

Fluvial niche reconnaissance of noteworthy bryophytes in Portugal

Cristiana VIEIRA^{a*}, Helena HESPANHOL^a, César GARCIA^b,
Manuela SIM-SIM^{b,c} & Cecília SÉRGIO^b

^a*Centro de Investigação em Biodiversidade e Recursos Genéticos (CIBIO)
& Rede de Investigação em Biodiversidade e Biologia Evolutiva (InBIO),
Vairão, Portugal*

^b*CE3C – Centre for Ecology, Evolution and Environmental Changes,
Museu Nacional de História Natural e da Ciência, Universidade de Lisboa,
1250-102 Lisboa, Portugal*

^c*Universidade de Lisboa, Faculdade de Ciências de Lisboa, Departamento
de Biologia Vegetal, 1749-016 Lisboa, Portugal*

Abstract – The new data here presented allow the reinforcement of the overall knowledge about distribution patterns and niche definition of some aquatic and semi-aquatic bryophytes of chorological and conservation interest (mosses: *Cyclodictyon laetevirens*, *Dendrocryphaea lamyana*, *Fissidens fontanus*, *Hookeria lucens*, *Orthotrichum rivulare*, *Racomitrium hespericum*, *Racomitrium lamprocarpum* and *Schistidium rivulare*; hepatics *Barbilophozia barbata*, *Pallavicinia lyellii*, *Porella pinnata* and *Radula holtii*). These species, considered rather vulnerable to hydrologic changes and with a threat status, were re-evaluated recently in the new Portuguese Atlas and Red Data Book and had extensive updates in their total distribution due to more recent efforts in herbarium revision and field studies in Portugal. As a result, we bring their distribution and auto-ecology up to date based on older records and new collections, showing the importance of systematic and extensive studies to narrow the definition of niches of taxa living in the ecotone amongst the aquatic and terrestrial environments. In the future, the improved field recognition of these taxa primary and secondary microhabitats and the protection of the mesohabitats with which they are associated will be the crucial steps for achieving their conservation at national level.

Distribution / Conservation / Mesohabitat / Microhabitat

Résumé – Les nouvelles données présentées ici complètent la connaissance sur les modes de distribution et la définition de niche de certains bryophytes aquatiques et semi-aquatiques, de leur chorologie et de la nécessité de leur conservation (mousses: *Cyclodictyon laetevirens*, *Dendrocryphaea lamyana*, *Fissidens fontanus*, *Hookeria lucens*, *Orthotrichum rivulare*, *Racomitrium hespericum*, *Racomitrium lamprocarpum* et *Schistidium rivulare*; hépatiques: *Barbilophozia barbata*, *Pallavicinia lyellii*, *Porella pinnata* et *Radula holtii*). Ces espèces, plutôt considérées comme vulnérables aux changements hydrologiques et avec un statut d'espèce menacée, ont été réévaluées récemment dans la nouvelle édition de l'Atlas et du Livre Rouge des Bryophytes Portugaises; grâce à aux récents efforts dans la révision des spécimens d'herbier et aux récoltes récentes, la distribution globale des bryophytes au Portugal a été précisée. Aussi, nous donnons ici une mise à jour de leur distribution et leur auto-écologie sur la base des plus anciens documents et des nouvelles collections, montrant

* Corresponding author: cristianavieir@gmail.com

alors l'importance des études systématiques et étendues pour restreindre la définition de niche des taxons vivants dans l'écotone dans les milieux aquatiques et terrestres. Dans l'avenir, la reconnaissance de des micro-habitats primaires et secondaires de ces taxons et la protection des mésohabitats avec lesquels ils sont associés seront les étapes cruciales pour la réalisation de leur conservation au niveau national.

Distribution / Conservation / Mésohabitat / Microhabitat

INTRODUCTION

Rare species are often defined as having low local abundance, small range size, and/or high habitat specificity (Rabinowitz, 1981). In fact, despite many other factors important in determining bryophyte occurrence at different scales (Hedderson, 1992; Hallingbäck, 2002; Söderström & During, 2005; Hylander & Dynesius, 2006; Pharo & Zartman, 2007), the rarity of bryophytes at a regional landscape level is, in part, a function of the mesohabitat (land use, i.e., the surrounding natural or semi-natural vegetation formations or artificial land uses) and suitable microhabitat (substrate) quality and frequency (Vitt & Belland, 1997).

Currently, global or national accurate databases on the mesohabitat and microhabitat preferences of aquatic and semi-aquatic species are not so common and, in many text books or floras, their niche is summarily pointed as “in the river margins”, “in the stones of rivers”, “in fountains” or “in mountain rivulets”, with no more information on substrate preference, occurrence patterns in the transversal or longitudinal axis of a watercourse, mesohabitat context or secondary habitats. Moreover, whenever sampling presents added difficulties, and even swimming or boats are not viable options, these taxa occurrence patterns remain widely underestimated. Fluvial niches of bryophytes are quite specialized since each is defined by an intricate interaction between hydrologic and geomorphologic parameters, margins and catchment land use and disturbance events (Suren & Ormerod, 1998; Tremp *et al.*, 2012; Vieira *et al.*, 2012a).

Recently, sampling efforts in Portugal generated improved databases and scattered publications on some fluvial Portuguese taxa at regional or national scales (Vieira *et al.*, 2004a, 2004b, 2005, 2007, 2012b, 2012c; Sérgio *et al.*, 2007a, 2007b, 2007c, 2007d, 2010, 2011; Garcia *et al.*, 2010), greatly contributing to more precise threat assessments in the Portuguese Bryophyte Red Book (Sérgio *et al.*, 2013), when compared with other editions of previous Portuguese and Iberian Red Lists (Sérgio *et al.*, 1994, 2006).

In this context of knowledge strengthening, we aimed at completing national cartography and compile niche information of a selection of taxa considered rather vulnerable to hydrologic changes and threatened in several European countries, and for which a scattered and conceptually weak niche definition was available in the Southern European contexts.

METHODS

Fluvial characterization

The Portuguese climate is a result of the interplay between the influence of the Atlantic Ocean and the Mediterranean Sea, with a predominance of Mediterranean territories. Typically there are mild winters but hot and dry summers. Northern rivers

are at a mean altitude of 506 ± 300 m above sea level (a.s.l.), have a small catchment area (25 ± 17 km²), an annual precipitation of 1944 ± 379 mm and an annual temperature of $11.9 \pm 1.5^\circ\text{C}$. Southern rivers are located at lower altitudes (< 190 m a.s.l.), have variable sizes of catchment area (up to 388.3 ± 1080.5 km²), a maximum annual precipitation of 743 ± 85 mm and all annual temperature above 15°C (Agência Portuguesa do Ambiente, 2008). Portuguese rivers are characterized by heterogeneous fluvial conditions depending on the underlying geology: steep, headwater streams dominated by siliceous (granite or schist) bedrock and boulders, fast permanent currents and sequences of pools, riffles, waterfalls and rapids mostly in the northern region; and lowland temporary calcareous segments with meanders and sediment deposits in the southern region (INAG, 2008).

At a national context, springs, flushes and rivers are important habitats for bryophytes but the relatively small area of occupancy of fluvial landscapes multiplies their vulnerability to destruction and disturbance, caused by drainage, losses or alterations to forestry and agriculture management solutions, heavy grazing, water pollution (both acidification and nutrient enrichment), riverbank erosion and water flow management (INAG, 2008; Feio *et al.*, 2014).

Studied taxa

Due to important paleoclimatic events that constrained taxa distribution, a mixture of Atlantic, Boreal and Mediterranean taxa, as well as some endemics, relicts and disjunctions (Allorge, 1947; Sérgio, 1990, 2001a) can be found in watercourses, along with several species considered threatened at the national level (Sérgio *et al.*, 2013). Although the mainland Portuguese territory corresponds to the limit of distribution of many of these taxa, intensive studies of Portuguese fluvial bryophyte communities were initiated only in the XXI century due to academic studies (Vieira *et al.*, 2004b, 2005, 2007, 2011) or surveys of impact studies on various watersheds due to the implementation of Water Framework Directive. In this context, we selected twelve taxa that occur in microhabitats of Portuguese watercourses to focus our analysis on: two Austral disjuncts (*Cyclodictyon laetevirens* (Hook. & Tayl.) Mitt. and *Racomitrium lamprocarpum* (Müll. Hal.) A. Jaeger), two Atlantic European endemics (*Dendrocryphaea lamyana* (Mont.) P. Rao and *Radula holtii* Spruce), an Iberian endemic (*Racomitrium hespericum* Sérgio, J. Muñoz & Ochyra), an European sub-Mediterranean taxon (*Fissidens fontanus* (Bach. Pyl.) Steud.), two Holarctic taxa (*Hookeria lucens* (Hedw.) Sm. and *Orthotrichum rivulare* Turner), a sub-Boreal species (*Barbilophozia barbata* (Schmidel ex Schreb.) Loeske) and three taxa with restricted distribution worlwlde (wide-boreal: *Schistidium rivulare* (Brid.) Podp.; southern-Temperate and sub-Oceanic: *Pallavicinia lyellii* (Hook.) Carruth.; southern-Temperate and Oceanic: *Porella pinnata* L.). Their nomenclature follows Ros *et al.* (2007) for hepatics and Ros *et al.* (2013) for mosses and their chorological classification follows Düll (1983, 1984, 1985).

Sampling and data recollection approach

The ecological and chorological information presented here represents a gathering of multiple sources: (1) literature data (corresponding to less than 10% of the total mapped points); (2) herbaria revisions of specimens collected until 2013 (corresponding to more than 90% of all the mapped points, of vouchers of COI, LISU, and PO, since INA did not have specimens of the studied taxa); and,

paradoxically, (3) scattered field collections until 2014 from unexplored areas surveyed for dams construction impact assessment studies, which revealed many bryophytic populations that will soon be destroyed to some extent.

All the literature references (including regional catalogues, see Appendix 1), bibliographic records and cartographic databases published for the Iberian Peninsula (Casas *et al.*, 1992, 1996) were consulted. Moreover, duplicates of records corresponding to the same locality (published by different authors in successive dates) were evaluated and confirmed if they were duplicated or erroneous references, and only the primary citation kept. For each taxon the number of specimens supporting each UTM reference, together with their geographical coordinates, cited in results are listed in Appendix 1. In fact, for the twelve taxa studied, we compiled herbarium and cartographic records in the total number of 454 UTM records from which 420 are sustained with herbarium vouchers (from LISU, PO and to a lesser extent from COI) revised by us and 34 correspond to records we could not find the voucher supporting the published cartography/map/bibliographic reference (see Appendix 1, cf. Supplementary Materials: doi/10.7872/cryb/v37.iss1.2016.Suppl.Mat.1).

Maps with the presently known distribution of each taxon, within the surveyed Portuguese provinces (Fig. 1), are presented in maps (Figs 2-13) and according to UTM grids (1 × 1 km) (Appendix 1, cf. Supplementary Materials: doi/10.7872/cryb/v37.iss1.2016.Suppl.Mat.1). Geographical distribution is presented according to three different periods to highlight the importance of sampling efforts directed to fluvial microhabitats to generate data on these selected species: references or samples before 1950 (since the 19th century was when the first collectors and bryologists began their studies in Portugal), between 1950 to 2000 (the period of scattered collections not directed towards fluvial habitats) and from 2001 to 2014 (the period when a Ph.D. specific for the study of fluvial bryophytes (Vieira, 2008) and many impact assessment studies were performed in fluvial habitats in Portugal (e.g. Tua, Sabor and Tâmega rivers)). We also present some considerations about the international and national distribution trends of taxa, evidencing the originality of the chorological data here presented.



Fig. 1. Portuguese continental territory (study area) and its geographical location and provinces: (Mi) Minho; (TM) Trás-os-Montes e Alto Douro; (DL) Douro Litoral; (BA) Beira Alta; (BL) Beira Litoral; (BB) Beira Baixa; (E) Estremadura; (R) Ribatejo; (AAI) Alto Alentejo; (BAI) Baixo Alentejo; (Ag) Algarve.

Autoecology classification

Since no common sampling methodology was used in the previously referred sampling approaches and periods, we compiled all the ecological information available for each herbarium specimen and, as part of it enlarges the niche definition in southern Europe, we comment on microhabitat and mesohabitat patterns to reinforce the originality of some ecological findings in respect to (1) the type of watercourse segment in the longitudinal axis of a river, (2) the fluvial microhabitat in relation to the water velocity and local slope, (3) the shading, as the amount of channel with no direct light incidence, (4) the nature of substrate, (5) and the range of altitude where populations were found. The natural habitats in the river margins where taxa were found were also registered when possible and presented as a summary of information to be recognized of additional importance (European Natural and Semi-natural Habitats), coded and designated according to Habitats Directive (ALFA, 2004).

RESULTS

Taxa distribution data and habitats

Cyclodictyon laetevirens (Hook. & Tayl.) Mitt.

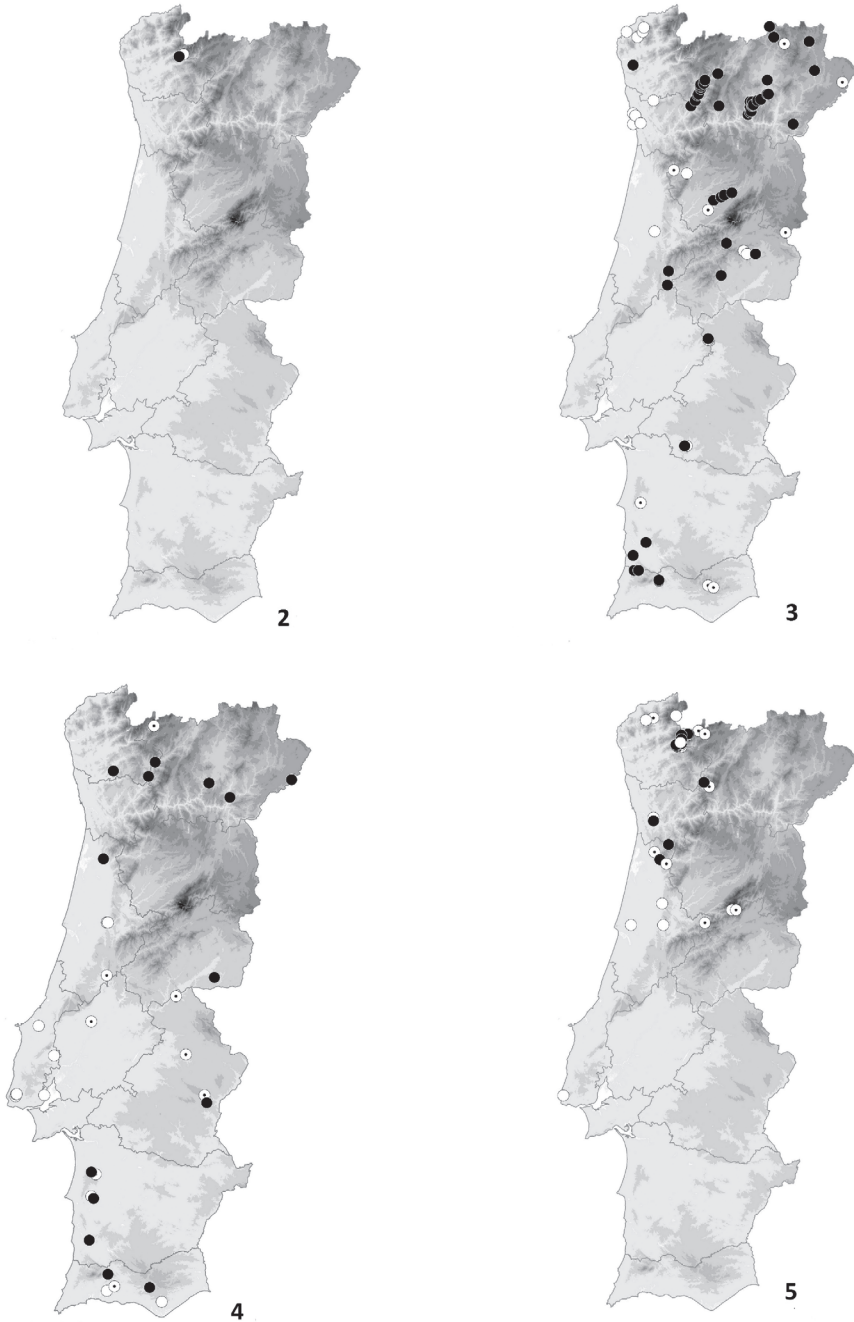
This bryophyte is an element with a disjunctive bipolar distribution, between the regions of Guinea Gulf, Madagascar, Mozambique and Cape region in South Africa (O'Shea *et al.*, 1997), and the hyper-Oceanic fringes of Europe mainland Europe, such as in Ireland, South of England, France, North of Spain and Portugal, and Atlantic islands of Azores, Madeira and the Canary Islands (Hedenäs, 1992). In mainland Europe it is considered a nationally rare species in several countries and a priority species for conservation (Preston, 2006), but, although it is more frequent in Azores and Madeira, in the Canary Islands it is critically endangered (Sérgio, 1990; González-Mancebo *et al.*, 2012; Sim-Sim *et al.*, 2014). Considered vulnerable in the Iberian Peninsula (Sérgio *et al.*, 2006) and endangered in Spain (Brugués & González-Mancebo, 2012), it is only known for five 10 km² UTM squares in the Iberian Peninsula (Casas *et al.*, 1992), one of which is located in continental Portugal, within Peneda-Gerês National Park, where it was seen in two different times, one hundred years apart (Machado, 1920) (Fig. 2). In Portugal this species is considered critically endangered – CR B2ab (ii, iii, iv) in the newest Portuguese Red Data Book (Sérgio *et al.*, 2013), because of its single presently known occurrence. This corresponds to a highly sensitive small population in the margins of a permanent spring waterfall on the brink of a regional road, where it occurs next to other conservation interest taxa such as *Bryoerythrophyllum campylocarpum* (Müll. Hal.) H.A. Crum, *Dumortiera hirsuta* (Sw.) Nees, *Radula holtii* and *Saccogyna viticulosa* (L.) Dumort. Like some populations in the British Isles, the Portuguese population occurs in a permanently wet dripping zone of a waterfall, in zones with 70-100% of shading, growing over granite surfaces, at approximately 500 m of altitude, in a watercourse surrounded by oak woods in a high rainfall region. In total, two records were listed in Portugal for this taxon, which are supported by PO herbarium vouchers (Appendix 1, cf. Supplementary Materials: doi/10.7872/cryb/v37.iss1.2016.Suppl.Mat.1).

***Dendrocryphaea lamyana* (Mont.) P. Rao**

It is considered a threatened species throughout its European range, showing an Atlantic to sub-Atlantic distribution restricted to United Kingdom (Plantlife International, 2003), scattered localities in France, Italy, Spain and Portugal (Lara *et al.*, 2006) and a few scattered ancient records in continental Europe that have proved doubtful (Charissou & Leblond, in press). In Portugal, this taxon is more frequently found in lower altitude valleys and, until 1992, this species was reported from eleven 10 km² UTM squares in the Iberian Peninsula (Casas *et al.*, 1992) being, therefore, considered rare in the first Portuguese Red List (Sérgio *et al.*, 1994). However, and after intensive river surveys since 2000, it was proved to be three times more frequent than previously assumed, and new to Alto Alentejo region, occurring in a total of 71 UTM squares (1 km²) all over mainland Portugal (Fig. 3). In the last Portuguese Red List (Sérgio *et al.*, 2013) it was considered of least concern (LC) due to the presently known national abundant representation. Nevertheless, it seems that most of the recently found localities are typically in the continental part of the country, away from the anthropogenic-impacted rivers of the coastal zone, where the most ancient observations of this species were registered but currently could not be found mostly due to pollution and habitat alteration. Most of the Portuguese populations of this taxon were found on lowland river segments with permanent flow (3th to 5th order rivers), in microhabitats submerged by seasonal to extremely high discharge of moorh or turbulent flows, in zones with 30-80% of shading, growing over schist, granite or tree roots and trunks of *Alnus glutinosa* (L.) Gaertn., *Fraxinus* spp. or *Salix* spp., up to 600 m of altitude. In total, 71 records were listed in Portugal for this taxon, of which 65 are supported by LISU or PO herbarium vouchers (Appendix 1, cf. Supplementary Materials: doi/10.7872/cryb/v37.iss1.2016.Suppl.Mat.1).

***Fissidens fontanus* (Bach. Pyl.) Steud.**

In mainland Europe, it was reported from Austria, Belgium, Britain, Czech Republic, Estonia, France, Germany, Italy, Poland, Romania, Slovakia, Spain, and Switzerland, being considered a sub-Mediterranean species (Sérgio *et al.*, 2010). Its distribution across Europe indicates that it is probably a widespread but infrequent species. Considered a rare or threatened moss in several other European countries, including North and Central Europe and Mediterranean areas (Sérgio *et al.*, 2010), it was considered rare in the first Portuguese Red List (Sérgio *et al.*, 1994), since, at the time, from the 10 localities recognized in Portugal, only three were post-1960. After the update on its distribution, ecology and conservation (Sérgio *et al.*, 2010), its known distribution was enlarged with data of another eleven localities (Fig. 4) and it is now considered of least concern (LC) in the national territory (Sérgio *et al.*, 2013). Additionally, these field expeditions demonstrated a more comprehensive distribution towards the Temperate territories away from its wider Mediterranean distribution. Portuguese populations of this taxon were found either on permanent springs (aquifer resurgences or artificial tanks), or in lowland river segments with permanent flow (3th to 5th order rivers), in the zones permanently to seasonally submerged by smooth flow, in zones with 50-100% of shading, growing over schist, granite or tree roots and trunks of undesigned riparian species (older herbarium material), up to 400 m of altitude, in watercourses of plain to montane levels. Many of the newly found populations are located in the northern rivers, where it was found both in natural and man-made aquatic habitats, such as tanks and fountains. Although it was recorded in relatively polluted river stretches, in such sites its populations



Figs 2-5. Distribution of the mentioned taxa within the Portuguese continental territory. **2.** *Cyclodictyon laetevirens*. **3.** *Dendrocryphaea lamyana*. **4.** *Fissidens fontanus*. **5.** *Hookeria lucens*. Different symbols in the maps correspond to three periods of collection: white circle – before 1950; white circle with dot – 1950 to 2000; black circle – 2001-2014.

were weaker and probably correspond to populations in regression that endure the increasing levels of eutrophication and pollution. In total, 34 records were listed in Portugal for this taxon, of which 33 are supported by LISU or PO herbarium vouchers (Appendix 1, cf. Supplementary Materials: doi/10.7872/cryb/v37.iss1.2016.Suppl.Mat.1).

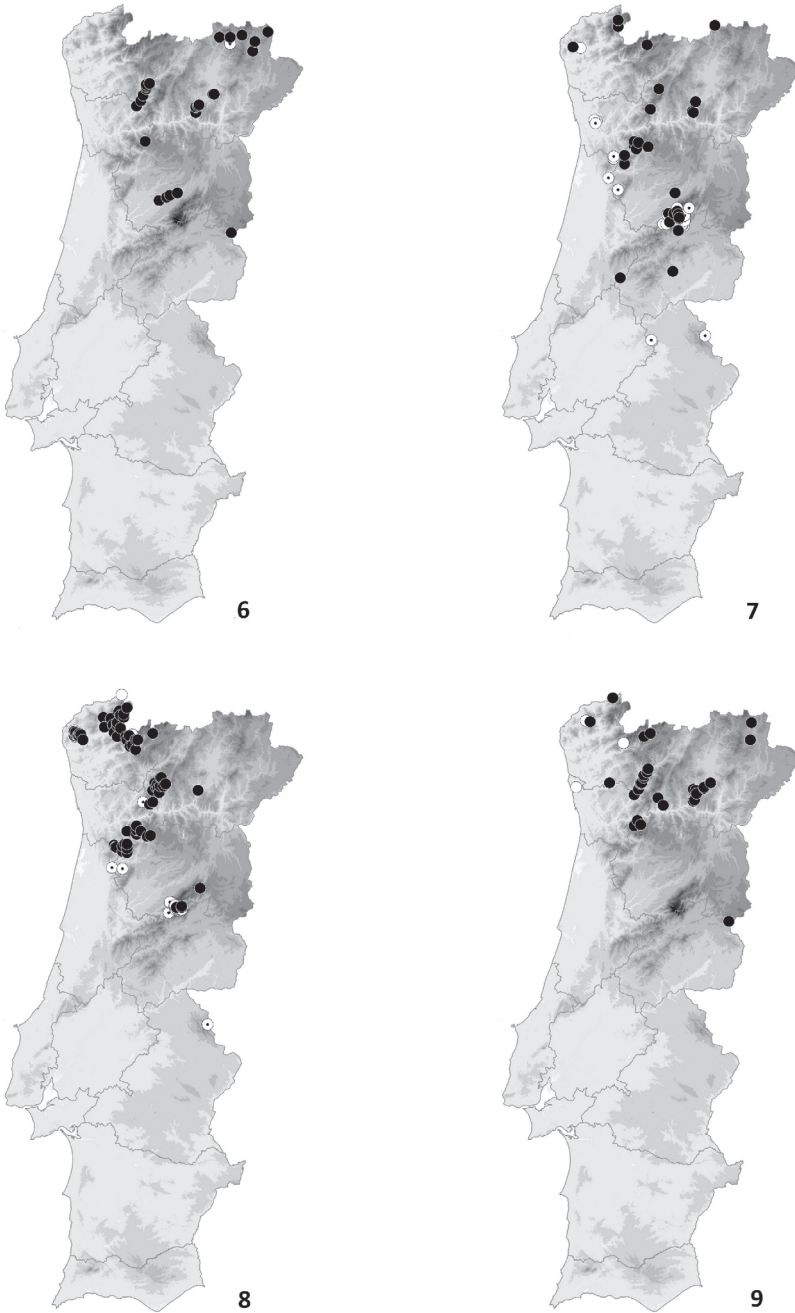
Hookeria lucens (Hedw.) Sm.

With a wide Holarctic and Macaronesian distribution (Dierssen, 2001), this sub-Oceanic Temperate species can become restricted to fewer localities in some southern European drier areas, despite being relatively more common in Temperate zones and in the Atlantic islands of Madeira and Azores (Hedenäs, 1992). It was one of the first species of bryophyte recorded in Portugal, with the first samples taken in Gerês by Brotero, Link and Welwitsch (XVIIIth and XIXth centuries) (Machado, 1917). Classically known from localities within the Peneda-Gerês National Park, this species was recently found in other coastal regions. Up until 1992 the species was recorded in twelve 10 km² UTM Portuguese squares (Casas *et al.*, 1992), and after 2000 it was found in 15 localities, some in Beira Litoral, Beira Alta, Trás-os-Montes and Estremadura. Since the publication of the new Portuguese Red List (Sérgio *et al.*, 2013), two new localities were found, all adjacent to the previously known occurrences, emphasizing its Atlantic distribution (Fig. 5). This species is consistently found in margins of mountain watercourses with temporary to permanent flow or in dripping zones of waterfalls or permanent springs, in deeply shaded zones (70-100%), growing over schist, granite or soil, in locations from the sea level to 1993 m of altitude. Although recently new UTM squares were discovered, this species preference for watercourses running through well-preserved autochthonous forests will probably determine its future decline, as the rareness of these forests increases in the national territory. In total, 41 records were listed in Portugal for this taxon, of which 34 are supported by LISU or PO herbarium vouchers (Appendix 1, cf. Supplementary Materials: doi/10.7872/cryb/v37.iss1.2016.Suppl.Mat.1).

Orthotrichum rivulare Turner

A taxon with a typical disjunct distribution between Europe and North America (Dierssen, 2001). It is relatively frequent in the Iberian Peninsula and, until recently, the majority of known localities and most of its extent of distribution have been reported in Spanish territories (Lara *et al.*, 2006). Considered a very rare taxon in Portugal until 2006 (Sérgio *et al.*, 2006) it was classically mentioned only in one locality (in Trás-os-Montes e Alto Douro). Since 2000 we specifically focused our attention in searching for this species in its riparian habitat, with fruitful results for 25 new localities in the valleys of the Tua, Tâmega and Mondego rivers (Fig. 6). These new occurrences in Portugal enlarge its Atlantic and austral distribution limits in the Iberian Peninsula. Since the publication of the new Portuguese Red List where it was considered “near threatened” (Sérgio *et al.*, 2013), five new localities were found, reinforcing its northern continental distribution.

Portuguese populations of this taxon were found on lowland river segments with permanent flow (3th to 5th order rivers), in microhabitats seasonally submerged by smooth or turbulent flow, in zones with 30-80% of shading, growing over granite or tree roots and trunks (*Fraxinus* spp., *Populus* spp.), from 100 to 1150 m of altitude. In total, 26 records were listed in Portugal for this taxon, all supported by LISU or PO herbarium vouchers (Appendix 1, cf. Supplementary Materials: doi/10.7872/cryb/v37.iss1.2016.Suppl.Mat.1).



Figs 6-9. Distribution of the mentioned taxa within the Portuguese continental territory. 6. *Orthotrichum rivulare*. 7. *Racomitrium hespericum*. 8. *Racomitrium lamprocarpum*. 9. *Schistidium rivulare*. Different symbols in the maps correspond to three periods of collection: white circle – before 1950; white circle with dot – 1950 to 2000; black circle – 2001-2014.

Racomitrium hespericum Sérgio, J. Muñoz & Ochyra

This Iberian endemic species described by Sérgio *et al.* (1995) was first collected in Portugal by Newton in 1879, in the Douro Litoral region, and after its description, herbarium and field samples were mostly found in northern, western and central parts of the Peninsula (Casas *et al.*, 1996) where it can be locally common. Originally known to occur in the Portuguese regions of Minho, Beira Litoral, Beira Alta and Alto Alentejo (García *et al.*, 2008; Vieira *et al.*, 2012c). More recently, we found populations in Trás-os-Montes e Alto Douro province, strengthening the known distribution of this species in the north and central eastern territories (Fig. 7). Since the publication of the new Portuguese Red List where it was considered a “special attention” taxon (LC-Att) (Sérgio *et al.*, 2013), three new localities were found, one of which is the most northern and inland one yet known, enlarging the continental range of this species in the national territory. Its populations, frequently fertile, although found from sea level to 1993 m of altitude, are more abundant in mountainous territories where watercourses with temporary to permanent flow (1st to 3rd order streams) create microhabitats with permanent spray or which are seasonally submerged by smooth or turbulent flow of high discharge. Apparently indifferent to sun exposure (but found more frequently in the shade), this seems to be a saxicolous taxon restricted to granite or schist substrates of watercourses. In total, 71 records were listed in Portugal for this taxon, of which 67 are supported by LISU or PO herbarium vouchers (Appendix 1, cf. Supplementary Materials: doi/10.7872/cryb/v37.iss1.2016.Suppl.Mat.1).

Racomitrium lamprocarpum (Müll. Hal.) A. Jaeger

Originally considered as an Iberian endemic, this species has now several synonyms with species of the South Hemisphere (Ochyra *et al.*, 1988; Bednarek-Ochyra & Ochyra, 2012). Therefore, this is a disjunct element of a global population with its main center of distribution in the Southern Hemisphere where it has a pan-Holantarctic temperate range from Iles Kerguelen and sub-Antarctic to South Africa (Bednarek-Ochyra & Ochyra, 1998). The Iberian Peninsula is its only known area of occurrence in the Northern Hemisphere. Its initially known Iberian distribution (Casas *et al.*, 1992) was widely updated with the specimens found after 2000 in several Portuguese regions (García *et al.*, 2008; Vieira *et al.*, 2012c) (Fig. 8), and it became considered a non-threatened species at the Iberian level (Sérgio *et al.*, 2006). Nevertheless, in Portugal, it was recently considered a “special attention” taxon (LC-Att) (Sérgio *et al.*, 2013), for its geographical uniqueness and its strict dependence on well-preserved fast-flowing microhabitats in mountainous areas (Vieira *et al.*, 2012c). Since the year 2000, 68 localities have been added to its distribution, reinforcing its occurrence in the northern and central mountainous territories. The populations were found in segments with temporary to permanent flow (1st to 3rd order streams), in permanent spray areas of waterfalls and in microhabitats seasonally submerged by high discharge flow, either smooth or turbulent. More likely to be found in deeply shaded locations, this taxon, like *R. hespericum*, is restricted to granite or schist substrates of riverbeds. In total, 107 records were listed in Portugal for this taxon, of which 99 are supported by LISU or PO herbarium vouchers (Appendix 1, cf. Supplementary Materials: doi/10.7872/cryb/v37.iss1.2016.Suppl.Mat.1).

Schistidium rivulare (Brid.) Podp.

Species widely distributed in North America, Asia, America, Antarctica and Australasia (Dieryssen, 2001). In Europe this species is common in mountainous

areas (Bremer, 1980) and, in Portugal, until 1950, it was known only in the northern part of the country (Minho region) being, therefore, considered extinct by the time the first Portuguese Red List was published (Sérgio *et al.*, 1994). After 2000, 31 localities extended extensively the known distribution to more continental and northern territories of Douro Litoral, Beira Alta and Trás-os-Montes e Alto Douro regions, and, very recently, to the Beira Baixa region (Fig. 9). These new records emphasize how overlooked this species was until direct efforts were made to locate it in its specific fast-flowing habitat in mountainous territories. In the new Portuguese Red List it was considered “near threatened” (Sérgio *et al.*, 2013) and after that, eight localities were found in Tua River valley. Unfortunately these correspond to populations that will soon disappear due to a hydroelectric power scheme construction.

This taxon appears to be more common in valley river segments with permanent flow (2nd to 5th order rivers), usually in the driest habitats of the riverbed, only seasonally submerged during the high discharge events, in fully-exposed to deeply shaded niches, always growing as a saxicolous taxon over granite or schist, and was found over a range of altitude from 200 to 1993 m. In total, 34 records were listed in Portugal for this taxon, of which 33 are supported by LISU or PO herbarium vouchers (Appendix 1, cf. Supplementary Materials: doi/10.7872/cryb/v37.iss1.2016.Suppl.Mat.1).

***Barbilophozia barbata* (Schmidel *ex* Schreb.) Loeske**

An example of a sub-Boreal species with a representation in montane areas of the northern half of the Iberian Peninsula (Casas *et al.*, 2009) and infrequent in Mediterranean countries (Bischler, 2004), this species was first reported from Portugal in the highest mountain of the continental territory (Serra da Estrela) (Allorge, 1931). Up until 2000, old herbarium material was revised and only other two localities were added for Peneda-Gerês National Park and Serra de Marofa (Sérgio & Séneca, 1994). After the extensive work on fluvial habitats since 2000, this liverwort has been recorded in the vicinities of the classic localities and also in many more continental localities of Trás-os Montes e Alto Douro, reinforcing its known eastern limit definition in Portugal (Fig. 10). Despite the nine new localities recently found, in the new Portuguese Red List it continued to be considered a “vulnerable” taxon (Sérgio *et al.*, 2013), since the populations observed since 2000 are small and locally restricted to the margins of well-preserved watercourses all in Trás-os-Montes e Alto Douro. Its populations were found in mountain watercourses with temporary to permanent flow, in deeply shaded microhabitats splashed only during high discharge by smooth flow, growing over schist, soil or trunk roots of *Quercus* spp. from 500 to 1000 m of altitude. In total, 14 records were listed in Portugal for this taxon, which are all supported by LISU or PO herbarium vouchers (Appendix 1, cf. Supplementary Materials: doi/10.7872/cryb/v37.iss1.2016.Suppl.Mat.1).

***Pallavicinia lyellii* (Hook.) Carruth.**

Despite its occurrence in all continents (except Antarctica), this species is known to show restricted distributions in Mediterranean areas (Bischler, 2004). In the Holarctic region it shows a suboceanic tendency and in Europe it is considered vulnerable, since it is threatened or considered extinct in several countries (ECCB, 1995). In the Iberian Peninsula it is more commonly distributed in the west, being rarer in the northeast and not considered threatened (Sérgio *et al.*, 2006). In Portugal it was primarily found in southern territories, the first in Algarve in the XIXth century. In the period up until 2000, more localities were found mostly in the center of the



Figs 10-13. Distribution of the mentioned taxa within the Portuguese continental territory. **10.** *Barbilophozia barbata*. **11.** *Pallavicinia lyellii*. **12.** *Porella pinnata*. **13.** *Radula holtii*. Different symbols in the maps correspond to three periods of collection: white circle – before 1950; white circle with dot – 1950 to 2000; black circle – 2001-2014.

country, but localities in the north, along with further populations in central territories, were found only after 2000 (Claro *et al.*, 2012) (Fig. 11). Essentially, the number of localities known in each decade for this species remains continuously small, and corresponds to highly preserved hygrophilous acidic habitats concomitantly with high precipitation levels (> 900 mm/year), rare in the Mediterranean regions (Bischler, 2004). Since the publication of the new Portuguese Red List, where it was considered “vulnerable” (Sérgio *et al.*, 2013) due to the decline of old populations and potential risk of the newly found, two new localities were added, one of which in Peneda-Gerês Park that redefines the northernmost limit of the species in mainland Portugal. This taxon’s populations are known to occur in bog springs (upper mountain peaty areas), permanent springs (aquifer resurgences) and on the margins of mountain watercourses with temporary (mostly winter) flow, in the dripping walls and waterfall splash and spray areas, on very deeply shaded granite or schist walls, from sea level to 1700 m of altitude. In total, 19 records were listed in Portugal for this taxon, of which 12 are supported by LISU, PO or COI herbarium vouchers (Appendix 1, cf. Supplementary Materials: doi/10.7872/cryb/v37.iss1.2016.Suppl.Mat.1).

***Porella pinnata* L.**

This species is known to occur in some countries of central and western Europe, North Africa, North America and Central America (Bischler, 2004). In the Iberian Peninsula, it is present in the northwestern area: in Spain it is limited to Galicia and Asturias (Garilleti & Albertos, 2012), and in Portugal, it was collected for the first time in the early twentieth century in Minho and Douro Litoral. By the time the first Iberian Red List was published, it was considered extinct in Portugal and no localities were found for more than 50 years (Sérgio *et al.*, 1994). After 2000, fluvial surveys added sixteen new localities in coastal region of Minho (Vieira *et al.*, 2005), and also more continental localities, in Douro Litoral and Trás-os-Montes e Alto Douro regions (Garcia *et al.*, 2010). Since the publication of the latter paper, one new locality was added in Vouga watershed in Beira Litoral region, corresponding to the southernmost Iberian population known so far (Fig. 12). This taxon’s populations were found more commonly in valley river segments with permanent flow (2nd to 5th order segments), usually in the marginal microhabitats of the riverbed, only seasonally submerged during the high discharge events by smooth or turbulent flow, in medium-exposed to deeply shaded niches, growing as a saxicolous taxon over granite or as an epiphyte on the base of the trunk and roots of the riparian tree *Fraxinus angustifolia* Vahl, over a range of altitude up to 450 m. In total, 21 records were listed in Portugal for this taxon, which are all supported by LISU or PO herbarium vouchers (Appendix 1, cf. Supplementary Materials: doi/10.7872/cryb/v37.iss1.2016.Suppl.Mat.1).

***Radula holtii* Spruce**

This is a species known in Atlantic Europe from Ireland, Scotland, the Iberian Peninsula (NW Spain and Portugal) and Macaronesia (Azores, Madeira, and Canary Islands) (Vieira *et al.*, 2004a), and considered an endangered taxon in many of these countries (Vieira *et al.*, 2004a; González-Mancebo *et al.*, 2012). In Portugal it was first collected by A. Machado in two localities of Minho (Machado, 1925), followed by several authors in the same region until 1947-1949 (Sérgio & Schumacker, 1992). Since no other observations of this species were made during more than 50 years, it was considered extinct in the first Iberian Red List (Sérgio *et al.*, 1994). Between 2002 and 2010 it was rediscovered in various locations of the Peneda-Gerês National Park, as well in other localities of Minho (Vieira *et al.*, 2005,

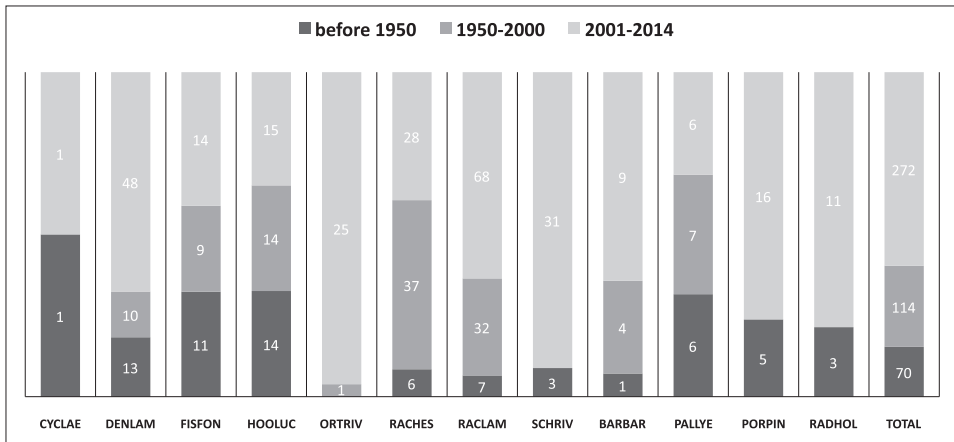


Fig. 14. Number of observations (corresponding to number of 1×1 km UTM squares) in each period contributing to each taxon's total amount of observations. CYCLAE: *Cyclodictyon laetevirens*; DENLAM: *Dendrocryphaea lamyana*; FISFON: *Fissidens fontanus*; HOOLUC: *Hookeria lucens*; ORTRIV: *Orthotrichum rivulare*; RACHES: *Racomitrium hespericum*; RACLAM: *Racomitrium lamprocarpum*; SCHRIV: *Schistidium rivulare*; BARBAR: *Barbilophozia barbata*; PALLYE: *Pallavicinia lyellii*; PORPIN: *Porella pinnata*; RADHOL: *Radula holtii*.

2012c). Subsequently, it was observed in Trás-os-Montes e Alto Douro region, enlarging the distribution area of this species to a new province and a much more continental territory (Sérgio *et al.*, 2013) (Fig. 13). Currently, this taxon is considered vulnerable (VU) in mainland Portugal due to its restricted distribution and habitat specificity. This taxon seems to show a specific preference for mountain segments with permanent flow (1st to 3rd order streams), running through vertical granite surfaces and forming dripping or spray zones, where it occurs in more deeply shaded niches located from 50 to 800 m of altitude. In total, 14 records were listed in Portugal for this taxon, of which 13 are supported by LISU or PO herbarium vouchers (Appendix 1, cf. Supplementary Materials: doi/10.7872/cryb/v37.iss1.2016.Suppl.Mat.1).

Data meta-analysis

Appendix 1 presents all the UTMs (1×1 km squares) and geographic coordinates where each taxon was known to occur, in each time period. Fig. 14 graphically summarizes the number of observations (corresponding to 1×1 km UTM squares), in each period considered, contributing to each taxon's total amount of observations. Fig. 14 shows that more than 50% of *Dendrocryphaea lamyana*, *Orthotrichum rivulare*, *Racomitrium lamprocarpum*, *Schistidium rivulare*, *Barbilophozia barbata*, *Porella pinnata* and *Radula holtii* observations were done after the year of 2000. Sixty percent of the total amount of collections of the twelve noteworthy taxa were also done in the last 14 years, contrasting with the amount of data collected in the period of more than one hundred years of previous bryological observations in Portugal.

Fig. 15 summarizes the information on meso-habitat preferences (in more recent collections made by the authors). Alluvial forests with “*Alnus glutinosa* and *Fraxinus excelsior* (*Alno-Padion*, *Alnion incanae*, *Salicion albae*)” (91E0) and “Galicio-Portuguese oak woods with *Quercus robur* and *Quercus pyrenaica*” (9230),

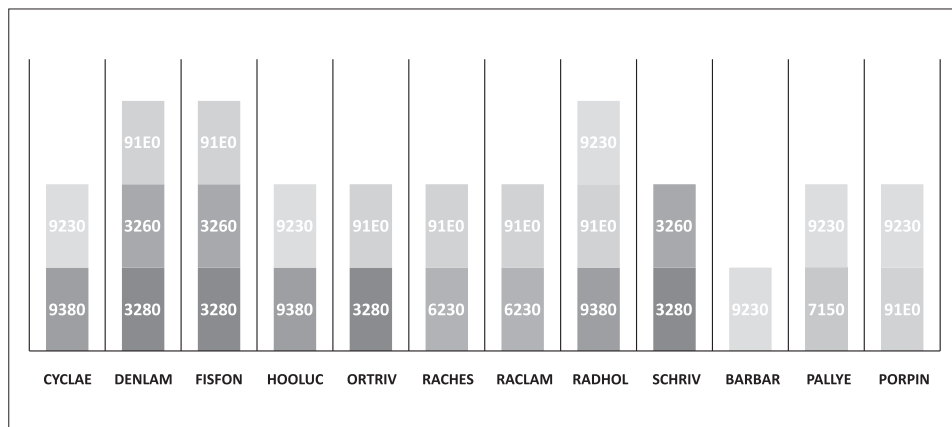


Fig. 15. Qualitative information on the types of Habitats (correspondence to Habitats Directive codes and classification) found associated with the collections of each taxa. Species abbreviations as in Fig. 14. Code and designation of European Natural and Semi-natural Habitats as listed in Habitats Directive (ALFA, 2004): 3260 – Watercourses of plain to montane levels with the *Ranunculion fluitantis* and *Callitriche-Batrachion* Vegetation; 3280 – Constantly flowing Mediterranean rivers with *Paspalo-Agrostidion* species and hanging curtains of *Salix* and *Populus alba*; 6230 – Species-rich *Nardus* grasslands, on siliceous substrates in mountain areas (and submountain areas, in Continental Europe); 7150 – Depressions on peat substrates of the *Rynchosporion*, 91E0 – Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (*Alno-Padion*, *Alnion incanae*, *Salicion albae*); 9230 – Galician-Portuguese oak woods with *Quercus robur* and *Quercus pyrenaica*; 9380 – Forests of *Ilex aquifolium*.

are the woodland mesohabitats that are typical of the watercourse surroundings for more taxa, but the mesohabitat of "Mediterranean rivers with *Paspalo-Agrostidion* species and hanging curtains of *Salix* and *Populus alba*" (3280) is also the natural riparian context where many of the taxa appear.

DISCUSSION

In this study we analysed data from twelve taxa corresponding to 324 different UTM squares (1×1 km), from which 79 have more than one of the twelve species selected for this paper. Taking into consideration that these taxa correspond to perennial populations, it is important to underline the importance of maintaining the monitoring of these UTMs and the conservation of the watersheds concerned. As shown in Fig. 14 almost all of the species had their data expanded substantially in the most recent, but shortest, period (2001-2014), when a higher number of specialists directed their efforts for a specific search in fluvial habitats which are seldom overlooked because of added difficulties in sampling. Nevertheless, this primary knowledge is essential and internationally recognized as a means of assessing the bryological importance of watercourses and justifying thorough surveys for any particular hydroelectric proposal with adverse impacts on the bryophyte flora (Averis *et al.*, 2012).

In the more recently published Portuguese Atlas and Red Data Book of Endangered Bryophytes (Sérgio *et al.*, 2013) it was evaluated the conservation status of many fluvial bryophytes using the current IUCN Red List criteria and the results showed the responsibility of Portuguese territories in preserving some of the European

southernmost populations of Atlantic populations in Mediterranean watercourses, particularly well represented in our country. Moreover, this Red Data Book showed that the threat status of these species is an ongoing trade-off between the changes in their fluvial habitat quality and the continuously improved occurrence data.

Many of these twelve bryophytes occur in the ecotone microhabitats of two very different environments – the aquatic and the terrestrial – which determines their dependence on the quality of the hydrologic regimes and water quality, and the integrity of the surrounding mesohabitats, many of which have a very restricted spatial representation in the country (e.g. “Species-rich *Nardus* grasslands, on siliceous substrates in mountain areas and submountain areas, in Continental Europe (6230)”, “Depressions on peat substrates of the *Rhynchosporion* (7150)” or “Forests of *Ilex aquifolium* (9380)”).

All the species presented here grow in unpolluted rivers not prone to silting up and where the continuity and health of riparian vegetation are vital to their survival, depending on trees for substrate or for the creation of the adequate humid and shaded environment. Some taxa persist because of their ability to disperse and survive in (un-)expected secondary habitats (Vanderpoorten & Engels, 2002, 2003): we found some populations of *Porella pinnata* on walls built in the river margins with granite blocks, *Radula holtii* populations growing on a dripping granite wall or in drainage ditches of a thermal park, *Racomitrium hespericum* populations on old dripping granite walls of railway tracks running next to the river and *Dendrocryphaea lamyana* populations on the stones of bridge pylons. Nevertheless, these populations are ecological outliers and are not the major, reproductive, nuclear populations in the Portuguese territory, persisting only because of the stability of the constructed structures and the pure quality of the water running by.

Over the last few decades the reaches of Portuguese watercourses have certainly been irreversibly changed through embankments, hydroelectric power schemes construction, nutrient enrichment and increased sedimentation. This habitat’s decline has certainly provoked major effects on the presented taxa’s populations. With this paper we intend to contribute for international conservation of these taxa, contribute to a more comprehensive knowledge of their niche and chorology, improve the possibility of finding new populations in the field and increase the confidence of their conservation assessment in national and global Red Lists (IUCN, 2008).

Acknowledgements. CV and HH are funded by the Fundação para a Ciência e Tecnologia (FCT) under a Postdoctoral fellowship (SFRH/BPD/63741/2009 and SFRH/BPD/64665/2009, respectively) co-funded by the Programa Operacional Ciência e Inovação – 2010 and Fundo Social Europeu.

REFERENCES

- ALFA, 2004 — *Tipos de Habitat Naturais e Semi-Naturais do Anexo I da Directiva 92/43/CEE (Portugal Continental): Fichas de Caracterização Ecológica e de Gestão para o Plano Sectorial da Rede Natura 2000*. Lisboa, ICNE.
- ALLORGE P., 1931 — Notes sur la flore bryologique de la Péninsule Ibérique. VIII. Additions a la flore portugaise. *Revue bryologique* 4: 32-36.
- ALLORGE P., 1947 — Essai de Bryogeographie de la Péninsule Ibérique. *Encyclopédie biogéographique et écologique* 1: 1-105.

- AGÊNCIA PORTUGUESA DO AMBIENTE., 2008 — Atlas do Ambiente (Maps I.16.4, I.13, I.9, I.6, I.1, I.4.1, III.1, I.2). Available at: <http://www.ambiente.pt/atlas/est/index.jsp>. Accessed 12th July 2008.
- AVERIS A.B.G., GENNEY D.R., HODGETTS N.G., ROTHERO G.P. & BAINBRIDGE I.P., 2012 — *Bryological assessment for hydroelectric schemes in the West Highlands*. 2nd edition. Scottish Natural Heritage Commissioned Report No.449b. 28 p.
- BARROS G.R., 1944 — Briófitos da Serra do Gerês. *Boletim da sociedade Broteriana, Série 2*, 19: 247-257.
- BEDNAREK-OCHYRA H. & OCHYRA R., 1998 — *Racomitrium lamprocarpum* (Müll. Hal.) Jaeg.-an addition to the moss flora of Iles Kerguelen and Subantarctic. *Journal of bryology* 20: 525-528.
- BEDNAREK-OCHYRA H. & OCHYRA R., 2012 — The taxonomic status of *Racomitrium capense* (Bryophyta, Grimmiaceae) from South Africa. *Cryptogamie, Bryologie* 33: 97-106.
- BISCHLER H., 2004 — Liverworts of the Mediterranean. *Bryophytorum bibliotheca* 61: 1-252.
- BREMER B., 1980 — A taxonomic revision of *Schistidium* (Grimmiaceae, Bryophyta) 2. *Lindbergia* 6: 89-117.
- BRUGUÉS M. & GONZÁLEZ-MANCEBO J.M., 2012 — Lista Roja de los Briófitos Amenazados de España. In: Garilleti R. & Albertos B. (eds), *Atlas y Libro Rojo de los Briófitos Amenazados de España*. Madrid, Organismo Autónomo Parques Nacionales, pp. 26-42.
- CASAS C., BRUGUÉS M., CROS R.M. & SÉRGIO C., 1992 — *Cartografia de briòfits. Península Ibèrica i les Illes Balears, Canàries, Açores i Madeira. Fascicle III*. Barcelona, Institut d'Estudis Catalans, pp. 101-150.
- CASAS C., BRUGUÉS M., CROS R.M. & SÉRGIO C., 1996 — *Cartografia de briòfits. Península Ibèrica i les Illes Balears, Canàries, Açores i Madeira. Fascicle IV*. Barcelona, Institut d'Estudis Catalans, pp. 151-200.
- CASAS C., BRUGUÉS M., CROS R.M. & SÉRGIO C., 2009 — *Handbook of Liverworts and Hornworts of the Iberian Peninsula and the Balearic Islands*. Barcelona, Institut d'estudis Catalans, 177 p.
- CHARISSOU I. & LEBLOND N. (in press) — Répartition de *Dendrocryphaea lamyana* (Mont.) P. Rao en France et dans le Monde. *Bulletin de la société botanique du Centre-Ouest*.
- CLARO D., SÉRGIO C. & GARCIA C., 2012 — Estudo preliminar sobre a diversidade dos Briófitos das Fragas de São Simão, Figueiró dos Vinhos (Portugal). *Boletín sociedad Española de briología* 38-39: 41-50.
- DIERSSEN K., 2001 — Distribution, ecological amplitude and phytosociological characterization of European bryophytes. *Bryophytorum bibliotheca* 56: 1-289.
- DÜLL R., 1983 — Distribution of European and Macaronesian liverworts (Hepaticophytina). *Bryologische Beiträge* 2: 1-115.
- DÜLL R., 1984 — Distribution of European and Macaronesian mosses (Bryophytina). *Bryologische Beiträge* 4: 1-113.
- DÜLL R., 1985 — Distribution of European and Macaronesian mosses (Bryophytina). *Bryologische Beiträge* 5: 110-232.
- ECCB, 1995 — *Red Data Book of European Bryophytes*. Trondheim, ECCB, 291 p.
- FEIO M.J., AGUIAR F.C., ALMEIDA S.F., FERREIRA J., FERREIRA M.T., ELIAS C., SERRA S.R., BUFFAGNI A., CAMBRA J., CHAUVIN C., DELMAS F., DORFLINGER G., ERBA S., FLOR N., FERREOL M., GERM M., MANCINI L., MANOLAKI P., MARCHEGGIANI S., MINCIARDI M.R., MUNNE A., PASTERGIADOU E., PRAT N., PUCCINELLI C., ROSEBERY J., SABATER S., CIADAMIDARO S., TORNES E., TZIORTZIS I., URBANIC G. & VIEIRA C., 2014 — Least Disturbed Condition for European Mediterranean rivers. *Science of the total environment* 476-477: 745-756.
- GARCIA C., SÉRGIO C. & JANSEN J., 2008 — The bryophyte flora of the natural park of Serra da Estrela (Portugal): Conservation and Biogeographical approaches. *Cryptogamie, Bryologie* 29: 49-73.
- GARCIA C., VIEIRA C. & SÉRGIO C., 2010 — New data on the presence of *Porella pinnata* L. (Porellaceae, Jungermanniales, Hepaticae) in Portugal. *Cryptogamie, Bryologie* 31: 107-110.
- GARILLETI R. & ALBERTOS B., 2012 — *Atlas y Libro Rojo de los Briófitos Amenazados de España*. Madrid, Organismo Autónomo Parques Nacionales. 288 p.
- GONZÁLEZ-MANCEBO J., DIRKSE G., PATIÑO J., ROMAGUERA F., WERNER O., ROS R. M. & MARTÍN J., 2012 — Applying the IUCN Red List criteria to small-sized plants on oceanic islands: conservation implications for threatened bryophytes in the Canary Islands. *Biodiversity and conservation* 21: 3613-3636.

- HALLINGBÄCK T., 2002 — Globally widespread bryophytes, but rare in Europe. *Portugaliae acta biologica* 20: 11-24.
- HEDDERSON T.A., 1992 — Rarity at range limits; dispersal capacity and habitat relationships of extraneous moss species in a boreal Canadian National Park. *Biological conservation* 59: 113-120.
- HEDENÄS L., 1992 — Flora of Madeiran Pleurocarpous mosses (Isobryales, Hypnobryales, Hookeriales). *Bryophytorum bibliotheca* 44: 1-165.
- HENRIQUES J., 1886 — Hepáticas colhidas em Portugal. *Boletim da sociedade Broteriana* 4: 234-249.
- HENRIQUES J., 1889 — Musgos. Catálogo dos Musgos encontrados em Portugal. Bryinae anomalae. *Boletim da sociedade Broteriana* 7: 181-223.
- HYLANDER K. & DYNESIUS M., 2006 — Causes of the large variation in bryophyte species richness and composition among boreal streamside forests. *Journal of vegetation science* 17: 333-346.
- INAG I.P., 2008 — *Tipologia de rios em Portugal continental no âmbito da Implementação da Directiva Quadro da Água. I – Caracterização abiótica*. Lisboa, Ministério do Ambiente, Ordenamento do Território e do Desenvolvimento Regional, Instituto da Água IP, 32 p.
- IUCN, 2008. *Guidelines for Using the IUCN Red List Categories and Criteria. Version 7.0. Prepared by the Standards and Petitions*. Working Group of the IUCN SSC Biodiversity Assessments Sub-Committee in August 2008.85 pp.
- LARA F., GARILLETI R., ALBERTOS B., MEDINA R. & MAZIMPAKA V., 2006 — Nuevos datos sobre la distribución en la Península Ibérica de *Orthotrichum sprucei* Mont., *O. rivulare* Turn. y *Dendrocryphaea lamyana* (Mont.) P. Rao. *Boletín de la sociedad Española de briología* 28: 61-66.
- LUISIER A., 1910 — Notes de Bryologie portugaise. 1. *Annaes scientificos da academia polytechnica do Porto* 5: 73-79.
- MACHADO A., 1915 — Notas de Briologia Minhota e a ideia de espécie em Briologia. *Annaes scientificos da academia polytechnica do Porto* 10: 116-122.
- MACHADO A., 1917 — Notas de Briologia Portuguesa – Plantas novas para Portugal. *Brotéria, série botânica* 15: 8-11.
- MACHADO A., 1920 — Apontamentos de Briologia Portuguesa. *Boletim da sociedade Broteriana* 28: 165-167.
- MACHADO A., 1925 — Sinopse das Briófitas de Portugal. 1ª parte: Hepáticas. *Boletim da sociedade Broteriana, série 2*, 3: 5-87.
- MACHADO A., 1932 — *Sinopse das Briófitas de Portugal, 2ª parte (continuação)*. Coimbra, 188 p.
- O'SHEA B.J., EGGERS J., PURSELL R.A., SOLLMAN P. & STEVENSON C.R.N., 1997 — New bryophyte taxon records for tropical countries 1. *Tropical bryology* 13: 175-183.
- OCHYRA R., SÉRGIO C. & SCHUMACKER R., 1988 — *Racomitrium lamprocarpum* (C. Muell.) Jaeg., an austral moss disjunct in Portugal, with taxonomic and phytogeographic notes. *Bulletin du jardin botanique national de Belgique/Bulletin van de Nationale plantentuin van België* 58: 225-258.
- PHARO E.J. & ZARTMAN C.E., 2007 — Bryophytes in a changing landscape: The hierarchical effects of habitat fragmentation on ecological and evolutionary processes. *Biological conservation* 135: 315-325.
- PLANTLIFE INTERNATIONAL, 2003 — *Cryphaea lamyana*: the multi-fruited river-moss. Back from the Brink Management Series, 4 p. Available at: http://www.plantlife.org.uk/uploads/documents/management-guide-Cryphaea-lamyana-the-multi-fruited-river-moss-english_.pdf. Accessed 9th July 2015.
- PRESTON C.D., 2006 — A revised list of nationally scarce bryophytes. *Field bryology* 90: 22-30.
- RABINOWITZ D., 1981 — Seven forms of rarity. In: Syngé H. (ed), *The Biological Aspects of Rare Plant Conservation*. New York, John Wiley & Sons Ltd., pp. 205-217.
- ROS R.M., MAZIMPAKA V., ABOU-SALAMA U., ALEFFI M., BLOCKEEL T.L., BRUGUÉS M., CANO M.J., CROS R.M., DIA M.G., DIRKSE G.M., EL-SAADAWI W., ERDAĞ A., GANEVA A., GONZÁLEZ-MANCEBO J.M., HERRNSTADT I., KHALIL K., KÜRSCHNER H., LANFRANÇO E., LOSADA-LIMA A., REFAI M.S., RODRÍGUEZ-NUÑEZ S., SABOVljević M., SÉRGIO C., SHABBARA H., SIM-SIM M. & SÖDERSTRÖM L., 2007 — Hepatics and Anthoceroles of the Mediterranean, an annotated checklist. *Cryptogamie, Bryologie* 28: 351-437.
- ROS R.M., MAZIMPAKA V., ABOU-SALAMA U., ALEFFI M., BLOCKEEL T.L., BRUGUÉS M., CROS R.M., DIA M.G., DIRKSE G.M., DRAPER I., EL-SAADAWI W., ERDAĞ A., GANEVA A., GABRIEL R., GONZÁLEZ-MANCEBO J.M., GRANGER C., HERRNSTADT I., HUGONNOT V., KHALIL K., KÜRSCHNER H., LOSADA-LIMA A., LUÍS L., MIFSUD S., PRIVITERA M., PUGLISI M., SABOVljević M., SÉRGIO C.,

- SHABBARA H.M., SIM-SIM M., SOTIAUX A., TACCHI R., VANDERPOORTEN A. & WERNER O., 2013 — Mosses of the Mediterranean, an annotated checklist. *Cryptogamie, Bryologie* 34: 99-283.
- SÁ-NOGUEIRA G.B., 1950 — Catálogo dos Musgos do Gerês. *Agronomia Lusitana* 12: 179-200.
- SABINO DE FREITAS S.J., 1948 — Contribuição para o estudo das Hepaticas em Portugal. *Broteria, série ciencias naturais* 17: 145-171.
- SÉRGIO C., SIM-SIM M., CASAS C., BRUGUÉS M. & CROS R.M. 1988 — A vegetação briológica das formações calcárias de Portugal-IV. O Maciço Calcário Estremenho. Serras de Aire, Candeeiros e Sicó. *Memórias da sociedade Broteriana* 28: 93-135.
- SÉRGIO C., 1990 — Perspectiva biogeográfica da flora briológica Ibérica. *Anales del jardín botánico de Madrid* 46: 371-392.
- SÉRGIO C. & SCHUMACKER R., 1992 — Contribuição para o estudo da flora briológica do Parque Nacional da Peneda-Gerês. *Portugaliae acta biologica* 16: 107-137.
- SÉRGIO C. & SÉNECA A., 1994 — Briófitos novos ou raros para a Brioflora Portuguesa. Espécies da região norte e centro de Portugal. In: Sérgio C. (ed.), *Notulae bryoflorae Lusitanicae V. Revista de biologia* 15: 191-195.
- SÉRGIO C., CASAS C., BRUGUÉS M. & CROS R.M., 1994 — *Lista Vermelha dos Briófitos da Península Ibérica. Red List of Bryophytes of the Iberian Peninsula*. Instituto de Conservação da Natureza (ICN). Lisbon, Museu, Laboratório e Jardim Botânico, Universidade de Lisboa (MLJB), 45 p.
- SÉRGIO C., MUÑOZ J. & OCHYRA R., 1995 — *Racomitrium hespericum*, a new species from the Iberian Peninsula. *The bryologist* 98: 112-117.
- SÉRGIO C., 2001a — L'influence Atlantique et Méditerranéenne dans la bryoflore Portugaise. *Braun-Blanquetia* 31: 15-17.
- SÉRGIO C., 2001b — Hepáticas novas ou raras para a brioflora de Portugal. In: Sérgio C. (ed.), *Notulae bryoflorae Lusitanicae VII.2. Anuário sociedade Broteriana* 5: 94-96.
- SÉRGIO C., BRUGUÉS M., CROS R.M., CASAS C. & GARCIA C., 2006 — The 2006 Red List and updated checklist of bryophytes of the Iberian Peninsula (Portugal, Spain and Andorra). *Lindbergia* 31: 109-125.
- SÉRGIO C., VIEIRA C., ALBUQUERQUE A., RODRÍGUEZ-GONZÁLEZ P. & SILVA I., 2007a — Novos dados sobre algumas Amblystegiaceae em Portugal (1). *Notulae bryoflorae Lusitanicae X. Portugaliae acta biologica* 22: 190-193.
- SÉRGIO C., VIEIRA C., GARCIA C. & SILVA I., 2007b — Novas localidades para espécies dadas como ameaçadas em Portugal (5). *Notulae bryoflorae Lusitanicae X. Portugaliae acta biologica* 22: 198.
- SÉRGIO C., VIEIRA C. & SILVA I., 2007c — Novos dados de *Cirriphyllum crassinervium* (Taylor) Loeske & M. Fleisch (Brachytheciaceae) em Portugal (13). *Notulae bryoflorae Lusitanicae X. Portugaliae acta biologica* 22: 198.
- SÉRGIO C., VIEIRA C. & SILVA I., 2007d — Recent records of *Cinclidotus* (Musci, Pottiaceae) in Portugal: *Cinclidotus aquaticus* (Hedw.) Bruch & Schimp. and *Cinclidotus riparius* (Host ex Brid.) Arn. *Boletín de la sociedad Española de briología* 30/31: 33-36.
- SÉRGIO C., VIEIRA C., SILVA I., BRUGUÉS M., CROS R. & STOW S., 2010 — Update on the distribution, ecology and conservation of *Fissidens fontanus* in Portugal. *Field bryology* 101: 7-12.
- SÉRGIO C., VIEIRA C. & CLARO D., 2011 — *Conocephalum salebrosum* Szwedkowski, Buczkowska & Drzzykoski (Marchantiopsida): modelling the occurrence of a hygrophytic species new to the bryophyte flora of Portugal, Madeira and Azores. *Journal of bryology* 33: 30-34.
- SÉRGIO C., GARCIA C.A., SIM-SIM M., VIEIRA C., HESPANHOL H. & STOW S., 2013 — *Atlas e Livro Vermelho dos Briófitos ameaçados de Portugal (Atlas and Red Data Book of Endangered Bryophytes of Portugal)*. Lisboa, MUHNAC, 463 p.
- SIM-SIM M., RUAS S., FONTINHA S., HEDENÁS L., SÉRGIO C. & LOBO C., 2014 — Bryophyte conservation on a North Atlantic hotspot: threatened bryophytes in Madeira and Selvagens Archipelagos (Portugal). *Systematics and biodiversity* 12: 315-330.
- SÖDERSTRÖM L. & DURING H.J., 2005 — Bryophyte rarity viewed from the perspectives of life history strategy and metapopulation dynamics. *Journal of bryology* 27: 261-268.
- SUREN A.M. & ORMEROD S.J., 1998 — Aquatic bryophytes in Himalayan streams: testing a distribution model in a highly heterogeneous environment. *Freshwater biology* 40: 697-716.
- TREMP H., KAMPMANN D. & SCHULZ R., 2012 — Factors shaping submerged bryophyte communities: A conceptual model for small mountain streams in Germany. *Limnologia — Ecology and management of inland waters* 42: 242-250.

- VANDERPOORTEN A. & ENGELS P., 2002 — The effects of environmental variation on bryophytes at a regional scale. *Ecography* 25: 513-522.
- VANDERPOORTEN A. & ENGELS P., 2003 — Patterns of bryophyte diversity and rarity at a regional scale. *Biodiversity and conservation* 12: 545-553.
- VIEIRA C., LUÍS L., SÉNECA A., SIM-SIM M. & SÉRGIO C., 2004a — New National and Regional Bryophyte records: *Radula holtii* Spruce. *Journal of bryology* 26: 307.
- VIEIRA C., SÉNECA A. & SÉRGIO C., 2004b — The Bryoflora of Valongo – the refuge of common and rare species. *Boletín de la sociedad Española de briología* 25: 1-16.
- VIEIRA C., SÉNECA A. & SÉRGIO C., 2005 — Threatened bryophytes occurrence in Portuguese stream habitat. *Boletín de la sociedad Española de briología* 26-27: 103-118.
- VIEIRA C., SÉRGIO C. & SÉNECA A., 2007 — Some remarkable bryophytes from the aquatic habitats of the northwest of Portugal. *Cryptogamie, Bryologie* 28: 1-8.
- VIEIRA C., 2008 — *Briófitas reófilas saxícolas dos cursos de montanha do Noroeste de Portugal Continental*. Ph. D. Thesis, Universidade do Porto, Porto, 281 p.
- VIEIRA C., SÉNECA A., FERREIRA M.T. & SÉRGIO C., 2011 — The use of bryophytes for fluvial assessment of mountain streams. In: Boon P. and Raven P. (eds), *River Conservation and Management*. Hoboken, New Jersey, Wiley-Blackwell, pp. 134-158.
- VIEIRA C., SÉNECA A., SÉRGIO C. & FERREIRA M.T., 2012a — Bryophyte taxonomic and functional groups as indicators of fine scale ecological gradients in mountain streams. *Ecological indicators* 18: 98-107.
- VIEIRA C., HESPANHOL H., GONÇALVES J., MARQUES J. & BOTA A., 2012b — Biological valuation in mountain landscapes as a tool for the conservation of bryophytes in Baixo-Tâmega, Portugal. *Studia botanica Hungarica* 43: 69-84.
- VIEIRA C., SÉNECA A. & SÉRGIO C., 2012c — Floristic and ecological survey of bryophytes from Portuguese watercourses. *Cryptogamie, Bryologie* 33: 113-134.
- VITT D.H. & BELLAND R.J., 1997 — Attributes of rarity among Alberta mosses: patterns and prediction of species diversity. *The bryologist* 100: 1-12.
- WERNER J., 1997 — Some remarkable bryophytes from Serra da Freita and Serra do Arestal (N Portugal). 18: 295-301.