Chapter

Diversity of Epiphytic Mosses (Bryophyta) in Forests of *Polylepis* (Rosaceae) in the Urubamba Mountain Range, Cusco, Peru

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Abstract

The diversity of mosses was evaluated in four *Polylepis* (Rosaceae) forests in the Cordillera del Urubamba, Cusco region – Peru. Epiphytic mosses were collected from the lower base of the trunk, canopy area, and terminal branches in paper bags, selecting specimens with sporophytes. Twenty-seven species distributed in seven orders, 13 families, and 17 genera were determined. Three species are new records for Peru, that is, *Neckera ehrenbergii*, *Zygodon quitensis,* and *Didymodon challaense*. Fourteen species are reported for the first time in the Cusco region. These chorological novelties demonstrate the importance of *Polylepis* forests as stores of cryptogamic diversity.

Keywords: diversity, mosses, canopy, terminal branches, new records

1. Introduction

In the upper parts of the Cusco region – Peru, the vegetation is mostly in the form of grasslands and small shrubs, with the genus *Polylepis* (Rosaceae) being the only dominant tree element. These forest patches are vital for protecting the soil against erosion, retain nutrients, sediment, and produce a vital amount of oxygen, and host a unique diversity of birds and plants, among other organisms. Despite their importance, these forests are in danger of extinction due to the growing pressure of the Andean population, as a product of numerous economic, social, and cultural factors [1]. There are several studies carried out on *Polylepis* in terms of flora and fauna in Peru and especially in Cusco, but not so on the epiphytic mosses that are found predominantly in these arboretums.

The *Polylepis* forests in the Urubamba valley constitute one of the largest population concentrations and the largest center of genetic diversity in the Andes with six species of the 10 cited for the national territory, *Polylepis besseri, P. racemosa, P. subsericans, P. pauta, P. sericea,* and *P. microphylla*, the same ones that house a great diversity of mosses that play a fundamental role in the conservation and maintenance of ecosystems due to their hydrophilicity, responsible for keeping these habitats moist; making necessary to know its diversity.

The Musci are the most complex group within the Bryophytes, not only because of the morphology of their gametophytes but particularly because of the structure of their sporophytes. They make up the group of Bryophytes with the most species; it is estimated that worldwide there are between 8000 and 12,800 species in 900 genera. The number of mosses estimated for the Andean region of Colombia, Ecuador, and Peru is likely to reach around 900–950 species. Among these countries, Peru requires more work both in terms of additional inventories and published results; however, around 829 taxa are currently known for the entire territory, of which 797 are reported for the Andean region [2]. There is a gradual increase in the diversity of taxa according to elevation, with a maximum between 2500 and 3000 m, beyond this altitude interval, there is a marked decrease in diversity, notably above 3500 m. Thus, in Bolivia, a greater diversity was recorded between 2000 and 2500 m, followed by the 2500–3000 m interval [3].

In this regard, Menzel [4] cites 181 species for the department of Ayacucho, the vast majority collected by Hegewald & Hegewald, who carried out explorations in various departments of Peru between 1973 and 1977, including Ayacucho, some were carried out in the province of Huamanga. Opisso [5, 6] carried out an inventory of pleurocarpous mosses in the province of San Ignacio – Cajamarca, registering 40 species, 32 genera, and 15 families. He also recorded 55 species of mosses for the Pomahuaca-Cajamarca district with 47 genera and 30 families. Opisso and Churchill [7] carried out a study in the surroundings of the Yanachaga-Chemillén National Park in the department of Pasco, in which they indicate the existence of 134 species of bryophytes distributed among 92 genera and 45 families (32 liverworts, 2 hornworts, and 100 mosses).

In the Cusco region, studies on Bryophytes began in 1921 with Fortunato L. Herrera in his work "Flora del Departamento del Cuzco" reporting 26 species of mosses, among which he mentioned *Hygrodicranum herrerai* Williams, *Leptodontium brachyphyllum*, *Tortula affinis* Hampe, *Bryum andicola* Hook, *Ortothrichum elongatum* Taylor, and *Polytrichum antillarum* Rich. Galiano [8] carried out a study on the flora of the high tropical Andean Forest of Yanacocha, in the province of Urubamba, registering 13 species of mosses, belonging to 10 genera and eight families. Tupayachi [9], when evaluating the flora of the Cordillera del Vilcanota, reported 35 species of bryophytes, belonging to 24 genera and 14 families. Galiano et al. [10], when studying the flora of the Cusco Valley, determined 14 species of mosses. Acurio [11] evaluated the diversity and distribution of mosses in the area of Wiñay Wayna, Historic Sanctuary of Machu Picchu-Cusco in an altitude range of 2500–3100 m, finding 129 species in 72 genera and 29 families. Subsequently, Huallparimachi et al. [12] reported for the Sanctuary 50 species of mosses included in 23 genera and 15 families, highlighting *Bartramia*, *Brachythecium*, *Bryum*, *Campylopus*, *Lepyrodon*, *Neckera*, *Plagiothecium*, *Polytrichum*, *Sematophyllum*, *Sphagnum*, *Tortula*, *Trichostomun*, *Thuidium,* and *Zygodon*.

For its part, Carhuapoma [13] carried out the study of mosses of the Historical Sanctuary of the Pampa de Ayacucho in an altitude range of 3350 to 4100 m, registering 67 species belonging to 45 genera, 21 families, and 11 orders. The Pottiaceae family was the most representative with 10 species, followed by Orthotrichaceae, Brachytheciaceae, and Bartramiaceae with six species each, reporting 23 new records for Ayacucho and the third report for Peru of *Philonotis scabrifolia* (Hook. f. & Wilson) Braithw. expanding its distribution to the south of the country. Despite all these reports, there is still little progress in this division, and it is necessary to encourage these studies and expand our knowledge about the existing bryoflora in Peru and particularly in the Cusco region. The present study is carried out in order to determine the composition of mosses in each of the *Polylepis* forests in the Urubamba Mountain range.

2. Methods

3. Study area

The scope of study territorially includes the Huarán basin with the towns of Canchacancha (13° 14′ 34.9” S and 72° 01′ 13.4” W) located at 4548 m.a.s.l. and Contorkayku (13° 16′ 03.7” S and 72° 01′ 02” W) at 4310 m.a.s.l. between the limits of the provinces of Calca and Urubamba; the Wayoqhari-Yanacocha basin, locality K′elloq'ocha (13° 16′ 34.3” S and 72° 03′09.7” W) at 4343 m.a.s.l. belonging to the district of Huayllabamba, and the Manthanay basin, locality Manthanay (13° 12′ 08.4” S and 72° 08′ 42.8” W) at 4778 m.a.s.l. located in the heights of the Yanahuara Valley in the province of Urubamba, Peru.

3.1 Natural life zones

3.1.1 Subtropical sub-Andean very humid páramo (pmh-SaS)

This life zone also known as wet puna in the South of Peru; it presents a total annual precipitation that varies between 640 mm and 800 mm and an average annual biotemperature between 6°C and 3°C. It is a cold climate zone. According to the Holdridge Diagram, this life zone has potential evapotranspiration that varies between a quarter (0.25) and a half (0.5) of the average total precipitation per year. Life includes the dense forests of *Polylepis*, located from 3900 to 4500 m. of altitude, with a thick forest of shrubs and herbs as well as an abundant presence of mossy mattresses between the rocks of the forest floor and the trunks of the trees, which is due to the high humidity prevailing inside [14].

3.1.2 Subtropical sub-Andean pluvial tundra (tp-SaS)

Life zone includes the ecological system of the cold Andean desert of the humid puna. It is located on the very humid-subalpine and subtropical paramo and below the Nival floor. It has a cold climate, the soils are mostly rocky due to erosion of the old glacial mountains, in whose cracks there is scattered and discontinuous vegetation conditioned and adapted to the daily alternation of ice-thaw and where *Polylepis subsericans* ascends through the tongues of cryoturbated soils in a clear process of colonization toward the rocky crests caused by glacial erosion. Altitudinally, they are above 4500 m [14].

4. Sampling

Using the protocol of Gradstein et al. [15], four forests were selected, in which 16 *Polylepis* arboretums were evaluated. A total of 10 plots per arboretum were evaluated (four in the bolus, four in the canopy, and two in the terminal branches). Each plot was 20 × 30 cm in the bolus and canopy, and in branches the plots were 10 × 60, making a total of 600 cm^2 each plot.

In each forest, epiphytic mosses were collected from the lower base of the trunk, canopy area, and terminal branches. The collection was made using craft paper bags and/or recycled paper envelopes, preferably selecting specimens with a sporophyte as this is often necessary for identification.

4.1 Identification process

To identify the species in the laboratory, it was necessary to rehydrate the samples, so that they recover their natural form. It was enough to submerge a few plants in water for them to rehydrate in a few seconds. In some species of phyllidia or thicker thallus, this operation took a little longer, but it is almost never more than a minute.

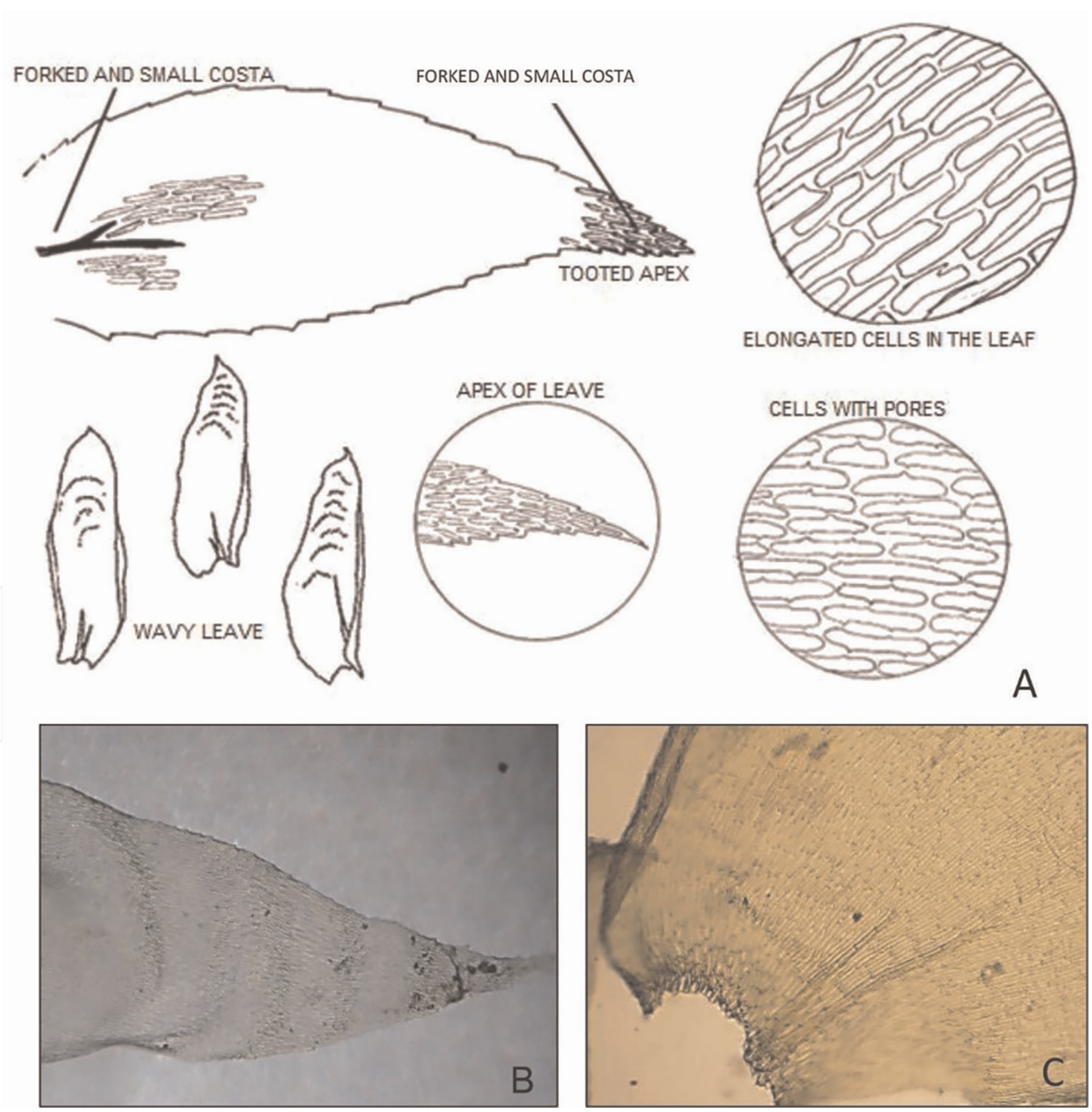

Figure 1.
A. Morphological characteristics of Neckera ehrenbergii *Müll. Hal.; B. undulate leaf 40x; C. bifurcate costa at leaf base 40x.*

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Once the sample was rehydrated, with the help of fine-tipped tweezers and a pair of lancets, the parts that we are interested in observing were separated: phyllidia, caulydia, capsules, etc. Something important to keep in mind, before separating the samples, is that the details of the plant's shape must be observed, such as the arrangement of the phyllidia on the plant (distichous, more or less together or separated) and the type of branching.

Cross sections of the phyllidia of many species of mosses were also made to observe the structure of the central nerve, the thickness (number of cells) of the phyllidia, the presence of papillae or nipples, etc. (**Figures 1**-**8**).

The main characteristics observed were as follows:

Habit (acrocarpic, pleurocarpous moss).

Shape of the phyllidia.

Shape and dimensions of the cells of the phyllidia, presence of papillae, etc.

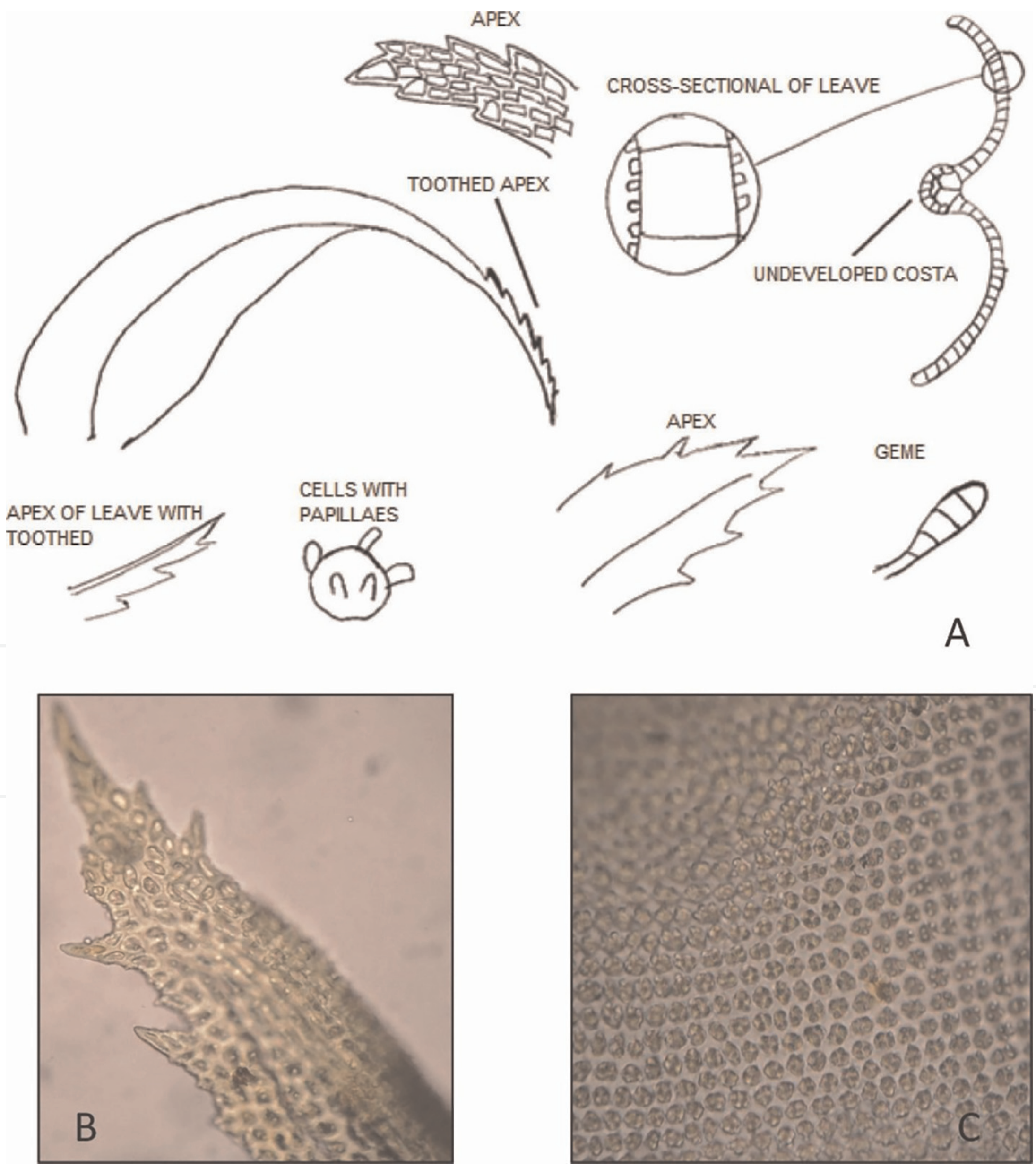

Figure 2.
A. Morphological characteristics of Zygodon quitensis *mitt; B. dentate apex 40x; C. Pluripapillose cells in the leaf lamina 40x.*

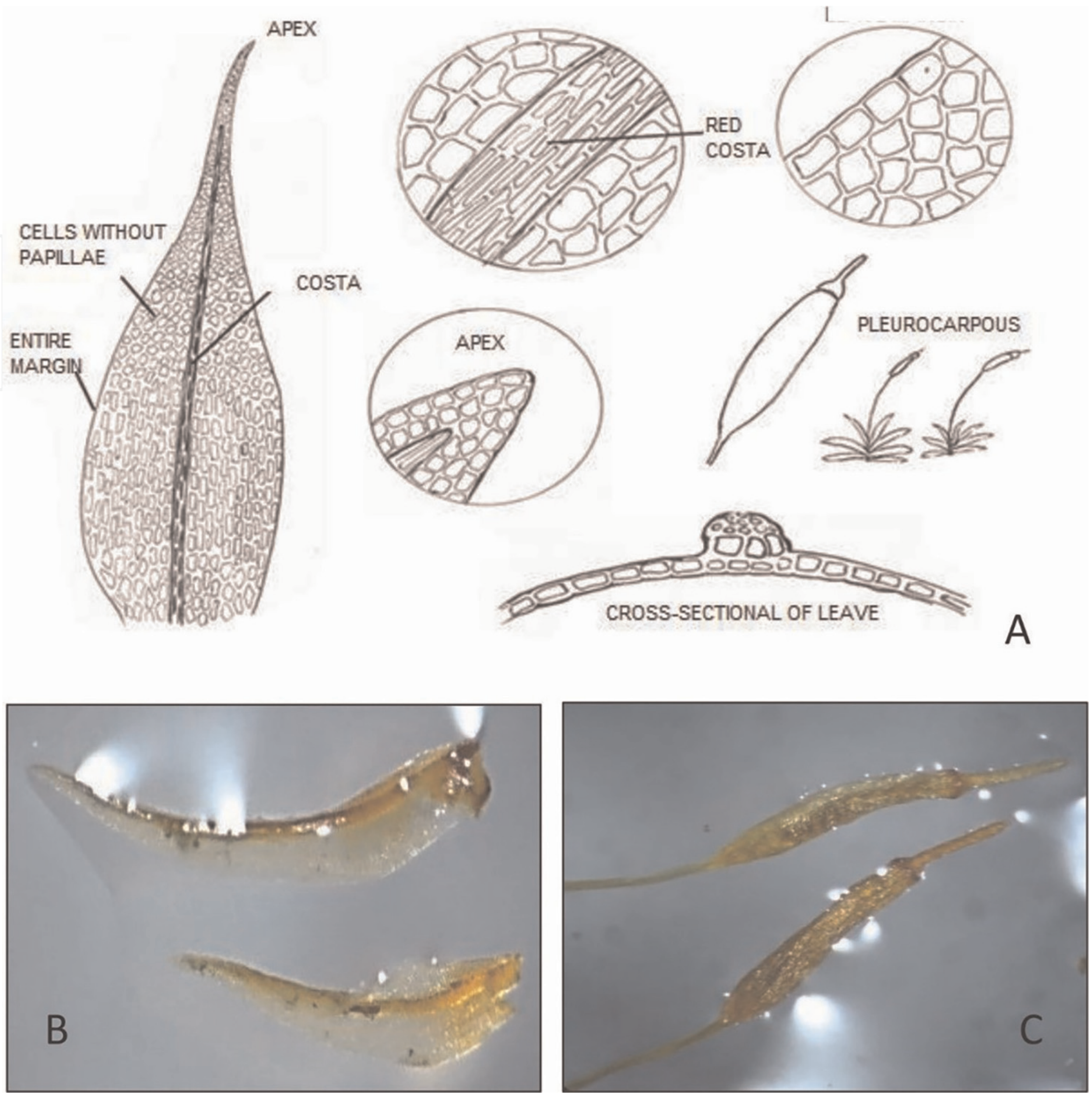

Figure 3.
A. Morphological characteristics of Didymodon challaense *(broth.) R.H. Zander; B. leaves 10x; C. Acrocarppic sporophytes 20x.*

Characteristics of the central nerve of the phyilidia.
Shape and dimensions of the cells of the phyllidia, presence of papillae, etc.
Characteristics of the margin of the phyllidia.
Presence of gems or other vegetatively reproducing structures.
Characteristics of the sporophyte.

5. Taxonomic identification

To determine the species, we first proceeded to separate the samples collected from other nonvascular epiphytes (lichens and liverworts), as well as from the bark of the trees, then proceeded to identify the samples following dichotomous keys [16], photographs of each of the species were taken using a stereoscope and an optical microscope, exhaustively describing and making drawings of the observations. Some of the samples were sent to the city of Santa Cruz in Bolivia for review by a moss specialist.

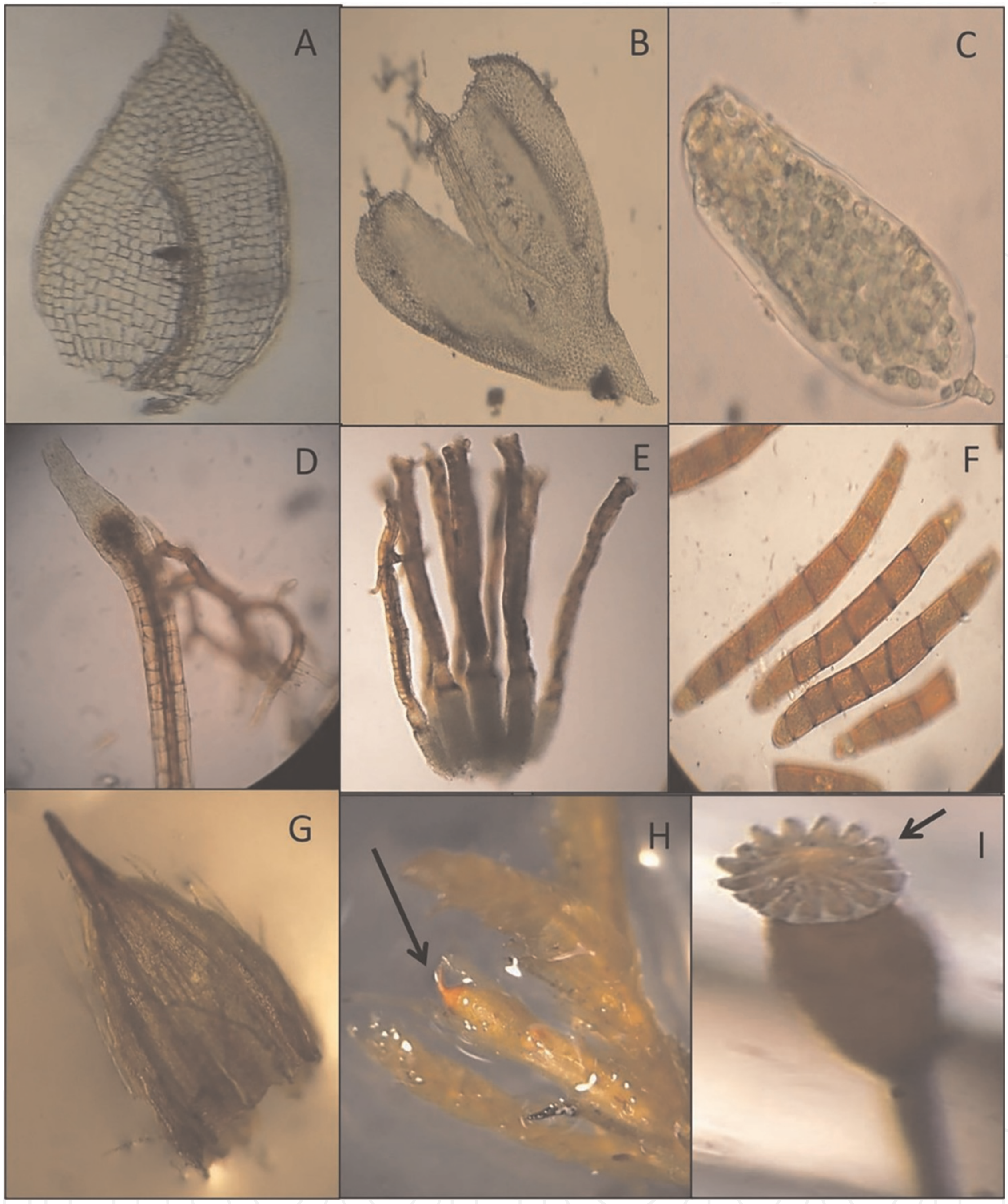

Figure 4.
A. Simple costae of leaf of Daltonia *sp.; B. forked costae of leaf in* T.peruvianun *mitt. 40x; C. leaf gemmae of* Zygodon *sp. 100x; D. Archaegonium of* Z. fragilis *H. rob. 100x; E. Archaegonia of* O. elongatum *Taylor 100x; F. propagules of* Zygodon quitensis *mitt. 100x; G. Calyptrae of* Semathophllum swartzii *(Schawägr) W.H. Welch & H. a, H. Crum; H. Operculum of* Neckera ehrenbergii *Müll. Hal. I. Peristomium of* Bartramia *sp.*

6. Results

In the forests of Manthanay K′elloq'ocha Contorkayku and Canchacancha, a total of 27 morphospecies of moss were found, which are distributed in seven orders, 13 families, and 17 genera. Twenty of these mosses are identified to species, six to genus, and one only at the family level (**Table 1**).

Three species are new records for Peru, that is, *Neckera ehrenbergii* Müll. Hal., *Zygodon quitensis* Mitt., and *Didymodon challaense* (Broth.) R.H. Zander. Likewise, 14 species are reported for the first time for the Cusco region, that is, *Bartramia potosica*

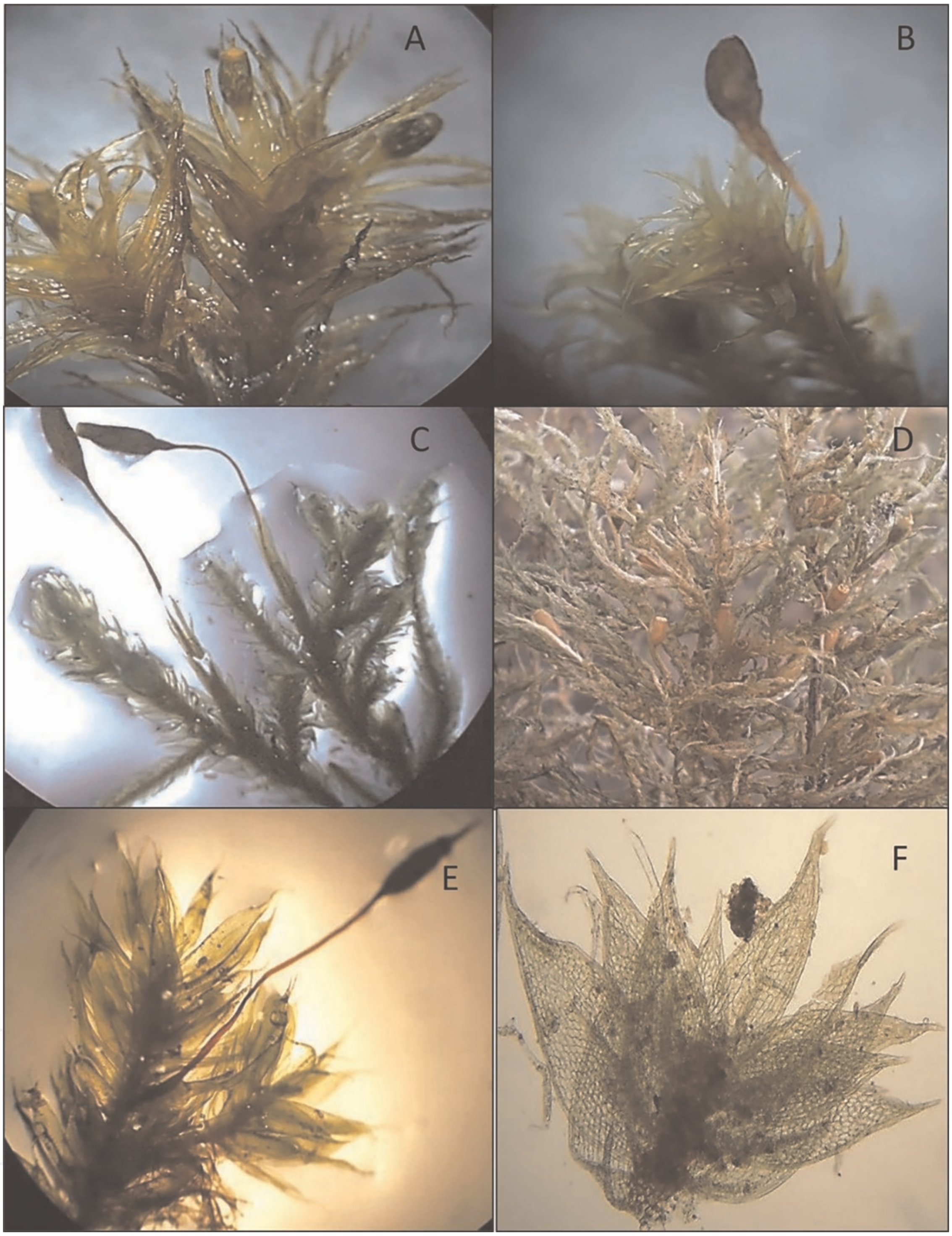

Figure 5.
Gametophytes and sporophytes of **a**. Orthotrichum elongatum *Taylor; B.* Zygodon reinwardtii *(Hornsch.) a. Braun; C.*: Lepyrodon tomentosus *(hook.) mitt.; D.* Neckera ehrenbergii *Müll. Hal.; E.* Daltonia trachyodonta *mitt.; F.* Daltonia *sp. costa.*

Mont, *Brachythecium occidentale* (Hampe) A. Jaeger, *B. andicola* Hook, *Bryum subapiculatum* Hampe, *Daltonia trachyodonta* Mitt, *Campylopus areodictyon* (Müll. Hal.) Mitt, *Chorisodontium mittenii* (Müll. Hal.) Broth, *Braunia cirrhifolia* (Mitt.) A. Jaeger, *Neckera andina* Mitt, *Orthotrichum elongatum* Taylor, *Zygodon fragilis* H. Rob, *Leptodontium tricolor* (R.S. Williams) R.H. Zander, *Syntrichia andicola* (Mont.) Ochyra and *Lepyrodon tomentosus* (Hook.) Mitt.

Figure 6.
A. Leave with costa of Daltonia *sp.*, 100x; *B. homogeneous leave cross-sectional in* Chorisodontium mittenii (Müll. Hall.); *C. alar cells in* Sematophyllum swartzii *(Schwägr.) W.H. Welch & H.a. 40x; D. Heterogeneous leave cross-sectional in* Daltonia trachyodonta mitt.; *E. Heterogeneous leave cross-sectional in* Syntrichia andicola *(Mont.)*; *F. leave geme in* Braunia cirrhifolia *(mitt.) a. jaeger. 100x.*

As seen in **Table 1**, some morphospecies are almost exclusive to a single forest, such as *Orthotrichum sp*., *B. subapiculatum* Hampe, and *Didymodon challaense* (Broth.) R.H. Zander. for the Canchacancha forest, *B. potosica* Mont. *Bartramia sp*. for Kelloq'ocha and *Syntrichia sp*. for Mantanay. Other species are more common, for

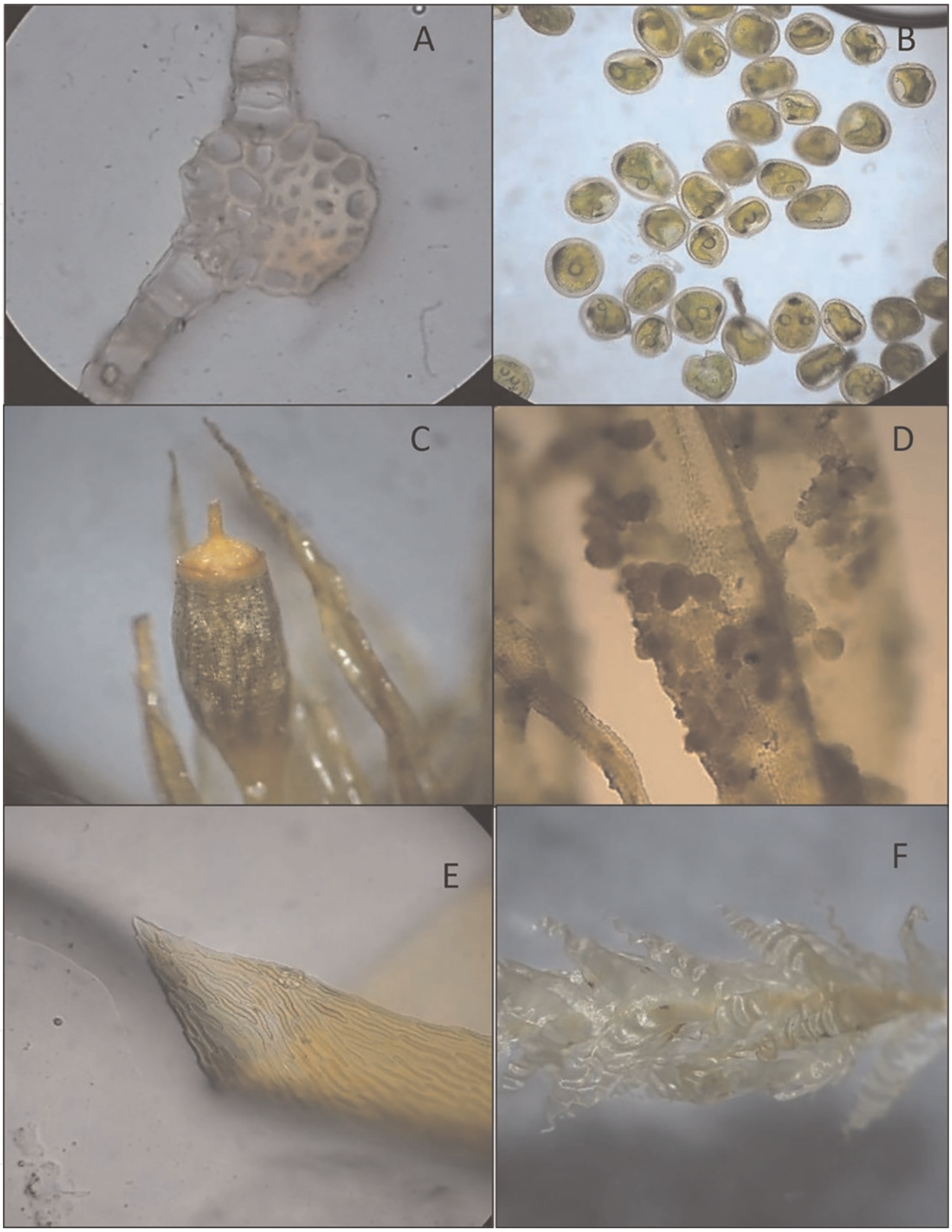

Figure 7.
A. Heterogeneous leave cross-sectional Bryum andicola *hook. 40x B. Gemes*, Orthotrichum elongatum *Taylor*. 100x; *C. sporophyte with operculum in* Orthotrichum elongatum *Taylor*. 20x. *D. Leave geme in* Zygodon *sp. 20x E. Apice of the leaf in* Neckera andina Mitt.40x *F. wavi leaf of* Neckera ehrenbergii Müll. Hal. 10x.

example,. *Zygodon quitensis* Mitt. *Zygodon fragilis* H.Rob and *Lepyrodon tomentosus* (Hook.) Mitt. which are shared in the four study areas. Other species such as *Zygodon reinwardtii* (Hornsch.) A. Braun, *Neckera andina* Mitt,*Thuidium peruvianum* Mitt. and *Sematophyllum swartzii* (Schwägr.) W.H. Welch & H.A. can be found in Kello'qocha and Manthanay.

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Order/Family	Species	1	2	3	4
Orthotrichales/ Orthotrichaceae	*Zygodon quitensis* Mitt.	x	x	x	x
	Zygodon fragilis H.Rob.	x	x	x	x
	Zygodon reinwardtii (Hornsch.) A. Braun	—	x	x	—
	Zygodon sp.	—	x	x	x
	Orthotrichum elongatum Taylor	x	x	—	—
	Orthotrichum sp.	x	—	—	—
Hedwigiaceae	*Braunia cirrhifolia* (Mitt.) A. Jaeger	—	x	x	x
Leucodontales/Neckeraceae	*Neckera ehrenbergii* Müll. Hal.	x	x	—	—
	Neckera andina Mitt.	—	x	x	—
Dicranaceae	*Campylopus areodictyon* (Müll. Hal.) Mitt.	x	—	x	x
	*Chorisodontium mittenii (*Müll. Hal.) Broth.	—	—	x	—
Bryaceae	*Bryum subapiculatum* Hampe	x	—	—	—
	Bryum andicola Hook.	—	—	—	x
Bartramiaceae	*Bartramia potosica* Mont.	—	—	x	—
	Bartramia sp.	—	—	x	
Hypnales/Brachytheciaceae	*Brachythecium sp.*	x	x	—	x
	Brachythecium occidentale (Hampe) A. Jaeger	x	x		x
Thuidiaceae	*Thuidium peruvianum* Mitt.	—	x	x	—
Sematophyllaceae	*Sematophyllum swartzii* (Schwägr.) W.H. Welch & H.A. Crum	—	x	x	—
Dicranales/Pottiaceae	*Syntrichia andicola* (Mont.) Ochyra	x	—	—	x
	Leptodontium tricolor (R.S. Williams) R.H. Zander	x	x	x	x
	Syntrichia sp.	—	—	—	x
	Daltonia trachyodonta Mitt.	—	x	x	
	Didymodon challaense (Broth.) R.H. Zander.	x	—	—	—
Hookeriales/Daltoniaceae	*Daltonia* sp.	x	—	—	x
Leucodontales/ Leptodontaceae	*Morphospecies (1)*	x	x	—	—
Lepyrodontaceae	*Lepyrodon tomentosus* (Hook.) Mitt.	x	x	x	x

Table 1.
Species of mosses in the forests of Canchacancha (1), Kontorkayku (2), Kelloq'ocha (3), and Manthanay (4).

Figure 9 shows an important beta diversity for the 4 *Polylepis* forests in terms of species, genera, and families, where the Manthanay forest has the least diversity for each taxon.

In the box plot, (**Figure 10**) the richness of species of the four forests is shown graphically, we can observe that there are atypical data for the Kellococha and Manthanay forests, an important aspect to point out is that the box of this last forest presents a great difference when compared to the Canchacancha and Contorkayku

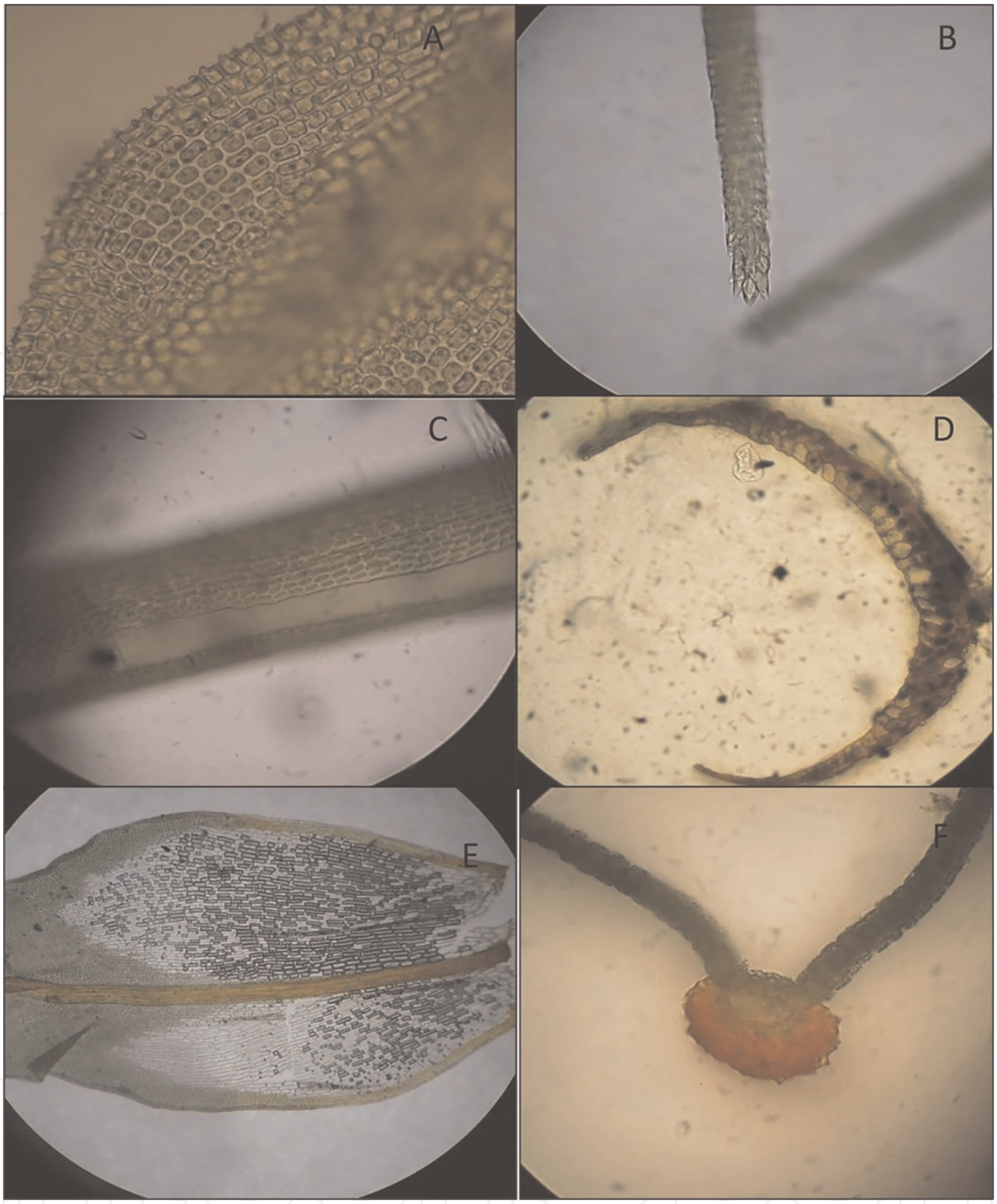

Figure 8.
A. Cells with two papillae in Thuidium peruvianun Mitt.40x *B. leave apex in* Campylopus areodictyon (Müll. Hal.) mitt. 40x*; C. involute leave in* Chorisodontium mittenii (Müll. Hal.) broth. *40x D. Clorocistos and hialocistos, phyllidia of* Chorisodontium mittenii (Müll. Hal.) broth *40x. E. Cancellinae cells in* Leptodontium tricolor (R.S. Williams) R.H. Zander 40x *F. cross-sectional of leaf in* Syntrichia andicola (Mont.) *40x.*

boxes, that is why we say that the Manthanay forest presents a difference in terms of the richness of moss species.

In the box plot, (**Figure 11**) the richness of species there is no significant difference in species richness between living and dead arboretums. The floristic composition between living and dead arboretums is different; however, it was observed that in dead arboretums the species richness is equal to that of living arboretums.

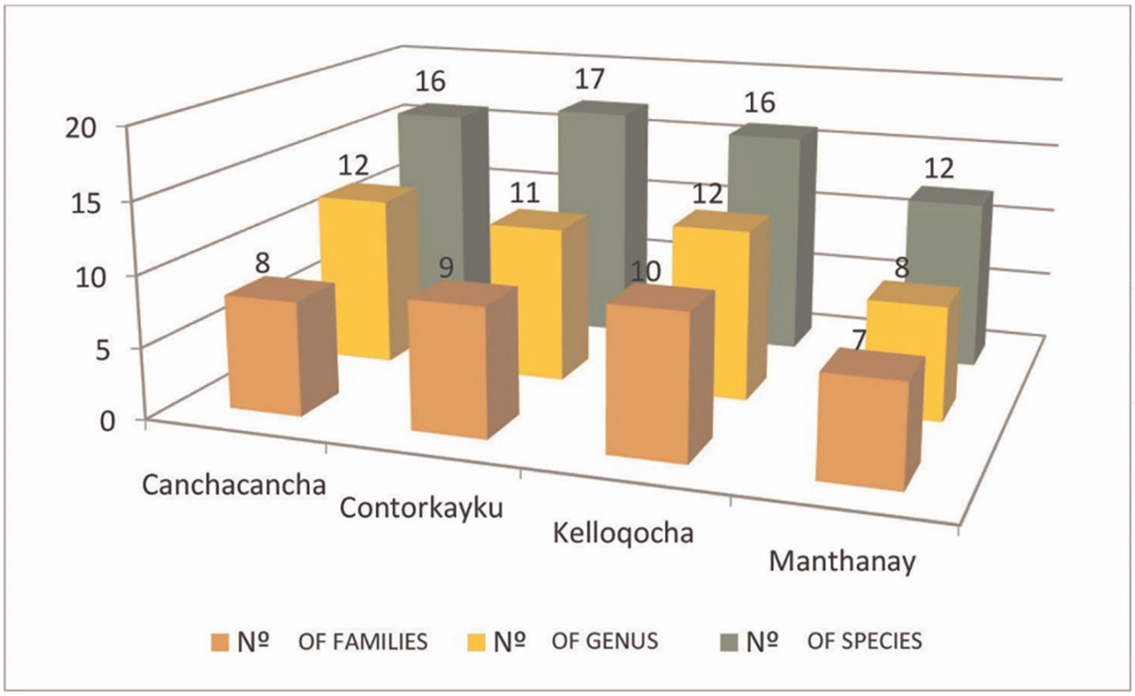

Figure 9.
Distribution of families, genera, and morphospecies in the four forests of Polylepis *spp.*

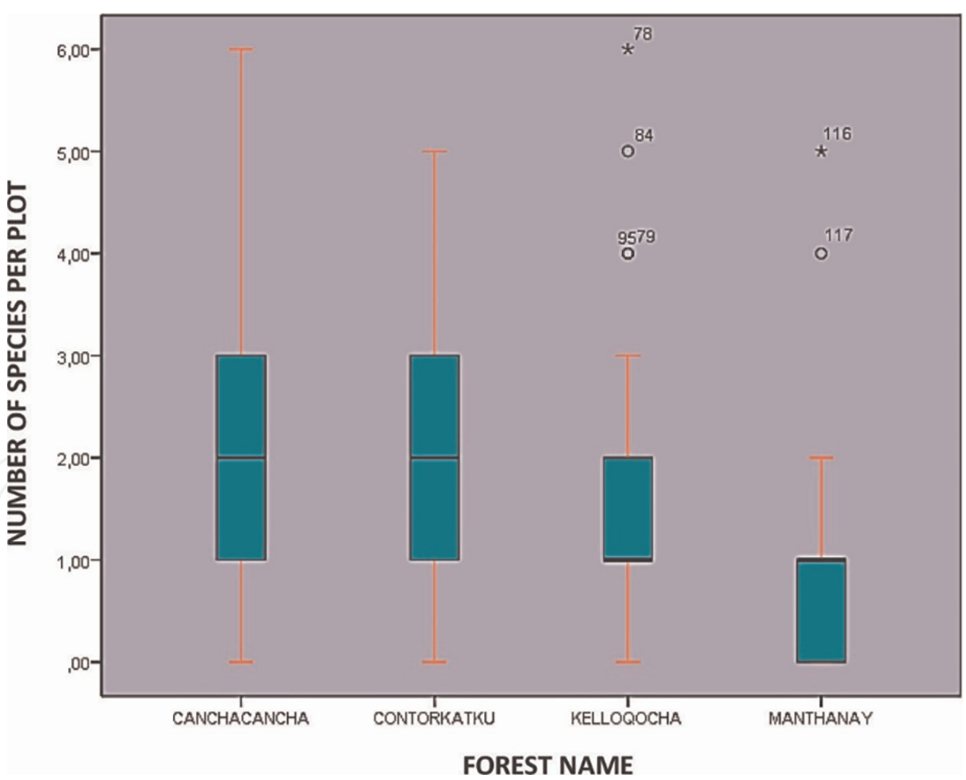

Figure 10.
Box and whisker plot for species richness per plot of each forest.

7. Discussions

Acurio [11] carried out an exhaustive study of the diversity of mosses in the Wiñay Wayna – Machupicchu area – Peru, finding a total of 129 species of mosses in 72

Figure 11.
Box and whisker plot for species richness per plot of each estate of the tree.

genera and 29 families. Making a comparison with the present study we have that: Acurio collected mosses in an altitude range of 2500 to 3100 m, on the other hand, this study was carried out in an altitude range of 4300 to 4800 m, and in investigations carried out by Churchill et al. [3], it was found that the elevation zone with the highest number of moss species is between 2000 and 3000 m. Lithophytic, epiphytic, and terrestrial mosses were evaluated; however, in the present study, only epiphytic mosses were taken, and according to Churchill et al. [3], the most common substrate among mosses is soil, followed by rocks and finally epiphytes. Therefore, the ecological conditions for Wiñay Wayna seem to be much more favorable, which allows the existence of a greater diversity of species. Despite the differences regarding the study area, it is necessary to highlight that, of the 129 species cited by Acurio, three of these species were also reported for this study: *Zygodon reinwardtii* (Hornsch.) A. Braum, *Thuidium peruvianum* Mitt., and *Sematophyllum swartzii* (Schwägr.) W.H. Welch & H.A. Crum.

Fuentes & Churchill [17] found, in the Madidi region (Bolivia), a total of 369 species in 168 genera and 54 families, of which seven species are shared with the present study: *Bartramia potosica* Mont., *Chorisodontium mittenii* (Müll. Hal.) Broth., *Braunia cirrhifolia* (Mitt.) A. Jaeger, *Orthotrichum elongatum* Taylor, *Z. reinwardtii* (Hornsch.) A. Braum, *Leptodontium tricolor* (R.S. Williams) R.H. Zander, *Thuidium peruvianum* Mitt. To understand the proportion of the number of species that were obtained in this study, it is necessary to highlight that the studied area comprises approximately 30,000 km^2, likewise, the climate is varied and includes mountain ranges that reach 6000 m, low mountain ranges, wide and narrow valleys, and plains above 200 m. Gradstein et al. [16] stated that in the neotropics, the diversity of mosses depends on the heterogeneity of the habitats, together with the vegetation zoning provided by the topographic relief. Likewise, Churchill et al. [18] discovered that, if the topographic relief is poor, the diversity of mosses is low. Starting from this premise, we can infer that the richness of the bryoflora in the study area is due to the geographical and ecological conditions that the study area presents (topographical relief, edaphology, climate, vegetation, etc.)

For its part, Carhuapoma [13] carried out the study of mosses of the Historical Sanctuary of the Pampa de Ayacucho in an altitude range of 3350 to 4100 m.a.s.l., registering the Pottiaceae as the most representative family with 10 species, followed by Orthotrichaceae, Brachytheciaceae, and Bartramiaceae with six species, which shows that the results are similar to those reported in the present investigation.

It was believed that the adaptation of *Polylepi*s did not allow the development of epiphytes on trunks (bolus, low canopy) and branches because the bark is constantly being renewed [19], but despite this difficult condition, lichens colonize and settle on branches and trunks of *Polylepis* trees, to later allow the development of mosses, liverworts and other vascular plants by ecological succession.

8. Conclusions

Studies of mosses in the high mountains of Peru, particularly in *Polylepi*s forests, are still very scarce, however, we can see that beta diversity is high, with large differences in the composition of species in each forest, which is interesting and needs further studies.

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Conflict of interests

The authors do not incur conflicts of interest.

Ethical/legal aspects

The authors declare that they have not incurred any violation of an ethical or legal nature.

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