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Article

Bryophytes Collection of the UB Herbarium, Brazil

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Abstract: A herbarium is a library of preserved dried samples of vascular plants, bryophytes, fungi, algae and/or lichens and is maintained for educational and scientific purposes, and provides detailed information on taxonomy, systematic, biodiversity, ecological and evolutionary research studies. Globally, there are more than 3,000 active public herbaria that preserve around 400 million exsiccates. In Brazil there are 216 active herbaria, of which 162 are indexed in the *Index Herbariorum* and in the Central region there are 21 herbaria. In this context, the Herbarium of the University of Brasília (international code UB) was founded in 1963 together with the Department of Botany of UnB and is located at the Institute of Biological Sciences of the Campus Darcy Ribeiro, Brasília and it is fifth largest herbarium in Brazil and presents approximately 277 thousand samples. In this study, we present here the bryophytes collection at the UB Herbarium. The collection of bryophytes of UB herbarium has 30,902 samples of all continents and 79 countries and most come from Brazil, Papua New Guinea, Malaysia, United States of America and Argentina.

Keywords: biological collections; herbaria; historical collections; *Index herbariorum*; taxonomy; type

1. Introduction

Biological collections, including herbaria, are crucial sources of biodiversity data that are used to map the distribution of organisms over time and space. They are fundamental for understanding the impact of climate change in the Anthropocene era [1]. According to [2], knowledge about biodiversity allows us to understand the past and learn how to better manage the future.

Herbaria are like libraries of preserved plant dried samples, as well as other groups such as fungi, lichens, and algae, along with their associated collection data, auxiliary collections (e.g., photographs), and library materials (MSU Herbarium, 2023). They represent invaluable and irreplaceable sources of information about plants and the ecosystems. Herbaria provide essential comparative material for studies in taxonomy, systematic biology, ecology, anatomy, morphology, conservation biology, biodiversity research, ethnobotany, and paleobiology. Additionally, they serve educational purposes and are accessible to the public. These collections serve as a treasure trove of information and form the basis of comparative biology.

Currently, more than 396 million specimens are maintained in over 3,000 active herbaria, serving as the foundational documentation for all formally described plant species [3,4], and this number continues to grow. The five largest herbaria alone house approximately 36 million specimens (P-Paris, NY-New York, K-Kew, MO-Missouri, and LE-St. Petersburg; *Index Herbariorum* Online: http://sweetgum.nybg.org/science/ih/). In Brazil, there were 216 active herbaria in the year 2018 [5]. Of these, 162 (75%) are registered in the *Index Herbariorum*. In total, the Brazilian Cerrado has 21 herbaria [5].

Indeed, herbarium studies should not be limited to the examination of the most recent specimens but should also encompass historical specimens [6], which have proven to be fundamental in various biological disciplines. This applies to fields traditionally inclined toward herbarium use [7] as well as more recent approaches addressing climate change, biodiversity, phenology, nature conservation, biological invasions, DNA bank and phylogenomics [4–12] and others.

Herbaria serve as repositories for nomenclatural types and contain valuable data for studies on threatened species or documentation of taxa that have become extinct in historical times [13].

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Accessing historical herbarium specimens provides a unique window into the past, allowing researchers to investigate changes in plant distributions, phenological patterns, and biodiversity over time. This historical perspective is especially valuable in understanding the impact of environmental changes, human activities, and other factors on plant life and ecosystems.

The Herbarium of the University of Brasília (UB) was established in 1963, by Dr. João Murça Pires (1917-1994), together with Dr. Graziela Maciel Barroso (1912-2023) and they were the first taxonomists responsible for the UB Herbarium. Notable botanists, such as Ezechias Paulo Heringer (1905-1987), also contributed to the compilation and cataloguing of botanical specimens from the Cerrado domain [14].

Over time, the institution expanded its activities, becoming a significant reference center for taxonomic and botanical studies in the Brazilian Central region. Today, it stands as the largest Brazilian Savana herbarium globally, containing specimens from various Brazilian vegetation types, as well as collections from different parts of Latin America and the world [14].

The Herbarium UB of the University of Brasília is registered in the *Index Herbariorum* (https://sweetgum.nybg.org/science/ih/) and belongs to the Brazilian Herbaria Network of the Brazilian Botanical Society (https://www.botanica.org.br/a-rede-brasileira-de-herbarios/). It ranks among the top 3 herbaria in Brazil, with a collection of 277,243 samples, encompassing both cryptogams and phanerogams [15] (http://ub.jbrj.gov.br/v2/herbarios.php).

Among the cryptogams, the UB Herbarium houses a valuable collection of bryophytes. Bryophytes include liverworts (Division Marchantiophyta), mosses (Division Bryophyta), and hornworts (Division Anthocerotophyta). These organisms cover the soil, trunks, stems, branches, and leaves of flowering plants in humid tropical forests and other vegetation types, playing a crucial role in ecosystems {16]. Bryophytes contribute to nutrient cycling, colonization of bare substrates, soil formation and retention (preventing river flooding and siltation), water retention (maintaining moisture and preventing droughts), soil erosion reduction, and nitrogen fixation [16]. They serve as substrates for other plants, provide shelter for small animals, and can be used as ecological, paleoecological, mineral deposit, water, and air pollution bioindicators [16].

The bryophyte collection at the UB Herbarium not only enriches the University's holdings but also contributes to the understanding of national and international biodiversity. It serves as a valuable resource for researchers, students, and enthusiasts, providing essential data such as collection location, habitat, and morphological characteristics that are crucial for future studies and research. The careful maintenance of the collection, using appropriate preservation techniques, ensures not only the integrity of the specimens but also the preservation of the scientific knowledge associated with each.

Although there are no specific records of the date of its creation, the bryological collection originated in the 1960s with a few specimens primarily collected by undergraduate Biology students at UnB-University of Brasilia [17]. The bryophytes collection is the culmination of decades of collection and research efforts, contributing to the understanding of a botanical group that has been relatively underexplored. The bryophyte collection received a new impetus in 1979 with the arrival of cryptogamist Dr. Lauro Xavier Filho at UnB. Dr. Lauro remained at UnB until 1982 when he was succeeded by the phycologist Dr. Pedro Américo Cabral Senna, who played a significant role in the collection's growth [17].

The collection expanded through the incorporation of specimens collected by the American botanist H.S. Irwin in the late 1960s and early 1970s. Additionally, the bryophyte specialist Daniel Moreira Vital from the São Paulo Botanical Institute contributed to the collection's growth. Invited by Dr. Pedro Américo, Vital conducted various expeditions to collect bryophytes in the Distrito Federal in November 1985. These expeditions included sites such as the Reserva Ecológica do IBGE, Rio Descoberto, Estação Ecológica Águas Emendadas, Mumunhas waterfall, and the forests along the tributaries of Lake Paranoá [17].

In 1992, Dr. Pedro Américo left UnB, leaving behind a collection of 1,100 bryophyte specimens at UB herbarium. Most of these specimens originated from the Distrito Federal, and the collectors were primarily Irwin, Vital, and their undergraduate students [17]. In 2002, the first master's

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dissertation in the Cerrado domain focusing on the flora of bryophytes was completed by Paulo E.A.S. Câmara, then a student, contributing to the enrichment of the collection [17].

In 2009, Dr. Paulo Câmara became the first specialist in bryophytes hired to join the staff of the UB Herbarium. By this time, the bryophyte collection had around 1,600 specimens, having grown by only about 500 specimens in 17 years [17]. The presence of a specialist brought significant advancements to the collection, allowing for the identification of numerous undetermined plants. Various master's dissertations and doctoral theses led to intensive collections throughout Brazil, enriching the herbarium's holdings [17]. The bryophyte collection, which in 2017 facilitated the publication of the "Flora do Distrito Federal: Briófitas" [18], boasted the highest number of specimens from the region, including many taxa represented solely in this collection [17].

Another significant factor was the receipt of duplicates from Dr. Câmara's collections in Southeast Asia, a result of his doctoral work at the Missouri Botanical Garden. This expanded the regional nature of the bryophyte collection, further enhanced by the exchange of specimens from various herbaria, including BM, CAS, L, MO, NY, PRE, S, W and national herbaria such as FLOR, HPAN, RB, SP, and TANG [17].

Our goal is to enhance the visibility and importance of the UB Herbarium's bryophyte collection on both the national and international stages. This involves modernizing the dissemination of information and providing detailed descriptions of the infrastructure, human resources, and specific features of the bryophyte collection at the UB Herbarium in Brasília, Brazil. This effort aims to showcase the significance of the collection in the broader scientific community and facilitate access for researchers and institutions interested in the study of bryophytes and biodiversity.

2. Materials and Methods

The UB Herbarium is located at the University of Brasília at the Darcy Ribeiro campus in Brasília, Distrito Federal, Brazil. The collection has acquired a new space and has been physically separated from the collections of other plants due to the increasing need for physical space (Figure 1).

The herbarium's abbreviations adhere to the *Index Herbariorum* [19]. The total number of specimens deposited in the UB Herbarium and the taxa with the highest representation among bryophytes were surveyed using a Microsoft Excel spreadsheet loaded on the Jardim Botânico do Rio de Janeiro website and UB Herbarium was selected (http://ub.jbrj.gov.br/v2/consulta.php), and data were also gathered from the *Specieslink* website (https://specieslink.net/search/). The survey encompasses the entire period from the inauguration of the herbarium to the present (2023).

Maps were created using QGIS 3.22.16- Bialowieza (qgis.org), and shapefiles (vectors) were utilized for the World, Brazil, and Phytogeographic Domains of IBGE [20]. Phytogeographic domains are based on [21]. The heat map (Kernel Density Estimation) was employed for the Brazil maps in the QGIS software [22] to visualize regions with a higher density of records. Parameters used for Brazil include a radius of 100,000 meters, lines 4480, columns 4381, pixel size x and y: 1 thousand, Kernel shape Quartic, SRC: ESG:5880 – SIRGAS 2000 / Brazil Polyconic, rendering type: single-band false-color, Band 1 (Gray), cumulative cut count.

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Figure 1. Bryophyte collection of the UB Herbarium. **A.** Botany Department at the University of Brasília. **B.** Bryophyte collection. **C.** Plate indicating the bryophyte collection. **D.** Cabinets with small drawers adapted for bryophyte species. **E.** Sematophyllaceae cabinets. **F.** Detail of Sematophyllaceae cabinets showing one letter. **G.** One specimen of Sematophyllaceae.

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3. Results

The bryophyte collection at the UB Herbarium is currently represented by 30,902 specimens, of which 5,000 are undetermined (Figure 2). Collections have been made from all continents (Table 1). Seventy-nine countries are represented with collections including Brazil with 19,553 specimens, Papua New Guinea with 1,032, and Malaysia with 791 records, among others (Table 2). Other important collections are from islands and archipelagos with 5,950 records and most of these are islands of Antarctica with 1,011 specimens, Falklands (Malvinas) with 743, South Georgia with 674, Trindade Island with 601 and Fernando de Noronha with 558 specimens (Table 3).

The primary collectors are Câmara, P.E.A.S with 3,866 collections, Soares, A.E.R. with 2,079 collections, Valente, D.V. with 1,616, and Faria, A.L.A. with 1,204, among others (Table 4). The main determiners of the specimens are Câmara, P.E.A.S. with 3,332 identifications, Peralta, D.F. with 2,074, Sousa, R.V. with 1,342, Faria, A.L.A. with 820, and Soares, A.E.R. with 740, among others (Table 5).

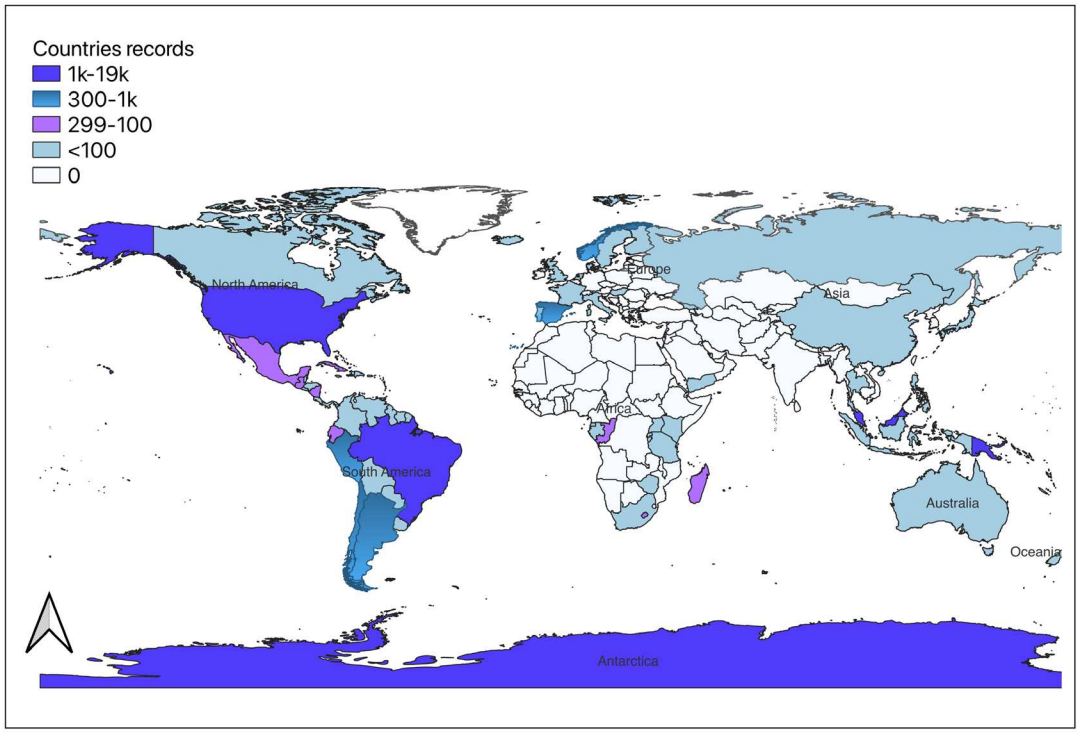

Figure 2. Records of bryophytes in countries collected and deposited at UB Herbarium.

Table 1. Number of specimens deposited at UB herbarium in different continents.

Continents	Records
South America	14,081
Antarctica	5,871
Asia	1,298
Oceania	1,032
Africa	502
North America	454
Europe	381

[1] Continents collected.

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Table 2. Top ten countries collected.

	Country	Records
1.	Brazil	19,553
2.	Papua New Guinea	1,032
3.	Malaysia	791
4.	United States of America	710
5.	Argentina	577
6.	Chile	565
7.	Bolivia	108
8.	Japan	107
9.	Spain	50
10.	Netherlands	40

Table 3. Number of specimens deposited at UB herbarium in different islands and archipelagos.

Country	Records
1. Antarctic Islands	1,011
2. Falklands (Malvinas)	743
3. South Georgia	674
4. Trindade	601
5. Fernando de Noronha	558

Table 4. Top ten collectors of bryophytes at the UB Herbarium.

Collectors	Records
1. CÂMARA, PEAS	3,866
2. SOARES, AER	2,079
3. VALENTE, DV	1,616
4. FARIA, ALA	1,204
5. GAMA, R	934
6. CARVALHO-SILVA, M	837
7. SOUSA, RV	827
8. DANTAS, TS	687
9. VITAL, DM	523
10. CUNHA, MJ	338

Table 5. Top ten determiners of bryophytes at the UB Herbarium.

Determiners	Records
1. CÂMARA, PEAS	3,332
2. PERALTA, DF	2,074
3. SOUSA, RV	1,342
4. FARIA, ALA	820
5. SOARES, AER	740
6. EVANGELISTA, M	483
7. CUNHA, MJ	389
8. SOUZA, RV	149
9. CARVALHO-SILVA, M	109
10. STEERE, WC	80

In Brazil, the main regions of collection are the Midwest and Southeast, including the Distrito Federal, Goiânia, and Mato Grosso, followed by São Paulo, Minas Gerais, and Rio de Janeiro (Figure 3). The primary phytogeographic domains collected in Brazil are Cerrado, Atlantic Forest, and

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Pantanal (Figures 4 AND 5), However the herbarium has the best collections of the Brazilian islands of Fernando de Noronha and Trindade Island.

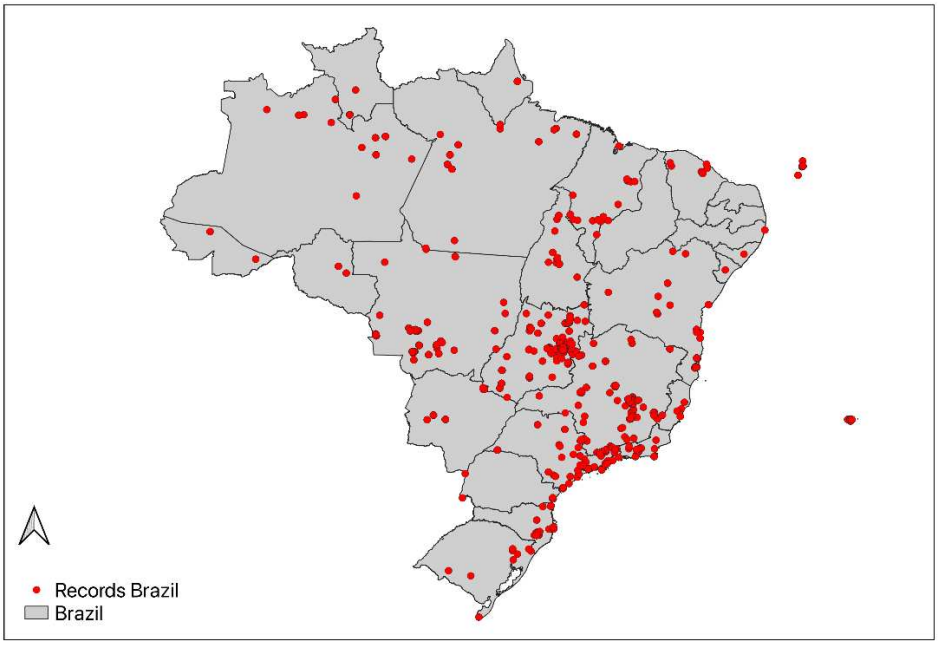

Figure 3. Bryophyte records from Brazil deposited at the UB Herbarium.

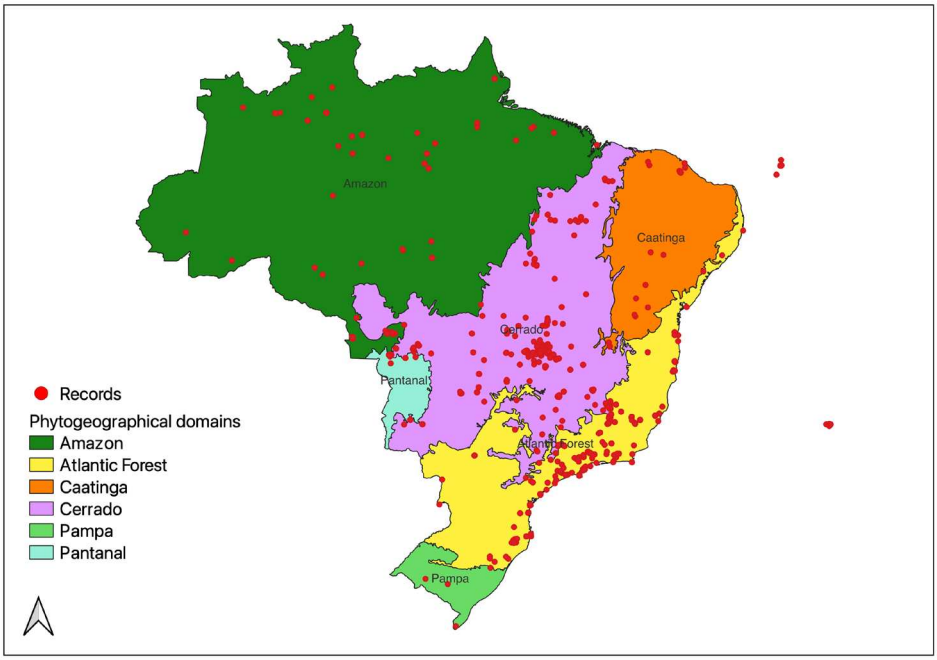

Figure 4. Bryophyte records from the phytogeographical domains in Brazil deposited at the UB Herbarium.

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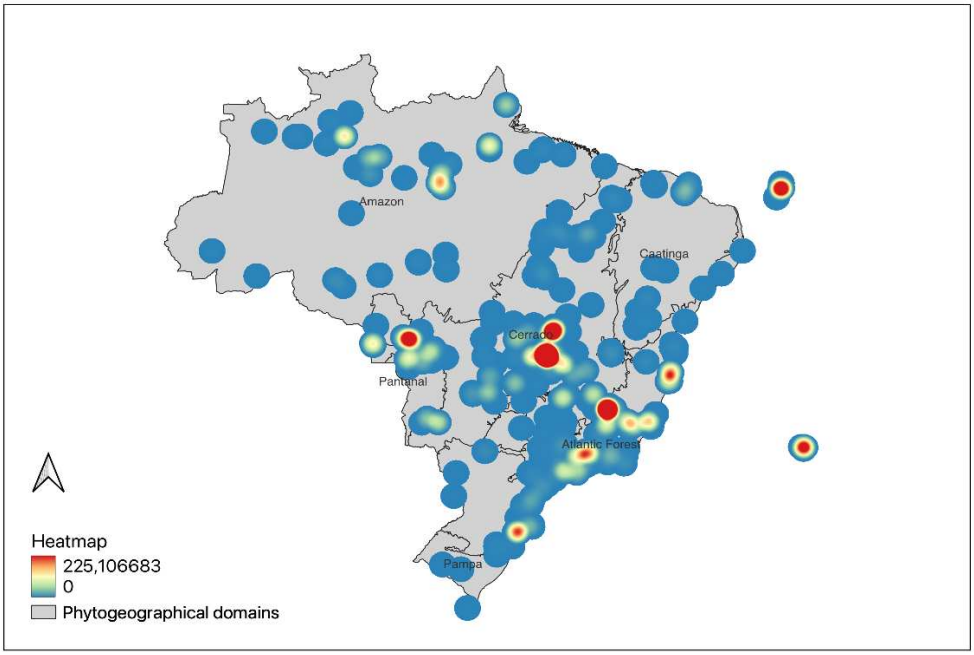

Figure 5. Heatmap (Kernel density) of bryophyte records from the phytogeographical domains in Brazil.

Most of the records are mosses (93%), followed by liverworts (7%); there are 27,353 specimens of the Division Bryophyta Schimp. Musci, and the most representative families are Sematophyllaceae Broth with 21% (3,738), Bryaceae Schwägr. with 11% (1,955), Pottiaceae Schimp. with 11% (1,952), Polytrichaceae Schwägr. with 10% (1,702), Leucobryaceae Schimp. with 9% (1,644), Hypnaceae Schimp. with 8% (1,320), Pylaisiadelphaceae Goffinet & W.R.Buck with 7% (1,154), Calymperaceae Kindb. with 7% (1,209), Bartramiaceae Schwägr. with 5% (926), Fissidentaceae Schimp. with 5% (854), and Dricanaceae Schimp. with 5% (784), and other families with 1% (Figure 6). Subsequently, there are 1,924 specimens of the Division Marchantiophyta Stotler & Crand.-Stotler, with the most representative families being Lejeuneaceae Cavers with 44% of the records (1,140), Plagiochilaceae (Joerg.) K.Müll. with 14% (365), Frullaniaceae Raddi with 12% (303), Metzgeriaceae Raddi with 7% (187), Lepidoziaceae Limpr. with 7% (177), Radulaceae K. Müll. with 3% (82), Lophocoleaceae De Not. with 4% (99), Pallaviciniaceae Mig. with 3% (82), Marchantiaceae (Bisch.) Lindl. with 3% (77), and Aneuraceae H.Klinggr. with 2% (67), and other families with 1% (Figure 7).

Lastly, there are 44 specimens of the Division Anthocerotophyta Rothm. ex Stotler & Crand.-Stotl., with the most representative families being Notothyladaceae Grolle with 64% of the records (29), Anthocerotaceae Dumort. with 27% (12), and Dendrocerotaceae J. Haseg. with 7% (3), and other families with 2% (Figure 8). It is noteworthy that the collection includes 95 type materials belonging to the families Hypnaceae, Leskeaceae Schimp., Mniaceae Schwägr., Pylaisiadelphaceae, Sematophyllaceae, Sphagnaceae Dumort., and Thuidiaceae Schimp. The main life forms of the specimens in general are tuft with 38% of the records (4,298), mat with 33% (3,664), foliose with 27% (3,063), thallose with 2%, and other life-forms (Figure 9).

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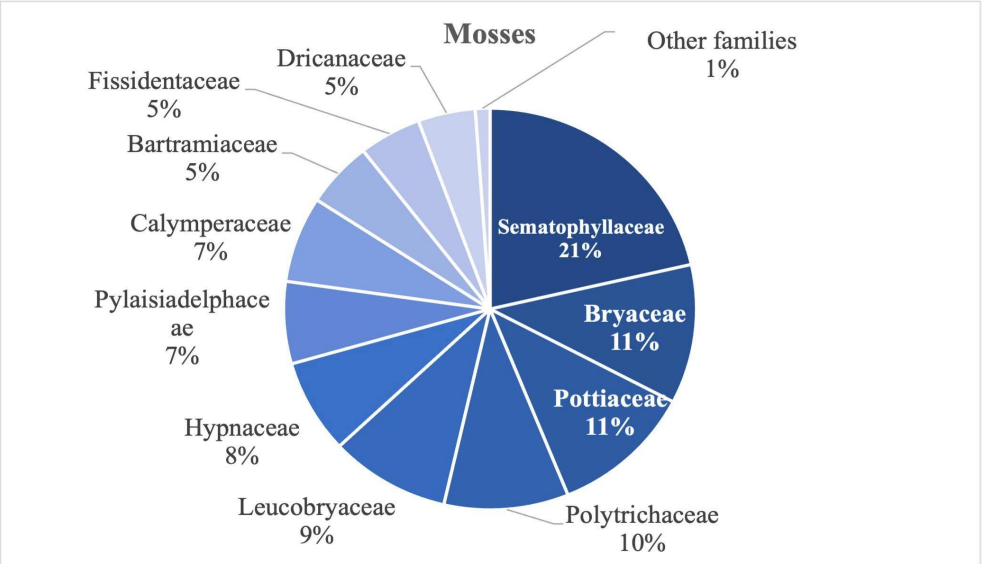

Figure 6. Most represented families of mosses (Division Bryophyta).

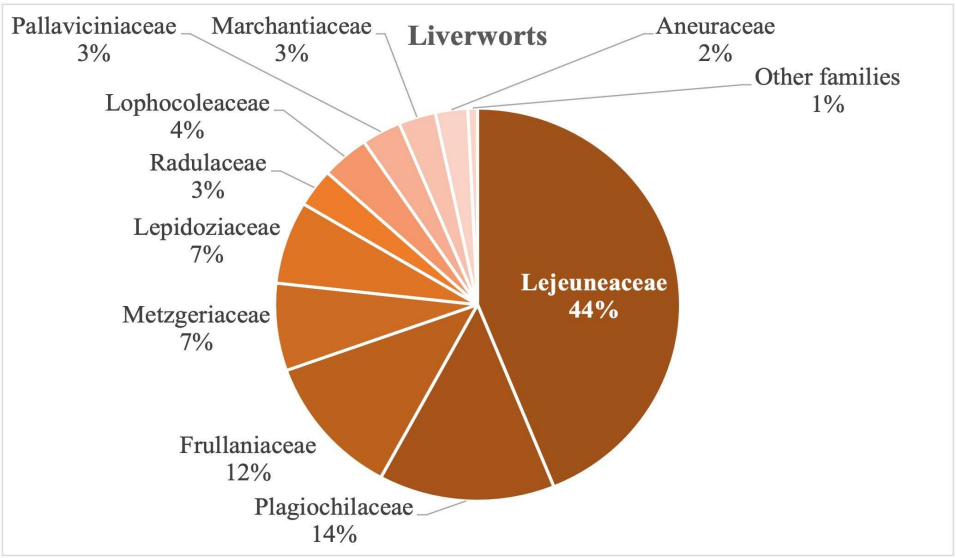

Figure 7. Most represented families of liverworts (Division Marchantiophyta).

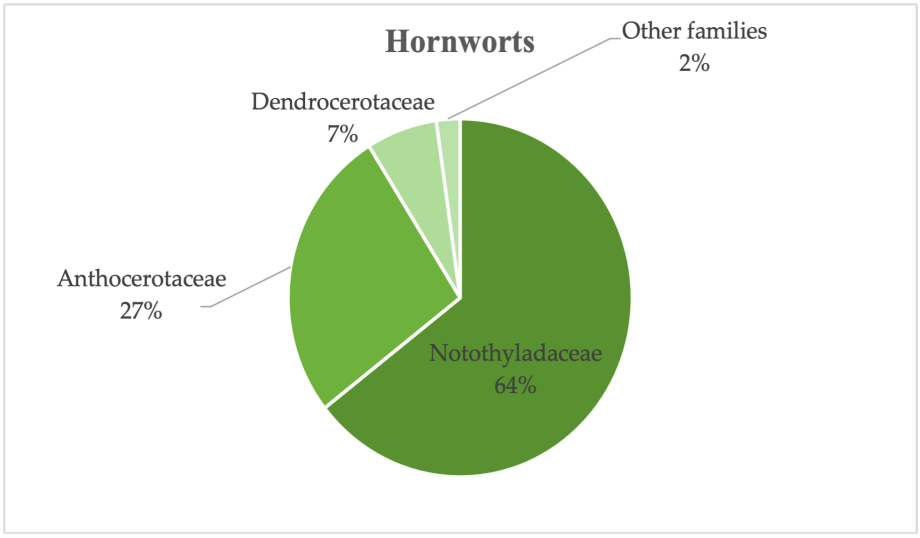

Figure 8. Most represented of hornworts (Division Anthocerotophyta).

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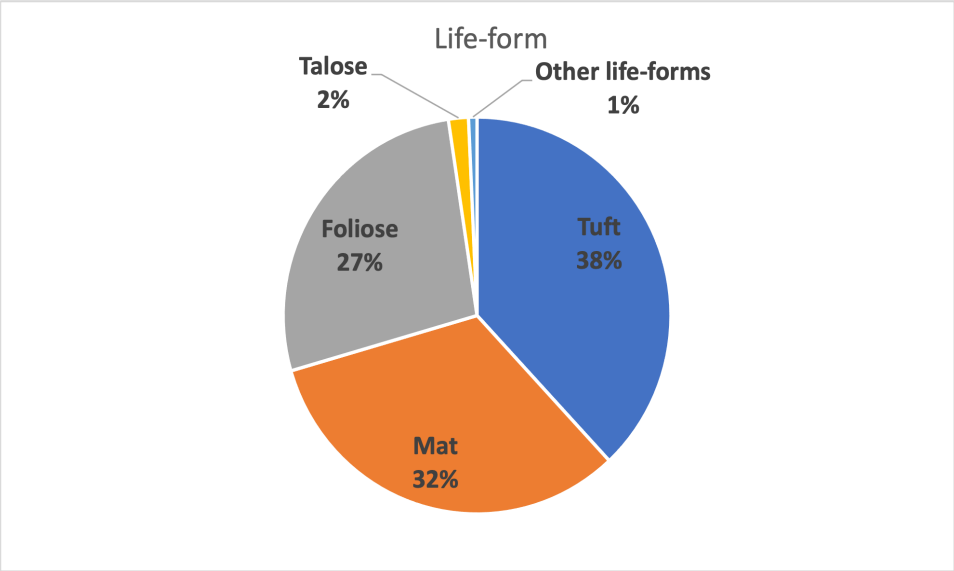

Figure 9. Main life forms of the total sample.

The presence of numerous taxa not found in Brazil is of paramount importance for research and the training of future taxonomists. The bryophyte collection at UB plays a vital role in supporting studies and facilitating the development of taxonomic expertise. The exchange program has contributed to UB's collection by bringing in rare and ancient plants, including specimens collected in the 19th and 20th century by renowned collectors. Notably, the herbarium has received contributions from pioneers in polar research, such as Robert Peary (Table 6).

Our herbarium holds specimens that are currently threatened with extinction in Brazil; they belong to Division Marchantiophyta, *Marchantia berteroana* Lehm. & Lindenb. (EN) "B2ab (i,ii)" and *Riccia ridleyi* A.Gepp. (CR) "B2ab (i,ii,iii)". *Marchantia berteroana* is not endemic to Brazil and exhibits a circumpolar distribution pattern, with extensions in high-altitude areas in Oceania, the tropical Andes, Galápagos, Costa Rica, Ecuador, Peru, and Bolivia (Costa, pers. comm.). In Brazil, it is found in the Atlantic Forest in the states of the Southeast region (Minas Gerais, Rio de Janeiro) and the South region (Rio Grande do Sul and Santa Catarina). The species has an extent of occurrence (EOO) of 16 km² and is subject to no fewer than five threatening situations, considering the states where the species occurs and its vulnerability to wildfires and habitat fragmentation, which directly affect its dispersal and reproduction.

There is suspicion of a low collection effort for this species, which displays a disjunction that may reflect a lack of comprehensive studies. Therefore, it is necessary to direct research efforts and collect field data to assess the status of subpopulations and their occurrence areas. *M. berteroana* has been categorized as "Endangered" (EN) according to CNCFlora [23].

Riccia ridleyi is not endemic to Brazil and is also found in Venezuela and Peru (Bischler-Causse et al., 2005). In Brazil, it occurs only on the island of Fernando de Noronha, *R. ridleyi* is considered rare [24]. It has an area of occurrence (AOO) of less than 10 km² and is subject to only one threatening situation. In the 19th century, the archipelago underwent extensive deforestation, leading to a significant decline in the area and quality of the habitat in the region. Parameters identified in a phytosociological study suggest that the insular ecosystem in the locality is fragile. Coupled with the species being extremely sensitive to environmental disturbances arising from tourism in the region, this highlights the need for conservation actions and monitoring of the species' subpopulations, which are considered rare [23].

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Table 6. Rare and ancient collections deposited in the UB Herbarium.

Species	Collector	Collection date	Location
Bracrythecium plumosum Hedw.) Schimp.	*Pringle, CG 394.*	2-X-1880	USA, Vermont Brooks
Ptilium crista-castrensis (Hedw.) De Not.	*Pringle, CG s.n.*	2-X-1880	USA, Vermont Underwill
Thuidium subserratum Renauld & Cordot	*Humblot, L s.n.*	1890	Monaco
Haplocladium riograndense Mull. Hal.	*Ule, E 96*	1890	Brazil, Santa Catarina
Braunia andrieuxii Lorentz	*Pringle, CG 742*	09-XI-1890	México, Michocoan
Rhaphidorrhynchium cyparissoides (Hornsch.) Broth.	*Ule, E 64*	VI-1890	Brazil, Santa Catarina Serra Geral
Jungermannia grandiretis Lindb.	*Tolf, R 34*	13-VI-1890	Sweden Östergötland
Mnium intermedium Kindb.	*Holzinger, JM s.n.*	V-1890	USA, Bear Creek Minessota
Jungermannia guttulata Lindb. & Arnell	*Arnell, HW 34 Gestri;*	04-VIII-1900	Sweden
Thuidium liliputanum Broth	*Watts, WW s.n*	V-1900	Australia New South Wales
Acroporium pungens (Hedw.)	*Britton, NL 703*	08-IX-1901	Saint Kitts Nevi St. Kitts
Thuidium schistocalyx (Mull. Hal. Mitt)	*Ule, E 282*	VII-1901	Brazil, Jurua
Thuidium subdelicatulum Hampe & Broth	*Schiffner 479*	12-IX-1901	Brazil, Rio de Janeiro
Polytrichastrum alpinum G.L. Smith	*Peary, RE 13*	1902	Fort Conger, Greenland

4. Discussion

In comparison with other Brazilian herbaria, the bryophyte collection at UB is the second largest, exceeded only by the SP Herbarium, which has around 100,000 specimens. However, UB's collection stands out as the most diverse, with samples collected from all continents, including Antarctica, and representing 79 countries, and representatives from little known oceanic islands with few collections due to difficult access, such as Trindade, Falklands (Malvinas) and South Georgia, and covers all the Brazilian phytogeographical domains. UB's collection is also the largest of Antarctic plants in Latin America, comprising approximately 5,871 specimens.

The predominance of mosses deposited in the herbarium was expected, considering that this division is the most abundant in Brazil, with 896 species, and globally there are 12,900 species [25,26]. The high diversity of mosses can be explained by their morphology, as the structure of their gametophyte and the different life forms within this group allow them to thrive in dry, exposed, or high-altitude environments [27–29].

The most abundant families were Sematophyllaceae, Bryaceae, and Pottiaceae, listed as frequent in tropical forests [30]. Additionally, Bryaceae is one of the moss families with broad richness and distribution, encompassing approximately 660 cosmopolitan species [31]. Regarding the division Marchantiophyta, Lejeuneaceae was the richest family, possibly due to the affinity of its representatives with common substrates in forested areas, such as branches, trunks of living or decomposing trees, rocks, soils, and living leaves [28]. Concerning the division Anthocerotophyta, hornworts are the least diverse among bryophytes, with around 300 species worldwide and 18 confirmed occurrences in Brazil. This lower species incidence was expected [25,32].

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5. Conclusions

The UB Herbarium plays a fundamental role in advancing scientific knowledge, serving as a valuable source for various disciplines. Its significant contribution to taxonomy allows for the determination and confirmation of plant identifications, as well as the discovery of new species. The herbarium plays a strategic role by providing crucial information for future studies and offering material for morphological measurements and DNA analyses, contributing significantly to research in systematics, evolution, genetics and other studies.

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