Arquipelago - Life and Marine Sciences ISSN: 0873-4704

Bryophytes of Azorean parks and gardens (I): "Reserva Florestal de Recreio do Pinhal da Paz" - São Miguel Island

CLARA POLAINO-MARTIN, ROSALINA GABRIEL, PAULO A.V. BORGES, RICARDO CRUZ AND ISABEL S. ALBERGARIA

Polaino-Martin, C.P., R. Gabriel, P.A.V. Borges, R. Cruz and I.S. Albergaria 2020. Bryophytes of Azorean parks and gardens (I): "Reserva Florestal de Recreio do Pinhal da Paz" - São Miguel Island. *Arquipelago*. Life and Marine Sciences 37: 1 – 20.

Historic urban parks and gardens are increasingly being considered as interesting refuges for a great number of species, including some rare *taxa*, otherwise almost absent from urban areas, such as many bryophytes and other biota that are not their main focus. After a bibliographic work, the "Reserva Florestal de Recreio do Pinhal da Paz" (RFR-PP), in São Miguel Island (Azores), stood out as one of the least studied areas of the region, without any bryophyte' references. Thus, the aim of this study was to identify the most striking bryophyte species present along the main visitation track of RFR-PP, in order to increase its biodiversity knowledge. Bryophytes growing on rocks, soil or tree bark were collected *ad-hoc*, in 17 sites, ca. 100 m apart from each other. In total, 43 species were identified: 23 mosses, 19 liverworts, and one hornwort, encompassing five classes, 15 orders and 27 families. Seven species are endemic from Europe and three from Macaronesia. No invasive bryophytes were found in the surveyed area. These results update the distribution data of São Miguel Island, show that Azorean parks and gardens contribute to the community dynamics of bryophytes at lower elevation and add a new layer of interest to the visitors of RFR-PP.

Key words: Parks & Gardens, Mosses, Liverworts, Hornworts, Macaronesian endemic species, Azores.

Clara P. Martin[1] (e-mail: clarapolaino@gmail.com), R. Gabriel[1], P.A.V. Borges[1], R. Cruz[2] and I.S. Albergaria[2]. [1]cE3c/ABG – Centre for Ecology, Evolution and Environmental Changes / Azorean Biodiversity Group and University of the Azores, FCAA - Faculty of Agriculture and Environment, Rua Capitão João d'Ávila, sn. 9700-042 Angra do Heroísmo, Portugal. [2]CHAM – Centro de Humanidades e Universidade dos Açores, FCSH - Faculty of Social Sciences and Humanities, Rua da Mãe de Deus, 9500-321 Ponta Delgada, Portugal.

INTRODUCTION

The Urban gardens and recreational parks are well known for their contribution to ecosystem services. These areas protect the soil against erosion, increase water infiltration, mitigate the urban heat island effect, improve air quality – absorbing carbon from the atmosphere, act ashabitat for endemic and native species, and serve as nodes on a network of natural populations for species occurring in several land-uses (Cardoso et al. 2009; Roberts et al. 2007; Goddard et al. 2009; Mexia et al. 2018). Besides, parks and gardens are especially important for their cultural and recreational services (Sasidharan et al. 2005; Voigt et al. 2014).

In the Azores, urban gardens and parks constitute an important heritage due both to their

biological, geological and hydrological interest, and to their historical, biogeographical and landscape importance (Albergaria 2005; Castel-Branco & Albergaria 2017). Since the XV century, Azorean native ecosystems have suffered major land-use alterations and degradation, with large areas of native vegetation, especially native forests, claimed for urban settlements, agriculture and forestry (Gaspar et al. 2008; Borges et al. 2019). Parks and gardens, especially those occurring at lower elevations, may constitute alternative habitats for different biota.

Azorean parks and gardens, including a high number and cover of tree species and particular ecological conditions, may thus serve as refuge for different *taxa*, as occurs in different regions and countries (Aleffi 2015, 2017). Similarly to many other parks and gardens, the vast majority of ornamental vascular plant species used in Macaronesia are exotic, introduced originally from different archipelagos and continents (e.g. Quintal 2007). More recently, indigenous (native and endemic) species are being used in Azorean gardens, such as the "Faial Botanic Garden" or the recent extension of "Duque da Terceira Garden", likewise what is observed in other parts of Europe (e.g. Zerbe et al. 2003). Notwithstanding the high number of exotic species that constitute the core of most Azorean parks and gardens (e.g. Bogas 2003; Albergaria 2005), and their role as sources of invasive species (e.g. Silva et al. 2008; Gabriel 2019), native species do occur in these areas – namely lichens, bryophytes, invertebrates (e.g. Pérez Santa-Rita et al. 2018) and birds, all contributing to the ecosystem functioning.

Among these particular groups, bryophytes are probably the most striking in area of occupation and one of the richest in number of native species, contributing to the unique landscape of Azorean gardens. In fact, the particular climatic and geographic conditions of these islands, promote the presence and conservation of a considerable diversity of bryophyte species and communities. In 1995, the European Committee for the Conservation of Bryophytes identified in this archipelago six, out of 60, European Areas of Special Interest for Bryophytes (ECCB 1995), mostly included in the natural parks of the Azores. Presently near 500 taxa of bryophytes are known from the Azores (Gabriel et al. 2010; Gabriel et al. 2011), including 53 considered of conservation concern in Europe (Hodgetts et al. 2019). Bryophyte species perform important ecosystem services, being engaged in water retention, minerals recycling, and organic matter decomposition, while protecting and occupying different substrates, many as pioneer species (e.g. Porley & Hodgetts 2005).

Nevertheless, there is still a general lack of information about the bryophyte communities present in recreational parks and gardens, which may be potential refuges of native biodiversity. Since the first publication in 1937 (Silveira 1937), which refer to the collections of Pierre and Valentine Allorge and Hermann Persson, other information followed (e.g. Allorge & Allorge, 1950, 1952; Hübschmann 1974; Sérgio 1991; Claro 2008), but publications have been few and far apart, with no systematic collection of specimens. In fact, among the vast bryological literature of the Azorean Islands (cf. Gabriel et al. 2011), only 25 works mention these habitats for three islands (São Miguel, Terceira and São Jorge).

The Recreation Forest Reserve "Pinhal da Paz" (RFR-PP) (Ponta Delgada county, São Miguel Island) is a good example of the lack of knowledge regarding bryophytes. Although it has been studied in terms of economic value (Pacheco 2012), and the biodiversity of vascular plants (Tavares 2016), the richness of other taxonomic groups had never been considered.

The aims of this paper are: i) to start a systematic documentation through taxonomic identification of the bryophytes present in the Recreation Forest Reserve "Pinhal da Paz", and to analyse their main biogeographic affinities, life strategies, and life and growth forms; ii) to start a series of publications aiming to document the bryological diversity of historic and recreational parks and gardens in the Azores. This characterization is of value as bryophytes are important components of these systems, which are under threat due to the effects of climate change, increasing urbanization and general biodiversity loss.

MATERIALS AND METHODS

Study area

The Recreational Forest Reserve "Pinhal da Paz" (RFR-PP) is a public forest park classified as a recreational reserve "Reserva Florestal de Recreio" by the Regional Legislative Decree no. 15/2000 of June 21. It is located in the municipality of Fajã de Cima, in Ponta Delgada council (São Miguel Island, Azores, Portugal) (37º 47 '10 .126 " N; -25º 38 '24.129" W), between 240 m and 330 m a.s.l. (Figures 1 and 2).

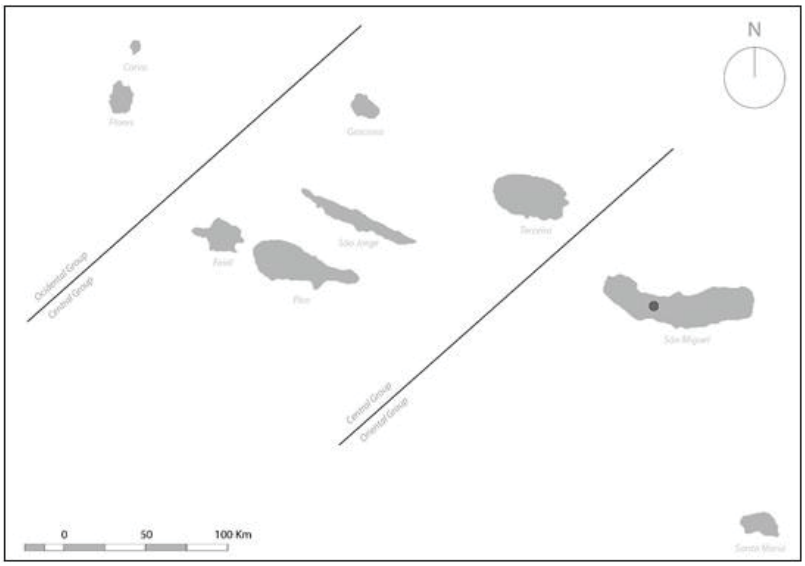

Fig. 1. Azores archipelago in the North Atlantic Ocean.

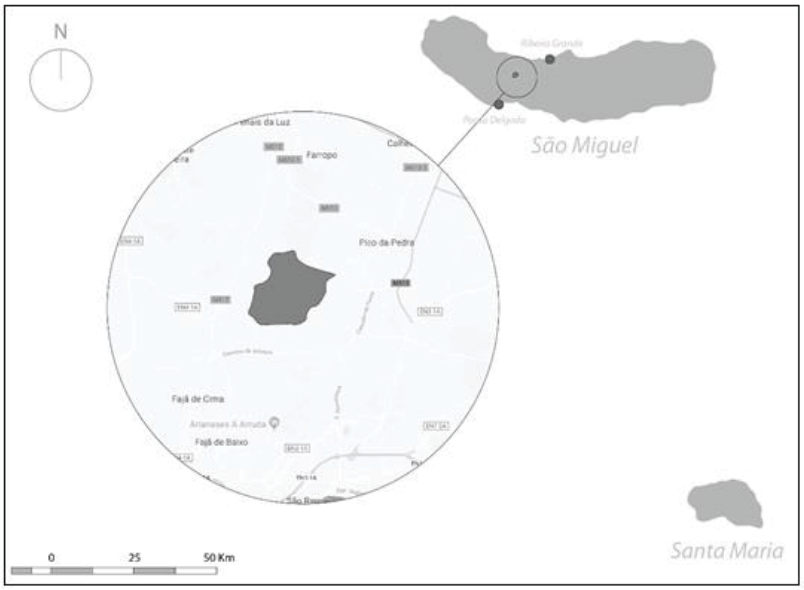

Fig. 2. Location of the Recreational Forest Reserve "Pinhal da Paz" in São Miguel Island (Azores).

Formerly a private property, this 49 ha Recreation Forest Reserve was acquired by the Regional Government of the Azores in 1982. Before opening to the public, the Forest Services of Ponta Delgada proceeded to several works of maintenance and cleaning of roads, management of the forested area and general landscaping, thus creating a central lawn, a playground for children and a snack area (Figure 3). The number of visitors of "Pinhal da Paz" exceeds 100 000 per year, mostly during the summer months (Pacheco 2012).

The average temperature of the Recreation Forest Reserve is mild, ranging from 14º C (minimum) to 25º C (maximum) throughout the year, but air humidity is high (80% approximately), and the average precipitation per year is of 1930 mm, with an evapotranspiration of 580 mm (DROTRH & SRA 2001).

The vascular plants of RFR-PP includes plenty of exotic species, planted mainly with ornamental purposes. Among them there are shrubs such as hydrangeas *(Hydrangea macrophylla*), azaleas (*Rhododendron indicum*), camellias (*Camellia japonica*), different palm species (e.g. *Washingtonia robusta, Archontophoenix cunninghamiana*), and other trees as eucalyptus (*Eucalyptus robusta*), acacias *(Acacia melanoxylon*), pines (*Pinus pinea, P. pinaster*), and cedars (*Cryptomeria japonica, Cupressus sempervirens, Chamaecyparis lawsoniana*) (Tavares 2016). A few Azorean or Macaronesian endemic species such as *Morella faya*, *Juniperus brevifolia*, *Picconia azorica* and *Erica azorica* may be observed among the dominant exotic species (Tavares 2016).

Fig. 3. View of the central lawn in RFR-PP (Photo by PB).

Field work

The sampling of bryophytes at the Recreational Forest Reserve of "Pinhal da Paz" took place on the 2nd June 2018. The authors RG, PAVB and RC collected 17 samples of ca. 10 cm x 5 cm, *ca.* 100 m apart from each other, along one of the most common paths for those visiting the Park (cf. Figure 4).

The substrates sampled were mostly rock and

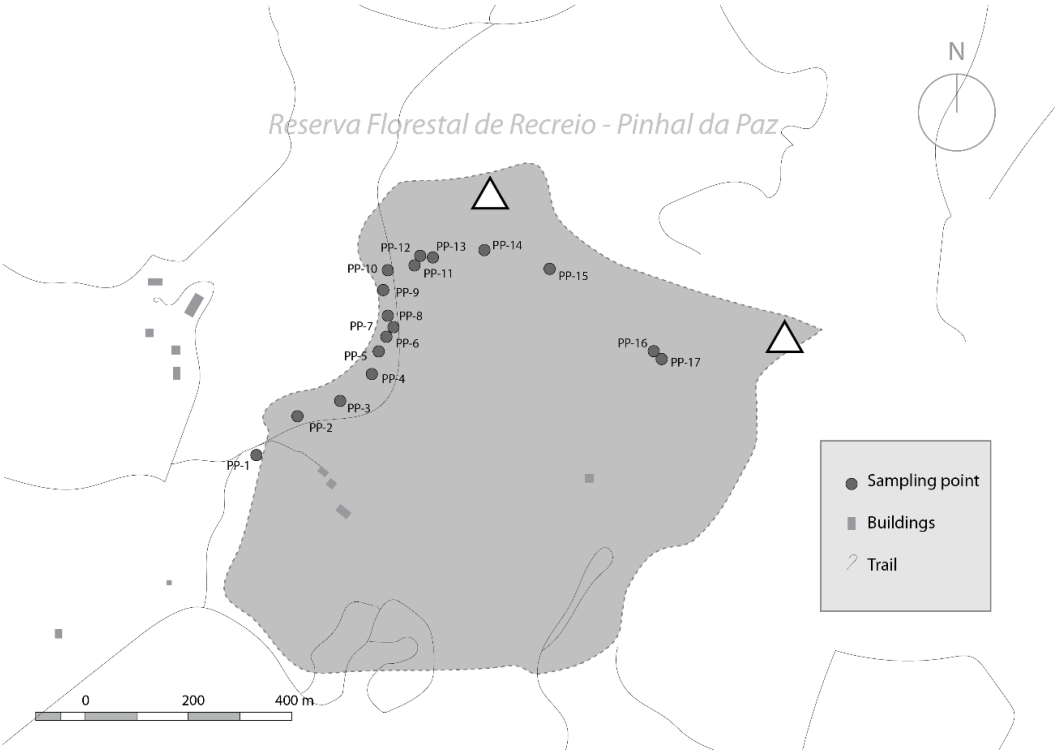

Fig. 3. Map of "Reserva Florestal de Recreio do Pinhal da Paz", São Miguel Island (Azores). The park has an area of 49 ha and lies from 240 – 330 m a.s.l.. Red dots represent the 17 sampling points.

soil, but also the bark of trees and shrubs such as *Persea indica, Acacia melanoxylon* and *Erica azorica* were studied (cf. Table 1). The samples were kept in paper bags and dried at room temperature, in a dark atmosphere, at the Ecology Laboratory of the Faculty of Agrarian and Environmental Sciences, University of the Azores (FCAA-UAz, Angra do Heroísmo, Terceira Island).

Laboratory work

All samples were identified to the species level by CP and RG using identification guides and floras, namely Paton (1999), Schumacker & Váňa (2005) and Casas et al. (2009) for hornworts and liverworts and Casas et al. (2006), Homem & Gabriel (2008) and Smith (2004) for mosses. The nomenclature followed Hodgetts (2015) for mosses and Söderström et al. (2016) for liverworts.

The specimens are kept at the Cryptogamic Collection of the Herbarium of the University of Azores (AZU, FCAA-UAz).

Table 1. Short description of the collection points along the trail in RPP (June 2018).

	Substrate	Inclination (º)	Distance from soil (cm)	Altitude (m)	Coordinates
PP-01	Soil – border of the path	10º	0	261	37.786869, -25.639527
PP-02	Rock on soil	40º	10	262	37.787406, -25.639128
PP-03	Soil – border of the path	10º	0	266	37.787499, -25.638589
PP-04	Soil – slope of the path	75º	0	268	37.787649, -25.637973
PP-05	Soil – slope of the path	75º	0	266	37.787607, -25.638499
PP-06	*Dicot* stump	50º	20	266	37.787738, -25.637643
PP-07	Soil – border of the path	10º	0	272	37.788784, -25.636595
PP-08	*Persea indica* - bark	90º	100	274	37.788546, -25.636784
PP-09	Soil – border of the path	10º	0	274	37.789113, -25.636566
PP-10	*Acacia melanoxylon* – bark	90º	100	278	37.789546, -25.636653
PP-11	*Pittosporum undulatum* – dead trunk	90º	20	281	37.789956, -25.635952
PP-12a	*Erica azorica* – bark	90º	40	279	37.790070, -25.635550
PP-12b	Rock on soil	70º	10	279	37.790070, -25.635550
PP-13	Soil – slope of the path	75º	0	281	37.790093, -25.635816
PP-14	Soil – border of the path	10º	0	292	37.790162, -25.634399
PP-15	Soil – border of the path	10º	0	305	37.788472, -25.630667
PP-16	Rock wall	90º	60	305	37.788472, -25.630667
PP-17	*Dicot* stump	50º	20	305	37.788366, -25.630507

Analysis

The chorological data and the life strategies, growth and life forms follows the BRYOTRAIT-AZO database (Henriques et al. 2017), a comprehensive trait dataset for the Azorean bryoflora. The BRYOLAT-AZO summarizes information coming from different sources: namely, geographic information regarding biomes and Eastern limit categories were attributed based on the work of Hill & Preston (1998); life strategies were used as proposed by During (1979), and life forms by Bates (1998). An ecological analysis was performed using the Ellenberg indicator values for moisture, light and soil reaction to the substrate. These ecological indicator values have been assigned to bryophytes by Düll (1992), and later updated and validated by some authors (Dierßen 2002; Hill et al. 2007; Henriques et al. 2017). The IUCN category was assigned based on the recent European Red List (Hodgetts et al., 2019).

To evaluate the completeness of the collection, we calculated the projected number of species using the first-order Jackknife species richness estimator, which calculates the relationship between the number of species and the number of species found in one sample (SDR-IV, 2019).

RESULTS

Floristics and diversity

The investigated area presented a total number of 43 bryophyte species (cf. Table 2; Annex 1), including 23 mosses (Division Bryophyta), 19

liverworts (Division Marchantiophyta), and a single species of hornwort (Division Anthocerothophyta) (Plate 1), exhibiting a high ratio of liverworts + hornworts / mosses (0,87). Considering the first-order Jackknife estimator, the number of identified species is not complete, and there is a projected value of 65 species for the area, with a rate of completeness of 66,5%.

Table 2. Taxonomy and number of bryophyte records (N) collected at the Recreational Forest Reserve "Pinhal da Paz" in June 2018.

Division	**Class**	**Order**	**Family**	**Species**	**N**
Bryophyta	Bryopsida	Bartramiales	Bartramiaceae	*Philonotis rigida*	1
		Bryales	Bryaceae	*Anomobryum julaceum*	1
				Ptychostomum capillare	1
		Dicranales	Ditrichaceae	*Ceratodon purpureus*	1
			Fissidentaceae	*Fissidens asplenoides*	3
				Fissidens taxifolius	3
			Leucobryaceae	*Campylopus pilifer*	2
			Rhabdoweisiaceae	*Dicranoweisia crispula*	1
		Grimmiales	Ptychomitriaceae	*Ptychomitrium nigrescens*	1
		Hookeriales	Leucomiaceae	*Tetrastichium virens*	4
		Hypnales	Amblystegiaceae	*Amblystegium confervoides*	1
				Amblystegium serpens	1
			Brachytheciaceae	*Brachythecium velutinum*	1
				Kindbergia praelonga	6
			Hypnaceae	*Andoa berthelotiana*	8
				Hypnum jutlandicum	2
				Hypnum uncinulatum	1
			Sematophyllaceae	*Sematophyllum substrumulosum*	3
		Orthotrichales	Orthotrichaceae	*Zygodon rupestris*	1
		Pottiales	Pottiaceae	*Tortella nitida*	1
				Trichostomum brachydontium	3
	Polytrichopsida	Polytrichales	Polytrichaceae	*Atrichum angustatum*	1
				Polytrichum juniperinum	1
Marchantiophyta	Marchantiopsida	Lunulariales	Lunulariaceae	*Lunularia cruciata*	3
		Marchantiales	Aytoniaceae	*Reboulia hemisphaerica*	1
	Jungermanniopsida	Jungermanniales	Calypogeiaceae	*Calypogeia fissa*	2
			Geocalycaceae	*Saccogyna viticulosa*	2
			Lophocoleaceae	*Lophocolea bidentata*	7
				Lophocolea fragans	2

Division	Class	Order	Family	Species	N
				Lophocolea heterophylla	2
		Metzgeriales	Metzgeriaceae	*Metzgeria furcata*	1
			Aneuraceae	*Riccardia multifidia*	2
		Porellales	Frullaniaceae	*Frullania acicularis*	2
				Frullania azorica	1
				Frullania microphylla	1
			Lejeuneaceae	*Harpalejeunea molleri*	4
				Lejeunea lamacerina	9
				Cololejeunea azorica	1
				Drepanolejeunea hamatifolia	1
			Porellaceae	*Porella canariensis*	1
			Radulaceae	*Radula aquilegia*	1
				Radula wichurae	4
Anthocerotophyta	Anthocerotopsida	Anthocerotales	Anthocerotaceae	*Anthoceros caucasicus*	1

Mosses are represented by two classes, nine orders and 14 families, while, liverworts are represented by two classes, five orders and 11 families. About one third of the moss species belong to the Hypnales (8 spp.; 34,8%), including three species from the Family Hypnaceae. More than half of the liverwort species belong to the Porellales (10 spp.; 52,6%), including four species belonging to Lejeuneaceae (Table 2).

Four species were collected more than five times, two pleurocarpous mosses (*Andoa berthelotiana* [Plate 1c,d]; *Kindbergia praelonga*) and two leafy liverworts (*Lejeunea lamacerina; Lophocolea bidentata*).

It is quite striking that three of the five species of the genus *Frullania* referred to the Azores archipelago may be found in this area, including the recently described *F. acicularis* (Figure 5).

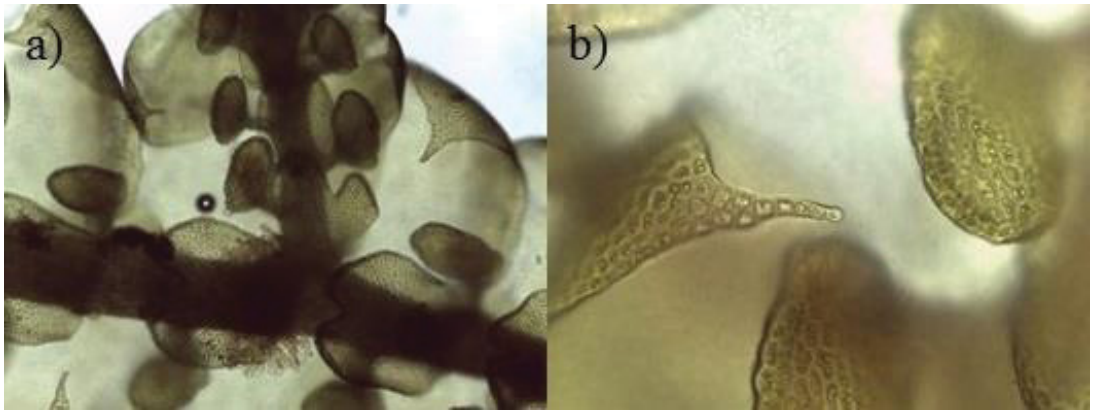

Fig. 4. The leafy liverwort *Frullania acicularis* recently described for the Azores; a) ventral view of a shoot, with lobules sac-shaped, underleaves not decurrent and rhizoids at the base of an underleaf (magnification 10 x 10);b)

apex of the lobe, with the long needle like leaf apices characteristic of the species (magnification 10 x 40) (Photos by RG).

Biogeography

The taxa found in RFR-PP belong to seven of the nine biomes described by Hill & Preston (1998): Boreo-arctic Montane, Wide boreal, Boreal-Montante, Temperate, Southern-temperate and Mediterranean-Atlantic (Figure 6).

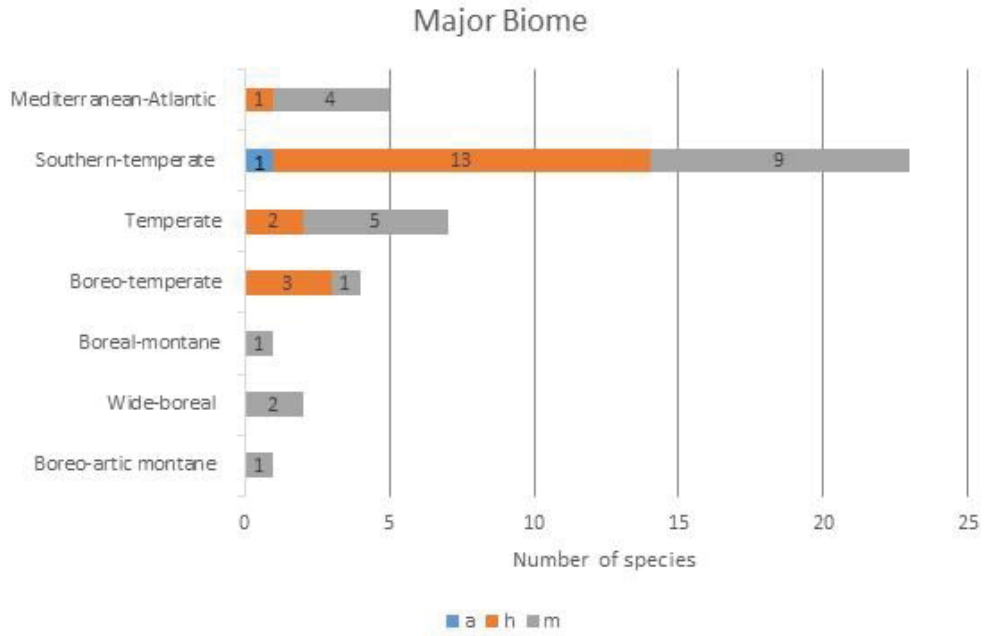

Fig. 5. Distribution of bryophytes from "Reserva Florestal de Recreio Pinhal da Paz" according to their geographic affinities. (a, Anthocerotophyta; h, Marchantiophyta; m, Bryophyta).

Most of the bryophytes present in this recreational park have their main distribution area in temperate and southern-temperate biomes. Among the southern-temperate bryophytes, there are species with a relatively restricted geographic distribution, including the hornwort *Anthoceros caucasicus*, three leafy liverworts (*Frullania azorica, F. microphylla, Porella canariensis*), an acrocarpous moss (*Ptychomitrium nigrescens*) and two pleurocarpous mosses (*Hypnum uncinulatum, Sematophyllum substrumulosum*). Besides, three Macaronesian endemic species are present in the area: one liverwort *(Radula wichurae*) and two pleurocarpous mosses (*Andoa berthelotiana and Tetrastichium virens*). However, none of the Azorean endemic bryophyte species was found in the area at this time.

A few moss species whose distribution centre is on Northern biomes are also represented in RFR-PP, namely the wide-boreal species *Ceratodon purpureus* and *Polytrichum juniperinum* (Plate 1a).

Considering the Eastern limit of distribution in Eurasia, which corresponds quite closely with a scale of continentality, it is clear that the large majority of liverworts and most mosses have oceanic distributions (including hyperoceanic, oceanic and suboceanic) (Figure 7).

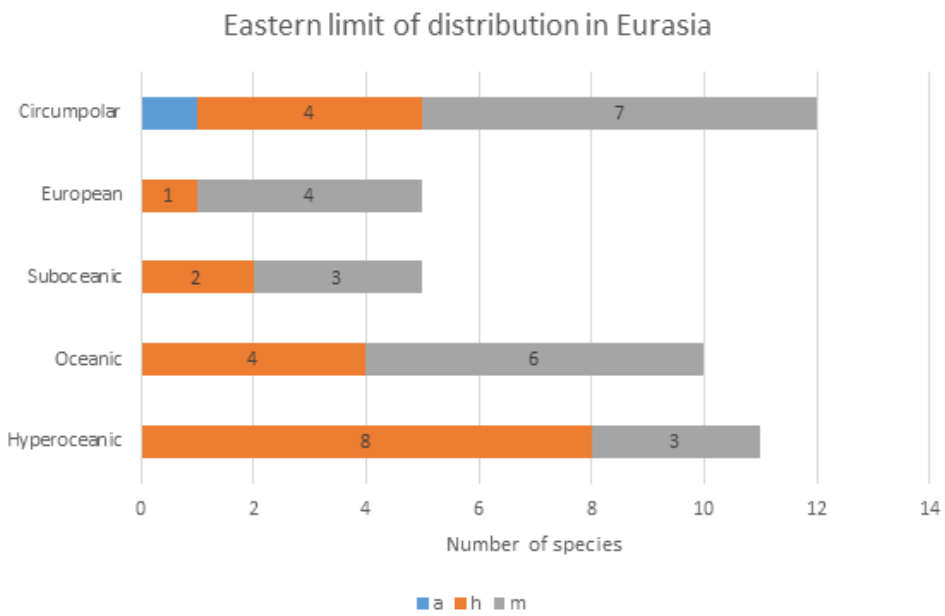

Fig. 6. Distribution of bryophytes from "Reserva Florestal de Recreio Pinhal da Paz" according to their Eastern limit of occurrence in Eurasia. (a, Anthocerotophyta; h, Marchantiophyta; m, Bryophyta).

Notwithstanding, almost a quarter of the represented species in RFR-PP have circumpolar distributions, namely the liverwort Reboulia hemisphaerica and the epiphytic moss Zygodon rupestris.

Ecology

Bryophytes of RFR-PP comprise species of four major life-forms (Figure 8a) – turfs, cushions, mats and wefts. All liverworts form mats (Plate 1e), which is the second largest category for mosses. The pleurocarpous moss *Kindbergia praelonga* is the only specie collected in the area that forms wefts.

With respect to life strategy (Figure 8b), more than half of the species include plants with long potential life spans and with low reproduction effort (long-lived shuttle, perennial stayer and stress-tolerant perennials), especially among the liverworts (73,7%) (e.g. *Lejeunea lamacerina* and *Radula wichurae* (Plate 1f). Eight mosses species exhibit a colonist strategy, frequent in the acrocarpous species (e.g. *Anomobryum julaceum*, *Ceratodon purpureus*, *Zygodon rupestris*). Considering the Ellenberg indicator values (EV) with regard to light (Figure 8c), it is observed that sciophytic species (EV: 1-5) predominate in the Park, reaching 62,8% of the total flora, followed by the photo-sciophytic (EV: 6-7; 25,6%) species. Photophytic species (EV: 8-9; 11,6%) include four mosses (e.g. *Tortella nitida*, *Trichostomum brachydontium*) and the single hornwort found in the RFR-PP at this time.

Regarding water availability (Figure 8d), unsurprisingly in the Azores, about half of the bryophytes are hygrophytic (Figure 8d) (EV: 7-9; 25,6%) and meso-hygrophytic (EV: 6; 25,6%), while xerophytic species (EV: 1-3; 7,0%) are a minority (e.g. *Campylopus pilifer*).

About two thirds of the species (69,8%) occur in acidic soils/substrates and although half of the moss species are from basic soils/substrates (EV: 6-9), only three liverworts are characteristic such basic substrate, including the common thallose species *Reboulia hemisphaerica*, and *Lunularia cruciata* (Figure 8e).

Three environmental parameters, productivity values (related to nitrogen requirement) (Figure 8f), salt and heavy-metal tolerance (Figures 8g, 8h), show that these species occupy mostly

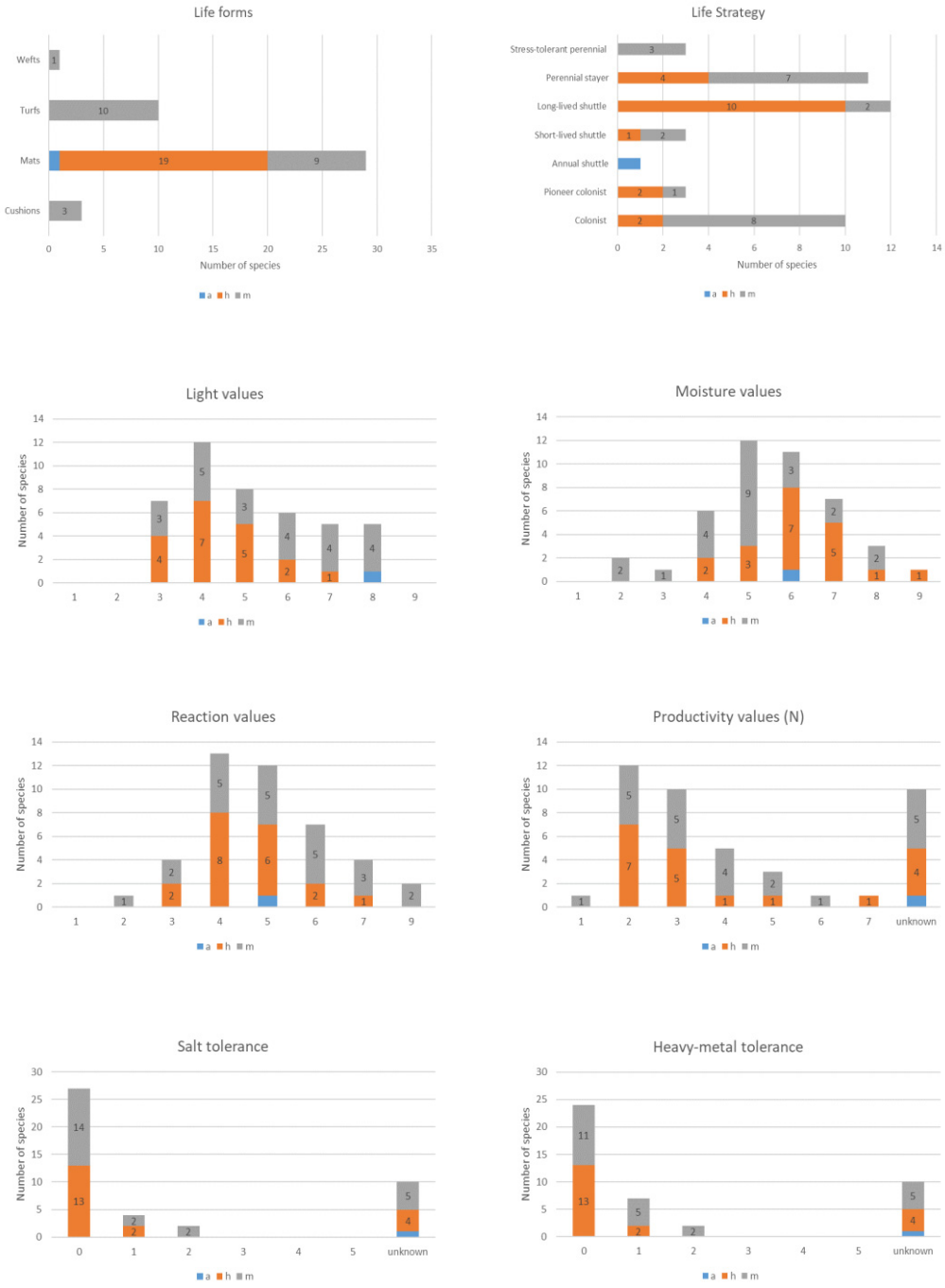

Fig. 8. Information on ecological variables regarding the 43 bryophyte species (one hornwort [a], 19 liverworts [h] and 23 mosses [m] found in RFR-PP during June, 2018. From left to right and top to bottom it is possible to check the spectrum for Life form, Life Strategy, and the Ellenberg indicator values for Light, Moisture, Reaction, Productivity and Salt and Heavy-metal tolerance. Further details in text.

oligotrophic, not-polluted' sites. In fact, seven liverworts and six moss species are only able to grow on sites where the nitrogen concentration is low, while species indicating rich, fertile places (with high nitrogen concentration values) (e.g. *Lunularia cruciata*) are quite scarce in the Park. Furthermore, only a few species collected in RFR-PP are able to tolerate saline or heavy-metal conditions; one of the most striking examples is the acrocarpous moss *Trichostomum brachydontium*, often found in coastal areas.

Conservation concern species

Most of the bryophyte species found in RFR-PP (n=34; 79,1%) are included in the Least Concern IUCN category (Hodgetts et al., 2019). However, this park can be considered a refuge for three Vulnerable mosses (*Andoa berthelotiana*, *Atrichum angustatum* and *Philonotis rigida*) and one liverwort (*Cololejeunea azorica*), as well as for three Near Threatened species (the liverworts *Frullania acicularis*, *Radula wichurae* and the moss *Tetrastichium virens*).

DISCUSSION AND CONCLUSION

Parks and gardens are generally considered safe areas for many bryophytes (e.g. Glime 2007) but these habitats have not been extensively studied. The Azores archipelago, well-known for its high diversity of bryophyte species, is exemplary: no previous systematic collection of bryophytes had been made before the start of the project "Green Gardens Azores" in 2015, while vascular plant species were at least enumerated for most of them.

In particular, no bryophyte species had ever been reported from the Recreational Forest Reserve "Pinhal da Paz", and with this study it was possible to identify a large number of *taxa*. The gathered information represents the first data concerning the bryophyte biodiversity of the Azorean parks and gardens, representing a new centre of interest for all those visiting RFR-PP. In fact, bryophytes are easily spotted by visitors along the main track, not only because they include relatively large species (e.g. *Andoa berthelotiana, Kindbergia praelonga*), but also because bryophytes cover relatively large areas, on tree trunks and shrubs but also on soil and rocks.

The analysis of the ecological indicator values reveals a community of bryophytes mainly sciophytic, hygrophytic, acidophytic, adapted to low nitrogen concentration and intolerant to salt and heavy-metals. These characteristics are to be expected from low intervention areas and constitute a baseline upon which further environmental change will be assessed by comparing these results with those coming from future studies in the area.

The presence of exotic species and anthropic habitats that dominate the area is expected to alter habitat conditions and is likely to reduce biodiversity (Gabriel 2019). In fact, the number of bryophyte species found in this environment is relatively low when compared with other, more natural ecosystems, such as native forests at similar elevation (e.g. Sjögren 1978; Gabriel & Bates 2005), but further samplings should be made in order to elevate the completeness level of the sampling (66,5%). Notwithstanding, the richness of species, particularly liverworts (19 species), is still remarkable and similar to those found in larger areas, such as Castel Gandolfo (Vatican State), from where 15 liverwort species were recently recorded (Aleffi 2017).

Considering that island ecosystems are particularly sensitive to environmental impacts, such as climate change (Patiño et al., 2016), the introduction of exotic species (Silva et al. 2008), and increasing urbanization and associated fragmentation of ecosystems (Borges et al. 2019), recreational parks and gardens may indeed play a decisive role to preserve bryophytes in the Azores, reinforcing the importance of urban greenery as refuge for native species. The present study is a first contribution to the knowledge of the bryoflora of Azorean parks and gardens and to promote the conservation of the natural heritage for the future generations. The presence of bryophytes in RFR-PP offers the opportunity to enrich the visitor's knowledge of the undervalued world of bryophytes, and increase their appreciation of the Azorean ecosystems.

ACKNOWLEDGMENTS

The authors would like to thank the following financing institutions and programs: the Operational Program Azores 2020, financed in 85% by FEDER and 15% by Azorean Public funds, through the project GreenGA - Green Gardens (ACORES-01-0145-FEDER-000070) for missions and through the project AZORESBIOPORTAL – PORBIOTA (ACORES-01-0145-FEDER-000072), for laboratory equipment; the first author, CP was partially funded by the program Eurodisseia – Açores (project 961/2018). We would also like to thank the cooperation of "Direção Regional dos Recursos Florestais", during the visit to the "Reserva Florestal de Recreio do Pinhal da Paz".

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Submitted 13 Nov 2019. Accepted 9 Jan 2020.
Published online 18 Feb 2020.

Annex 1. Catalogue of bryophytes identified in the Recreational Forest Reserve "Pinhal da Paz" (São Miguel Island, Azores).

Below it is presented a list of all species collected in the Recreational Forest Reserve "Pinhal da Paz" (São Miguel Island, Azores) in June 2018, alphabetically organized by Division (Anthocerotophyta, Marchantiophyta and Bryophyta). The code of the sampling point and a brief description of the taxa, mostly based in Casas et al. (2006, 2009) and Schumacker & Vana (2005) are also included.

DIVISION ANTHOCEROTOPHYTA - Hornworts

***Anthoceros caucasicus* Steph. (PP-15)**

Thallose species, prostrate, with globose *Nostoc* (cyanobacteria) colonies; thalli cells with one chloroplast per cell, rhizoids unicellular, smooth; spores with a wide smooth band along the trilete mark.

DIVISION MARCHANTIOPHYTA - Liverworts

***Calypogeia fissa* (L.) Raddi** (PP-9, PP-14, PP-16)

Leafy liverworts, with prostrate stem, abundant rhizoids, leaves longer than wide, widest one third from the base, usually with lobe apex bidentate or more or less acute and underleaves wider than long, divided, with one lateral tooth or protuberance at one or both sides.

***Cololejeunea azorica* V.Allorge et Jovet-Ast** (PP-8)

Minute leafy liverwort, withprostrate stem, oblong leaves, ventral lobule abut half the length and 80% width of the dorsal lobe, bearing a central tooth. Without underleaves.

***Drepanolejeunea hamatifolia* Hook.) Schiffn.** (PP-8)

Minute leafy liverwort, pale green to yellowish green, dorsal lobe convex at base, abruptly narrowed in an often reflexed, acute or acuminate apex, with 1-2-celled teeth at the end; underleaves bilobed, with acuminate, diverging lobes.

***Frullania acicularis* (J.-P.Frahm) Hentschel & von Konrat** (PP-6, PP-7)

Small leafy liverwort, with leaves imbricate with apex incurved for about one third of the length of the lobe, ending in a very acute tip. Tip gradually narrowed into a long acumen, which ends in a unicellular row of 4-5 cells. Underleaves not decurrent.

***Frullania azorica* Sim-Sim et al.** (PP-10)

Small leafy liverwort, generally reddish or dark brown. Leaves imbricate, bilobed, conduplicate; ventral lobules as long as wide, helmet-shaped; underleaves with acute lobes and lateral margins with 1-2 acute teeth.

***Frullania microphylla* (Gottsche) Pearson** (PP-8)

Small leafy liverwort, generally reddish. Leaves imbricate, bilobed, conduplicate; ventral lobules longer than wide, sac-shaped. Leaf cells with walls uniformly thickened, without trigones. Ocelli in two rows on the dorsal lobe (especially on robust shoots) and sometimes also dispersed.

***Harpalejeunea molleri* (Steph.) Grolle** (PP-8, PP-10, PP-12, PP-13)

Minute leafy liverwort, generally yellowish or greenish yellow; mid-leaf cells without oil-bodies or trigones; underleaf lobes rounded, 4-6 cells wide at base; commonly found growing as bryo-epiphyte on other bryophytes.

***Lejeunea lamacerina* (Steph.) Schiffn.** (PP-4, PP-7, PP-9, PP-12, PP-13, PP-14, PP-15, PP-16, PP-17)

Very small leafy liverwort, usually light green; leaves bilobed, incubus, conduplicate and wide underleaves. Free part of the lobes at a 120-160° angle to the keel. Terrestrial and epiphytic.

***Lophocolea bidentata* (L.) Dumort.** (PP-6, PP-7, PP-9, PP-13, PP-14, PP-15, PP-17)

Small to medium-size leafy liverwort, pale green to yellowish green. Leaves alternate, spreading, longitudinally inserted, succubus, bilobed; upper

lobes bilobed, with acuminate lobes; leaf large (25-50 μm). Terrestrial and epiphytic.

***Lophocolea fragrans* (Moris et De Not.) Gottsche, Lindenb. et Nees** (PP-16, PP-17)
Small leafy, aromatic liverwort. Leafs mostly 3-lobed, especially at the apex, mostly with dentate margin.

***Lophocolea heterophylla* (Schrad.) Dumort**. (PP-5, PP-11)
Small leafy, liverwort. Leaves with different shape along the stem, upper leaves simple with rounded or retuse apex, while lower leaves may be bilobed to one third, with lobes acute or acuminate.

***Lunularia cruciata* (L.) Dumort ex. Lindb**. (PP-7, PP-14, PP-15)
Thallose liverwort, glossy green on dorsal side; with thalli furcate with sinuous margins and dorsal epidermis reticulate with striking lunate gemma receptacles on the dorsal surface.

***Metzgeria furcata* (L.) Corda** (PP-10)
Small thallose prostrate liverwort, light green, translucent. Thalli plane with marginal hairs, where present, single, straight; midrib on the ventral face not, or hardly, hairy.

***Porella canariensis* (F. Weber) Bryhn** (PP-12)
Medium-sized leafy liverwort, generally brownish, usually without a metallic sheen. Lobes bilobed, conduplicate, incubus; Median cells of dorsal lobe relatively small (18-25 μm) with uniformly thickened walls; large underleaves, paucispinose.

***Radula aquilegia* (Hook. F. et Taylor) Gottsche et al**. (PP-7)
Small leafy liverwort, olive green colour. Leaves bilobed, concave, cell walls thickened with distinct trigones; lobules approximately rectangular; keel region inflated and often strongly arched.

***Radula wichurae* Steph.** (PP-6, PP-7, PP-8, PP-10)
Small leafy liverwort, olive green colour. Lobes bilobed; mature leaves bordered with 1-3 rows of small hyaline cells, more or less collapsed or partly broken; this feature may also be seen in the lobules.

***Reboulia hemisphaerica* (L.) Raddi s.l.** (PP-13)
Thallose liverwort 1-3 cm long, light to dark green colour with reddish spots and margins; margins sinuose, undulate, unistratose. Air pores, on the dorsal side, with 4-5 concentric rings of cells, and radial walls thickened.

***Riccardia multifida* (L.) Gray** (PP-9, PP-14)
Small thallose liverwort with fragile, dark green thalli, with branches parallel-sided up to their apex; ultimate lobes with unistratose, 2-5 cells wide translucent margins.

***Saccogyna viticulosa* (L.) Dumort.** (PP-7, PP-14)
Medium-sized leafy liverwort, prostrate; Leaves succubus, obliquely inserted, with a rounded apex; well-developed triangular underleaves, bilobed or toothed.

DIVISION BRYOPHYTA - Mosses

***Amblystegium confervoides* (Brid.) Schimp**. (PP-12)
Small sized pleurocarpous moss, with procumbent, irregularly branched stem. Leaves with entire margin and nerve lacking; plants saxicolous, growing mostly on calcareous rocks.

***Amblystegium serpens* (Hedw.) Schimp.** (PP-9)
Small and slender pleurocarpous moss, with procumbent, irregularly branched stem. Leaves ovate lanceolate, up to 1 mm length; margin finely denticulate.

***Andoa berthelotiana* (Mont.) Ochyra (**PP-4, PP-5, PP-7, PP-9, PP-14, PP-15, PP-16, PP-17)
Medium-sized to large pleurocarpous moss. Concave, densely imbricated leaves with denticulate acuminate apex.

***Anomobryum julaceum* (P. Gaerth., B. Mey. et Scherb.) Schimp**. (PP-1)

Small acrocarpous moss, up to 1,5 cm tall, glossy light green. Shoots julaceous, filiform, with appressed leaves, ovate or oblong-lanceolate, with median vermicular cells.

***Atrichum angustatum* (Brid.) Bruch et Schimp**. (PP-5)
Medium-sized acrocarpous moss, usually dark green. Stiff, narrow leaves, with 4-7 lamellae over the central nerve, 6-9 cells high.

***Brachytheciastrum velutinum* (Hedw.) Ignatov et Huttunen** (PP-12)
Small pleurocarpous moss, slender, light to dark green. Stem leaves narrowing until a fine dentate acumen and rectangular alar cells. Leaf margin slightly recurved, more or less dentate.

***Campylopus pilifer* Brid**. (PP-1)
Medium-sized acrocarpous moss with very rigid stems and strongly imbricate leaves. Basal cells narrow, rectangular, hyaline, extending up margins in a V-shape; nerve with dorsal lamellae (2-)3-4 cells high and numerous stereid groups.

Ceratodon purpureus* (Hedw.) Brid. subsp. *purpureus
Small acrocarpous moss, forming green or reddish turfs to 2 cm high. Leaves erect-patent with apex slightly denticulate; leaf margin recurved; stout nerve, percurrent or excurrent.

***Dicranoweisia crispula* (Hedw.) Lindb. ex Milde** (PP-16)
Medium-sized acrocarpous moss, up to 3 cm tall. Plants crisped when dry. Leaves with unistratose margin and apex. Median cells of the leaves small (6-8 μm wide).

***Fissidens asplenioides* Hedw.** (PP-9, PP-15, PP-16)
Small to medium-sized acrocarpous moss. Leaves with three blades, oblong-lingulate; apices often strongly inrolled towards the substrate when dry; crenulate-serrulate margins towards the apex.

***Fissidens taxifolius* Hedw.** (PP-7, PP-13, PP-14)
Small acrocarpous moss, yellowish to dark green. Leaves with three blades, long, oblong-lanceolate and acute or broadly acute apex. The nerve is stout and usually excurrent.

***Hypnum jutlandicum* Holmen et E. Warncke** (PP-5, PP-7)
Medium-sized, pale green, pleurocarpous moss. Leaves from straight to falciform, ovate or oblong-lanceolate, loosely imbricate; alar cells more or less homogeneous and rectangular.

***Hypnum uncinulatum* Jur**. (PP-6)
Medium-sized, pale green to brownish pleurocarpous mosses. Leaves falciform, gradually narrowed to acuminate apex (triangular shape) and margin denticulate. Alar cells irregular and heterogeneous.

***Kindbergia praelonga* (Hedw.) Ochyra** (PP-5, PP-9, PP-13, PP-14, PP-15, PP-17)
Medium-sized to large pleurocarpous moss, dark green or greenish brown. Stem and branch leaves with different leaves shapes: narrowly decurrent and widely ovate or cordate-triangular at the stem, and ovate or lanceolate at the branches.

***Philonotis rigida* Brid.** (PP-13)
Small acrocarpous moss, with radiculose erect stems. Densely imbricate leaves; leaf margin plane with simple teeth; nerve mamillose at back.

***Polytrichum juniperinum* Hedw**. (PP-2)
Large acrocarpous moss, up to 8 cm tall, dark green. Stem not tomentose or with sparce brown tomentum. Long leaves, spreading when dry, excurrent in short or long arista; nerve with filaments on ventral side; apical cells of lamellae pyriform in cross-section, smooth.

***Ptychomitrium nigrescens* (Kunze) Wijk et Marg**. (PP-12)
Small acrocarpous moss, up to 1 cm tall, blackish to green along the stem. Leaves patent, crisped when dry, linear-lanceolate with acute apex.

***Ptychostomum capillare* (Hedw.) Holyoak & N. Pedersen** (PP-13)
Small acrocarpous moss. Leaves ovate, oblong or

spathulate, abruptly tapering in more or less long point; nerve excurrent or ending below aped, margin formed by longer cells along the whole leaf. Red to brown rhizoidal gemmae, when present.

***Sematophyllum substrumulosum* (Hampe) Britton** (PP-4, PP-8, PP-9)
Slender pleurocarpous moss. Leaves narrowly lanceolate with long, filiform apex, without nerve and large alar group, with 4-6 inflated cells.

***Tetrastichium virens* (Cardot) S. P. Churchill** (PP-14, PP-15, PP-16, PP-17)
Medium-sized pleurocarpous moss, irregularly branched, with complanated stem leaves. Leaves lanceolate to ovate-lanceolate, margin entire to slightly denticulate near the apex, and small median cells (10-16 μm wide).

***Tortella nitida* (Lindb.) Broth.** (PP-13)
Small acrocarpous moss, up to 1 cm tall. Lanceolate leaves, with very fragile lamina; basal cells smooth, hyaline, ascending up margin; leaf margin incurved, and nerve conspicuous, excurrent and glossy back.

***Trichostomum brachydontium* Bruch** (PP-5, PP-7, PP-9)
Small acrocarpous moss, up to 2 cm long. Long leaves, erect-patent, with margin plane, entire; nerve excurrent in stout apiculus.

***Zygodon rupestris* Schimp. ex Lorentz** (PP-10)
Small acrocarpous moss up to 3 cm tall. Leaves contorted or flexuose when dry, with unistratose lamina in the upper part and median leaves cells with 3-6 low papillae per cell. Gemma 20-30 μm wide, without longitudinal walls.

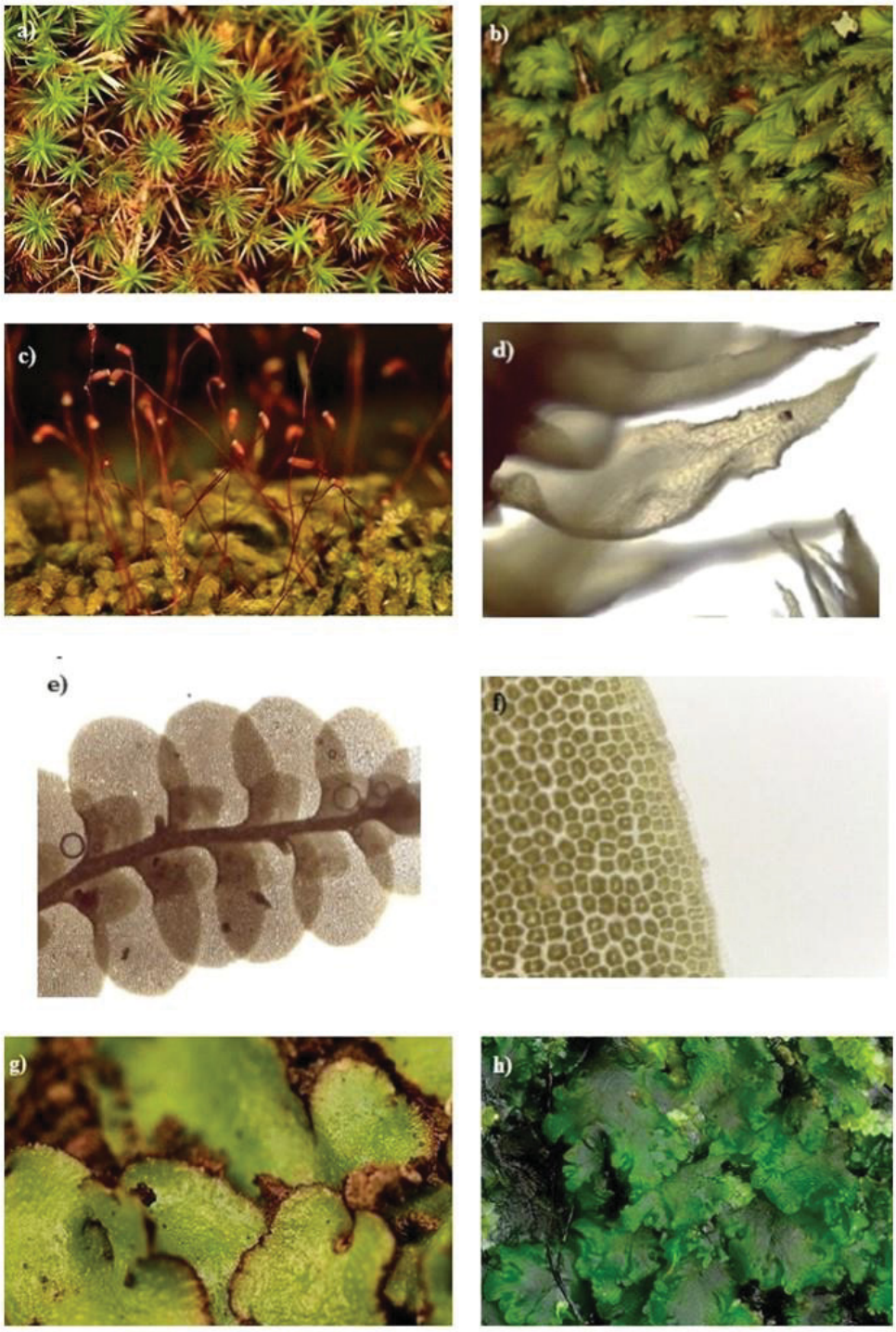

Plate 1. Polytrichum juniperinum; b) Fissidens asplenioides; c) and d) Andoa berthelotiana; e) and f) Radula wichurae; 1g) Reboulia hemisphaerica; 1h) Anthoceros caucasicus.