Beyond the Obvious: Unveiling the Cryptic Bryophyte Diversity of the Eastern Afromontane Biodiversity Hotspot

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Abstract: Soromessa, T.; Hailegiorgis, T. (2026): Beyond the Obvious: Unveiling the Cryptic Bryophyte Diversity of the Eastern Afromontane Biodiversity Hotspot. *Frahmia* 44:1-18*.

The Eastern Afromontane Biodiversity Hotspot (EABH) is a major center of plant diversity and endemism in Africa, yet its bryophyte flora remains incompletely documented and taxonomically underexplored. Although bryophytes constitute an ecologically significant component of montane ecosystems and are widely used as indicators of environmental conditions, comprehensive syntheses of their diversity, distribution, and taxonomic status within the EABH are lacking. This review critically evaluates existing bryological knowledge from the Eastern Afromontane region, with particular emphasis on historical and contemporary collection efforts, taxonomic coverage, species richness, endemism, and biogeographic patterns. Available evidence indicates that bryophyte diversity in the EABH is substantial but unevenly sampled, with pronounced geographical and taxonomic biases across countries and mountain systems. Habitat loss and environmental change pose increasing threats to bryophyte assemblages, further complicating accurate taxonomic assessment and documentation. Major gaps persist in floristic inventories, taxonomic revisions, and species-level ecological data, limiting the robust interpretation of diversity patterns and endemism. Addressing these deficiencies through targeted field surveys, integrative taxonomic approaches, and regional syntheses is essential for advancing bryological systematics and for improving the baseline knowledge required for future ecological and conservation studies in the Eastern Afromontane Biodiversity Hotspot.

Key words: Bryophytes; Diversity; Eastern Afromontane Biodiversity Hotspot; Endemism; Floristics.

* Published online: January 2, 2026

1. Introduction

Bryophytes are one of the key components of biodiversity in the Eastern Afromontane Biodiversity Hotspot (EABH), which is amongst the eight and thirty-six known biodiversity hotspots in Africa and the World, respectively. It is also the most astonishing places on Earth and notable for both its highly prominent level of biodiversity and endemism, accompanied by the life-sustaining systems (Myers et al., 2000; CEPF 2012).

Despite the gap in research compared to vascular plants, bryophytes represent the second largest group of green land plants after flowering plants with approximately older figures of 20,000 species estimated by (Shaw, 2001; Patiño and van der Poorten, 2018) to 25,000 species (Crum, 2001) and a nearly global distribution (Gignac, 2001; Proctor and Tuba, 2002). However, the current estimate of bryophytes is approximately 20,000 species, 1,822 genera, and 177 families (http://www.theplantlist.org/1.1/browse/B/).

As a part of the hotspot, bryophytes are an ecologically significant component of the ecosystem in a densely distributed manner all over the region. Even though, bryological collection and their diversity have been well studied and documented in some parts of the hotspot in the past (Pócs and O'Shea, 1991); and recorded recent regional checklists of moss O'Shea (2006) and liverwort and hornwort (Wigginton, 2018), much remains relatively unknown especially about in remining part of hotspot and in Africa in general (O'Shea, 1997; Wigginton et al., 1999). Additionally, at the continent level, there are incomplete floras and identification guides in tropical Africa (De Sloover, 2003), West Africa (Wigginton, 2004), in the hotspot, Kenya (Chuah Petiot, 2003; Wilding et al., 2016), and Rwanda (Fischer, 2013). Moreover, there is an overwhelming research gap, and most research carried out in the hotspot has been on angiosperms.

The objective of this review was to explore what bryophytes are in the hotspot, their diversity, endemism, economic significance, and ways of threatening. Besides, it looks over a huge gap in the limited development of bryoflora in the countries, an incomplete collection of species, an untouched area of bryophyte role in their biological diversity, ecosystem value, and its aspect to society. In addition, the relationship of bryophytes with other plant groups and organisms is also an unexamined part. Totally, a group of plants with a wonderful role for the hotspot as well as the world biomass, but as a result of no or little information about them, leads to unclear endanger causes to their diversity due to poor or limited research (Bates, 2008). Or this review has addressed (1) What does the diversity of bryophytes look like in the hotspot? (2) What is the current status of bryophytes flora in the hotspot, how many species are collected, and how many of them are endemic to the hotspot areas? and (3) What does the literature tell us about the vegetation, diversity, endemism, the important role, and the threat, with their impacts on bryophytes of the hotspot? Lastly, what are the current research gaps of the hotspot in bryophytes?

2. Materials and Methods

This review is based on a comprehensive analysis of published floristic treatments, monographs, checklists, and specimens from major herbaria. Geographic records were compiled to map species richness and endemism hotspots.

3. Geographical Location of EABH

The Eastern Afromontane Biodiversity Hotspot (EABH) is a significant ecological region characterized by its high levels of biodiversity, particularly the presence of endemic species. This hotspot spans multiple countries in eastern Africa, from Saudi Arabia and Yemen in the north to

Zimbabwe in the south (Gordon et al., 2012; Mairal et al., 2017, see Figure 1), covering an extensive area of more than one million square kilometres. The region follows the East African Rift Valley, stretching over 7,000 kilometres and encompassing various mountainous landscapes (Gordon et al., 2012). Key geographical features include the Ethiopian Highlands, the volcanic mountains of Uganda, Rwanda, and Burundi, and the Eastern Arc Mountains in Kenya and Tanzania. These areas are notable for their complex ecosystems and unique flora and fauna, which face significant threats due to habitat loss and environmental changes (Myers et al., 2000).

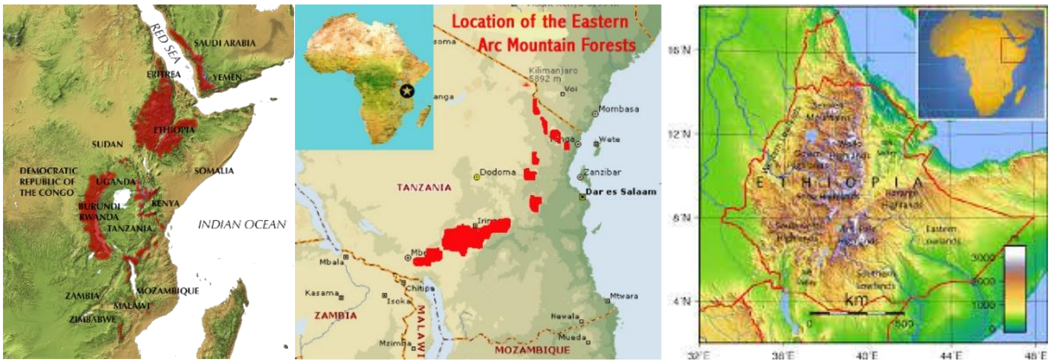

Figure 1. Map of the Eastern Afromontane Biodiversity Hotspot showing major montane blocks and relative bryophyte research areas. Darker shading indicates areas with comparatively higher bryological sampling (e.g., Eastern Arc Mountains, Ethiopian Highlands), while lighter shading denotes under-explored regions. The fragmented, "sky-island" configuration of the hotspot has promoted isolation and local diversification of bryophyte assemblages.

The EABH has been recognized not only for its ecological significance but also for its vulnerability. Conservation efforts are critical in this region to protect the unique biodiversity and address the challenges posed by habitat degradation and climate change. The work of various researchers, including Mairal et al. (2017) and others, highlights the urgent need for action to conserve this irreplaceable natural heritage. EABH is categorized by a series of isolated and biogeographically similar montane islands (including the highest peaks in Africa and Arabia) and extensive plateaus. It extends over 44 degrees of latitude and is bisected by the equator. The highest point is on Mount Kilimanjaro, which reaches 5,895 meters above sea level, and forests and woodlands included within the ecoregions (relatively large units of land or water that contain distinct biodiversity) extend as low as 300 meters above sea level in some areas. Generally, the hotspot is cooler and more humid than the surrounding lowland regions, due to its wide, spectacular altitudinal range.

4. The Vegetation of EABH

Vegetation of EABH is well-known by a diversified group of plants, including non–vascular, distributed in diverse geographical regions. It contains the East African Montane forests, Southern Rift Montane Forest-Grassland mosaic, the Albertine Rift, and the Ethiopian Upper Montane Forests, Woodlands, Bushlands and Grasslands, and the addition of the Southern Montane islands in Malawi, Zimbabwe, and Mozambique (Gordon et al., 2012). The Albertine Rift alone is home to about 15 % of mainland Africa's plant species, with at least 300 endemics. The grasslands of the Southern Rift are rich in orchids, with more than 500 species. Farther south, the Chimanimani Mountains have a quartzite grassland that holds at least 73 plants found nowhere else. Within the Arabian Peninsula portion of the hotspot, 110 plant species are known to be endemic, with a substantial number of additional endemic plant species still to be described.

The EABH is described by incomparable species richness and a high endemicity level of vegetation, making it exceptionally vulnerable to changes in its habitat under great human land-use pressure (Rodrigues et al., 2004; Burgess et al., 2007). Out of the more than 10,000 plant species found in this region (7,600 vascular plants), about one third are endemic, thus it is due to their unique climatic region and variations of altitudinal range. This pattern of endemism has been attributed to long-term climatic stability, favouring lineage diversification and species accumulation over time, mainly due to isolated and fragmented geographic distribution.

The EABH vegetation type is comprised of three distinct altitudinal belts, the lowermost Afromontane Forest (1300–3000 m), the ericaceous belt (3000–4100 m), and the uppermost Afroalpine zone (> 3550 m) (Hedberg, 1951; Gehrke and Linder, 2014; Linder, 2014), each with unique floristic composition (Kebede et al., 2007; Mairal et al., 2017) and transects into diverse ecological conditions. The hotspot flora shows much uniformity and continuity (though changing in composition with increasing altitude) and a lower altitudinal limit largely between 1,500 and 2,000 meters (lower away from the equator). Only 10.5 percent (106,870 square kilometres) of the original vegetation remains more or less intact, with about 15 percent of the total area (154,132 square kilometres) under some level of official protection. Overall, the hotspot holds nearly 7,600 species of plants, of which more than 2,350 are endemic (Gordon et al., 2012).

The hotspot flora shows much uniformity and continuity (though changing in composition with increasing altitude) and a lower altitudinal limit largely between 1,500 and 2,000 meters (lower away from the equator). The most widespread tree genus is Podocarpus, although Juniperus is commonly found in drier forests of northeastern and eastern Africa, and a zone of bamboo is often found between 2,000 and 3,000 meters, above which there is often a *Hagenia* forest zone up to 3,600 meters. Many species common in montane forests have economic importance, while several crops, including coffee and teff (a cereal crop) from the Ethiopian Highlands, have been domesticated. EABH has also been suggested as one of the main centres of bryophyte diversity and endemism in Africa (Geffert et al., 2013; von Konrat et al., 2008), due to the vast nature of altitudinal ranges and comprise of mountains.

5. Diversity of Bryophytes in EABH

Bryophytes are collective terminology of mosses, liverworts and hornworts (Sousa, et al., 2020) which are approximately about 20,000 species, 1,822 genera and 177 families (http://www.theplantlist.org/1.1/browse/B/, Crum, 2001; Bahuguna et al., 2013) found everywhere in the world except in the sea, but they prefer humid climates to thrive, but can be found all over the world, even in arid regions (Zechmeister et al., 2003), especially damp, humid and shaded environments from excessive sunlight (Ogwu, 2019).

Bryophytes are ideal for revealing different environmental patterns thrive from sea level to polar regions within different substrates everywhere in the world, on trees, rocks, in the soil, in lakes, and in rivers from the Tundra of the Northern hemisphere to Antarctica as well as forming biological associations with other organisms (Ogwu, 2019) and also colonize nearly every kind of terrestrial substrate (e.g., bare stones, bark, skeletons, etc.).

EABH is biologically a wealth ecoregion in Africa (Tusiime et al., 2007), mostly thriving in the mountainous parts of the hotspot (Hallingback and Hodgets, 2000), such as the Virunga, Tanzania highlands, Ethiopian highlands, Mt. Rwenzori, Mt. Elgon, and Mt. Kenya. This is a result of the immense variety of niches (microhabitats) and fragmented habitats; thus, the hotspot supports a great diversity of bryophytes.

Habitat associations and functional insights

Bryophyte diversity in the EABH is strongly linked to habitat type (Fig. 3). Moist montane and cloud forests are dominated by epiphytic and corticolous taxa, while riverine forests, shaded rocks, and wetland habitats support hygrophilous mosses and liverworts. Afro-alpine zones exhibit a clear shift towards terricolous and saxicolous species, often with cushion-forming or mat-like growth forms to withstand environmental stressors. These habitat associations underscore the ecological specialization of bryophytes along environmental gradients and their potential as indicators of forest integrity and microclimatic stability.

Figure 2. Habitat associations of bryophytes in Eastern Afromontane ecosystems. Major habitat types supporting bryophyte diversity in the Eastern Afromontane Biodiversity Hotspot. Moist montane forests are dominated by epiphytic liverworts and pleurocarpous mosses, while shaded rock faces, riverine habitats, and afro-alpine zones support distinct, often highly specialized bryophyte assemblages.

Bryophytes are major biodiversity components of many ecosystems, including deserts, grassland, tropical, alpine, polar, and forest, and vary depending on altitudinal range. Bryophyte species richness increased along the altitudinal gradient, and species diversity increases with altitude (have wider distribution and longer altitudinal gradient than vascular plants, but they prefer the mid-elevations to get optimum temperature and humidity (Maul et al., 2020). Besides, their distribution is also controlled by macroclimatic factors rainfall and temperature (Maul et al., 2020), and microclimatic factors, such as type of substrate, light intensity, humidity, pH, nutrient level, and cloud cover etc.

Table 1. Dominant bryophyte families by habitat type and altitudinal zone in the Eastern Afromontane Biodiversity Hotspot. Dominant bryophyte families show clear segregation along altitudinal and habitat gradients (Table 1), with epiphytic liverworts of Lejeuneaceae and Plagiochilaceae reaching maximum prominence in upper montane cloud forests." "Afro-alpine assemblages are characterized by stress-tolerant moss families such as Grimmiaceae and Polytrichaceae, contrasting sharply with the epiphyte-dominated communities of lower elevations (Table 1)."

Altitudinal zone	**Dominant habitat type**	**Dominant moss families**	**Dominant liver-wort families**	**Notes on ecologi-cal affiliation**
Sub-montane (c. 800–1,500 m)	Moist forest floor; shaded rocks	*Bryaceae; Fissiden-taceae; Pottiaceae*	*Ricciaceae; Fos-sombroniaceae*	High tolerance to disturbance and seasonal moisture variability

Altitudinal zone	Dominant habitat type	Dominant moss families	Dominant liverwort families	Notes on ecological affiliation
Lower montane (c. 1,500–2,200 m)	Tree trunks; decaying wood	*Orthotrichaceae; Hypnaceae*	*Lejeuneaceae; Frullaniaceae*	Increasing epiphytic diversity with rising humidity
Upper montane (c. 2,200–3,000 m)	Cloud forest trunks and branches	*Sematophyllaceae; Hypnaceae; Neckeraceae*	*Lejeuneaceae; Plagiochilaceae*	Peak bryophyte richness; dominance of epiphytes
Upper montane (c. 2,200–3,000 m)	Shaded rock faces; stream banks	*Thuidiaceae; Brachytheciaceae*	*Metzgeriaceae; Jungermanniaceae*	Stable humidity supports hygrophilous taxa
Afro-alpine (c. >3,000 m)	Soil, peatlands, exposed rocks	*Grimmiaceae; Polytrichaceae; Dicranaceae*	*Scapaniaceae; Antheliaceae*	Stress-tolerant, cold-adapted growth forms
Afro-alpine (c. >3,000 m)	Wetlands; flushes	*Amblystegiaceae; Calliergonaceae*	*Aneuraeae*	Cushion-forming and semi-aquatic specialists

6. Comparative Summary of Bryoflora in Ethiopia vs. Eastern Arc Mountains

Bryophyte assemblages of the Ethiopian Highlands and Eastern Arc Mountains exhibit both shared and distinctive patterns. In Ethiopia, bryophyte diversity peaks in upper montane forests (c. 2,400–3,200 m) and afro-alpine zones (>3,200 m), where moss families such as *Sematophyllaceae, Hypnaceae, Polytrichaceae*, and liverwort families such as *Lejeuneaceae, Plagiochilaceae, Scapaniaceae* dominate (Table 2). These assemblages are shaped by extreme elevation, pronounced diurnal temperature variation, and the isolation of high plateaus, resulting in unique afro-alpine specialists and cold-tolerant taxa. In contrast, the Eastern Arc Mountains reach lower maximum elevations (c. 2,500 m) and are characterized by persistent cloud forest conditions, high humidity, and low seasonal variation, which favour epiphytic liverworts such as *Lejeuneaceae and Plagiochilaceae* and mosses like *Sematophyllaceae* and *Neckeraceae* (Table 3). While both regions support epiphytic-dominated upper montane forests, the Eastern Arc exhibits higher local endemism within cloud forest taxa, reflecting long-term climatic stability and habitat continuity, whereas the Ethiopian Highlands show stronger representation of afro-alpine specialists adapted to extreme conditions. These contrasts underscore the influence of elevation, microclimate, and historical isolation in shaping bryophyte composition across the Eastern Afromontane Biodiversity Hotspot. In the Ethiopian Highlands, afro-alpine bryophyte assemblages are dominated by cold-tolerant moss families such as *Polytrichaceae* and *Grimmiaceae*, contrasting with epiphyte-rich upper montane forests (Table 2).

Table 2. Dominant bryophyte families by habitat and altitudinal zone in the Ethiopian Highlands (Eastern Afromontane Biodiversity Hotspot).

Altitudinal zone	**Dominant habitat type**	**Dominant moss families**	**Dominant liverwort families**	**Notes on distribution and ecology**
Sub-montane (c. 1,000–1,800 m)	Forest floor; disturbed soils	*Bryaceae; Fissidentaceae; Pottiaceae*	*Ricciaceae; Fossombroniaceae*	Common in seasonally dry forests and disturbed landscapes
Lower montane (c. 1,800–2,400 m)	Tree trunks; decaying wood	*Orthotrichaceae; Hypnaceae*	*Lejeuneaceae; Frullaniaceae*	Increasing epiphytic diversity with altitude and moisture
Upper montane (c. 2,400–3,200 m)	Moist montane forest; cloud-affected zones	*Sematophyllaceae; Neckeraceae; Hypnaceae*	*Lejeuneaceae; Plagiochilaceae*	Highest bryophyte richness in Ethiopian forests
Upper montane (c. 2,400–3,200 m)	Shaded rocks; streams	*Brachytheciaceae; Thuidiaceae*	*Metzgeriaceae; Jungermanniaceae*	Hygrophilous taxa associated with stable humidity
Afro-alpine (c. >3,200 m)	Soil; peatlands	*Polytrichaceae; Dicranaceae*	*Scapaniaceae; Antheliaceae*	Cold-tolerant taxa in open, high-elevation habitats
Afro-alpine (c. >3,200 m)	Exposed rocks	*Grimmiaceae*	—	Saxicolous specialists adapted to freeze–thaw cycles

Eastern Arc cloud forests support exceptionally rich epiphytic liverwort communities dominated by *Lejeuneaceae* and *Plagiochilaceae*, reflecting long-term climatic stability and habitat continuity (Table 3).

Table 3. Dominant bryophyte families by habitat and altitudinal zone in the Eastern Arc Mountains (Tanzania–Kenya)

Altitudinal zone	**Dominant habitat type**	**Dominant moss families**	**Dominant liverwort families**	**Notes on distribution and ecology**
Sub-montane (c. 600–1,200 m)	Lowland–sub-montane forest floor	*Bryaceae; Calymperaceae; Fissidentaceae*	*Ricciaceae; Aneuraceae*	Warm, humid forests with pantropical affinities

Altitudinal zone	**Dominant habitat type**	**Dominant moss families**	**Dominant liverwort families**	**Notes on distribution and ecology**
Lower montane (c. 1,200–1,800 m)	Tree trunks; lianas	*Orthotrichaceae; Sematophyllaceae*	*Lejeuneaceae; Frullaniaceae*	Strong epiphytic signal due to persistent humidity
Upper montane (c. 1,800–2,500 m)	Cloud forest canopy and trunks	*Sematophyllaceae; Hypnaceae; Neckeraceae*	*Lejeuneaceae; Plagiochilaceae*	Peak liverwort diversity and local endemism
Upper montane (c. 1,800–2,500 m)	Shaded rock faces; waterfalls	*Thuidiaceae; Brachytheciaceae*	*Metzgeriaceae; Pallaviciniaceae*	High moisture stability supports relic taxa
Upper montane–subalpine (c. >2,500 m)	Forest margins; heath-like vegetation	*Dicranaceae; Polytrichaceae*	*Scapaniaceae*	Transition to cooler, more open habitats
Wetlands (various elevations)	Swamps; forested streams	*Amblystegiaceae; Calliergonaceae*	*Aneuraeae*	Persistent saturation favors semi-aquatic specialists

The distribution and diversity of bryophytes is influenced by numerous environmental variables ultimately by precipitation and temperature and altitudinal gradient (Figure 3) and microhabitats and niches which is determined by its nature of substrates, light intensity, soil pH and streams (Tusiime et al., 2007) and also influenced by soil fertility levels which is driving force for biomass production which facilitates the activity of soil microorganisms and provides refugium for preservation of bryophytes as well as support a great diversity of bryophytes. Insolation, frost, fog, lithology, evapotranspiration rate, vertical gradients of light, wind speed, and temporal variability inside a forest are other environmental factors that influence bryophyte distribution within a geographical location (Ogwu, 2019). In addition, the nature of the forest provides richness and diversity, creates a natural refuge for bryophyte species, and promotes bryophyte diversity. Lastly, EABH, where climatic conditions are favourable due to the presence of extremities of stream sides, mountainous forest with an immense variety of niches and habitats, promises the greatest diversity of bryophytes (Tusiime et al., 2007).

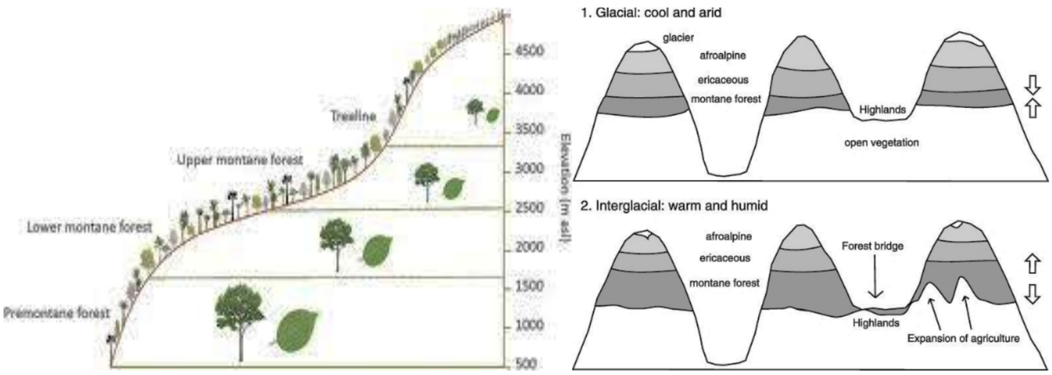

Figure 3. Altitudinal gradient of bryophyte diversity and functional groups. Conceptual representation of bryophyte diversity along an altitudinal gradient in the Eastern Afromontane region. Species richness generally increases from sub-montane forests to upper montane and cloud forest zones, driven by high humidity and habitat heterogeneity, before declining at afro-alpine elevations where specialized, stress-tolerant taxa predominate.

Species of bryophytes in EABH countries in Africa vary greatly in the level of bryological exploration of its countries. The known number of species is summarized from the checklists of Hepaticae (Grolle, 1995; Wigginton and Grolle, 1996) and for Musci (O´Shea, 1995). This list reflects more the level of exploration of the different countries than their real species richness, especially, there is a great discrepancy between the given species number and the size and habitat diversity of the concerned country. The table below shows the number of species in EABH countries. We presume that areas under EABH in these countries could harbor over 75% of the total 5,594 species. The most diverse genera in the region are the genus *Fissidens*, followed by the genus *Cololejeuna* and the genus *Plagiochila*.

Table 4. Number of bryophyte species in EABH countries (source: Frahm, 2003)

S.No.	Country	Hep.	Musci	Total
1	Burundi	88	69	157
2	Congo (Zaire)	291	579	870
3	Eritrea	15	75	90
4	Ethiopia	119	285	404
5	Kenya	208	464	672
6	Malawi	122	223	345
7	Mozambique	53	77	130
8	Rwanda	223	293	516
9	Somalia	4	19	23

S.No.	Country	Hep.	Musci	Total
10	Sudan	10	31	41
11	Tanzania	389	780	1169
12	Uganda	153	376	529
13	Zambia	59	141	200
14	Zimbabwe	135	265	400
15	Yemen and Saudi	NA	NA	48
Total				**5,594**

7. Endemism of Bryophytes in EABH

Endemism describes taxa that are distributed in particular areas, so there are more than 2,350 endemics out of nearly 7,600 species of plants in EABH. The Albertine Rift alone is home to about 14 percent (about 5,800 species) of mainland Africa's plant species, with more than 300 endemic species; the Eastern Arc has even more endemics (550 species) (Gordon *et al.,* 2012). This pattern of endemism has been attributed to long-term climatic stability, favouring lineage diversification and species accumulation over time.

The value of analysing endemism is twofold: that identify the factors, historical or current patterns of speciation or range restriction (Myers *et al.,* 2000; Shaw, *et al.,* 2016), as well as their importance for conservation planning. Endemic vascular plants are well studies in each country of the EABH, bryophytes of these countries haven't been discussed previously, due to the lack of completed list, accepted names and actual data on their distribution area of a country, and defining endemism in the case of bryophyte is questionable, due to information gap about their presence and absence in EABH (Pócs, 1998). However, the endemic taxa of the different parts of EABH are explored poorly, especially in the Eastern Arc (Pócs, 1998), such as bryophyte endemism in the Eastern Arc Mountains of Uganda, and the proportion of endemism (altogether 32 species, 4.57 %) is not high compared to phanerogams, but is high when compared with the bryoflora of similar areas. Moreover, the family Lejeuneaceae that is endemic to Tanzania was also explored (Van Rooy, et al., 2019). Finally, this hotspot is mainly characterized by isolated mountains with a wide range of altitudes, which are rich in a range of habitats, microhabitats, as well as the origin of freshwater or humid ecosystems, which are suitable for the growth of bryophytes. All these sum factors provide a favourable environment for their luxuriant growth and promise endemism of the hotspot is undeniable.

8. Impact of Climate Change and Threats to Bryophytes in EABH

Even though the EABH is one of the Earth's most biologically rich, also the most threatened ecosystems in Africa, it needs to be prioritized for conservation and other biodiversity investments (CEPF, 2012). Even if bryophytes are a highly adapted group of plants that can survive in quite a diverse environment, including terrestrial environments (even deserts) except in marine habitats, widely distributed throughout the world, bryophytes are troubled in different ways, similar to those shown by vascular plants (Schofield and Crum, 1972).

The major threats to bryoflora include habitat loss & degradation, where the primary threat is from clear-cutting for agriculture (tea, coffee, subsistence farming) and timber; climate change which altered precipitation regimes and rising temperatures threaten moisture-dependent species, potentially compressing elevational ranges; fire that increased frequency and intensity of fires degrade Afroalpine and moorland habitats; invasive species where woody invasives (e.g., *Pinus*, *Acacia*) alter microclimates and outcompete native understory flora; and knowledge gap in which the lack of specialist taxonomists and baseline data impedes effective assessment and conservation. Of all the major threatening ways to bryophytes' diversity is the world's climate change and anthropogenic activities. Even if it is difficult to determine the level of threatened bryophytes that provides information for conservation action (Van Rooy, *et al.,* 2019), EABH biodiversity is highly lost or threatened particularly Tanzania (Global Wildlife Conservation, 2014).

Climate change is also directly affecting bryophyte ecophysiology in the hotspot. The stability of world water, light, and temperature availability influences the species composition and richness within bryophyte communities

Anthropogenic factors such as deforestation of vascular plants and habitat destruction are the most important pressing issues next to climate change, for the current decline of biodiversity. As bryophytes are closely linked to their habitats (microhabitats), damage to these habitats has far-reaching impacts on their affiliated diversity (Qing, 1999). Mainly, habitats are disturbed by human interference via degradation (Gignac, 2001; Pykälä, 2019) and fragmentation, which are the major threats in this hotspot (CEPF, 2016). This is caused by expanding agriculture (Oyesiku, 2012), plantation forestry, which interferes with increasing yield production (Zewdie, et al., 2022), logging, fires, invasive alien plants, mining, infrastructure development, and gathering of firewood, which leads to the total extinction of bryophytes from their natural habitats.

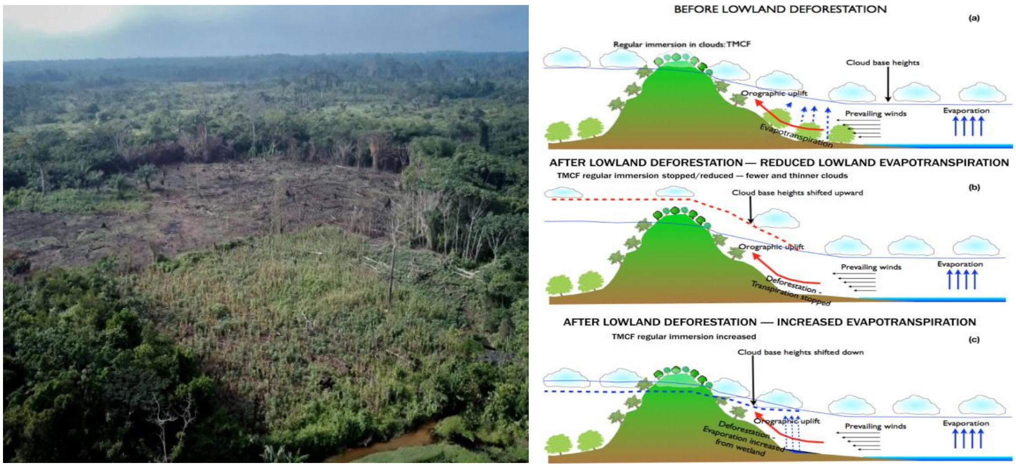

Figure 4. Threat pathways affecting bryophytes. A model of major anthropogenic pressures affecting bryophyte communities in Eastern Afromontane ecosystems. Forest degradation and climate change interact to reduce habitat continuity and microclimatic stability, disproportionately impacting moisture-dependent and range-restricted bryophyte taxa.

Deforestation of higher plants and agricultural expansion into to forest are the main factors for loss of bryophyte diversity, particularly the epiphytic one (Hylander, *et al.,* 2013). Cutting forests reduces the amount of habitat, isolates the remaining patches (habitat fragmentation), and alters the local or regional microclimate (Lawton, *et al.*, 2001), resulting in loss of species.

The diversity of bryophytes is also adversely affected through mining activities, which release heavy metals and are absorbed by the tissue of bryophytes. In the Eastern Afromontane biodiversity hotspot, conservation studies are getting increased attention because of its high endemicity levels and shrinking geographic distribution, but it is restricted only to angiosperm plants and faunas, so the remaining biodiversity components are lost alarmingly time to time due to a lack of consideration. And insufficiency of scientific studies with a detailed flora on bryophytes lead to increases the vulnerability of bryophytes as it is difficult to implement necessary conservation measures without understanding the status of species and accurate identification of species and also it is again difficult to identify or measure the impact of stresses or the causes of degradation or destruction of bryophytes due to least attention on bryophytes, so bryological exploration of Africa should be stepped up to increase our knowledge of species occurrences and threats and to facilitate the red-listing and the conservation of rare and threatened bryophytes (Van Rooy, *et al.,* 2019) and generating interest in bryophytes through their benefits to humans maybe be an effective conservation strategy. Otherwise, these highly specialized and sensitive organisms would disappear. The hotspot is characterized by unique isolated “sky island” habitats that are rich in endemics and unique species, also under threat from land use change and climate change, coupled with other drivers of biodiversity loss (Kidane, 2019); thus, losing them is irreplaceable, and the upward shift of species has ended, particularly in these Afroalpine ecosystems.

9. Research Gaps on Bryophytes of EABH

In reference to present-day conditions, bryophytes have an important role with respect to environmental conditions. The species richness of bryophytes is very high and is placed after Angiosperms and has a great capability to grow even in adverse conditions, while other vascular plants are not able to do so. Bryophytes are the best pollution indicators. However, this lower group of plants received less attention in EABH and remained neglected in exploration, due to their less direct economic potential. Compared to their vascular counterpart, they are rarely collected and characterized. Hence, many taxonomic gaps continue to exist. Climate change is causing a decline in bryophyte species, which has also heightened the neglect of this plant group in research.

Bryophyte Flora is still not present in many biogeographic regions and may not be sufficient where they exist. However, it is not too late to collect, document, and characterize these plant groups to checkmate future declines (Ogwu, 2019). In different studies on bryophytes of EABH countries, for instance, in Ethiopia, a large proportion of new species are recorded at different times, suggesting that Ethiopia is bryologically very under-explored, and that further exploration will reveal many additional species.

Compared to vascular plants, the knowledge about bryophyte biology, ecology, and distribution is relatively limited. The shortage of knowledge is a serious problem when evaluating what appropriate actions to take, including prioritizing the actions to be taken. Information on actual hotspots and the species distribution, the population size of species, as well as its susceptibility to anthropogenic environmental changes, is all crucial to the development of efficient and effective conservation measures (Hallingbäck & Tan, 2010). Bryophytes are not well known to the general public, even among some conservationists. This leads to the distraction of bryophytes in the area. Therefore, it is necessary to continue to highlight the importance of their presence in nature and their beneficial role in the ecosystem.

Even if bryophytes provide medicinal value, limited research has been done about the ethnobotanical aspects of bryophytes and the pharmacological properties of these plants when compared to rest countries. Moreover, vascular plants are used as green roofs worldwide, particularly in urban areas as tools to support decentralized local water cycles and combat the urban heat island effect (Köhler and Kaiser, 2021). These practices need labor to treat them, and waste huge amounts of water compared to bryophytes, but there is a huge gap in propagation and selection of species in these practices. In bryophytes, because of their very small size and the difficulty associated with their collection and identification (Asakawa *et al*., 2013), information is limited on the diverse economic relevance of bryophytes.

Climate change is also causing a decline in bryophyte species, which has also heightened the neglect of this plant group in research. The extent of this decline can be ascertained through a comparative assessment of older records (Lockhart *et al*., 2012), i.e., if such records exist. Bryophytes form different biological associations, yet the relation between bryophytes and the rest plant groups, with animals and is poorly understood, except for the epiphytic ones.

In general, there has been no comprehensive list of EABH bryophytes, except the annotated check -list of bryophytes in some countries among them vicinity of Ibb in Yemen (Kürschner, 2015); Wolo (Wigginton, 2001), Tigray, Kafa (Bonga) (Müller and Flügel, 2016), Bale Mountain (Pócs, 1999), Illubabor province, Beletta Forest Province; Pare, Nguru, Ukaguru Mountain in Uganda, Chyulu Range (Pócs, 2007) Turkana, rift valley, Nyanza, central (Karura Forest) Province, Taita Hills mountain in Kenya (Enroth, et al., 2019); Kilimanjaro, Udzungwa mountains scrap (Pócs, 2020) Udzungwa, Usambara and Uluguru mountains of Tanzania (Pócs, 1980; Pócs, 1998), Zaire in Dem. Rep. Congo and Rwanda (Bruggeman-Nannenga, 1993); Uganda (Porley, et al., 1999; Wigginton, et al., 1999 and 2001; O'Shea, et al., 2003; Bruggeman-Nannenga, 2006), annotated checklist of Zimbabwe (Best, 1990), is well known, but remains in the remaining province of the hotspot. To do so, bryologists and botanists should be interested in filling this gap, followed by conservationists, because bryophytes are crucial in scientific studies to predict valuable information about taxa and minerals and the status of the global climate.

The new records encountered prove that many of the hotspot species listed are still incomplete in different times and places, implying that bryoflora is not fully completed as angiosperm plants (Tusiime, et al., 2007; Müller and Flügel, 2016).

10. Conclusion

The Eastern Afromontane Biodiversity Hotspot supports a rich and distinctive bryophyte flora shaped by altitude, habitat, and historical isolation. Upper montane and cloud forests are dominated by epiphytic liverworts and mosses, whereas afro-alpine zones host cold-adapted, terricolous, and saxicolous taxa. Comparative analysis shows that the Ethiopian Highlands are characterized by afro-alpine specialists adapted to extreme conditions, while the Eastern Arc Mountains exhibit high local endemism among cloud forest epiphytes.

Despite these patterns, bryophyte diversity remains under-documented, with significant geographic and taxonomic gaps. Addressing these gaps requires targeted field inventories, integrative morphological and molecular taxonomic studies, and ecological research to understand responses to environmental change. Inclusion of bryophytes in conservation planning is urgently needed, given their sensitivity to forest degradation, habitat fragmentation, and climate change. Strengthening bryophyte research and protection across the EABH will ensure that these ecologically important and evolutionarily informative taxa are preserved, contributing to the broader conservation of tropical montane biodiversity.

11. Recommendations

The bryophytes of the Eastern Afromontane Hotspot are not merely minor greenery; they are a fundamental, diverse, and threatened component of one of the world's most important biogeographic regions. Documenting and conserving them is essential to understanding and preserving the full spectrum of life in these iconic mountains. We propose a concerted, collaborative effort focused on:

a) Intensified field inventory: Targeted surveys in under-collected areas, especially in Tanzania, Malawi, and Ethiopia;

b) Taxonomic capacity building: Support for African students and researchers in bryology through training, equipment, and access to literature;

c) Molecular systematics: Employ DNA barcoding and phylogenomics to resolve species complexes, reveal cryptic diversity, and elucidate biogeographic history;

d) Conservation integration: Include bryophytes in Red List assessments, designate Important Plant Areas (IPAs) for cryptogams, and promote *in situ* protection of key microhabitats (e.g., epiphyte-laden old-growth trees, peatlands); and

e) Long-term monitoring: Establish permanent plots to track bryophyte community responses to climate change and land-use.

12. Acknowledgments

The authors gratefully acknowledge Addis Ababa University for providing the institutional and logistical support necessary to undertake this work.

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