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RESEARCH ARTICLE

Characterization of Lichens in Rocks (Saxicolous) in the Bukit Barisan Forest Park, Tongkoh, Karo District, Indonesia

Ashar Hasairin [1]*, Adi Hartono [2], Rosliana Siregar [3]

[1] Faculty of Mathematics and Natural Sciences, Universitas Negeri Medan, Medan, Indonesia

[2] Faculty of Tarbiyah Science and Teachers Training, Universitas Islam Negeri Sumatra Utara Medan, Indonesia

[3] Faculty of Teacher Training and Education Sciences, Universitas Islam Sumatera Utara, Teladan Medan, Indonesia

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***Corresponding Author:**

asharhasairin@unimed.ac.id

ABSTRACT

Lichens have a remarkable ability to thrive in various environments, including trees (corticolous), rocks (saxicolous), and soil (terricolous), without requiring elaborate living conditions. This study aims to gather data on saxicolous lichens in the Tahura (Taman Hutan Raya/Grand Forest Park) area, focusing on their diversity index, uniformity, kinship, distribution pattern, and ecological characteristics. Lichens were collected from rocks and identified directly at the State University of Medan Biology Laboratory. The roaming method was employed to study each lichen found on rocks. The findings revealed the presence of nine types of lichens with crustose thallus and foliose forms. The lichen diversity index (H' = 2.02) and uniformity index (E' = 2.776) were categorized as high. The distribution pattern of lichens showed clustering on Parmelia caperata, with a value of S' = 61.75. Genetic analysis divided the lichens into 7 groups, with the highest occurrence of the same character being 8 and the lowest 3. The habitat characteristics conducive to lichen growth and development in Forest Park include a temperature of 19.200 C, humidity of 87%, and rainfall of 130 mm. This study on saxicolous lichens in the Tahura area holds significant implications for biodiversity conservation and ecological understanding. By assessing these lichens' diversity, distribution patterns, and ecological characteristics, the research contributes to the conservation of unique habitats and provides valuable insights for their management. Additionally, the documentation of favorable environmental conditions for lichen growth provides baseline data for future studies on the impact of environmental changes. Overall, this study's findings shed light on the ecological significance of saxicolous lichens, aiding conservation strategies and advancing our understanding of these remarkable organisms in diverse environments.

INTRODUCTION

Bukit Barisan Grand Forest Park in Tongkoh, North Sumatra, is an ecologically diverse tropical rainforest ecosystem where many organisms flourish (Aschenbrenner et al., 2016). This forest comprises three distinct vegetation types: shrubs, secondary forest, and primary forest, encompassing a wide altitudinal range from lowlands to highlands and reaching an altitude of approximately 2000 m above sea level. The topography exhibits variations from flat plains to undulating hills, characterized by clay and sandy substrates. The forest area experiences a prolonged wet season with an average monthly rainfall of 7200 mm for nine consecutive months, a temperature range of 16.80 °C to 23.00 °C, and a relatively high humidity level of approximately 80%. These conditions confer a remarkable potential for lichenological proliferation within this region (Moya et al., 2017; Molins et al., 2019). However, the investigation of lichens in this particular forest area remains relatively scant.

As a taxonomic group, lichens constitute a component of the local biodiversity that has received limited scientific attention thus far (Aschenbrenner et al., 2016). Traditionally acknowledged as a mutualistic association between a fungus and a photosynthetic partner, such as green algae or cyanobacteria, lichens have undergone conceptual reevaluation in recent studies. These investigations have unveiled lichens as complex symbiotic entities that harbor a wide array of microorganisms, including bacteria (Aschenbrenner et al., 2016), other algae (Moya et al., 2017; Molins et al., 2019), and fungi (Spribille, 2018).

Lichens exhibit remarkable adaptability and colonize diverse substrates such as rocks, soil, and tree stumps. Notably, certain lichen species demonstrate an intriguing endolithic lifestyle with the ability to permeate and grow within the interstices of rocks. Endolithic lichen growth has been documented in natural rock formations and anthropogenic stone structures across different geographical regions, including Australasia, Europe, and Latin America (Gaylarde et al., 2012). While lichens contribute to physical weathering processes, their role in chemical weathering is even more significant (Jackson, 2015). They release bioactive compounds that profoundly affect the decomposition dynamics of organic matter and are likely to play a crucial role in the humification process (Beckett et al., 2013). Humification, as a fundamental aspect of soil formation, involves the transformation of organic substances into stable humic compounds that serve as vital components of soil ecosystems. Subsequently, the establishment of other plant species can be facilitated, justifying lichens' attribution as pioneer organisms.

Lichens exhibit an exceptional ability to thrive in moderately arid habitats where the establishment of vascular plants is restricted (Sadowsky and Ott, 2016). Their remarkable tolerance to extended drought periods can be attributed to their poikilohydric nature, which refers to their inability to regulate their water content actively. As autotrophic and heterotrophic organisms, Lichens demonstrate remarkable adaptability to extreme environmental conditions, including cold and hot deserts (Perez-Ortega et al., 2012). There has been a growing interest in studying the biodiversity patterns of lichens in arid habitats in recent years due to their recognized significance in shaping and maintaining ecosystem functioning within such dry environments.

The ubiquity of lichens and their resilience makes them easily discoverable in various habitats. Although lichens dwelling on rocks may desiccate under intense solar radiation, they possess the extraordinary capacity to revive and resume metabolic activities upon exposure to rainfall. Furthermore, the growth rate of lichen thalli could be faster, with an average annual extension rarely exceeding one centimeter. The existence and distribution of lichens can be influenced by environmental disturbances, as these organisms exhibit high sensitivity to atmospheric changes and microclimate fluctuations (De Silva et al., 2015).

Regarding literature studies, the exploration of lichen diversity on Saxicolous rocks has been relatively limited, especially within the TAHURA area of Tongkoh. Consequently, the comprehensive investigation of lichens inhabiting rocks in Tahua, Tongkoh, represents a significant knowledge gap. Therefore, conducting dedicated research on lichens thriving on Saxicolous rocks in TAHURA Bukit Barisan Tongkoh, Karo Regency, is imperative for a more profound understanding of lichenological dynamics in the region.

LITERATURE REVIEW

Lichens, as fascinating symbiotic entities consisting of a fungal partner and a photosynthetic partner (green algae or cyanobacteria), have garnered scientific interest due to their adaptability, diversity, and ecological significance. This literature review section delves deeper into the scientific terminology associated with lichens, focusing on saxicolous lichens in the Tahura (Taman Hutan Raya/Grand Forest Park) area.

Lichen diversity and distribution

Extensive research has shed light on lichens' remarkable taxonomic diversity and distribution patterns across varied habitats, including saxicolous (rock-dwelling) environments. Studies have highlighted the diverse assemblage of lichen species and their distribution across different ecosystems (Rull, 2005; Blasco et al., 2008; Chowdhury et al., 2022). The investigation in the Tahura area identified nine types of lichens with crustose thallus and foliose forms, underscoring the richness and taxonomic variability of the saxicolous lichen community.

Lichen diversity index and uniformity

Quantifying lichen diversity and uniformity indices is essential for understanding their ecological dynamics. These indices reflect the richness, evenness, and balance of lichen populations within an ecosystem (Rull, 2005). A high lichen diversity index (H' = 2.02) and uniformity index (E' = 2.776) were found in this study. This shows that the saxicolous lichen community in the Tahura area is strong and well-balanced.

Distribution patterns and kinship

Investigating the spatial distribution patterns of lichens and their genetic kinship elucidates their colonization strategies and ecological interactions. Studies have revealed that lichens exhibit clustering or dispersal patterns influenced by specific environmental conditions and interactions with other organisms (Otálora et al., 2011). In this study, Parmelia caperata showed a clustering distribution pattern (S' = 61.75), which could mean that it likes certain substrate characteristics or microclimatic conditions.

Habitat characteristics

The significance of habitat characteristics for lichen growth and development has been extensively documented. Environmental factors, including temperature, humidity, and rainfall, play pivotal roles in lichen colonization and survival (Pearson, 1969). The present investigation documented a temperature of 19.2°C, humidity of 87%, and rainfall of 130 mm in the Tahura area, indicating favorable habitat conditions for saxicolous lichen growth and establishment.

While previous studies have examined lichen diversity in various environments, including saxicolous habitats, investigating lichens in the specific context of the Tahura area in Tongkoh still needs to be improved. The literature review underscores the knowledge gap concerning lichen diversity and distribution on saxicolous rocks in this region. So, this study fills an important research gap by focusing on lichens that thrive in the saxicolous habitat of the Tahura area. This gives us important information about how lichenology works in this ecological setting.

The literature review highlights lichens' remarkable adaptability, diversity, and ecological significance. Saxicolous lichens, in particular, have received limited scientific attention, underscoring the importance of the present study. By exploring the existing literature, this review emphasizes the significance of understanding lichen diversity, distribution patterns, and habitat characteristics. The findings from this study in the Tahura area contribute to the overall knowledge of lichens in diverse ecosystems, providing a foundation for further scientific exploration in lichenology.

MATERIALS AND METHODS

The research occurred in the Bukit Barisan Tongkoh Grand Forest Park, Karo Regency, North Sumatra, for 6 months. Lichens were identified at the Biology laboratory of the State University of Medan. The research employed an exploratory approach using the "Roaming Method" and direct inventory listing at the research site.

Sample collections

Purposive sampling was conducted on lichens found in Saxicolous rocks. The lichen samples were collected and preserved as dry herbarium specimens, obtained by scraping them from the growth medium and storing them in envelopes. Each sample was labeled and captioned for identification purposes.

Phenotypic characterization

For lichens to be identified by their growth form, a hand lens was used to look at the type and shape of the thallus, its surface, its edge, its growth pattern, the presence of soredia or isidia, cilia, and the condition of the underside of the thallus. Additionally, the type of lichen spore was examined anatomically through the incision of the apothecia. The identification of lichen species was conducted using reference books such as "Key to the Lichen Genera of Bogor, Cibodas, and Singapore" (Sipman, 2009), "Key to the Lichen Genera of the Pacific Northwest" (McCune, 2010), and "Key Identification of Lichens" (Schumm & Aptroort, 2010). Chemical analysis of lichens was performed through color tests and microcrystal tests. The color test involved applying calcium hypochlorite (C) and potassium hydroxide (K or KOH) reagents to the thallus or medulla surface, and a color change, often red or yellow, indicated a positive result. A yellow K+ test result suggested the presence of atronine. Data analysis encompassed identifying and calculating diversity indices (H'), uniformity indices, distribution patterns, and ecological characteristics correlated with the diversity index. Kinship analysis used the "Group Average Clustering" grouping method (Dunn and Everitt, 2004). The Diversity Index was calculated using the Shannon-Wiener formula (Odum, 1993). Kinship analysis employed the UPGMA (Unweighted Pair Group Method with Arithmetic Mean) method through the MEGA 5.05 program cluster analysis.

RESULTS AND DISCUSSION

Diversity of lichens

The comprehensive survey within the Bukit Barisan Forest Park Area in Tongkoh, Tanah Karo Regency, unraveled an expansive landscape spanning approximately 19,805 hectares. This scientific endeavor unveiled a heterogeneous topography with steep gradients ascending towards lofty mountain peaks interspersed with undulating contours and gentle slopes. The TAHURA tourism forest geographically occupies coordinates ranging from 00116" to 01937" north latitude and 981216" to 984100" east longitude, forming a spatial framework that allures the scientific community.

A diverse climatic mosaic unravels within this biogeographical realm, with precipitation playing a pivotal role. The forested region experiences an annual rainfall regime ranging from 1,430 to 2,500 mm, contributing to its hydrological dynamics. Climatological observations have documented the highest recorded air temperature within the TAHURA tourism forest, reaching a zenith of 32°C, while the coldest extremes dip to a refreshing 16°C. The ambient moisture content reveals a humidity quotient of approximately 80%, enveloping the environment in a moist microenvironment that influences ecological processes.

An abundance of lichen species thrives in this fertile ecological niche, exemplifying their adaptability and symbiotic relationships across heterogeneous substrates. These amazing organisms can be found in rough lithic formations, nutrient-rich edaphic soils, and dead tree parts, which shows their adaptability in their environment. The TAHURA tourism forest stands as an expanse of ecological magnificence, epitomizing the intricate tapestry of interspecies interactions and providing an awe-inspiring sanctuary for scientific inquiry and the myriad organisms that inhabit its realms.

Figure 1: Location research of TAHURA Bukit Barisan, North Sumatra

TAHURA is classified as a conservation forest due to its geographical location and is characterized by its natural state and abundant growth of lichens. These forests have not undergone extensive studies regarding the biodiversity and distribution of lichens on Saxicolous rocks. Six genera and nine lichens have been identified on the rocks, with two main types of thallus: Crustose and Foliose. The identified lichen types include Parmelia caperata, Parmelia saxatilis, Pertusaria amara, Pertusaria coralline, Lecanora campestris, Vecarucaria sp., Opegrapha atra, Lepraria sp., Lepraria incana. Lichens are classified based on their thallus shape, including foliose, fructicose, crustose, squamolose, leprose, filamentous, and placodioid (Dobson et al., 1992). However, the predominant forms found are foliose, fructicose, and crustose (Rout et al., 2010).

Lichens exhibit diverse characteristics regarding thallus shape, color, and edge. The shapes of the lichens found vary from rounded to irregular. The dominant color of lichens is green, and the thallus edges can be curved, wavy, or circular. These characteristics depend on the substrate and environmental conditions in which the lichen thallus grows. The thallus, for instance, may become darker with age and is usually affected by environmental factors. Pollutant gases can also alter the color of lichen thallus by causing changes in chlorophyll levels. Crustose lichens are more commonly found in areas with higher precipitation (Giordani et al., 2014), and a similar trend is observed when considering aridity. Crustose lichens prefer sites with lower aridity levels (Matos et al., 2015). Crustose lichens, in the form of crusts, exhibit a strong attachment to the substrate, while foliose forms resemble leaves and have a weaker attachment, making them more easily detached. Figure 2 illustrates the lichens found on rocks.

Figure 2: Lichens morphology on saxicolous (rocks); a. Parmelia caperata, b. Parmelia saxatilis, c. Pertusaria amara, d. Pertusaria coralline, e. Lecanora campestri, f. Vecarucaria sp.

The lichens discovered at the research site were classified into two categories of thallus: Crustose and Foliose. However, Fructicose and Squamulose thallus types were not observed. Crustose thallus species included Lecanora campestris, Lepraria incana, Vecarucaria sp., and Opegrapha atra, differing only in colour. Opegrapha atra exhibited a grey-green thallus colour, and Lecanora campestris had a green thallus colour with a powdery surface and circular edges. The shape of the thallus was irregularly rounded, growing attached to the substrate. The thallus lacked cilia but had sores. The crust-like structure tightly adhered to the substrate with varying colours. According to Dobson et al. (1992), most lichens are crustose and foliose, with only a few taxa exhibiting fructicose and squamulose thallus types.

Foliose thallus, resembling leaves, was commonly observed in green to grey shades. Most of the lichens were Parmelia saxatilis, Pertusaria amara, and Pertusaria coralline, which have lobes that are arranged like leaves and have a foliose shape. The lobes were loosely attached to the substrate, with distinct colours on the top and bottom and rhizine attaching them to the substrate. Parmelia caperata and Parmelia saxatilis exhibited foliose thallus types, with variations in thallus colour ranging from green to grey. The thallus surface was not powdery, and the edges were curved. The thallus shape was irregular, and it grew by attaching itself to the substrate. Similar to the crustose thallus, it lacked cilia but had sores. Pertusaria amara and Pertusaria coralline also displayed a foliose thallus type, differing in the thallus colour (green and grey). Notably, the colour, surface, and shape of the thallus exhibited significant variations among lichen species.

The crustose thallus consisted of five species from four families, while the foliose thallus consisted of four species from two families. Crustose lichens were more commonly found due to their crust-like shape, which allowed them to adhere closely to the substrate, resulting in lower water requirements. This suggests that crustose thallus types are easier to grow. According to Giordani et al. (2014), the characteristics of the host plant as well as variables like temperature and humidity affect the growth of lichens. The environmental factors, including plant species as substrates and abiotic factors like temperature, humidity, and light intensity, strongly supported lichen growth in the research area. This indicates that these lichen species exhibit a broad tolerance for environmental conditions. In established forests, lichens can absorb water from rain and atmospheric moisture through their thallus surface. Some taxa possess structures such as cyphellae and pseudocyphellae, facilitating gas exchange and enabling higher water uptake and accumulation of contaminants. These adaptations help mitigate flooding in the spring and river droughts in the summer, as well as reducing soil erosion caused by water.

Lichens represent a type of organism that primarily inhabits rock surfaces. The diverse range of rocks available as substrates for lichens, along with the associated lichen metabolites, implies numerous interactions among them. Lichen acids play a role in determining their tolerance to acidity and the choice of substrate (Favero-Longo et al., 2015). Different species within the same genus, containing distinct metabolites, dominate different types of rocks. The types of lichens found on rocks are summarised in Table 1.

Table 1: The species of lichens found in rocks

No	Species Lichens	Family	Type Thallus	Thallus Form	Total Thallus
1	Parmelia caperata	Parmeliaceae	Foliose	Tidak Beraturan	13
2	Parmelia saxatilis	Parmeliaceae	Foliose	Tidak Beraturan	46
3	Pertusaria amara	Pertusariaceae	Foliose	Membulat	42
4	Pertusaria coralline	Pertusariaceae	Foliose	Membulat	36
5	Lecanora campestris	Lecanoraceae	Crustose	Membulat	11
6	Vecarucaria sp.	Vecarucariaceae	Crustose	Membulat	30
7	Opegrapha atra	Opegraphaceae	Crustose	Membulat	30
8	Lepraria sp.	Leprariaceae	Crustose	Membulat	29
9	Lepraria incana	Leprariaceae	Crustose	Tidak Beraturan	29
Total					266
Diversity Index (H ')					2,02
Uniformity Index (E')					2.776

Based on the information in Table 1, nine different types of lichens were collected, with varying quantities of each thallus. Apart from the differences in quantity, lichens also exhibit distinct characteristics from one species to another. In the TAHURA tourism forest, the Saxicolous (rock) diversity index value is H' = 2.02, indicating good condition (high) based on Odum (1993) criteria, as H' is greater than 2. This can be attributed to the research location's favorable environmental factors, such as fertility and supportive physicochemical conditions for lichen growth and development. Species diversity is influenced by the distribution of multiple species; however, if the distribution of individuals is uneven, it results in low species diversity. The evident diversity observed demonstrates the stability of the community, which is further supported by the primary forest's high heterogeneity at the research location. Consequently, the varying levels of diversity can provide insights into the maturity of the surrounding plant community's organization (Hasairin et al., 2018). Greater lichen diversity indicates a higher level of organization within the community, facilitated by favorable ecological factors in both locations.

The Uniformity Index value, E' = 2.776, falls within the high uniformity category. According to Odum (1993), the uniformity index (E) ranges from 0 to 1. A value close to 0 suggests low uniformity due to the dominance of certain species, while a value close to 1 indicates high uniformity, implying the absence of a dominant species. The calculated results indicate a high degree of species uniformity. The availability and utilization of different nutrients contribute to variations in diversity and the uniformity index. For more detailed information, please refer to Figure 3 below.

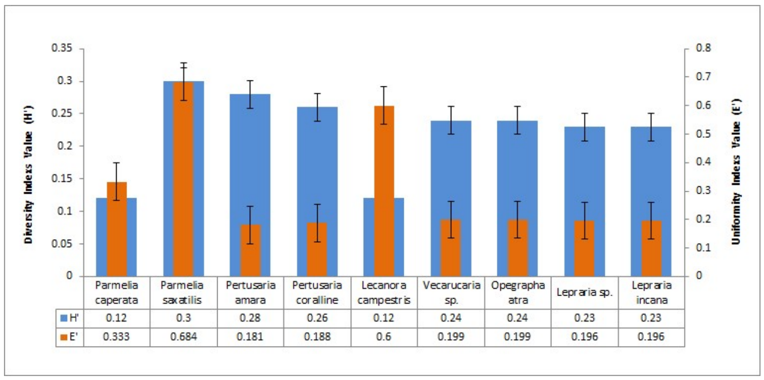

Figure 3: Value of Diversity Index (H ') and Uniformity Index (E')

Barbour et al. (1980) explained that a community can have high species diversity when it consists of numerous equally or nearly equally abundant species. Similarly, Odum (1993) emphasized that more incredible species richness increases diversity. In Figure 2, the graph illustrates that Parmelia saxatilis exhibits the highest Diversity Index (H') and Uniformity Index (E') among other types, owing to its larger number of talus. In this study, Parmelia saxatilis, a cosmopolitan lichen, is characterized by a foliose type with loosely attached thallus, pale grey color, broad lobes, and effigurate pseudocyphellae with a white medulla. It predominantly grows on poor bedrock.

Conversely, Lecanora campestris demonstrates the smallest number of talus but possesses a high Diversity Index (H' = 0.12) and Uniformity Index (E' = 0.60). This lichen exhibits a crustose type with a yellowish-green thallus, resembling a crust, and firmly attaches to the rock surface. Removing this species without damaging the substrate can be challenging.

Figure 4: Parmelia saxatilis and Lecanora campestris using a light microscope with a magnification of 10x40

Lichens familial patterns

The variety of species within a community of organisms determines that community's diversity. Greater species abundance corresponds to higher biodiversity. The diversity index measures species richness within the community and indicates the equitable distribution of individuals among different species.

The identification results of lichens at the research site can be established by examining their morphological traits. These traits encompass the type of thallus, color, surface of the talus, edge of the talus, shape of the thallus, growth pattern of the thallus, presence of cilia, and soredia. These morphological characteristics are organized as matrix data and quantified as multistate quantitative data. The converted data is then used to calculate the dissimilarity between various encountered lichens. The resulting dissimilarity distance demonstrates the similarity in morphological characteristics, indicating the genetic relatedness among the identified species. Refer to Figure 5 for further details.

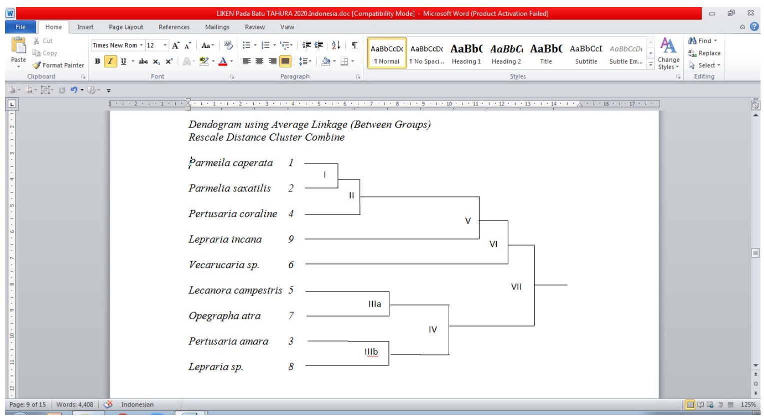

Figure 5: Dendogram based on lichens characteristics data

There are seven genetic kinship groups for lichens, each with a range of 3 to 8 shared traits. These groups were established based on eight identifiers: 1. Thallus type; 2. Thallus color; 3. Thallus surface; 4. Thallus shape; 5. Thallus Growth pattern; 6. Silia; and 7. Soredia.

The level of kinship among lichens within each group indicates the presence of either the same or different traits. Higher kinship levels correspond to more shared characteristics, leading to the classification of lichens in Group One. Conversely, lower kinship levels, resulting from fewer shared traits, lead to the classification of lichens in Groups Two to Seven.

The research findings reveal that Group I comprises Parmelia caperata and Parmelia saxatilis, which share all eight morphological characteristics. These traits include 1. Thallus Type, 2. Thallus Colour, 3. Thallus Surface, 4. Thallus Shape, 5. Thallus Growth Pattern, 6. Silia, and 7. Soredia.

Group II includes Parmelia caperata, Parmelia saxatilis, and Pertusaria coralline, sharing seven identifiers. These shared characteristics encompass 1. Thallus Type, 2. Thallus Colour, 3. Thallus Surface, 4. Thallus Shape, 5. Thallus Growth Pattern, 6. Silia, and 7. Soredia

Group III comprises two subgroups: Group III-a includes Lecanora campestris and Opegrapha atra, while Group III-b includes Pertusaria amara and Lepraria sp. These subgroups share six out of the eight morphological characteristics. Differences are observed in Thallus Type, Thallus Colour, Thallus Surface, and Thallus Shape.

Lacanora camprestis, Opegrapha artra, Pertusaria amara, and Lepraria sp. are all in Group IV. They all share four of the eight morphological traits: 1. Thallus Shape, 2. Thallus Growth Pattern, 3. Silia, and 4. Soredia.

Group V includes Parmeila caperata, Parmelia saxatilis, Pertusaria coralline, and Lepraria incana, sharing six morphological characteristics. These shared traits are 1. Thallus color; 2. Thallus surface; 3. Thallus shape; 4. Thallus Growth pattern; 5. Silia; and 6. Soredia.

Group VI comprises Parmeila caperata, Parmelia saxatilis, Pertusaria coralline, Lepraria incana, and Vecarucaria sp., which all share four of the eight morphological characteristics. These common traits include 1. Thallus Shape; 2. Thallus Growth Pattern; 3. Silia; and 4. Soredia

Finally, Group VII consists of Parmeila caperata, Parmelia saxatilis, Pertusaria coralline, Lepraria incana, Vecarucaria sp., Lecanora campestris, Ophographa atra, Pertusaria amara, and Lepraria sp. These lichens share three out of the eight morphological characteristics: 1. Thallus Growth Pattern; 2. Silia; and 3. Soredia.

Lichens distribution pattern

The lichen distribution pattern obtained exceeds a value of 1 (> 1) and can be classified into groups according to Odum (1993). The clustered distribution pattern occurs due to the presence of gregarious species forming clusters or due to the heterogeneity of the habitat, resulting in the grouping of lichens in areas with abundant food resources. Barbour et al. (1980) explains that there are two reasons behind the occurrence of clustered plant distribution patterns: (1) Plants that reproduce by seeds or fruits tend to fall near their parent plants, and plants that reproduce vegetatively through tubers or rhizomes result in new individuals being close to the parent plant; (2) the microenvironment plays a role, where a macroenvironment consisting of a homogeneous habitat contains several distinct microsites that provide suitable conditions for these plants to thrive, including appropriate air temperature, humidity, and light intensity.

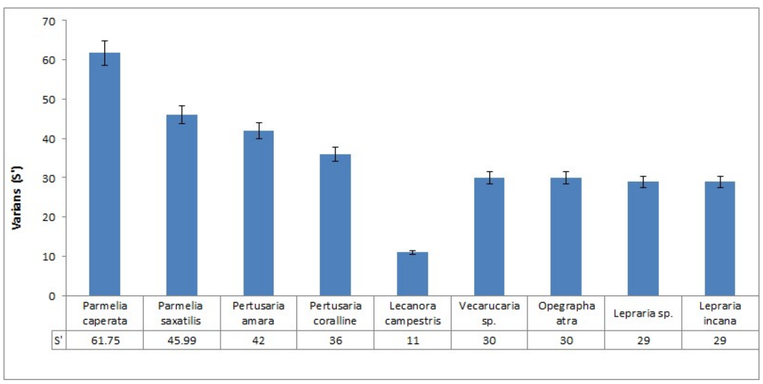

Figure 6: The distribution pattern of Lichens at the study site

Based on the data presented in the table above, it is evident that the lichens discovered in the TAHURA area of Bukit Barisan Tongkoh Karo Regency exhibit a clustered distribution pattern. Odum (1993) states that a distribution index greater than 1 indicates clustering. This pattern suggests that the distribution in the research area reflects variations in habitats, reproductive methods, group behavior, and other factors, including negative interactions such as competition for space, nutrients, or light among individuals.

Higher population densities of lichen species are observed in the most suitable microsites. Lichens reproduce vegetatively through fragmentation, soredia, and isidia, which can be spread by the wind or pieces of the thallus that fall near the parent lichen and stick together. This makes lichen colonies. Air humidity plays a crucial role in lichen distribution. Lichens are predominantly found on trees near rivers due to the influence of humidity. According to Baumgardner et al. (2012), green areas impact atmospheric variables like air temperature, wind speed, and humidity, improving climatic conditions and influencing lichen composition and diversity. Lichens can endure prolonged periods of drought but thrive optimally in humid environments. Different humidity levels indicate variations in species within the lichen community. The presence of a lichen community can serve as an indicator of air quality (McCune, 2010). Lichens are efficient bioaccumulators, trapping trace metal elements from the atmosphere (Bargagli, 2016; Belguidoum et al., 2021; Will-Wolf et al., 2017). Due to their sensitivity to pollution and ability to grow over large geographical areas, lichens are considered reliable and ideal bio-integrators for assessing air pollution (Antonucci et al., 2016; Loppi, 2019).

Based on the measurements, the average air humidity at the research site ranged from 87% to 77.9%, resulting in a limited variety of lichen types found in that location. Lichens, being poikilohydric in nature, meaning they cannot regulate their own water content, can withstand drought for relatively extended periods (Sadowsky and Ott, 2016). The growth and development of lichens in an area are influenced by air humidity and ecological characteristics such as temperature, rainfall, light intensity, and others. This aligns with the research findings of Attanayaka and Wijeyaratne (2013), which suggest that microclimatic factors affect moss distribution, including land use patterns, substrate pH, and light exposure.

Air temperature measurements at the TAHURA location ranged from 19.2°C to 21.2°C. The temperature conditions within this range support the growth and development of lichens, as they fall within the normal threshold for plants in general. According to Hadiyati et al. (2013), the optimal temperature for lichen growth is below 40°C. An air temperature of 45°C can harm the chlorophyll in lichens, disrupting photosynthetic activity.

Observations at the research site indicate that lichens with a crustose thallus morphology were encountered more frequently than foliose types. This illustrates that the crustose thallus type exhibits ease of growth. The current study reveals that crustose lichens exhibit higher diversity than foliose lichens (Kusmoro et al., 2019). Murningsih and Mafazaa (2016) states that the crustose thallus type is the most resilient compared to other types of thallus. This is because lichens with crustose thallus morphology are protected from potential water loss by attaching firmly to their substrate. Additionally, they possess a homoiomerous thallus network, where phycobionts (algae) are located around the hyphae. Lichens do not require demanding living conditions, can withstand prolonged drought, and resist scorching heat.

Theoretical implications of the study

Investigating saxicolous lichens in the Tahura (Taman Hutan Raya/Grand Forest Park) area holds several theoretical implications for lichenology and broader ecological research. The findings of this study contribute to the existing body of knowledge in the following ways:

Ecological Understanding of Lichens: This study examines saxicolous lichens' diversity, distribution patterns, and ecological traits. This helps us learn how lichen communities in different habitats work ecologically. The findings shed light on the adaptability of lichens to rock substrates and provide insights into their colonization strategies and interactions with the surrounding environment.

Lichen Functional Roles: The investigation of lichens in the saxicolous habitat of the Tahura area helps elucidate their functional roles in the ecosystem. Lichens are significant in physical and chemical weathering processes, nutrient cycling, and soil formation. The study contributes to understanding how saxicolous lichens contribute to these processes and their potential influence on ecosystem functioning.

Lichenological Patterns in Tropical Rainforest Ecosystems: The Tahura area represents a tropical rainforest ecosystem with unique environmental conditions. This study expands our knowledge of lichenological patterns in such ecosystems, providing insights into the composition and dynamics of saxicolous lichen communities. The findings contribute to a broader understanding of lichen biodiversity and ecology in tropical regions.

Application of Genetic Analysis in Lichen Studies: The genetic analysis conducted in this study to assess kinship relationships among saxicolous lichens offers a methodological contribution to lichen research. Genetic analyses can provide valuable insights into lichens' evolutionary processes, population dynamics, and dispersal patterns. The study demonstrates the utility of genetic tools in investigating lichen communities and their genetic diversity.

Conservation and Management Implications: The knowledge generated from this study has practical implications for the conservation and management of saxicolous lichen habitats. Understanding lichens' diversity, distribution, and ecological characteristics can inform conservation efforts, especially in protected areas such as the Tahura. The study highlights the importance of preserving rock substrates and maintaining suitable habitat conditions for saxicolous lichens within a larger conservation framework.

Overall, the theoretical implications of this study contribute to advancing our understanding of lichen ecology, highlighting their ecological roles, expanding knowledge in tropical rainforest ecosystems, providing methodological insights, and informing conservation practice. The findings have broader relevance for ecological research and contribute to the growing knowledge in lichenology.

Practical Implications of the Study

Investigating saxicolous lichens in the Tahura (Taman Hutan Raya/Grand Forest Park) area has several practical implications that can inform conservation, land management, and ecological restoration efforts. The findings of this study have direct relevance to practical applications in the following ways:

Biodiversity conservation: The study contributes to identifying and documenting saxicolous lichen diversity in the Tahura area. This information is valuable for conservation planning and management strategies aimed at preserving biodiversity. The findings can be used to establish conservation priorities, design protected areas, and monitor the health of saxicolous lichen communities. Conservationists and land managers can utilize this knowledge to ensure the long-term survival of saxicolous lichen species and maintain overall ecosystem integrity.

Habitat management: Understanding saxicolous lichens' habitat requirements and ecological characteristics can guide habitat management practices. The study provides insights into the specific environmental conditions, such as temperature, humidity, and rainfall, that favor saxicolous lichen growth and establishment. Land managers can use this information to implement habitat management techniques that promote suitable conditions for saxicolous lichens, such as rock preservation, controlling disturbance factors, and maintaining microclimatic conditions. Effective habitat management can support the persistence of saxicolous lichen populations and enhance overall ecosystem health.

Ecosystem restoration: Saxicolous lichens can indicate ecosystem health and restoration success. The findings of this study can guide the selection of appropriate lichen species for monitoring the progress of ecological restoration initiatives. Restoring suitable rock substrates and making small areas where saxicolous lichens can grow can make it easier for them to move in and help restore degraded ecosystems. This study offers practical insights into the factors that support saxicolous lichen colonization and can be utilized to enhance the success of restoration projects in similar habitats.

Education and awareness: The study of saxicolous lichens in a local forest park provides an opportunity for educational outreach and raising awareness about the importance of lichen diversity and ecosystem conservation. The findings can be disseminated to the general public, local communities, and educational institutions to foster an appreciation for the ecological significance of lichens and the need for their protection. Public engagement and awareness campaigns can promote responsible land use practices, encourage citizen science initiatives, and involve local stakeholders in conservation efforts.

Scientific research and collaboration: This study contributes to the scientific knowledge base on saxicolous lichens in the Tahura area. It is a foundation for further research and collaboration among scientists, facilitating future investigations on lichen diversity, distribution, and ecological dynamics. Researchers can build upon these findings to explore aspects of lichen biology, including their interactions with other organisms, responses to environmental changes, and potential applications in fields such as medicine or biotechnology.

In summary, this study's practical implications are wide-ranging and directly relevant to biodiversity conservation, habitat management, ecosystem restoration, education, and scientific research. The findings provide actionable information that can guide conservation and land management practices, inform restoration efforts, and promote public awareness of the ecological value of saxicolous lichens and their habitats.

Limitations of the current research

While the study on saxicolous lichens in the Tahura (Taman Hutan Raya/Grand Forest Park) area provides valuable insights into the diversity, distribution, and ecological characteristics of these lichens, it is important to acknowledge the limitations of the research. These limitations include:

Sample size and spatial coverage: A relatively small sample size of saxicolous lichens taken from rocks in the Tahura area may have hampered the study. A larger sample size and broader spatial coverage would provide a more comprehensive understanding of the saxicolous lichen community in the region. Including additional sampling locations and increasing the number of samples could enhance the representativeness of the findings and capture a more diverse range of saxicolous lichen species.

Taxonomic resolution: Identifying and classifying lichen species can be challenging, particularly at the species level. The study may have encountered taxonomic resolution limitations due to the lichen morphology's complexity and variability. Some lichen species were misidentified or classified at higher taxonomic ranks, which could have implications for interpreting the results. Employing advanced techniques, such as molecular analysis, could provide more accurate species identification and improve taxonomic resolution.

Lack of long-term data: The current research likely represents a snapshot of the saxicolous lichen community in the Tahura area at a specific time. Long-term monitoring data are essential for understanding temporal fluctuations, population dynamics, and responses to environmental changes. With longitudinal data, it is easier to draw conclusions about the saxicolous lichen community's stability or resilience and long-term conservation status. Future studies should consider implementing long-term monitoring programs to capture temporal variations in the saxicolous lichen population.

Genetic analysis limitations: While the genetic analysis conducted in the study provided insights into the kinship relationships among saxicolous lichens, limitations may be associated with the genetic markers or the sample size analyzed. Using a limited number of genetic markers or a small sample size can restrict the accuracy and representativeness of the genetic analysis results. Future studies could incorporate a more comprehensive suite of genetic markers and increase the sample size to enhance the robustness and reliability of the genetic analysis.

Lack of functional analysis: The study focused mostly on saxicolous lichens' diversity, distribution, and genetics. However, functional aspects, such as these lichens' specific ecological roles and contributions to ecosystem processes, should have been studied more in-depth. Understanding the functional traits and ecosystem services, saxicolous lichens provide is crucial for fully comprehending their ecological significance. Future research could explore the functional attributes of saxicolous lichens, such as their role in nutrient cycling, carbon sequestration, or microhabitat provision.

Limited generalizability: The findings of this study are specific to the saxicolous lichen community in the Tahura area and may not be directly applicable to other geographical regions or ecosystems. Environmental factors, microclimatic conditions, and the presence of specific rock substrates can vary across different locations, leading to differences in the composition and dynamics of the saxicolous lichen community. Therefore, caution should be exercised when generalizing the results to other regions or ecosystems, and further research in diverse habitats is necessary to validate the findings.

Acknowledging these limitations is important for contextualizing the scope and applicability of the study's findings. Addressing these limitations through future research endeavors would contribute to a more comprehensive understanding of saxicolous lichens and their ecological dynamics in the Tahura area and beyond.

Future research directions

The study on saxicolous lichens in the Tahura (Taman Hutan Raya/Grand Forest Park) area provides a foundation for further research on lichen diversity, ecology, and conservation. Building upon the current study, the following future research directions are suggested:

Long-term monitoring: Implementing long-term monitoring programs to track changes in the saxicolous lichen community over time is essential for understanding population dynamics, responding to environmental changes, and assessing conservation status. Longitudinal studies can provide insights into the resilience and stability of saxicolous lichen populations and their interactions with other organisms. Additionally, monitoring can help identify potential threats and inform adaptive management strategies.

Species-level identification: Further investigations should aim to improve the taxonomic resolution of saxicolous lichens by employing advanced techniques such as molecular analysis and DNA barcoding. Species-level identification is crucial for accurately assessing species composition, understanding species-specific ecological requirements, and evaluating conservation priorities. Integrating traditional morphological approaches with molecular methods can enhance taxonomic accuracy and facilitate comprehensive species inventories.

Functional ecology: Future research should explore saxicolous lichens' functional traits and ecological roles in their respective ecosystems. By looking into how saxicolous lichens contribute to nutrient cycling, carbon sequestration, the creation of microhabitats, and other ecosystem processes, we can learn more about their ecological importance. Functional studies can elucidate the mechanisms by which saxicolous lichens interact with other organisms and influence ecosystem functioning.

Climate change impacts: Assessing the potential impacts of climate change on saxicolous lichens is crucial, given their sensitivity to environmental conditions. Future research should investigate how changing climatic variables, such as temperature, precipitation patterns, and humidity, might affect saxicolous lichen species' distribution, abundance, and phenology. Modeling studies and experimental approaches can help predict future changes and inform adaptation strategies for conserving saxicolous lichens in a changing climate.

Restoration ecology: Research on restoring saxicolous lichen habitats can teach us a lot about how to do it well and how lichen communities can recover after disturbances to their habitats. Investigating how saxicolous lichens spread, how they change over time, and how they react to restoration efforts can help guide the creation of restoration protocols and make ecosystem restoration projects more successful.

Biotechnological Applications: Saxicolous lichens have been recognized for their potential biotechnological applications, including producing bioactive compounds with pharmaceutical, antimicrobial, and industrial uses. Future research should explore the bioactive properties, chemical composition, and potential applications of saxicolous lichen metabolites. Understanding the biotechnological potential of saxicolous lichens can contribute to developing novel drugs, bioremediation strategies, and other industrial applications.

Comparative studies: Conducting comparative studies across different geographical regions and ecosystems can provide a broader understanding of saxicolous lichen diversity, ecological patterns, and the factors influencing their distribution. Comparative studies can show how saxicolous lichen communities differ in different regions, what role certain environmental factors play, and how important biotic and abiotic drivers are. Collaborative research efforts among researchers from different regions can facilitate such comparative studies.

Pursuing these future research directions can achieve a more comprehensive understanding of saxicolous lichens and their ecological dynamics. The findings of these studies will contribute to the conservation and management of saxicolous lichens, inform policy decisions, and promote the sustainable use of these unique organisms and their habitats.

CONCLUSION

A comprehensive study conducted in saxicolous environments unveiled an intriguing discovery: a remarkable assortment of nine distinct lichen species, each boasting crustose or foliose thallus types. Evaluating the ecosystem's lichen diversity, a notable lichen diversity index of 2.02 was recorded, highlighting a rich and varied composition. Regarding uniformity, the Uniformity Index value E' reached an impressive 2.776, firmly placing it in the high category. As we looked more closely at the spatial distribution pattern, it became clear that the lichens had a fascinating tendency to group together, with Parmelia caperata being their preferred habitat most of the time. The concentration of lichens on this particular species was quantified through the S' value, reaching a significant 61.75.

Another intriguing aspect explored during the investigation was the genetic kinship among the lichens. The data revealed a division into eight distinct groups characterized by unique genetic characteristics. The highest genetic similarity score observed among the groups was 8, indicating a close relationship, while the lowest recorded score was 3, indicating a comparatively lesser degree of genetic similarity.

These findings shed light on the remarkable diversity, spatial preferences, and genetic relationships within the fascinating world of lichens thriving in saxicolous environments. Such comprehensive insights contribute to our understanding of the intricate dynamics of these symbiotic organisms and their crucial role within ecosystems.

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