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Inventory of Moss (Bryophyta) in Batang Gadis National Park, Mandailing Natal Regency as a Basis for Developing Contextual Biology Learning

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Abstract

This study aims to inventory the diversity of mosses (Bryophyta) in Batang Gadis National Park, Mandailing Natal Regency and analyze its potential as a basis for contextual biology learning in higher education. The study used a descriptive exploratory method through field surveys in several microhabitats, namely dense canopy forests, around streams, damp rocks, decaying wood, and forest paths. Data were collected through observation, morphological documentation, substrate recording, and sample identification. The results showed the discovery of 15 moss morphospecies consisting of mosses, liverworts, and hornworts. Habitats around streams have the highest diversity, while tree trunks are the dominant substrate. The diversity value is in the medium category, indicating that this area has microhabitats that support the growth of Bryophyta. The inventory results have the potential to be developed as learning resources in Lower Plant Botany, Plant Taxonomy, Plant Ecology, Biodiversity, and Conservation courses. This study contributes to the enrichment of local biodiversity data while supporting research-based biology learning and environmental potential.

Keywords: Bryophyta, Moss inventory, Batang Gadis National Park; Local biodiversity; Contextual biology learning

INTRODUCTION

Indonesia is a country with a very high level of biodiversity, both at the genetic, species, and ecosystem levels. This biodiversity includes not only large, easily recognizable flora and fauna, but also small organisms with important ecological functions, one of which is mosses or bryophytes. In biological studies, mosses are an important group of plants because they represent a form of simple land plants that have a close relationship with humidity, environmental quality, substrate, and microhabitat dynamics. However, in many biodiversity studies, non-vascular plant groups such as mosses often receive less attention than vascular plants. Yet, mosses have important value in taxonomic studies, ecology, conservation, bioindication, and environment-based biology education.

Mosses or Bryophyta are a group of non-vascular plants that lack true vascular tissue as found in vascular plants. In general, bryophytes include three main groups: mosses,

liverworts, and hornworts. This group has a simple body structure, is relatively small in size, reproduces by spores, and is highly dependent on humid environmental conditions. Sass-Gyarmati (2025) explains that bryophytes, which include Bryophyta, Marchantiophyta, and Anthocerotophyta, are one of the groups of ancient land plants that have a significant ecological role and environmental indicators despite their small body size.

The presence of moss in forest ecosystems has important ecological significance. Moss plays a role in maintaining microhabitat humidity, aiding soil formation, absorbing and retaining water, providing habitat for microorganisms and small fauna, and supporting ecosystem stability at the microscale. Furthermore, moss is highly sensitive to environmental changes. Its simple body structure makes it easily affected by changes in air, water, and soil composition, temperature, humidity, light intensity, and habitat disturbance. Therefore, bryophytes are often used in monitoring air quality, water quality, forest ecosystem conditions, and the impact of climate change.

The role of moss as a bioindicator is gaining increasing attention in recent research. Studies on bryophytes and environmental change indicate that moss can be used to detect changes in air quality, heavy metal pollution, water quality, and the structural condition of forest habitats. Sass-Gyarmati (2025) emphasized that sensitive epiphytic moss species can disappear from industrial areas with high levels of pollution, while certain species can indicate pollutant accumulation and changes in environmental conditions over time. Thus, moss is not only important as an object for flora inventory, but also as an ecological indicator that helps assess environmental health. Peran lumut sebagai bioindikator semakin mendapat perhatian dalam penelitian mutakhir.

Recent research in Indonesia also reinforces the importance of studying mosses as environmental indicators. Putrika et al. (2026) showed that terrestrial bryophytes are vulnerable to urban environmental stressors, such as high temperatures, low humidity, and poor air quality. The study found that the distribution of epiphytic mosses was influenced by temperature, relative humidity, bark pH, and air particulate concentration. These findings suggest that the presence of mosses is closely related to microclimate conditions and habitat quality. Besides being influenced by environmental factors, the presence of moss is also closely related to the type of substrate on which it grows. Moss can be found on tree trunks, soil, rocks, decaying wood, damp surfaces, cliffs, and areas around waterways. Wahyuningsih and Martiwi (2025), in a study of bryophyte diversity based on substrate type in the Karangkamulyan area, recorded 91 occurrences of moss, consisting of terrestrial, epiphytic, and epilithic mosses. These findings indicate that substrate variation is an important aspect in moss inventory studies because it influences the distribution and diversity of the species found.

In the context of conservation areas, moss inventory is even more urgent because natural forest areas typically provide a more complex variety of microhabitats than open or degraded areas. Forests with dense canopy cover, high humidity, varying elevations, water flows, damp rocks, old trees, and decaying wood are potential habitats for various moss species. Therefore, conservation areas such as national parks are not only crucial for the protection of wildlife and vascular plants, but also crucial for documenting non-vascular plants, which are often not systematically recorded. Batang Gadis National Park is a key conservation area in Mandailing Natal Regency, North Sumatra. According to the official profile of the Directorate General of Natural Resources and Ecosystems (KSDAE), Batang

Gadis National Park covers an area of 72,803.80 hectares. Administratively, this area is located in the provinces of North Sumatra and West Sumatra. Historically, it was established through Decree of the Minister of Forestry of the Republic of Indonesia Number SK.3973/Menhut-VII/KUH/2014, covering an area of 72,803.75 hectares in Mandailing Natal Regency, North Sumatra Province.

Ecologically, Batang Gadis National Park holds a strategic position as part of the Bukit Barisan landscape in northwestern Sumatra. This area is located within a landscape that is crucial for Sumatra's biodiversity corridor. The official KSDAE profile also notes that the lowland forest, at an elevation of approximately 660 meters above sea level, contains 240 species of vascular plants from 47 families. This data demonstrates that Batang Gadis National Park possesses significant flora richness, but documentation still predominantly features vascular plants, while non-vascular plant groups such as mosses have not been a primary focus of the region's biodiversity documentation.

This situation indicates a significant research gap. A moss inventory in Batang Gadis National Park is needed to enrich local biodiversity data, particularly for the bryophyte group, which has not been systematically documented. This inventory aims not only to record the moss species found but also to describe their morphological characteristics, habitat, substrate, microhabitat distribution, and ecological potential. Thus, this research can produce basic data that is useful for the development of studies on lower plant taxonomy, plant ecology, biodiversity conservation, and biology education based on local potential.

Research on bryophyte inventory in recent years has shown that moss studies in Indonesia remain relevant and continue to develop. Risnawati, Bahktiar, and Herman (2023) conducted an inventory of bryophyte diversity in the Madapangga River, Bima, West Nusa Tenggara, and positioned the study as part of an effort to document moss diversity in Indonesia. Another study by Waskito et al. (2023) found 10 families, 13 species, and 80 bryophyte colonies on the banks of the Susup River, which then used the results as the basis for developing science teaching materials. These findings demonstrate that moss inventories can provide a dual contribution: as biodiversity data and as a basis for developing learning resources. The novelty of this research lies in the selection of Batang Gadis National Park as the study location and the orientation of the research results, which are directed towards contextual biology learning for university students. Many flora inventory studies stop at the aspect of species data collection, whereas this study is directed further, utilizing the inventory results as a basis for learning. Thus, this research not only addresses ecological needs, but also pedagogical needs in higher biology education.

The novelty of this research lies in the selection of Batang Gadis National Park as the study location and the orientation of the research results, which are directed towards contextual biology learning for university students. Many flora inventory studies stop at the aspect of species data collection, while this research is directed further, utilizing the inventory results as a basis for learning. Thus, this research addresses not only ecological needs but also pedagogical needs in higher biology education. Student biodiversity literacy is a crucial aspect of biology learning in universities. Biology and biology education students are required not only to understand the definition of biodiversity but also to understand the value of conservation, biodiversity ethics, sustainability, biodiversity utilization, and the responsibility for species protection. Fajri et al. (2024) found that biodiversity literacy among Biology students still needs improvement, particularly in the aspects of concrete actions and

individual responsibility in biodiversity protection. These findings reinforce the need for biology learning that provides students with hands-on experiences in recognizing, documenting, and analyzing local biodiversity.

The results of the moss inventory in Batang Gadis National Park have significant potential for use in contextual biology learning at universities. Contextual learning in higher education not only means linking material to the surrounding environment but also utilizing the local environment as a source of scientific data and a natural laboratory. Students can learn through direct observation, specimen identification, substrate recording, environmental factor measurement, digital documentation, diversity index analysis, development of simple identification keys, and preparation of reports based on field data. Through these activities, students not only understand the concept of Bryophyta but also experience the scientific process as carried out in biodiversity research. Utilizing local potential as a biology learning resource has been shown to positively influence the quality of learning. Fajeriadi, Azzam, and Azzahra (2025), through a systematic literature review and meta-analysis, demonstrated that biology learning resources based on local potential positively impact student attitudes, including environmental and conservation awareness, and improve cognitive learning outcomes. This research confirms that learning resources based on local potential support contextual and constructivist approaches to biology learning.

From a student learning perspective, moss inventory can be integrated into several courses, such as Lower Plant Botany, Plant Taxonomy, Plant Ecology, Biodiversity, Natural Resource Conservation, Biological Research Methodology, and Biology Learning Resource Development. In the Lower Plant Botany course, students can learn about moss morphology, life cycles, reproduction, and classification. In the Plant Ecology course, students can analyze the relationship of moss to humidity, light intensity, temperature, substrate, and vegetation cover. In the Conservation course, students can understand the function of moss as part of the biodiversity of conservation areas and as indicators of environmental conditions. Furthermore, the results of the moss inventory can be developed into learning tools for students, such as field practicum modules, student worksheets, digital atlases of local bryophytes, morphological photo collections, simple herbariums, identification guides, presentation materials, and even mini-research projects. The development of these tools is crucial because prospective biology teachers need to be able to design learning based on local data. If students are accustomed to using local biological objects as learning resources, they will be better prepared to develop biology learning that is authentic, contextual, and relevant to the environment in which they will teach in the future.

Recent studies on local potential as a learning resource also show that the natural environment can be reconstructed into a biology learning context. Noviyanti et al. (2025), for example, examined the potential of Iboih marine ecotourism in Sabang as a contextual biology learning resource and found that local potential can be linked to topics on ecosystems, biodiversity, and ecological interactions. By the same logic, Batang Gadis National Park can be positioned as a natural laboratory for student biology learning, particularly on the topics of low plant diversity and microhabitat ecology.

The development of contextual biology learning based on moss inventory also aligns with the need for higher education to strengthen research-based learning. Students are not merely recipients of information but are involved in the process of constructing knowledge through field exploration. Moss inventory activities can encourage students to formulate

research questions, determine observation locations, observe morphological characteristics, record substrate types, compare habitat conditions, process diversity data, and conclude the relationships between organisms and their environments. This learning model is relevant to project-based learning, research-based learning, and case-based learning approaches in higher education.

RESEARCH METHODS

This study uses a descriptive exploratory approach with a field survey method. This approach was chosen because the study aims to inventory the types of moss or Bryophyta found in the Batang Gadis National Park area of Mandailing Natal Regency, describe the characteristics of the habitat and substrate where they grow, and analyze the potential of the inventory results as a basis for developing contextual biology learning in higher education. The descriptive exploratory method is relevant to use in the study of Bryophyta because moss often grows in certain microhabitats that are not always evenly distributed, so direct observation in the field is needed to find variations in species, substrates, and ecological conditions. Recent Bryophyta inventory studies also use a lot of field research, exploratory surveys, and purposive sampling to describe the types of moss in a particular area (Jamilah, 2025; Ristanto et al., 2025).

The location of this research is the Batang Gadis National Park area of Mandailing Natal Regency, North Sumatra. The location was selected purposively because this area is one of the important conservation areas in Sumatra that has a variety of habitats, vegetation cover, humidity, water flow, rocks, tree trunks, rotting wood, and moist soil that have the potential to be a place for moss growth. Based on the official profile of KSDAE, Batang Gadis National Park has an area of approximately 72,803.80 hectares and is a conservation area that was historically confirmed through the Decree of the Minister of Forestry of the Republic of Indonesia Number SK.3973 / Menhut-VII / KUH / 2014 covering an area of 72,803.75 hectares in Mandailing Natal Regency, North Sumatra Province.

Observation stations were determined using purposive sampling, selecting locations based on the presence of microhabitats predicted to be suitable for moss growth. Observation stations were determined in several habitat types, such as forests with dense canopy cover, areas around streams, damp rocks, tree trunks, decaying wood, damp soil, shady cliffs, and forest paths with varying light intensity. The purposive sampling technique was chosen because moss is strongly influenced by microhabitat factors, such as humidity, light, temperature, and substrate type. Jamilah's (2025) research on Bryophyta inventory in Pingaran Ulu Village also used field research with purposive sampling and exploratory survey techniques, while Ristanto et al. (2025) used an exploratory method with purposive sampling to compare the diversity and evenness of Bryophyta in the Bogor mountainous region.

Data collection was conducted using exploratory trail methods combined with observations on transect lines and quadrat plots. At each observation station, researchers explored areas with potential moss growth and recorded each moss species found on various substrates. Where field conditions permitted, 50–100-meter transect lines and 1 m × 1 m quadrat plots were established at specific intervals. At each plot, moss species, number of colonies, area of cover, substrate type, habitat conditions, and supporting environmental factors were recorded. Observations of epiphytic mosses on tree trunks were conducted at

accessible heights, for example, 0–2 meters above ground level. The use of exploratory methods in bryophyte research is considered appropriate because the objects of study are often found in specific micro-locations, as has been used in research identifying bryophyte diversity in several regions of Indonesia over the past five years (Risnawati et al., 2023; Silitonga et al., 2024).

The data collected in this study included taxonomic, morphological, ecological, and pedagogical data. Taxonomic data includes the species or morphospecies name, genus, and family of the moss found. Morphological data includes color, colony shape, gametophyte structure, sporophyte presence, leaf arrangement, pseudostem shape, and other observable external characteristics. Ecological data includes habitat type, substrate type, air temperature, air humidity, substrate humidity, light intensity, substrate pH, altitude, and observation location coordinates. Meanwhile, pedagogical data includes the potential use of moss inventory results as learning resources in Lower Plant Botany, Plant Taxonomy, Plant Ecology, Biodiversity, Natural Resource Conservation, and Biology Learning Resource Development courses.

Moss samples found in the field were first documented using a camera, using both habitat and morphological photographs. Samples that could not be directly identified in the field were collected in limited quantities, while still adhering to conservation principles. Each sample was coded by station, plot, substrate, and collection number to facilitate identification and analysis. Sampling was carried out carefully using tweezers or a small spatula to avoid damaging the moss population and the substrate on which it grows. In the context of a conservation area, specimen collection must be carried out in a minimal, ethical manner, and with permission from the Batang Gadis National Park management. Moss sample identification was carried out in two stages: field identification and laboratory identification. Field identification was conducted by observing macroscopic characteristics, such as color, growth pattern, colony shape, substrate type, and the presence of reproductive structures. Laboratory identification was performed using a magnifying glass, stereomicroscope, and light microscope to observe more detailed characteristics, such as leaf shape, leaf cell arrangement, costa, rhizoids, setae, capsules, and sporophyte structure. If identification to the species level was not possible due to limited taxonomic literature or the absence of reproductive characters, samples were first grouped as morphospecies. This approach is commonly used in initial inventories because the main objective of the research is to document the diversity of mosses in areas that have not been widely studied.

The inventory data were analyzed descriptively quantitatively and qualitatively. Quantitative descriptive analysis was used to calculate the species composition, number of colonies, frequency of occurrence, and level of moss diversity. The indices that can be used include the Shannon-Wiener diversity index, the Pielou evenness index, the Margalef richness index, and relative frequency. The Shannon-Wiener index was used to assess the level of species diversity, the Pielou index to determine the evenness of species distribution, and the Margalef index to determine species richness at each observation station. Qualitative analysis was used to describe the morphological characteristics of moss, substrate type, habitat conditions, and the relationship between moss presence and environmental factors.

In addition to biodiversity analysis, this study also analyzed the potential of the inventory results as a basis for developing contextual biology learning in higher education.

This analysis was conducted by mapping field findings to student learning needs, particularly in terms of graduate learning outcomes, course learning outcomes, study materials, practical activities, mini-research, and the development of learning resources. The results of the moss inventory can be developed into student worksheets, Lower Plant Botany practical modules, a digital atlas of local bryophytes, simple identification guides, local biodiversity teaching materials, or student mini-research projects. Waskito et al. (2023) demonstrated that bryophyte diversity data can be developed into teaching materials based on inventory results, while Fajeriadi et al. (2025) emphasized that biology learning resources based on local potential have a positive impact on learning competencies, environmental attitudes, and learning outcomes.

In the context of higher education, utilizing moss inventory results as a learning resource is crucial because students not only learn theoretical bryophyte concepts but also directly experience the scientific process through observation, identification, classification, documentation, data analysis, and report preparation. This activity aligns with research-based biology and contextual learning, as students are guided to connect theory to local biodiversity phenomena. Through this activity, students can develop biodiversity literacy, science process skills, critical thinking skills, and conservation awareness. Thus, Batang Gadis National Park serves not only as a conservation area but also as a natural laboratory for student biology learning.

Data validity was achieved through method triangulation, habitat triangulation, visual documentation, and expert validation. Method triangulation was conducted by comparing field observations, photo documentation, environmental factor measurements, and laboratory identification results. Habitat triangulation was conducted by comparing moss findings in several habitat types and substrates. Expert validation was conducted by seeking input from lower plant taxonomists or biology lecturers competent in Bryophyte identification. For pedagogical analysis, validation can be conducted through review by biology subject matter experts and biology learning experts to ensure that the inventory results are suitable for use as a basis for developing contextual biology learning in universities.

Research ethics were observed because the research location is in a conservation area. Researchers were required to obtain permission from the Batang Gadis National Park management before data collection. Sampling was carried out in limited quantities, without damaging the habitat, not taking excessive specimens, not opening new paths without permission, and maintaining the cleanliness of the area. The data obtained were used for academic purposes, conservation, and the development of biology learning. With these procedures, this research is expected to produce scientifically valid, ecologically valuable, and relevant Bryophyte inventory data as a basis for developing contextual biology learning for university students.

This study uses a descriptive exploratory approach with a field survey method. This approach was chosen because the study aims to inventory the types of moss or Bryophyta found in the Batang Gadis National Park area of Mandailing Natal Regency, describe the characteristics of the habitat and substrate where they grow, and analyze the potential of the inventory results as a basis for developing contextual biology learning in higher education. The descriptive exploratory method is relevant to use in the study of Bryophyta because moss often grows in certain microhabitats that are not always evenly distributed, so direct

observation in the field is needed to find variations in species, substrates, and ecological conditions. Recent Bryophyta inventory studies also use a lot of field research, exploratory surveys, and purposive sampling to describe the types of moss in a particular area (Jamilah, 2025; Ristanto et al., 2025).

RESULTS AND DISCUSSION

Based on an inventory of mosses in several microhabitat types in the Batang Gadis National Park area of Mandailing Natal Regency, a fairly diverse variety of mosses was found on tree trunks, damp rocks, damp soil, decaying wood, shaded cliffs, and around waterways. The park's relatively high humidity, forest vegetation cover, river flows, and varied topography support the presence of mosses, which are non-vascular plants that are highly dependent on microhabitat conditions. The official KSDAE profile states that Batang Gadis National Park covers approximately 72,803.80 hectares, is located in the Bukit Barisan region of northwestern Sumatra, with an elevation of 300–2,145 meters above sea level, a temperature of around 23–25.4°C, and a humidity of 80–90%. These conditions indicate that the area has ecological potential as a bryophyte habitat.

Field observations indicate that mosses are more commonly found in locations with high humidity, low to moderate light intensity, and relatively stable substrates. Moss growing on tree trunks is generally found on the lower parts of the trunk with rough, damp bark. Moss on rocks and cliffs is often found near waterways or in areas protected by the canopy of the forest. Meanwhile, moss growing on decaying wood and litter is found on damp, undisturbed forest floors. These findings demonstrate that moss distribution is influenced not only by the presence of water, but also by a combination of substrate, humidity, light, and microhabitat stability.

Overall, the preliminary inventory results indicate the presence of 15 moss morphospecies, grouped into three main groups: mosses, liverworts, and hornworts. The mosses were the most abundant, followed by liverworts and hornworts. The dominance of mosses is thought to be related to their ability to adapt to various substrate types, particularly tree trunks, rocks, and moist soil. In contrast, hornworts were found in more limited numbers because this group generally requires more specific habitat conditions.

Table 1. Distribution of moss groups based on the number of morphospecies and percentage

No.	Moss Group	Number of Morphospecies	Percentage
1	Bryophyta	9	60,00%
2	Marchantiophyta	5	33,33%
3	Anthocerotophyta	1	6,67%
	Amount	15	100%

Source: Inventory data, processed by researchers

This composition indicates that the Batang Gadis National Park area has the potential for interesting bryophyte diversity, warranting further study. Although the number of hornworts is relatively low, their presence remains significant as it indicates the diversity of non-vascular plant groups in the area. In the context of initial inventories, the use of

morphospecies categories can be a preliminary step before conducting more detailed taxonomic identification down to the genus or species level. Based on observation stations, stations located around streams and densely canopied forests showed a higher number of species than stations located in forest strips or more open areas. Stations near streams showed the highest number of morphospecies, with 12, while areas near forest strips or forest edges showed only 5. This difference suggests that more humid and sheltered habitats tend to support a greater diversity of bryophytes.

Table 2. Moss Diversity Based on Station and Habitat Type

Station	Habitat Type	Number of Morphospecies	Number of Colonies	H’	Category
I	Dense canopy forest	10	58	2,05	Currently
II	Around the river flow	12	64	2,26	Currently
III	Damp rocks/cliffs	8	31	1,77	Currently
IV	Rotten wood and litter	7	20	1,61	Currently
V	Forest path/forest edge	5	9	1,20	Medium low
Amount	—	15	182	2,41	Currently

The overall Shannon-Wiener diversity index value was in the moderate category. This value indicates that the moss community at the study site has a fairly good variety of species, but does not yet exhibit very high diversity. Station II had the highest H' value due to a combination of a greater number of species and colonies than the other stations. Meanwhile, Station V had the lowest H' value due to its location in a relatively more open area, more easily disturbed, and with lower microhabitat humidity.

The distribution of mosses based on substrate showed that tree trunks were the substrate with the highest number of findings, followed by moist rocks, moist soil, decaying wood, and moist cliffs. The abundance of mosses on tree trunks indicates that epiphytic substrates are important habitats for bryophytes in forest areas. Tree trunks with rough, moist surfaces and protected canopy provide stable growth spaces for mosses. Meanwhile, moist rocks and moist soil are also important substrates because they retain water and support the growth of moss colonies.

Table 3. Distribution of Moss Morphospecies Based on Substrate Type

Substrate Type	Number of Morphospecies	Number of Colonies	Ecological Information
Tree trunk	7	61	Dominant in shady, moist areas
Moist rocks	6	43	Found near watercourses
Moist soil	5	34	Common on the forest floor
Weathered wood	4	29	Prefers moist, organic habitats
Damp cliffs	3	15	Limited to shady, moist areas

Source: Moss inventory data based on substrate type

These results indicate that the substrate plays a crucial role in determining the presence of moss. Substrates that retain moisture and are protected from direct light tend to have more moss. This finding aligns with the basic characteristics of Bryophytes as non-vascular plants that absorb water and nutrients directly from their surroundings. Sass-Gyarmati (2025) explains that bryophytes are highly sensitive to changes in air, water, soil, humidity, temperature, and habitat conditions due to their simple body structure and the lack of developed vascular tissue like vascular plants.

In addition to generating ecological data, the results of this inventory also demonstrate the potential use of moss as a basis for developing contextual biology learning in universities. Mosses found on various substrates can be used as learning objects in courses on Lower Plant Botany, Plant Taxonomy, Plant Ecology, Biodiversity, Natural Resource Conservation, and Biology Learning Resource Development. Students can be involved in observation, morphological identification, substrate analysis, environmental factor measurement, digital documentation, development of simple identification keys, and mini-research reports.

The research results indicate that Batang Gadis National Park has potential as a moss habitat due to its moist ecological conditions, dense canopy, and diverse substrates. The presence of mosses on tree trunks, damp rocks, soil, decaying wood, and cliffs indicates that bryophytes can inhabit a variety of microhabitats as long as the humidity and light protection are relatively favorable. The physical conditions of Batang Gadis National Park, with 80–90% humidity, relatively cool temperatures, and mountainous topography, provide microclimatic conditions relevant to moss growth.

The dominance of bryophytes in the inventory results indicates that this group has a broader range of adaptations than liverworts and hornworts. Bryophytes are generally more readily found on a variety of substrates because their gametophyte structure is relatively robust and they are able to form distinct colonies. Liverworts are found primarily on moist substrates such as wet soil, decaying wood, and shaded cliffs. Meanwhile, hornworts are found in a limited range because this group typically requires more specific and humid habitats. Thus, differences in the composition of bryophyte groups reflect variations in each group's adaptability to microhabitat conditions.

These findings reinforce the view that bryophytes are highly responsive organisms to their environment. Bryophytes lack true root systems and vascular tissue, making their survival highly dependent on water availability and the condition of the substrate surface. Sass-Gyarmati (2025) emphasized that bryophytes have a simple structure and absorb water and nutrients through their body surfaces, enabling them to respond quickly to changing environmental conditions. Due to these characteristics, bryophytes are often used as bioindicators of environmental quality, forest conditions, water quality, air pollution, and climate change.

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Differences in diversity values between locations also indicate that moss inventory cannot simply be conducted by recording the number of species, but must be linked to habitat characteristics. In this study, tree trunk substrates were the most abundant growth sites for moss. This is understandable because tree trunks in tropical forests provide a stable, moist surface protected by the canopy. Furthermore, cracks in the bark retain water and organic particles, supporting the growth of moss colonies. Moist rock substrates also showed a relatively high number of occurrences due to their proximity to watercourses. Meanwhile, decaying wood provides an important habitat for certain mosses, providing organic matter and relatively stable humidity.

The presence of moss on decaying wood has important ecological significance. Sass-Gyarmati (2025) explains that bryophytes living on deadwood can be indicators of the naturalness and structural condition of forest habitats. The presence of moss on decaying wood indicates that the area contains microhabitat elements that support the continuity of the forest ecosystem. Therefore, the discovery of moss on decaying wood in Batang Gadis National Park can be interpreted as an indicator that forest microhabitat components still provide ecological space for non-vascular organisms.

From a conservation perspective, the results of this study confirm that mosses should be a key component of biodiversity documentation in conservation areas. Official data from Batang Gadis National Park records the presence of 240 species of vascular plants from 47 families in the lowland forest, as well as various important mammal species such as Sumatran tigers, tapirs, sun bears, deer, barking deer, and several primate species. However, data on non-vascular plants has not been widely presented as a primary component of the area's documentation. Therefore, the Bryophyte inventory in this study contributes to complementing local biodiversity data, particularly for smaller, often overlooked flora groups.

Pedagogically, the results of the moss inventory in Batang Gadis National Park have important value for contextual biology learning in universities. Biology students or biology education students often learn about Bryophytes through textbooks, images, or limited laboratory preparations. However, understanding of mosses will be stronger if students are directly involved in field observations, substrate identification, morphological documentation, and analysis of the relationships between mosses and their environment. Thus, the inventory data can serve as a bridge between lower plant taxonomic theory and local, environmentally-based scientific experiences.

The results of this inventory can be utilized in several learning formats. First, in the Lower Plant Botany course, students can learn the morphological characteristics of mosses, the diversity of mosses, liverworts, and hornworts, and the life cycle of bryophytes. Second,

in the Plant Taxonomy course, students can be trained in compiling morphological descriptions, comparing specimen characteristics, and creating simple identification keys. Third, in the Plant Ecology course, students can analyze the relationship of mosses to substrate, humidity, light, temperature, and microhabitat conditions. Fourth, in the Natural Resource Conservation course, students can understand that biodiversity conservation is not only related to large animals or vascular plants, but also small organisms that have important ecological functions.

The results of this research can also be developed into learning products in the form of student worksheets, field practicum modules, a digital atlas of Bryophytes in Batang Gadis National Park, a simple identification guide, and a local biodiversity research mini-project. Waskito et al. (2023) showed that the results of the Bryophyte diversity study can be used as a basis for developing teaching materials; Their research identified 10 families, 13 species, and 80 bryophyte colonies on the banks of the Susup River, and these results were then used to design a learning unit book. This strengthens the argument that moss inventory in Batang Gadis National Park is not only ecologically relevant but can also be converted into a biology learning resource.

In the context of university students, integrating inventory results into learning is also crucial for improving biodiversity literacy. Fajri et al. (2024) found that biodiversity literacy among Biology students still needs improvement, particularly in terms of concrete actions and individual responsibility in biodiversity protection. The study assessed dimensions of biodiversity literacy such as conservation, biodiversity ethics, sustainability, biodiversity protection actions, biodiversity use value, and the importance of species conservation. Therefore, moss inventory-based learning can be a strategy to strengthen students' biodiversity literacy through hands-on experience.

Locally-based learning also contributes to the quality of biology learning. Fajeriadi et al. (2025) demonstrated through a systematic literature review and meta-analysis that local-based biology learning resources positively impacted attitudes, environmental awareness, conservation, and cognitive learning outcomes. They also emphasized that local-based learning resources support contextual and constructivist approaches to biology learning. In the context of this research, Batang Gadis National Park can be positioned as a natural laboratory that provides real-world objects for students to learn about biodiversity, ecology, conservation, and the development of learning resources.

CONCLUSION

Based on the preliminary inventory results, the Batang Gadis National Park area has quite good potential for moss diversity, especially in humid microhabitats such as around streams, densely canopied forests, tree trunks, damp rocks, damp soil, and decaying wood. Moss diversity is in the moderate category, with a dominance of leaf mosses compared to liverworts and hornworts. Substrate factors, humidity, vegetation cover, and light intensity play an important role in determining the presence of moss. The results of this inventory have strong relevance as a basis for developing contextual biology learning in higher education because it can be used to strengthen learning in Lower Plant Botany, Plant Taxonomy, Plant Ecology, Biodiversity, Conservation, and the Development of Biology Learning Resources.

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