle favor a continuous soil re-mixing, increasing the germination of the spores.

The diaspore bank, compared to the aboveground bryoflora, is very paucispecific, characterized by few typical taxa well represented inside the ponds. Pleurocarpous, perennial bryophytes present in the aboveground vegetation tend to be underrepresented in the diaspore bank, because they have low reproductive effort and long life span. By contrast, acrocarpous colonists, and annual and short-lived shuttle species are dominant in the soil diaspore bank.. These bryophyte species have persistent spores and high sexual, asexual reproductive effort and short life span (Kövendi-Jakó et al., 2016; Maciel-Silva et al., 2011).

In the pond PSQ all taxa founded in the diaspore bank are present in the aboveground bryoflora. Contrarily in the case of PS3, *Archidium alternifolium*, *Riccia* sp. and *Fossombronia* sp. are not recorded in aboveground vegetation, probably because environmental site conditions were not yet favorable for their growth. The paule PS3 is very small with a high frequency of flooding and the pond was still flooded at the sampling time, this did not allow to find the species. In fact, important factors are the sampling cover and timing, the latter becoming of special importance in temporary wetlands where several populations, with relative fast lifecycles, germinate from the same place but at different times according to the succession of flooded to dry phases (Zedler, 1987; Grillas et al., 2004). Additionally, there are others factors that explain the absence of species recorded in the diaspore bank from aboveground vegetation. As for the diaspore bank we can assume that some species may produce spores that do not germinate simultaneously but gradually. Thus, their

abundance in the vegetation will never be conspicuous (Roberts, 1981). As commonly occurring in transient wetlands, the species only present in the bank and absent from the vegetation attained an important fraction of the total ecosystem species pool, pointing out the role diasporic banks play as diversity reservoir (Hock et al., 2008).

In the ponds studied, few taxa making up an overwhelming proportion of the diasporic bank. The spore production strategy, adopted by these species to replenish the diasporic bank and overcome the disturbance, is characteristic of populations that perish seasonally and are replaced annually during the favorable season (During, 1997). In fact, dominant common pleurocarpous mosses are rare in the diasporic bank, while short-lived species that only are present aboveground some time after disturbance are more common in the diasporic bank. The diasporic bank of Mediterranean temporary ponds is characterized by typically taxa present in Mediterranean temporary ponds, such as *Archidium alternifolium* and *Riccia* sp., characterized by shuttle strategy. Species following this strategy achieve their establishment and survival by the large spores which are present in a diasporic bank. This strategy allows a fast re-establishment of the communities over large areas when natural conditions are favourable (Cogoni et al., 2016; During, 1997).

Archidium alternifolium species is characterized by few and large spores. The cleistocarpous capsule has a very short seta and is hidden among the leaves. The spores are spread when the capsule wall is ruptured by decomposition. This suggests that wind dispersal is not likely in *Archidium* and other vectors should may be important, e.g. water (Lönnel, 2011). The same could be said about the species in the thallose liverwort genus *Riccia* which also have few and large spores. *Riccia* sp. are characterized by capsules immersed in the thalli, which open irregularly by dehiscence. The large spores remain as spore tetrads and were usually released when the thallus is destroyed by decay of surrounding tissues. Large spores may have advantages in that tend to live longer and more resistant to environmental stress, however, large spores have strong tendencies for short-range dispersal (Schuster, 1984). A successful establishment of species and populations is strongly correlated with the dispersal of diaspores. In general, short-range dispersal and long-range

dispersal has been distinguished which are correlated with the size of the spores, their dormancy, drought- and frost resistance. The longevity of spores is supposed to increase with size (Crum, 2001) as a result of the larger amounts of storage material in larger spores (Miles & Longton, 1990; During, 1997). Species, such as *Dicranella humilis* R.Ruthe found in both ponds and *Epipterygium tozeri* (Grev.) Lindb., found in the PSQ, characterized by numerous and small spores are present in all belts. These species following the colonist life strategy: this strategy enables a rapide establishment, but the high number of capsules and spores obviously compensates the risk of high mortality of gametophytes by erosional effects after strong rainfall and thunderstorms or long lasting aridity.

We found only a species with perennial life strategy, *Brachythecium rivulare* Schimp. in the PSQ. Species with reproductive perennial strategies are characterized characterized by numerous and small spores, most frequent in long lasting habitat under more or less constant environmental conditions. Nevertheless, the species such as *Brachythecium rivulare* is able to tollerate envinronmental stress, it is a strong competitor under humid and shady conditions.

The seasonal disturbance created by flooding and drying together with the high abiotic heterogeneity occurring along the topographical gradient may explain the pattern of species distribution among the defined belts, with the outer belt of the ponds supporting spores of colonist species commonly intolerant to inundation and in the inner belt spores of annual shuttle species that achieve their establishment and survival by the large spores. The same pattern of species distribution was found in the aboveground bryoflora (Cogoni et al., 2016).

Archidium alternifolium is a significative species in the macrogroup including the outer and central belts, but the genus *Riccia* in the inner belt, both species are characterized by few and large spores, with short-range dispersal.

Large spores, with short-range dispersal, are thus distributed around those adults, this generates a positive feedback in which species germinate at their highest rates in areas where they are most common as adults, perpetuating the zonation of the diaspore bank.

The diasporic bank presented the unique characteristics ascribed to Mediterranean temporary ponds:

- i) large spore that serve as reservoir of bryodiversity ii) remarkable richness of annual species and
- iii) zonation along a moisture gradient (Grillas et al., 2004).

Conclusions

This contribution showed the reserve accumulated potential of the species present, having important function in maintenance of the communities in the pond. This occurs because the success of the diasporic bank depends on density of diaspores ready to germinate when environmental conditions for establishment are favorable (Carvalho & Favoretto, 1995). The diasporic bank is an important component of biological diversity acting mainly as storage and source of diaspores, which also indicate dynamics and patterns of maintenance of bryodiversity. Density and composition are essential attributes of a diasporic bank that shall be approached (Simpson et al., 1989), hence, the understanding of species composition of these soil can help us improve the conservation and restoration efforts.

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Conclusions

This research project offers new results on the neglected or underrated bryoflora of Mediterranean temporary ponds and represents a remarkable improvement in floristic, biogeographic and ecological knowledge of bryophytic component in these ephemeral habitats. The bryoflora of Mediterranean temporary ponds is a substantial component of biodiversity of these environments.

This study define a typical group of bryophytes adapted morphologically, physiologically, and reproductively to wetland hydroperiods. The Mediterranean temporary pond environment exerts a strong selection on the bryoflora, creating a species assemblage mainly influenced by local factors, namely water table oscillation and microhabitat type. The bryoflora is characterized by i) the high percentage of Oceanic species, associated with humid environmental conditions; ii) the principal presence of xerophytic and hygro-mesophytic bryophytes, indicative of variability attributed to a typical small-scale zonation; iii) the predominance of turf life form, linked to the ability of the species to tolerate extreme aridity during the most critical period; iv) the major presence of species with colonist life strategy, that play an important ecological role, preventing high substrate desiccation and encouraging the establishment of other species.

The Mediterranean temporary ponds offer peculiar habitats for the survival and conservation of rare and endangered species. These species are particularly important as a benchmark for future monitoring actions in freshwater environments and biodiversity.

Bryophytes are distributed in concentric belts (outer, central, inner) according to their tolerance to floods: we observed a gradient from the outer belt, mainly composed by colonist and perennial, to the more humid inner one where annual shuttle dominates. Most of the species were found in the outer belt, less influenced by hydroperiods and water-level fluctuation. The central and inner belts host fewer species and their presence is strictly linked to water-level oscillation.

The distribution analysis of bryophytes in the belts allows us to suggest the bryophytes as useful bioindicators of the state of conservation of Mediterranean temporary ponds, since the presence of indicator species in the different belts enables us to monitor over time the changes in the flood level. This is the first study to focus on the role of diaspore banks of bryophytes in Mediterranean temporary ponds. In this study, we conclude that the role of the bryophyte diaspore bank is important in the re generation and maintenance of the bryophyte vegetation in these ephemeral habitats. The diaspore banks dynamics are driven by species traits and microhabitat characteristics, that contribute to fast (re)establishment of species when natural conditions are favourable. The diaspore bank of Mediterranean temporary ponds is characterized by typically taxa present in Mediterranean temporary ponds, that achieve their establishment and survival by the large spores which are present in the diaspore bank. Large spores may have advantages in that tend to live longer and more resistant to environmental stress. The diaspore bank is formed by a small group of species in particular short-lived mosses (colonists, short-lived shuttles) that dominate in the diaspore bank. In the diaspore bank we found the same pattern distribution present in the aboveground bryoflora. Large spores, with short-range dispersal, are thus distributed around those adults and germinate in areas where they are most common as adults, perpetuating the zonation of the diaspore bank. The bryoflora of Mediterranean temporary ponds is diversified and rich in rare and endangered species. Nevertheless, the information gathered on the bryophyte component is very scarce and fragmentary, despite its important applications. This study contributed to the knowledge on the species living in Mediterranean temporary ponds, their ecology and distribution at local and regional scale, information that are essential to complete the description of this habitat of European concern and propose effective conservation actions to preserve all its biotic components.