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Bryophyte literature records database of Aysén, Chilean sub-Antarctic ecoregion

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The Chilean sub-Antarctic ecoregion hosts the largest expanse of temperate forests, wetlands and peatlands, as well as the largest proportion of protected areas in the southern hemisphere. Bryophytes are highly diverse and ecologically essential in sub-Antarctic ecosystems and are considered as biodiversity loss indicators caused by the current socio-ecological crisis. However, knowledge about their biodiversity is rather limited. Integrating the available information on bryophyte diversity in regional platforms such as SIB-Aysén can be useful to acknowledge their ecological importance and remarkable biodiversity. This article integrates 345 records of 273 bryophyte taxa known in the region of Aysén and emphasizes the need to include citizen science as a tool to increase observations in lesser-known taxonomic groups.

Background & Summary

The Chilean sub-Antarctic ecoregion stands as one of the most remote and pristine areas globally, encompassing the administrative regions of Aysén in the north (43° - 49° S) and Magallanes in the south (49° - 56° S). This ecoregion hosts the largest expanse of temperate forests, wetlands, ice fields, and uncontaminated rivers in the southern hemisphere, housing most of Chile's protected areas[1]. Due to its unparalleled uniqueness, it has become a focal point of great scientific interest[2,3]. However, the region's recent colonization history, coupled with remoteness and limited accessibility, may explain the limited knowledge about its biodiversity, particularly bryophytes[4–7].

The rugged topography of the Aysén region is a result of the combined forces of tectonic activity, volcanism, and glaciers, shaping both archipelagos and peninsular surfaces that form part of the Patagonian Andes Mountain range. With a cold oceanic climate, the archipelagos experience abundant rainfall, while the continental zone features a cold steppe climate with lower precipitation. Predominantly, low-altitude forests of Lenga (*Nothofagus pumilio* [Poepp. & Endl.] Krasser), Coigüe (*N. dombeyi* [Mirb.] Oerst.), and Ñirre (*N. antarctica* [G.Forst.] Oerst.) thrive in this harsh environment, characterized by snow, strong winds, low temperatures, and glaciers. These forests are noteworthy for their diverse habitats, providing optimal conditions for the development of various bryophytes[8]. The biodiversity in this area results from various biogeological phenomena, such as the Andean uplift, and the presence of the "arid diagonal", a continuous strip of arid climate running southeast-northwest, isolating ecosystems in this region[9]. Although the peatlands of Aysén remain largely unexplored, recent research efforts have started to shed light on their bryophyte biodiversity[6,7].

Bryophyte diversity in the sub-Antarctic ecoregion. Bryophytes represent a crucial evolutionary link to terrestrial life for photosynthetic organisms, constituting the oldest group of plants with origins dating back approximately 500 million years ago[10]. Thriving in diverse environments from polar to tropical regions, they exhibit remarkable adaptability to varying environmental conditions[4]. With a simple body structure devoid of specialized tissues for water and nutrient transport, bryophytes absorb these essential elements directly from the air humidity through their tissues[5].

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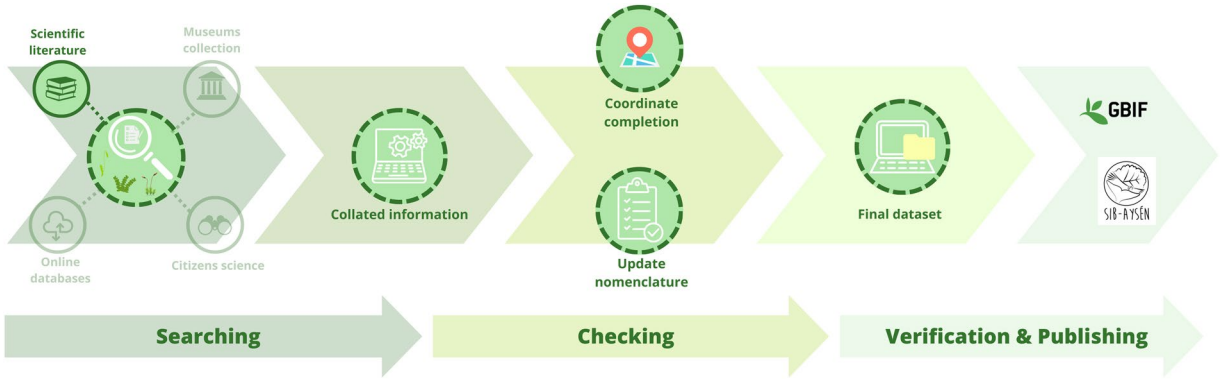

Fig. 1 The project "Biodiversity Information System for Aysén (SIB-Aysén)" aims to contribute to the knowledge and management of local natural biodiversity by facilitating access to quality and georeferenced scientific data. The SIB-Aysén is an interactive platform that is freely accessible online, developed by a multidisciplinary group of scientists and computer engineers from the University of Magallanes. Together with data obtained from specialized scientific journals and the GBIF platform, the bryophyte diversity published in the Aysén sub-Antarctic ecoregion was compiled and analyzed. This research aims to highlight a historically biased plant group in conservation efforts, based on published scientific observations, in order to provide a dataset for nature-based decision-making.

In temperate ecosystems, bryophytes contribute significantly to biomass and play key roles in regulating water availability[5] and carbon sequestration, particularly in peatlands, while also providing thermal regulation[11,12]. Despite these critical ecological functions, their inconspicuous appearance often leads to oversight, resulting in a scarcity of comprehensive studies[4,6].

Nonetheless, there is a growing interest in this taxonomic group, driven in part by their high vulnerability to disturbances, primarily due to their poikilohydric nature—lacking water regulation mechanisms. This vulnerability makes them excellent indicators of local-scale environmental variations[11]. Alongside microalgae and lichens, bryophytes are among the first colonizers during primary succession[13], forming a biological soil crust that enhances soil cohesion and stability, protecting it from erosive forces[14,15]. Consequently, bryophytes are increasingly considered an asset in climate change adaptation and mitigation efforts[11,16].

From a phylogenetic and taxonomic perspective, this group encompasses three phyla: Bryophyta *sensu stricto*, which includes mosses; Marchantiophyta, referring to liverworts due to their liver-shaped appearance; and Anthocerotophyta or hornworts, named for their horn-shaped sporophytes. Collectively, they comprise over 15,000 species, with approximately 10% of these found in Chile[17].

The 2023 IPCC report predicts a decrease in precipitation and an increase in average temperatures in Chile, contributing to the rapid retreat of glaciers and significant transformations in local and exotic biota[18,19]. Due to these rapid environmental changes, the distribution and diversity of bryophytes could shift in the medium term. A general hypothesis is that, with global warming, bryophyte species are expected to move up the altitudinal gradient together with the treeline. Also, subpolar tundra biomes dominated by bryophytes are shrinking due to forest incursions towards higher latitudes[20]. Species adapted to low-temperature niches have little potential for short-term acclimation to temperature increases, leading to intense desiccation and shorter periods of metabolic activity[21]. Because the mean temperature increase rate in polar and subpolar ecosystems is more than double that of the rest of the world[20], significant losses in bryophyte diversity are expected, particularly in tundra and alpine biomes in high-latitude areas[20,21].

Citizen, collaborative or participatory science. Collaborative science stands as a breakthrough in generating knowledge and enhancing scientific education. It opens avenues for highly specialized information that was once inaccessible to a broad audience, enabling local actions to have a global impact (e.g.[22]). The Global Biodiversity Information Facility (GBIF), available at <https://www.gbif.org>, exemplifies collaborative science by predominantly relying on citizen contributions to its data[23].

The "Biodiversity Information System for Aysén (SIB-Aysén)" project, launched in 2016[24], introduces an interactive platform aimed at improving the understanding and management of local natural resources. As the first regional Biodiversity Information System in Chile, it was designed and implemented by the Coyhaique University Center of the University of Magallanes. Funding for the project was provided by the Regional Government of Aysén through the Innovation Fund for Competitiveness (FIC), and the platform is freely accessible on the Internet. The system is built upon observations or records gathered from formal sources, field trips, and participatory science, including temporal and geographic references. This comprehensive approach enables the mapping of the occurrence of various species[25] (see Fig. 1), and this article is aligned with the goals of the SIB-Aysén initiative.

The objective of this research is to facilitate access to high-quality scientific information on the diversity of bryophyte species in the Aysén sub-Antarctic region. The aim is to make this information available on regional and global platforms that are universally and freely accessible. By doing so, the goal is to inform conservation measures based on scientific knowledge and, simultaneously, prevent redundancy in future sampling efforts.

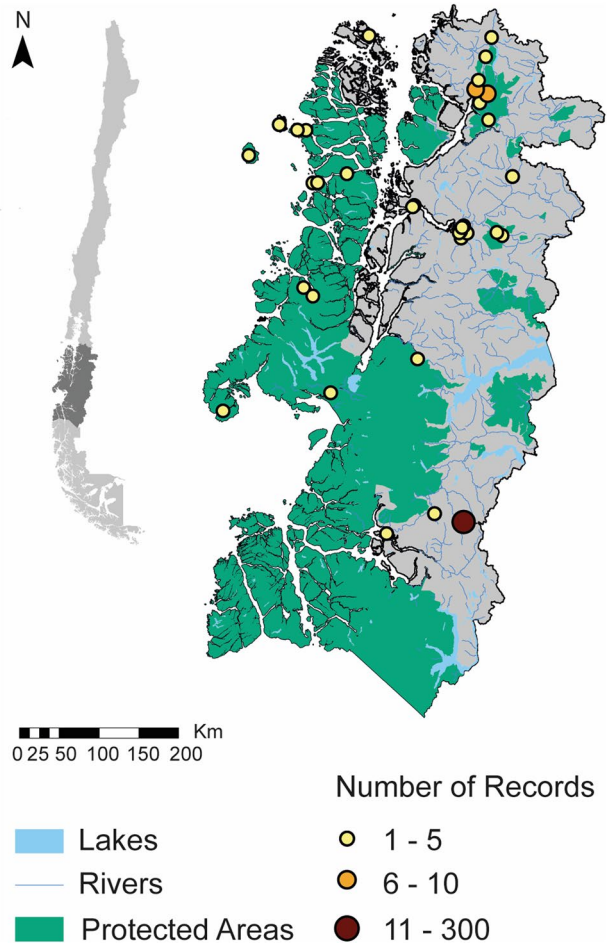

Fig. 2 Geographic location map of the Chilean sub-Antarctic ecoregion comprising the administrative regions of Aysén and Magallanes in the south. Mapping of the bryophyte records: Number of bryophyte records (color-coded by density) and provinces with the highest number of records. AY: Aysén, CP: Capitán Prat, GC: General Carrera, SNASPE: National System of State Protected Wildlife Areas (Spanish acronym). Created by the authors using ArcGIS version 10.8 software.

Methods

Study area. The digitized dataset encompasses the geographic extent of the Aysén del General Carlos Ibáñez del Campo Region, covering an area of 108,494.40 km^2, which constitutes 14% of Chilean territory. Located between latitudes 43.3° and 49.3° South and longitudes 78.5° and 69.1° West, this region features numerous maritime channels and fjords, all within a cold oceanic climate. As illustrated in Fig. 2, the region is part of the Sub-Antarctic ecoregion of Chile, characterized by recent human intervention and therefore highly significant for the study of the impacts of global socio-environmental changes[3,7,25,26].

Data collection. To ensure the robustness and transparency of our literature review, we conducted a search using Google Scholar with a combination of keywords in both English and Spanish: ('diversidad' OR 'biodiversidad' OR 'diversity' OR 'biodiversity') AND ('briófitos' OR 'bryophytes' OR 'musgos' OR 'mosses' OR 'hepáticas' OR 'liverworts' OR 'antocerotas' OR 'antocerotes' OR 'hornworts') AND ('Aisen' OR 'Aysen'). These parameters were selected to cover a broad spectrum of relevant studies while maintaining specificity to our study area. The comprehensive search aimed to include all possible variations in terminology, ensuring that no pertinent studies were overlooked. Conducted in March 2023, the search aimed to retrieve the most up-to-date information available at that time.

Our selection of 14 references was guided by their direct relevance to bryophyte records in the Aysén Region. Specifically, among references there are 10 specialized journals, three management plans, and one book published between 1972 and 2016.

During the process of refining references from the search results, the inclusion criteria were based on whether the paper mentioned bryophyte species diversity in the Aysén region. We also made sure to incorporate management plans of protected areas under the National System of State Protected Wildlife Areas (SNASPE). While attempting to explore alternative sources like collections at the Regional Museum or unpublished data from "Citizen Science" initiatives, no reliable data were available. Therefore, all our data sources referred to scientific literature.

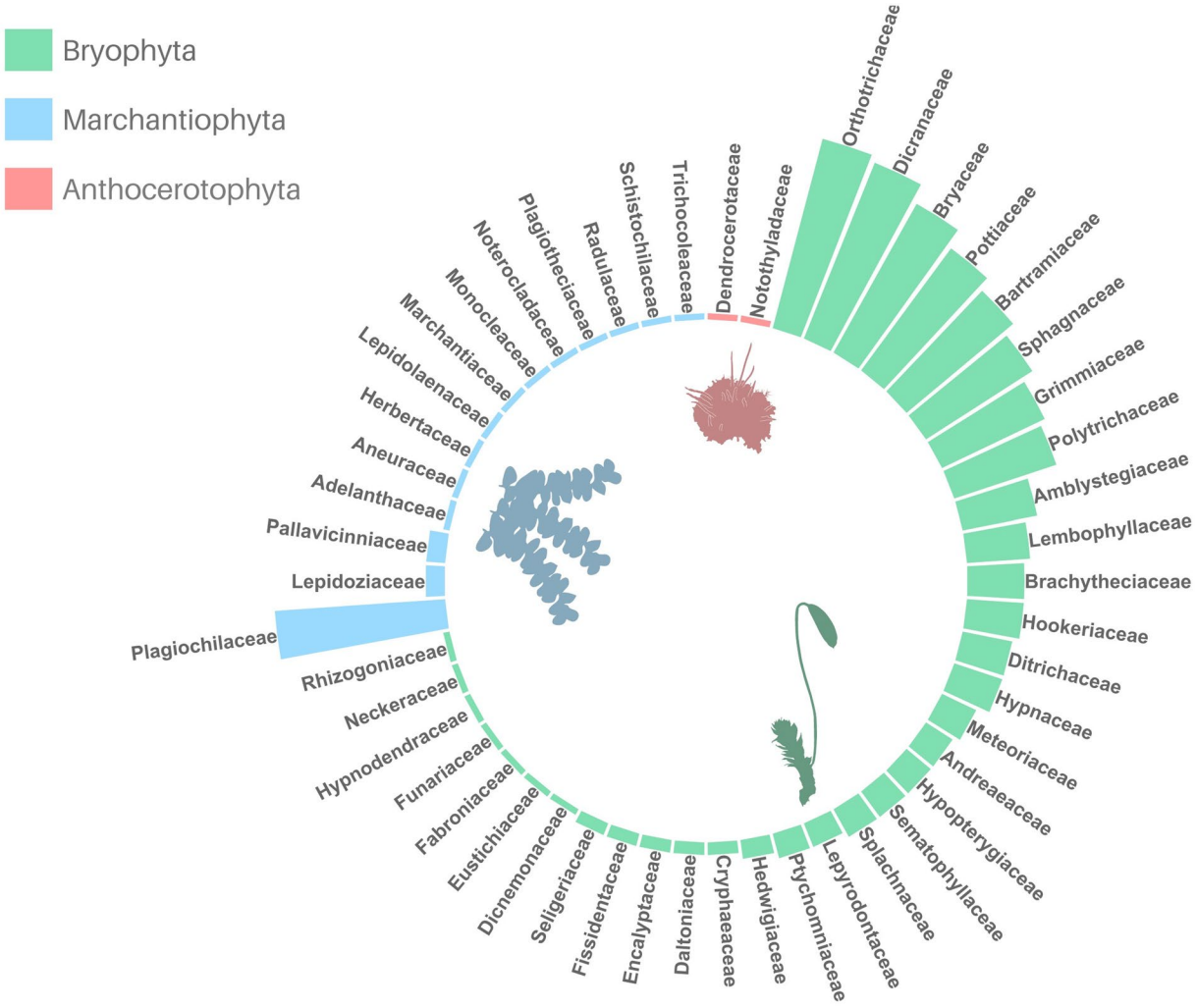

Fig. 3 Number of records of Bryophytes *s.l.* known in the Aysén region, classified by Family. The colors refer to the Phylum Bryophyta (green tones; 300 records with defined Families), Marchantiophyta (blue tones; 43 records with defined Families) or Anthocerotophyta (red tones; 2 records with defined Families). The first value refers to the number of species or records and the second to the percentage regarding the total.

This data collection initially received funding from the Regional Government of Aysén for the SIB-Aysén project and continued with the project "Open Laboratory for Sub-Antarctic Sciences." Future educational and research programs will complement citizens' observations, contributing to the ongoing update of Aysén's bryophytic data on a yearly basis. New contributions, whether from citizen initiatives or publications in specialized journals and scientific literature, will be systematically incorporated.

Data processing. The data collected was organized in a systematic way, resulting in a comprehensive dataset with taxonomic information, as well as location and dates on which the observations (events) were recorded as provided in the reviewed reference. In the final stage of the process, the information was arranged in accordance with the Darwin Core standard (Fig. 1). The systematization resulted in the generation of a file consisting of 48 fields (columns) and 345 bryophyte records (rows). These fields detail information regarding the taxonomic position, location, and vernacular names, whenever available. Specific aspects such as *type, language, license, rightsHolder, accessRights, institutionID, collectionID, institutionCode, collectionCode, datasetName, basisOfRecord, occurrenceID, catalogNumber, recordedBy, individualCount, associatedMedia, associatedReferences, eventDate, year, verbatimEventDate, continent, country, countryCode, stateProvince, county, municipality, locality, verbatimLocality, georeferenceRemarks, verbatimCoordinates, verbatimLatitude, verbatimLongitude, verbatimCoordinateSystem, decimalLatitude, decimalLongitude, scientificName, acceptedNameUsage, kingdom, phylum, class, order, family, genus, specificEpithet, infraspecificEpithet, taxonRank, scientificNameAuthorship*[25,27,28].

Cartography elaboration. We prepared a map with the bryophyte records found for the Aysén region using ArcGIS 10.8 software (Esri). ArcGIS® and ArcMap™ are the intellectual property of Esri and are used herein under license. Copyright © Esri. All rights reserved.

Phylum	Class	Order	Number of records
Bryophyta	Bryopsida	Bryales	61
		Dicranales	40
		Hypnales	36
		Orthotrichales	31
		Pottiales	26
		Grimmiales	18
		Polytrichales	16
		Hookeriales	14
		Leucodontales	12
		Isobryales	8
		Funariales	6
		Sphagnales	4
		Fissidentales	2
		Seligerales	2
		Hypopterygiales	2
	Sphagnopsida	Sphagnales	16
	Andreaeopsida	Andreaeales	5
	Polytrichopsida	Polytrichales	1
Marchantiophyta	Jungermanniopsida	Jungermanniales	34
		Pallaviciniales	3
		Porellales	2
		Metzgeriales	1
		Pelliales	1
	Marchantiopsida	Marchantiales	2
Anthocerotophyta	Anthocerotopsida	Dendrocerotales	1
		Notothyladales	1

Table 1. Number of records for each Phylum, Class and Order.

Data Records

The bryophyte occurrence dataset from this study is available through GBIF[29], comprising a total of 345 bryophyte records. All observations in this dataset stem from field observations and were previously documented in scientific literature. The observations span the years 1898 to 2012 and are confined within the regional boundaries of Aysén, Chile (see Fig. 2). Detailed information on taxonomic, geographic, and temporal coverages, along with the sources of information (previously published literature), is provided below. Additionally, a subsection is dedicated to endemic species to Chile or South America.

Taxonomic coverage. A total of 345 bryophyte records were documented, encompassing 273 taxa distributed among the Phyla Anthocerotophyta (2 records), Bryophyta (300 records), or Marchantiophyta (43 records). Table 1 illustrates the taxonomic distribution, with Bryopsida being the most abundant class, comprising 278 records corresponding to 233 species, accounting for 80% of the total records. It is followed by Jungermanniopsida (41 records, 16 species), Sphagnopsida (20 records, 3 species), Polytrichopsida (17 records, 12 species), Andreaeopsida (5 records, 5 species), Anthocerotopsida, and Marchantiopsida (2 records, 2 species each).

Furthermore, these classes are subdivided into 24 Orders, with Bryales (61 records), Dicranales (40 records), Hypnales (36 records), Jungermanniales (34 records), Orthotrichales (31 records), Pottiales (26 records), Sphagnales (20 records), Grimmiales (18 records), Polytrichales (17 records), Leucodontales (12 records), and Hookeriales (11 records). This is followed by Isobryales (8 records), Funariales (6 records), Andreaeales (5 records), Pallavicinales (3 records), Fissidentales, Marchantiales, Porellales, and Seligerales (2 records each). Finally, Dendrocerotales, Metzgeriales, Notothyladales, and Pelliales each have 1 record.

At the family level, Orthotrichaceae stands out with 31 records of 30 species, followed by Dicranaceae with 30 records of 27 species, and Bryaceae with 27 records of 27 species (see Fig. 3). Among the species, *Sphagnum magellanicum* has the highest number of records (16), followed by *Plagiochila lophocolecoides* (13 records) and *Plagiochila flexicaulis* (9 records).

Endemic species. The analyzed records encompass 23 species endemic to southern Chile and 62 species endemic to South America, as documented in the Missouri Botanical Garden database, available at https://tropicos.org. These species are classified into 33 different families, with 25 belonging to mosses (Phylum Bryophyta), 7 to liverworts (Phylum Marchantiophyta, including 6 in Class Jungermanniopsida and 1 in Marchantiopsida), and 1 in Phylum Anthocerotophyta (Table 2). Selected moss and liverwort species are illustrated in Figs. 4 and 5, respectively.

Geographic coverage. The recorded bryophyte occurrences are concentrated in three administrative counties within the region, with the majority reported in the Capitán Prat county (252 records), followed by 52 in the

Bryophyta			
Orthotrichaceae	*Orthotrichum brotheri* ○	Polytrichaceae	*Hebantia rigida* ○
	Ulota carinata ○		*Oligotrichum austroaligerum* ○
	Ulota germana ○		*Notoligotrichum minimum* ●
	Ulota macrodontia ●		*Notoligotrichum trichodon* ●
	Orthotrichum assimile ●	Lepyrodontaceae	*Lepyrodon patagonicus* ○
	Orthotrichum elegantulum ●		*Lepyrodon hexastichus* ●
	Orthotrichum ludificans ●		*Lepyrodon tomentosus* ●
	Pentastichella pentasticha ○	Sematophyllaceae	*Sematophyllum scorpiurus* ○
	Ulota macrocalycina ●		*Mahua enervis* ●
	Ulota magellanica ●		*Rhaphidorrhynchium callidum* ●
	Zygodon magellanicus ●	Splachnaceae	*Tayloria dubyi* ●
	Zygodon papillatus ●		*Tayloria magellanica* ●
	Zygodon pichinchensis ●		*Tayloria stenophysata* ●
Bartramiaceae	*Bartramia ithyphylloides* ○	Bryaceae	*Bryum macrophyllum* ●
	Breutelia angustiretis ●		*Leptostomum menziesii* ●
	Breutelia aureola ●	Cryphaeaceae	*Cryphaeophilum molle* ○
	Breutelia plicata ●		*Cryphaea consimilis* ●
	Breutelia subplicata ●	Hookeriaceae	*Achrophyllum anomalum* ○
	Philonotis esquelensis ●		*Achrophyllum haesselianum* ○
	Philonotis krausei ●	Meteoriaceae	*Ancistrodes genuflexa* ○
Dicranaceae	*Camptodontium cryptodon* ●		*Looseria orbiculata* ○
	Chorisodontium dicranellatum ●	Ptychomniaceae	*Ombronesus stuvensis* ○
	Chorisodontium spegazzinii ●		*Ptychomnion cygnisetum* ●
	Dicranoloma chilense ●	Brachytheciaceae	*Eriodon conostomus* ○
	Dicranoloma perremotifolium ●	Daltoniaceae	*Daltonia trachyodonta* ●
	Hymenoloma turpe ●	Dicnemonaceae	*Eucamptodon perichaetialis* ●
	Pilopogon schilleri ●	Fabroniaceae	*Fabronia jamesonii* ●
Grimmiaceae	*Grimmia andina* ●	Hypnaceae	*Hypnum skottsbergii* ●
	Grimmia humilis ●	Hypnodendraceae	*Hypnodendron microstictum* ●
	Grimmia navicularis ●	Hypopterygiaceae	*Arbusculohypopterygium arbuscula* ●
	Racomitrium heterostichoides ●	Neckeraceae	*Porotrichum arbusculans* ○
	Racomitrium laevigatum ●	Radulaceae	*Radula diversifolia* ●
	Scouleria patagonica ●		
Pottiaceae	*Syntrichia costesii* ○	**Marchantiophyta**	
	Tortula lithophila ○	Pallavicinniaceae	*Symphyogyna circinata* ●
	Didymodon fuscus ●		*Symphyogyna rubritincta* ●
	Syntrichia epilosa ●	Plagiochilaceae	*Plagiochila flexicaulis* ○
	Syntrichia pseudorobusta ●		*Plagiochila lophocoleoides* ○
	Syntrichia scabrella ●	Monocleaceae	*Monoclea gottschei* ●
Lembophyllaceae		Noterocladaceae	*Noteroclada confluens*
	Rigodium tamarix ○	Schistochilaceae	*Schistochila lamellata* ○
	Rigodium adpressum ●	Trichocoleaceae	*Leiomitra elegans* ●
	Rigodium brachypodium ●		
	Rigodium pseudothuidium ●	**Anthocerotophyta**	
		Dendrocerotaceae	*Nothoceros fuegiensis* ●

Table 2. Endemic species to Chile (empty dots) or South America (full dots) of mosses, liverworts and hornworts classified by Family.

Aysén county, and only one in the General Carrera county (see Fig. 2). Most of these records originate from a single reference that did not specify the exact locality but mentioned "Carretera Austral, between Puerto Bertrand and Villa O'Higgins, in the basins of the Baker, Bravo, and Pascua rivers"[30]. The locality was approximated using Google Earth. Additionally, 16 records were identified in Queulat National Park and 6 in Puyuhuapi, while the remaining records exhibit low density, ranging from 1 to 4 records per locality.

Temporal coverage. The references span a period of 44 years, from 1972 to 2016, with a notable concentration of 91.7% of the records published between 2007 and 2008. The oldest records include *Plagiochila flexicaulis* documented in 1898 and 1954, *Plagiochila lophocoleoides* in 1911 and 1918, and *Plagiochila longiflora* in 1939, as reported by Hässel de Menéndez[31]. Subsequently, Pisano[32], a pioneering Chilean botanist, conducted significant

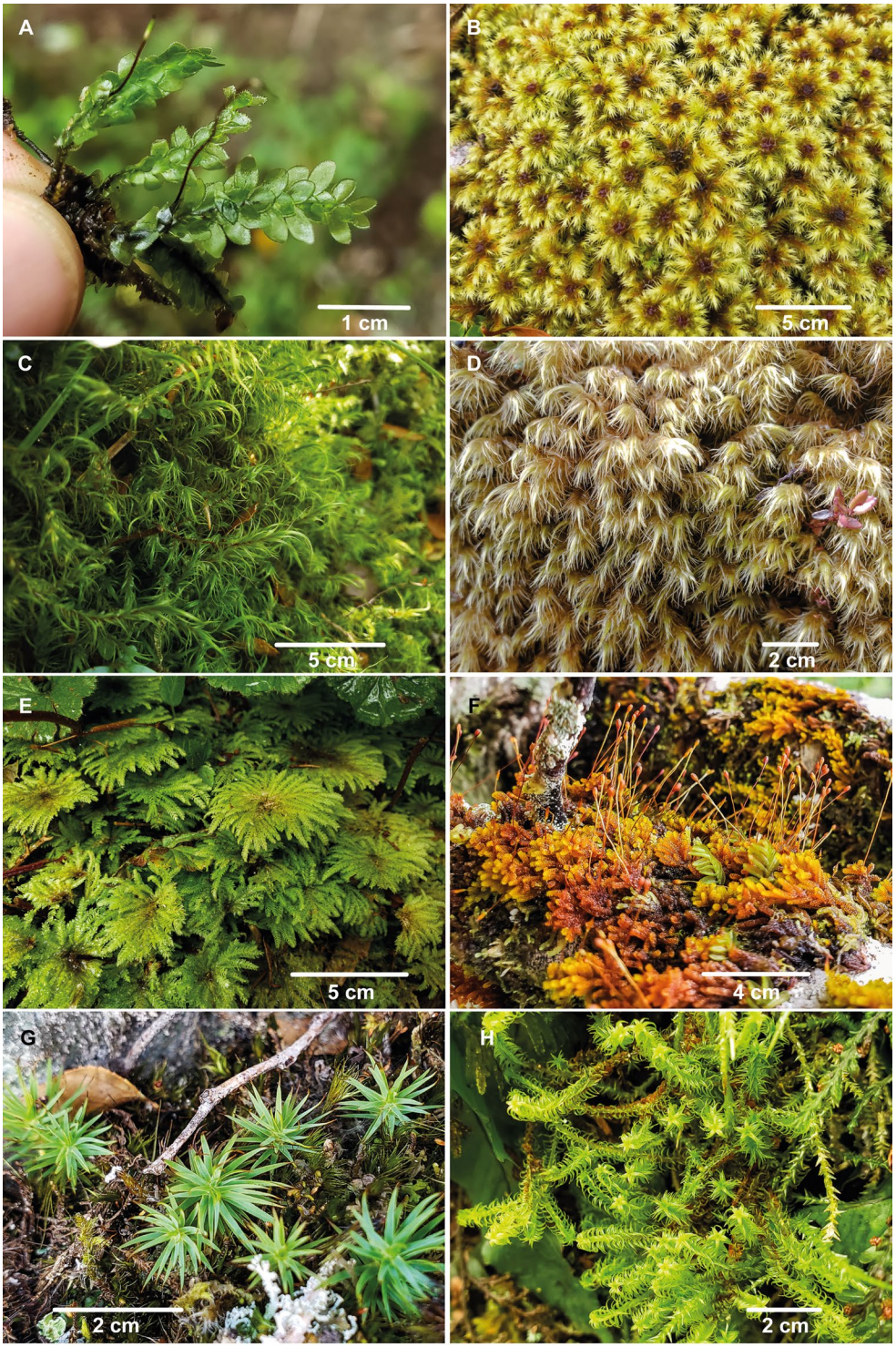

Fig. 4 Mosses from the Aysén region. (**A**) *Achrophyllum magellanicum* (Besch.) Matteri (**B**) *Breutelia dumosa* Mitt. (**C**) *Dicranoloma billarderii* (Brid.) Paris (**D**) *Dicranoloma imponens* (Mont.) Renauld (**E**) *Arbusculohypopterygium arbuscula* (Brid.) M. Stech, T. Pfeiff. & W. Frey (**F**) *Matteria gracillima* (Besch.) Goffinet (**G**) *Polytrichadelphus magellanicus* (Hedw.) Mitt. (**H**) *Zygodon pentastichus* (Mont.) Müll. Hal. Photographs by R. Mackenzie.

expeditions in the southern zone and Cape Horn, providing detailed descriptions of species and plant communities in remote locations in southern Patagonia. One notable species covered in his work is *Sphagnum magellanicum*, among others[33]. Although Pisano's remarkable contributions focused primarily on the very south of Aysén, his work was predominantly centered in the Magallanes region.

Fig. 5 Liverworts from the Aysén region. (**A**) *Leiomitra elegans* (Lehm. ex De Not.) Hässel (**B**) *Riccardia prehensilis* (Hook. f. & Taylor) C. Massal. (**C**) *Schistochila lamellata* (Hook.) Dumort. ex A. Evans (**D**) *Syzygiella colorata* (Lehm.) K. Feldberg, Váňa, Hentschel & Heinrichs. Photographs by R. Mackenzie.

Sources of information. Of all the records, 275 were sourced from articles published in international scientific journals[31,34], 39 from books[35], 14 from national scientific journals[30,32,36–41], and 17 from management plans for protected areas[42–44]. Most of the publications (11 out of 14) are in Spanish, with the remaining 3 in English. Most of these publications also contain records from other taxonomic groups, such as vascular plants, except for three references[31,34,35].

All 40 records from the publications of Ardiles[35] and Vidal[40] lack information on their geographic coordinates. In both cases, uncertainty about the exact location was indicated by using "absent locality (*Ubicación ausente* in Spanish)" in the field *georeferenceRemarks*, and the word "ambiguous (*ambigua*)" was added before the name of the locality in the field *verbatimLocality*.

Technical Validation

The records were integrated into a database with taxonomic information, location details, and dates of observation. Geographic coordinates were systematized from information provided in the references. When not explicitly indicated, coordinates were interpolated using Google Earth® based on the locality names provided in the publication (field *verbatimLocality*). This method of completing geographic information was documented in the dataset's *georeferenceRemarks* field using three possibilities: i) "exact location (*ubicación precisa* in Spanish)," when specified by the authors; ii) "approximated locality (*localidad aproximada*)," when coordinates were derived from the locality name using Google Earth; iii) "absent location (*ubicación ausente*)." In the last two cases, uncertainty was reported in the field *verbatimLocality* by adding the word "ambiguous (*ambigua*)" before the name of the locality.

Usage Notes

The database holds potential for use by researchers interested in bryophyte conservation, allowing assessments of large-scale changes in biodiversity over time. It is also valuable for those interested in managing local natural resources. Beyond academic use, there is encouragement for citizen science organizations to collaborate with universities and data repositories to utilize the method and enhance data accessibility. The described method has proven effective in leveraging citizen science records for bryophyte biodiversity. Similar groups are encouraged to review the dataset and plan expeditions using analogous techniques. By utilizing platforms like GBIF and iNaturalist for data sharing, knowledge of bryophyte biodiversity globally can be significantly improved.

Code availability

No original code was generated to produce the dataset. Figures were created using the ggplot2 package[45] and R Statistical Software v4.3.0[46]. Cartography was generated with ArcGIS version 10.8. The dataset was shared via GBIF.org using Integrated Publishing Toolkit (IPT), available at <www.gbif.org/ipt>.

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Author contributions

L.S.J. conceived the idea, supervised the project, provided guidance on data analyses and interpretation, and revised the manuscript. A.H.D. conducted the analyses and lead the manuscript writing. M.V. designed and developed the literature search. C.A.S. generated the location map. R.M. advised on species diversity, data interpretation and provided the photographs of some of the species studied in their natural environment. M.S. and B.A.G. contributed to the revision of the manuscript.

Competing interests

The authors declare no competing interests.

Additional information

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