International Journal of Multi Research

Online ISSN: 3107 - 7676
IJMR 2026; 2(1): 73-86
2026 January - February
www.allmultiresearchjournal.com

Received: 02-12-2025
Accepted: 04-01-2026
Published: 01-02-2026
DOI: **https://doi.org/10.54660/IJMR.2026.2.1.73-86**

Inventory and Diversity of Corticolous Lichens on *Azadirachta indica* (neem) at Three Sites in Berbice, Guyana: A Comparative Study

Lakhnarayan Kumar Bhagarathi [1*], Phillip N. B. Da Silva [2], Gomathinayagam Subramanian [3], Ferial Pestano [4], Zenesia Phillips-Henry [5], Safrina Ali [6], Mitra Udit [7], Naeem Khan [8], Sushmita Kalika-Singh [9], Yunita Arjune [10], Chalasa Cossiah [11], Lacram Kokil [12], Bissessar Persaud [13], Bibi Rafeena Ally-Charles [14], Maria A. Fraser [15], Rajendra Dasratt [16], Rahaman Balkarran [17]

[1*] M.D.R.M.-C.G., M.Sc., Post Graduate Diploma, B.Sc., Institute for Marine and Riverine Ecologies and Economies, University of Guyana, Berbice Campus, John's Science Centre, Corentyne, Berbice, Guyana
[2] M.Ed., M.Sc., Post Graduate Diploma, B.Sc., Institute for Marine and Riverine Ecologies and Economies, University of Guyana, Berbice Campus, John's Science Centre, Corentyne, Berbice, Guyana
[3] Ph.D., M.Sc., BSc., Faculty of Agriculture, University of Guyana, Berbice Campus, Tain, Corentyne, Guyana
[4] M.Sc., B.Sc., Faculty of Natural Sciences, University of Guyana, Berbice Campus, Tain, Corentyne, Guyana
[5] M.Sc., B.Sc., Faculty of Agriculture, University of Guyana, Berbice Campus, Tain, Corentyne, Guyana
[6, 7] B.Sc., Faculty of Natural Sciences, University of Guyana, Berbice Campus, Tain, Corentyne, Guyana
[8] B.Sc., Faculty of Agriculture, University of Guyana, Berbice Campus, Tain, Corentyne, Guyana
[9] Ph.D., M.Sc., B.Sc., Faculty of Natural Sciences, University of Guyana, Berbice Campus, Tain, Corentyne, Guyana
[10] M.Sc., Post Graduate Diploma, B.Sc., Faculty of Natural Sciences, University of Guyana, Berbice Campus, Tain, Corentyne, Guyana
[11] M.Ed., Post Graduate Diploma, B.Sc., Faculty of Natural Sciences, University of Guyana, Berbice Campus, Tain, Corentyne, Guyana
[12] M.Sc., B.Sc., Faculty of Agriculture, University of Guyana, Berbice Campus, Tain, Corentyne, Guyana
[13] M.D.R.M.-C.G., M.Sc., B.Sc., Faculty of Agriculture, University of Guyana, Berbice Campus, Tain, Corentyne, Guyana
[14] M.Sc., Post Graduate Diploma, B.Sc., College of Medical Sciences, University of Guyana, Turkeyen Campus, Greater Georgetown, Guyana
[15] M.Sc., B.Sc., Faculty of Natural Sciences, University of Guyana, Berbice Campus, Tain, Corentyne, Guyana
[16] M.Sc., B.Sc., School of Entrepreneurship and Business Innovation, University of Guyana, Turkeyen Campus, Greater Georgetown, Guyana
[17] B.A., Baruch College, Lexington Ave, New York, United States of America

Corresponding Author; **Lakhnarayan Kumar Bhagarathi**

Abstract

Lichens are symbiotic organisms composed of fungal and photosynthetic partners, exhibiting unique physiological and ecological traits that allow them to colonize diverse substrates. *Azadirachta indica* (neem), a fast-growing Meliaceae tree with ecological and medicinal importance, serves as a potential host for corticolous lichen communities; however, systematic studies on lichens inhabiting neem bark are limited. This study investigated lichen diversity, abundance on *A. indica* across three sites along the East Coast of Berbice, Guyana. A total of ten mature, healthy neem trees were sampled using standardized quadrats (50 × 100 cm) placed at 1.5 m above ground, and lichen species were identified via morphological and chemical spot tests, supported by taxonomic literature. Across all sites, thirteen lichen species representing six families and eight genera were recorded, with total abundance varying from 335 to 743 individuals per site. Parmeliaceae exhibited the highest species richness, with *Flavoparmelia soredians* and *Hypotrachyna laevigata* occurring at all sites, whereas species such as *Parmelia tiliacea* and *Flavoparmelia caperta* displayed site-specific distributions, indicating differential ecological tolerance and potential sensitivity to microenvironmental factors. Diversity indices (Shannon H′ 1.99-2.04; Simpson SDI 0.80-0.84) suggested moderately high diversity and generally balanced species evenness. Patterns of lichen presence across sites highlight a combination of generalist and host-specific taxa, underscoring the importance of bark characteristics, microclimate, and environmental heterogeneity in shaping epiphytic lichen communities. These findings provide baseline data for lichen biodiversity on neem trees in Guyana and emphasize the potential of *A. indica* as a host for lichen bioindicator species in monitoring ecosystem health and environmental changes.

Keyword: Lichen diversity, *Azadirachta indica*, Corticolous lichens, Tropical ecosystems

1. Introduction

1.1 Lichens

Lichens represent one of the most striking examples of symbiotic life in terrestrial ecosystems, historically challenging traditional concepts of organismality and ecological classification. Traditionally defined as stable, intimate associations between a fungal partner (mycobiont) and one or more photosynthetic partners (photobionts), typically green algae or cyanobacteria. Lichens exhibit a morphology, physiology, and ecological niche that is distinct from any of their constituent partners in isolation [8, 9, 10, 11, 13,14]. While about 15,000-20,000 lichen species have been described, the diversity of potential partnerships and the discovery of additional micro-organisms embedded within the lichen thallus are prompting a re-evaluation of the classic dual symbiosis paradigm [10, 11, 13].

Fundamentally, the lichen symbiosis is a complex mutualistic system in which the photosynthetic partner supplies organic carbon compounds via photosynthesis, while the fungal partner provides structural support, regulates water relations, and buffers the photobionts from environmental extremes [8, 9, 10, 11, 13]. This symbiosis allows lichens to colonize a wide array of substrates worldwide, including soil, rocks, and the bark of trees (phorophytes), without extracting nutrients from the host but rather using the surface as a substrate for growth and resource acquisition (e.g., moisture and light), making their relationship commensalistic rather than parasitic on trees themselves. This substrate association is influenced by bark chemistry, texture, moisture, and microclimate, and contributes to patterns of lichen diversity and composition across tree species and environments [56, 61].

Molecular and genomic analyses indicate that many lichen-forming fungi have undergone genome reduction in genes associated with independent saprotrophic lifestyles, consistent with the shift to obligate symbiosis, while also acquiring lineage-specific genes implicated in symbiosis establishment [10, 71]. This genomic evidence underscores that lichenization is not a static association but an evolutionary strategy involving deep physiological integration and regulatory complexity [10].

Moreover, lichens are not merely binary partnerships; they often host bacterial communities and additional fungal or algal micro-symbionts within their thalli, which influence nutrient cycling, stress tolerance, and inter-organismic signaling [6, 8, 9, 10, 11]. This expanded view positions lichens as microbial consortia, rather than simple two-species systems, with emergent properties that contribute to ecosystem processes such as soil formation, nutrient cycling, and environmental monitoring [10, 11].

Morphologically, lichens develop a composite body called a thallus, which manifests in characteristic growth forms such as crustose, foliose, and fruticose, each reflecting adaptation to specific environmental regimes [8, 9, 10, 11, 13]. Their ability to colonize extreme and nutrient-poor habitats, from deserts and polar regions to high mountain slopes, illustrates both their ecological versatility and their role as pioneer organisms in primary succession and ecosystem development [10].

Research in lichen biology highlights not only their ecological importance but also the challenges of lichen taxonomy and evolution. Because lichens integrate multiple lineages of fungi, algae, cyanobacteria, and bacteria, their classification cannot be resolved solely on morphological criteria; instead, it requires genetic and phylogenetic data to unravel the complex histories of symbiotic association and co-evolution [8, 9, 10, 11, 13, 62]. Collectively, lichens exemplify how interspecific cooperation can drive evolutionary innovation, expand ecological niches, and contribute to the resilience of ecosystems in the face of environmental stressors.

1.2 Lichens on Meliaceae Hosts

Within tropical and subtropical regions, Meliaceae (the mahogany family) includes many prominent tree species such as *Swietenia mahagoni* (Cuban mahogany), *Swietenia macrophylla* (big-leaf mahogany), *Khaya* species, and others that serve as substrates for diverse epiphytic and corticolous lichens. Meliaceae members are ecologically significant as dominant canopy trees across Neotropical forests and anthropogenic landscapes [73].

Azadirachta indica, commonly known as neem, is a fast-growing evergreen tree of the Meliaceae family that has played a central role in traditional medicinal systems such as Ayurveda, Unani, and Siddha for millennia [12, 28, 37].

Studies on corticolous lichen diversity in Guyana and adjacent Neotropical regions have found specific associations between lichen taxa and Meliaceae hosts, illustrating both generalist and host-preferential patterns. For example, in New Amsterdam, Berbice, Guyana, 14978 individual lichens representing multiple families were recorded on 41 trees sampled across urban and suburban environments, where *Swietenia mahagoni* hosted unique species such as *Cladonia parasitica, Hypotrachyna laevigata*, and *Usnea cornuta*; these species were recorded exclusively on *S. mahagoni* within the study, suggesting host specificity or preference correlated with bark traits and microhabitat conditions [5].

Taxon-specific records also demonstrate the presence of lichens on mahogany hosts. *Parmotrema aptrootii*, a foliose corticolous species in Parmeliaceae, was first described from bark of a mahogany tree in western Guyana, underscoring Meliaceae host use by Neotropical lichens and expanding the known host repertoire for corticolous taxa in the region [51, 64].

These host associations are supported by broader research showing that lichens frequently exhibit host preferences or host specificity, where a notable proportion of lichen species preferentially colonize particular tree species or bark types within local communities. Host specificity can relate to bark pH, texture, and chemical characteristics, all of which influence lichen colonization, establishment, and diversity patterns across tree species, including those within the Meliaceae [51, 64].

Overall, lichens on Meliaceae hosts demonstrate how fungal-photobiont symbioses exploit tree bark as habitat, with patterns of colonization driven by substrate features more than by direct nutrient extraction from the host. Continued studies that focus on specific host-lichen pairings, chemical and physical bark properties, and community-level interactions are crucial for better understanding the ecological roles and biodiversity of lichens associated with Meliaceae trees in tropical forests.

1.3 Lichens on *Azadirachta indica* Host

Despite neem's economic and medicinal prominence, systematic studies focusing specifically on lichens growing on *A. indica* bark are scarce in the lichenological literature. Most of our understanding of lichen diversity on tree hosts is derived from broader ecological studies that include host specificity, bark traits, and lichen community structure across landscapes rather than targeted neem inventories [7, 8, 9, 11].

General ecological studies indicate that host tree characteristics such as bark texture, pH, diameter, and microclimatic conditions are major determinants of epiphytic lichen diversity and composition. Research from tropical dry forests exemplifies that trees with particular bark traits support higher numbers and varied assemblages of lichens, suggesting that structural and chemical properties of host bark help regulate lichen establishment and persistence [7, 8, 9, 11]. Although these studies do not specifically list *A. indica*, the ecological principles they reveal are widely applicable to understanding how lichens might colonize neem bark under suitable conditions.

Studies conducted in Guyana provide valuable regional context for lichen biodiversity. For example, lichenological surveys from the Guianas document rich communities of foliicolous (leaf-dwelling) and corticolous lichens across tropical forests, contributing hundreds of species records and several new taxa for the region [43, 68]. While these works focus on canopy and leaf lichens and do not single out specific hosts like neem, they affirm that lichens are biodiversity components of Guyanese forests. In urban and suburban Guyana, research examining corticolous lichen diversity on tree bark demonstrates diverse lichens across different tree hosts, influenced in part by host tree identity and urban environmental gradients [4, 5]. These findings connect host tree diversity, including potential hosts like neem if present, as an important factor shaping local lichen communities.

Importantly, some research done in Guyana also addressed host specificity, showing that certain lichen species preferentially occur on particular tree genera in coastal agroecosystems, reflecting complex interactions between lichen traits, bark properties, and environmental conditions [8, 9]. While neem was not a focus in previous studies reported from Guyana, the documented patterns of host preference underscore the need for targeted investigation of lichens on specific hosts such as *Azadirachta indica* and similar tropical settings.

The general objective of this study was to identify and compare the diversity and abundance of lichens on *Azadirachta indica* at three sites in Berbice, Guyana. Overall, although there is limited direct documentation of lichens on *A. indica* in scientific literature, the general ecology of corticolous lichens and the documented lichen richness in Guyanese forests and urban landscapes support the view that neem trees likely serve as epiphytic lichen hosts where local environmental conditions, bark characteristics, and broader community dynamics allow. Further research specifically targeting lichen assemblages on neem bark, particularly in under-studied regions such as Guyana, would significantly enhance understanding of host-lichen relationships in tropical ecosystems.

2. Methodology

2.1 Study Location

This research was conducted along the East Coast of Berbice (Figure 1). The three (3) sites are: National Agricultural and Research and Extension Institute (NAREI) in Lesbiholden, Black Bush Polder; University of Guyana John's Science Centre, John's Village and Line Path 'C' village, Corriverton (Figure 1).

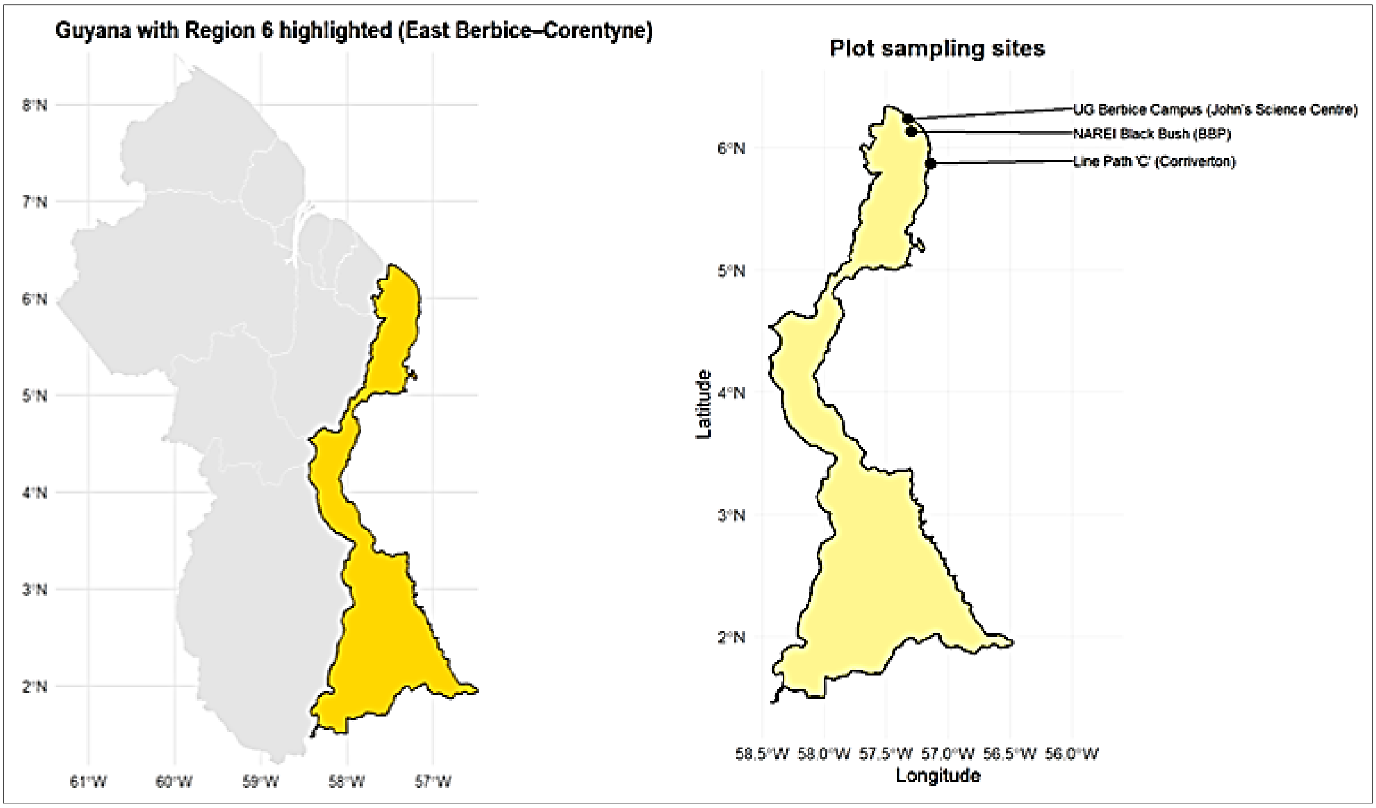

Fig 1: Map of Guyana showing the location of East Berbice Corentyne (Regions 6) and the three (3) sampling sites along the East Coast of Berbice: (i) University of Guyana John's Science Centre, John's Village, (ii) NAREI, Lesbiholden (Black Bush Polder), and (iii) Line Path 'C', Corriverton

2.2 Experimental Design

The method utilized for this research was adopted from prior studies by Asta *et al.*, 2002 [3]; Bacchus & Da Silva, 2021 [4]; Bacchus & Da Silva, 2023 [5]; Bhagarathi *et al.*, 2024a [8] and Bhagarathi *et al.*, 2024b [9]. The experimental design utilized for this study is quantitative non-experimental. Purposive sampling was utilized in this study since only *Azadirachta indica* hosts trees were selected. The host plants were selected using the following criteria: (i) trees must be undamaged especially on the bark area and (ii) the trunk of the selected tree must be 50 cm girth or more [9].

The conceptual framework of this research (Figure 2) visually represents the systematic flow of the study, from site selection to the interpretation of lichen diversity patterns on *Azadirachta indica* along the East Coast of Berbice, Guyana. It organizes the methodology into sequential stages: study site selection, host tree characterization, field sampling, lichen identification, data compilation, data analysis, and interpretation. Each stage builds upon the previous one, ensuring that sampling and data collection are standardized, identification is accurate, and analysis is meaningful.

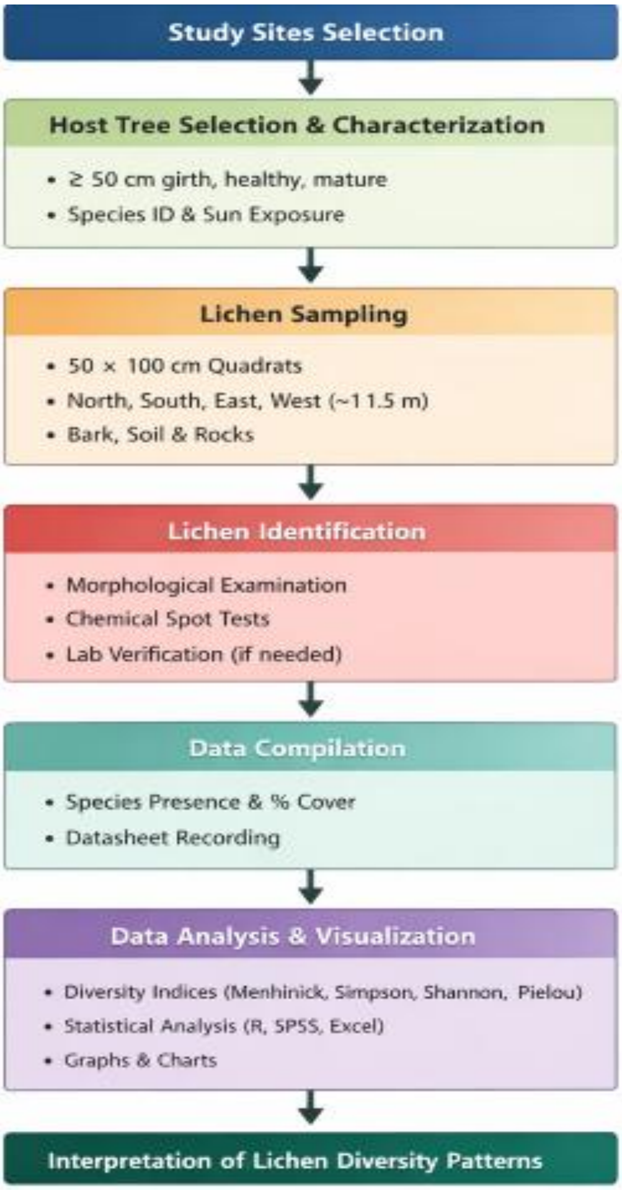

Fig 2: Conceptual Framework of the study

The conceptual framework (Figure 2) is important because it clarifies the research process by presenting a logical sequence of activities, allowing readers to understand how data were collected, processed, and analyzed. It also guides methodological rigor by mapping all steps, ensuring that sampling, identification, and analysis are conducted consistently and are replicable. Furthermore, the framework links variables and outcomes by illustrating how host tree characteristics, environmental factors, and sampling design influence lichen diversity, thereby facilitating the interpretation of ecological patterns. In addition, it enhances communication by providing a visual overview of the study design, making the methodology accessible to readers, reviewers, and other stakeholders. Overall, the conceptual framework strengthens the scientific integrity of the research by providing a structured roadmap that integrates fieldwork, laboratory analysis, and statistical interpretation.

2.3 Sampling and Data Collection

Sampling was done during the short-wet season period in Guyana during the month of December of 2025. Purposive sampling was the method used to select *Aadirachta indica* (neem) plants across multiple sites. A total of ten (10) neem trees were sampled in this study. Four (4) trees were sampled from National Agricultural and Research and Extension Institute (NAREI) in Lesbiholden, Black Bush Polder; two (2) neem trees were sampled from the University of Guyana John's Science Centre, John's Village and four (4) neem trees were sampled from Line Path 'C' village, Corriverton.

Healthy, fully mature trees were selected for sampling. Only undamaged, free-standing individuals with a girth ≥ 50 cm, measured at 2 m above ground level, were included to ensure that exclusively mature trees were sampled [3, 4, 8, 9, 63].

Each sampled host tree was identified, at minimum, to the species level [4, 8, 9, 35]. Sun exposure was quantified by measuring the amount of incident light reaching the trunk surface, considering shading effects from surrounding vegetation and nearby structures [8, 9, 39].

A total of ten (10) sampling quadrats were established across the three (3) sites, one for each host plants that were sampled. Lichen surveys were conducted using twine quadrats measuring 50 cm × 100 cm. On each host tree, quadrats were positioned on the north, south, east, and west aspects of the trunk at a standardized height of 5 ft (≈1.5 m) above ground level [4, 8, 9, 35]. Sampling was carried out within each quadrat on the trunk surface, as well as on soil and any rocks present within the quadrat area. The basal portion of the trunk was excluded to minimize variability among trees and to avoid microhabitat heterogeneity associated with the trunk base [4, 8, 9, 39].

All lichen species present and their frequencies within each 50 cm × 100 cm quadrat were recorded on a standardized lichen survey datasheet developed for this study. The surface cover of each target lichen species was estimated to the nearest cm² and subsequently expressed as a percentage of the sampled trunk area [4, 8, 9, 39].

2.4 Lichen Identification

Preliminary identification of lichen specimens was conducted *in situ* based on detailed morphological observations of the thalli and apothecia using a hand lens. Specimens were identified at minimum to the genus level, and to species level where diagnostic characters permitted.

Taxonomic identification was supported by standard lichenological literature, including Mosses and Lichens: A Popular Guide to the Identification and Study of Our Commoner Mosses and Lichens, Their Uses, and Methods of Preserving [46], A Reference Notebook: Identifying Mixed Hardwood Forest Lichens [16], and Collector's Handy Book: Algae, Fungi, Diatoms, Lichens, Desmids and Mosses [50]. Additional dichotomous keys and field guides consulted included Lichens: Two Lives [72], Field-Oriented Keys to the Florida Lichens [60], Heathland Lichens [23], and Lichen Identification Guide (2015) [41].

Standard chemical spot tests were performed by carefully removing a portion of the cortex with a sterile scalpel to expose the medulla, followed by the application of appropriate reagents using a pipette. Resulting color reactions were observed and recorded under magnification to aid in species identification [8, 9, 35]. Specimens that could not be reliably identified in the field were collected and transported to the laboratory for further taxonomic examination under expert guidance. Following identification, all observations and measurements were systematically compiled and tabulated on standardized lichen datasheets used throughout the field survey [8, 9].

2.5 Data Analysis

Diversity indices are quantitative measures that describe community structure by integrating both species richness (the number of species) and the relative distribution of individuals among species (evenness). Diversity values increase with greater species richness and more equitable abundance distributions, reaching a maximum when all species are equally abundant for a given number of taxa [8, 9, 58]. In this study, species diversity was assessed based on the number of species present and their proportional representation within the community. To facilitate comparative analyses, Menhinick's richness index, Simpson's diversity index, Shannon-Wiener diversity index, and Pielou's evenness index were calculated [8, 9, 35].

Data obtained from the study were subjected to statistical analysis using R software (version 4.2.2; R Studio interface), IBM Statistical Package for the Social Sciences (SPSS) version 23, and Microsoft Excel 2016. Descriptive and inferential analyses were performed as appropriate, and relevant charts, tables, and graphical visualizations were generated using the same software platforms to facilitate data comparison and interpretation.

3. Result and Discussion

3.1 Species/ Distribution of Corticolous Lichens

A total of six lichen families representing eight genera and thirteen (13) species (Table 1) were recorded across the three study sites, highlighting notable variation in taxonomic composition among locations. The family Parmeliaceae exhibited the highest diversity, with three genera and four species overall; Site 1 supported the full complement of three genera and four species, Site 2 had reduced diversity (two genera, two species), and Site 3 demonstrated intermediate richness (two genera, three species) (Table 1). Lecanoraceae was the family with the second highest species count recorded, with one genus and three species, and although a single genus occurred at all sites, species richness increased from two species at Site 2 to three species at Site 3 (Table 1). The family Arthoniaceae comprised one genus and two species, with Site 2 lacking representatives of this family, whereas both Site 1 and Site 3 harbored one genus each, but only Site 1 had both species present (Table 1). In contrast, Caliciaceae and Stereocaulaceae were the least diverse, each represented by a single genus and a single species that were consistently sampled across all sites (Table 1). Phlyctidaceae contributed modest diversity with one genus and two species, and these were uniformly present at every site with no apparent variation in richness (Table 1).

Table 1: Number of genera and species at each site

#	Family	Total # OF GEN.	Total # OF SP.	SITE # 1		SITE # 2		SITE # 3	
				# OF GEN.	# OF SP.	# OF GEN.	# OF SP.	# OF GEN.	# OF SP.
1	Parmeliaceae	3	4	3	4	2	2	2	3
2	Caliciaceae	1	1	1	1	1	1	1	1
3	Lecanoraceae	1	3	1	2	1	2	1	3
4	Arthoniaceae	1	2	1	0	1	2	1	0
5	Stereocaulaceae	1	1	1	1	1	1	1	1
6	Phlyctidaceae	1	2	1	2	1	2	1	2

Site 1 consistently exhibited the highest overall lichen richness in both genera and species, followed closely by Site 3, while Site 2 tended to support slightly lower diversity, particularly for families such as Arthoniaceae (Table 1). This spatial pattern suggests heterogeneity in lichen community structure across the sampling locations, potentially reflecting underlying environmental gradients or habitat conditions [2, 31].

Table 2: Species frequency distributed over each site sampled & overall total of each site

Family	Species	Thallus	Site # 1 *	Site # 2 *	Site # 3 *	Total at the 3 Sites *
Parmeliaceae	*Flavoparmelia soredians*	Foliose	201	24	57	282
	Flavoparmelia caperta	Foliose	102	0	43	145
	Hypotrachyna laevigata	Foliose	34	14	13	61
	Parmelia tiliacea	Foliose	27	0	0	27
Caliciaceae	*Dirinaria applanata*	Foliose	74	37	113	224
Lecanoraceae	*Lecanora chlarotera*	Crustose	0	43	92	135
	Lecanora muralis	Crustose	143	121	184	448
	Lecanora conizaeoide	Crustose	83	0	63	146
Arthoniaceae	*Arthonia purinata*	Crustose	0	13	0	13
	Arthonia radiata	Crustose	0	51	0	51
Stereocaulaceae	*Lepraria lobificans*	Crustose-leprose	29	3	21	53
Phlyctidaceae	*Pertusaria albescens*	Crustose	9	2	17	28
	Pertusaria amara	Crustose	41	27	36	104
Total			743	335	639	1717

Site # 1 *: National Agricultural and Research and Extension Institute (NAREI),
Site # 2 *: University of Guyana John's Science Centre, John's Village, and
Site # 3 *: Line Path 'C' village, Corriverton.

A total of one thousand seven hundred seventeen (1,717) lichen thalli representing six (6) families, eight (8) genera, and thirteen (13) species were recorded across the three sampling sites (Table 2), demonstrating pronounced spatial variation in both abundance and species composition. Site 1 (NAREI) yielded the highest overall frequency with seven hundred forty-three (743) individuals, followed by Site 3 (Line Path 'C', Corriverton) with six hundred thirty-nine (639) individuals, while Site 2 (University of Guyana John's Science Centre) supported the lowest abundance (three hundred thirty-five (335) individuals).

Across all sites, the family Parmeliaceae was a major contributor to total abundance, particularly *Flavoparmelia soredians*, which was the most frequent species overall (282 individuals), occurring at all three sites but showing strong dominance at Site 1. Similarly, *Dirinaria applanata* (Caliciaceae) and *Lecanora muralis* (Lecanoraceae) were widely distributed and abundant across all locations, with *L. muralis* being the single most abundant species overall (448 individuals), indicating broad ecological tolerance (Table 2).

Distinct site-specific patterns were evident in several taxa. Site 1 supported high frequencies of *Lecanora muralis* (143), *Flavoparmelia soredians* (201), and *Flavoparmelia caperata* (102), and was the only site where *Parmelia tiliacea* was recorded, suggesting unique microhabitat conditions favorable to this species (Table 2). In contrast, Site 2 was characterized by the exclusive occurrence of *Arthonia purinata* (13) and *Arthonia radiata* (51), while several Parmeliaceae species (*Flavoparmelia caperata* and *Parmelia tiliacea*) were absent, indicating possible environmental filtering or habitat constraints (Table 2). Site 3 exhibited high abundances of *Lecanora muralis* (184) and *Dirinaria applanata* (113), and showed the greatest frequency of *Lecanora chlarotera* (92), reflecting a community structure distinct from the other two sites (Table 2).

Although several species such as *Pertusaria amara*, *Pertusaria albescens*, *Lepraria lobificans*, and *Hypotrachyna laevigata* occurred across all sites, their relative frequencies varied considerably, contributing to differences in community composition and dominance structure (Table 2). Collectively, these results demonstrate that while a core assemblage of widespread lichen species was shared among sites, marked differences in abundance patterns and the presence or absence of particular taxa generated spatial heterogeneity in lichen community structure across the three locations.

The spatial variation in lichen species composition and abundance observed across the three study sites is consistent with patterns documented in other regional lichen ecology studies (e.g. Aragón *et al*., 2020 [1]; Nanda *et al*., 2021 [48]; & España-Puccini *et al*., 2024 [22]), where environmental gradients and habitat heterogeneity drive differential community structure. España-Puccini *et al.* (2024) [22] found significant differences in lichen species composition among four tropical dry forest sites in Colombia, highlighting the role of habitat heterogeneity in shaping community richness and β-diversity. Similarly, research by Nanda *et al*., (2021) [48] across multiple elevational transects in the Himalayan Arc demonstrated marked variation in macrolichen species identity and richness among spatially distinct sites, indicating that abiotic factors such as elevation and associated microclimatic conditions influence community assembly and species turnover. Additionally, comparative studies conducted by Aragón *et al*. (2020) [1] on epiphytic lichen communities across European beech forests have shown that climatic variables including temperature and precipitation gradients significantly affect lichen taxonomic diversity and spatial variation in community composition, underlining environmental drivers as key determinants of lichen distribution patterns.

Table 3: Comparison of Diversity data at the three (3) sites

Site	Shannon Diversity Index (H′)	Simpson Diversity Index (SDI)	Specie Richness (SR)	Specie Evenness (SDI/LN[SR])
#1	2.04	0.84	10	0.89
#2	1.99	0.80	10	0.86
#3	2.02	0.84	10	0.88

3.2 Estimated Species Diversity

The Shannon Diversity Index (H′) and Simpson Diversity Index (SDI) values across the three study sites indicate moderate to high lichen diversity and reveal subtle differences in community structure among locations. Shannon H′ quantifies species diversity by incorporating both species richness and evenness, with higher values reflecting a more diverse and evenly distributed community. In this study, Shannon H′ ranged from 1.99 (Site 2) to 2.04 (Site 1), suggesting that all three sites maintain a relatively comparable diversity of lichen species. Site 1 exhibited the highest Shannon index (2.04), indicating a slightly more even and diverse distribution of species compared to the other sites, whereas Site 2 had the lowest value (1.99), reflecting marginally lower diversity and potentially the dominance of a few abundant species.

The Simpson Diversity Index (SDI) complements Shannon's H′ by emphasizing species dominance and the probability that two randomly selected individuals belong to different species. SDI values in this study ranged from 0.80 (Site 2) to 0.84 (Sites 1 and 3), demonstrating that species dominance is relatively low and that no single species overwhelmingly dominates the lichen communities. The slightly lower SDI at Site 2 aligns with its lower Shannon H′, indicating that this site has a somewhat less even distribution of individuals across species. In contrast, Sites 1 and 3 share the highest SDI (0.84), suggesting more equitable abundance among species and a less skewed community structure.

Overall, both diversity indices consistently indicate that the three sites harbor comparable lichen diversity, with minor differences likely attributable to local environmental factors, microhabitat heterogeneity, or host tree conditions. Shannon H′ captures both richness and evenness, while SDI highlights the influence of dominant species, and together they provide a comprehensive understanding of community diversity.

3.3 Estimated Species Richness

In this study, all three sites exhibited equal species richness (SR = 10), indicating that each site harbored the same number of lichen species despite differences in abundance and community composition. This uniform richness suggests that the overall lichen species pool is relatively consistent across the sampled locations.

However, species richness alone does not account for the relative abundances of species; therefore, sites with identical richness may still differ in terms of dominance and evenness, as reflected in the Shannon and Simpson indices. For instance, although Site 2 has the same number of species as Sites 1 and 3, its slightly lower Shannon H′ (1.99) and Simpson D (0.80) indicate that some species are more dominant and the distribution of individuals among species is less even. Conversely, Sites 1 and 3 not only share equal richness but also higher evenness, suggesting a more balanced distribution of individuals among the ten species.

3.4 Estimated Species Evenness

Species evenness (E) measures how evenly individuals are distributed among the species present at a site. In this study, evenness values ranged from 0.86 (Site 2) to 0.89 (Site 1), indicating that lichen communities are generally well balanced, with no single species overwhelmingly dominating the community. Site 1 exhibited the highest evenness (0.89), suggesting a relatively uniform distribution of individuals across its ten species. In contrast, Site 2 had the lowest evenness (0.86), indicating a slightly more uneven distribution, where some species were more abundant than others. Site 3 had an intermediate value (0.88), reflecting a fairly balanced distribution similar to Site 1.

The evenness values corroborate the patterns observed in the Shannon and Simpson diversity indices: sites with higher evenness tend to show greater diversity (higher H′ and SDI), while lower evenness can reduce overall diversity despite identical species richness. In this study, evenness highlights that while species richness is constant across the three sites (SR = 10), the relative abundance of species varies slightly, contributing to subtle differences in community structure.

3.5 Site and Host Plant Specificity of Lichens

Table 4: Site Specificity of Corticolous Lichens towards *Azadirachta indica* as host plant

Lichen Family	Lichen Species	Site # 1	Site # 2	Site # 3
Parmeliaceae	*Flavoparmelia soredians*	✓	✓	✓
	Flavoparmelia caperta	✓	X	✓
	Hypotrachyna laevigata	✓	✓	✓
	Parmelia tiliacea	✓	X	X
Caliciaceae	*Dirinaria applanata*	✓	✓	✓
Lecanoraceae	*Lecanora chlarotera*	X	✓	✓
	Lecanora muralis	✓	✓	✓
	Lecanora conizaeoide	✓	X	✓
Arthoniaceae	*Arthonia purinata*	X	✓	X
	Arthonia radiata	X	✓	X
Stereocaulaceae	*Lepraria lobificans*	✓	✓	✓
Phlyctidaceae	*Pertusaria albescens*	✓	✓	✓
	Pertusaria amara	✓	✓	✓

✓-Lichen Species Present at Site, X-Lichen Species Absent at Site

The survey of lichen communities associated with *Azadirachta indica* across three sites revealed variability in both species presence and host specificity, highlighting differential ecological preferences among lichen taxa. Among the Parmeliaceae, *Flavoparmelia soredians* and *Hypotrachyna laevigata* were consistently recorded across all sites, indicating broad ecological tolerance and a generalist pattern of host association. In contrast, *Flavoparmelia caperta* was absent from Site #2, while *Parmelia tiliacea* was restricted to Site #1 only, suggesting a degree of site-specific colonization or sensitivity to microenvironmental factors, such as light intensity, humidity, or bark chemistry, that may vary between sites.

Within Caliciaceae, *Dirinaria applanata* was present at all three sites, further emphasizing the capacity of some lichen species to establish across multiple environmental contexts. The Lecanoraceae exhibited more variation, with *Lecanora chlarotera* absent from Site #1 but present at Sites #2 and #3, and *Lecanora conizaeoide* absent at Site #2. *Lecanora muralis*, however, showed a ubiquitous distribution across all sites, suggesting high ecological plasticity within this family. Notably, members of Arthoniaceae (*Arthonia purinata* and *Arthonia radiata*) were largely absent at Sites #1 and #3 but present at Site #2, indicating a restricted niche or high sensitivity to environmental conditions, possibly related to microclimatic variables or competition with other epiphytic species.

Species within Stereocaulaceae (*Lepraria lobificans*) and Phlyctidaceae (*Pertusaria albescens* and *Pertusaria amara*) were consistently recorded across all sites, reflecting both their generalist host utilization and likely tolerance to a range of environmental conditions. Overall, the observed patterns suggest that while certain lichen species demonstrate broad ecological amplitude and are capable of colonizing *Azadirachta indica* across varied sites, others display site-specific distributions, indicating differential sensitivity to local environmental variables such as moisture availability, light exposure, bark pH, and microhabitat structure.

These findings underscore the importance of considering both species-specific ecological traits and site-specific environmental factors when assessing lichen diversity and host specificity in coastal or terrestrial ecosystems. Moreover, the presence of generalist species across all sites could serve as reliable indicators for monitoring environmental changes, whereas the restricted species may act as sensitive bioindicators of subtle habitat alterations or stressors affecting *Azadirachta indica* populations. This study did not evaluate factors that affect host specificity, such as pH of the bark, content of water, permeability, degree of bark shading, and the appearance of tree sap [17]. Since various lichen species are found inhabiting different levels of a tree trunk, the fact that only a portion of the tree trunk was examined may account for the low number of species [36].

3.6 Diversity of Lichens in Coastal Ecosystems

Lichens are among the most ecologically versatile organisms on Earth, with the ability to colonize extreme habitats ranging from polar tundra to arid deserts and coastal zones. In coastal ecosystems, where abiotic factors such as salt spray, tidal submersion, high light intensity, and wind exposure create severe conditions, lichen diversity patterns are shaped by both physiological adaptability and environmental gradients [65, 70]. Coastal lichens often display zonation patterns where species composition changes markedly with distance from the sea and exposure to marine influences, reflecting strong environmental filtering along the seashore [65, 70].

One of the best-studied ecological responses among coastal lichens involves the intertidal and supralittoral zones. Classic descriptive research has demonstrated distinct “lichen belts” on rocky shores, where specific taxa occupy narrow vertical bands that correspond to gradients in immersion frequency and salt exposure [65, 70]. Marine cyanolichens such as *Lichina pygmaea* and *Lichina confinis* are adapted to regular tidal inundation, often dominating the lower supralittoral and upper intertidal zones. Modern molecular analyses reveal that these species do not host a single photobiont type, but rather a complex assemblage of cyanobacteria and green algae, which likely enhances ecological fitness under fluctuating conditions of salinity, desiccation, and light stress [20, 54]. This multi-partner symbiosis may be a key factor allowing lichens to thrive where other photosynthetic organisms fail [20].

Surveys of coastal lichen communities indicate considerable taxonomic richness and endemism, particularly in maritime protected areas and sand-dune systems. For example, research in the Marine National Park and Sanctuary of the Gulf of Kachchh (India) recorded 32 saxicolous lichen species across 19 genera in coastal habitats, with many taxa contributing to baseline knowledge and potential bio-monitoring use [57]. Similarly, coastal salt flats adjacent to mangroves in Ecuador have yielded 30 epiphytic lichen species, revealing high species richness and highlighting salt-flat ecosystems as underappreciated biodiversity refuges for lichenized fungi [62].

Across dynamic coastal dunes and sandy strandlines, patterns of lichen diversity are also shaped by abiotic gradients. Work in northern Portugal's coastal sand dunes documented 17 species and showed clear variation in lichen assemblages along sea-inland and biogeographic gradients, which has important implications for both conservation and understanding how coastal processes influence terrestrial cryptogams [69].

Lichen studies in polar coastal environments demonstrate that extreme environmental variability, such as temperature swings, freeze-thaw cycles, and nutrient limitations, still supports high β-diversity and species turnover. Although maritime Antarctica is dominated by mosses and lichens at a community level, local soil and microhabitat conditions strongly influence species richness and coverage patterns, suggesting that even in harsh polar coasts, microenvironmental heterogeneity drives lichen diversity [45].

Furthermore, coastal lichens serve as bioindicators of environmental change, particularly in relation to abiotic stressors like salinity and air quality. Their presence, absence, and community shifts reflect both natural gradients and anthropogenic pressures, making them useful proxies for monitoring coastal ecosystem health [69, 70].

In summary, research across a range of coastal habitats indicates that lichen diversity is a function of zonation driven by tidal and salinity gradients, complex symbiotic associations with diverse photobionts, and environmental heterogeneity across spatial scales. These findings emphasize the importance of incorporating fine-scale abiotic gradients, symbiotic complexity, and conservation priorities into future coastal lichen research.

3.7 Diversity of Lichens in Rural and Urban Areas

Lichens are widely recognized as sensitive indicators of environmental quality, particularly with respect to atmospheric pollution and land-use intensity. The distribution and diversity of lichen communities across urban and rural landscapes reflect gradients in air pollutants (e.g., NO_2, SO_2, particulate matter) and other anthropogenic stressors, making them valuable bioindicators in comparative ecological studies.

A broad pattern emerging from multiple studies is that urban areas often support lower overall lichen diversity than rural or peri-urban zones, predominantly due to elevated pollution levels associated with traffic, industrial activities, and urban infrastructure. In Ratnapura, Sri Lanka, urban landscapes exhibited significantly higher concentrations of NO_2 and SO_2 than rural sites, with a negative relationship between lichen diversity indices and atmospheric pollutant levels, suggesting that sensitive taxa are lost or replaced by tolerant species as pollution increases [19].

Similarly, work in urban Munich demonstrated that NO_2 pollution strongly drives lichen species composition, with polluted sites dominated by nitrophilous (nitrogen-tolerant) lichens, while species richness and evenness were also modulated by tree traits such as bark pH, a factor influencing colonization success [10, 11]. These patterns align with global observations that urban environments tend to select for pollution-tolerant functional groups, often at the expense of sensitive acidophytic or oligotrophic species.

Longitudinal research across urban-rural gradients in Oslo illustrates how historical pollution regimes can leave a lasting imprint on lichen diversity patterns. Following severe acid rain in the mid-20th century, macrolichen richness declined drastically and has only partially recovered decades later, even in rural locations adjacent to urban centers. This study emphasizes that declines and shifts in community composition associated with pollution can persist long after emissions are reduced, with nitrophilous taxa becoming more prevalent in urban and suburban sites [21].

In more pristine rural environments, lichens generally exhibit higher species richness and a greater presence of sensitive taxa compared to urban cores. The Benin City study found that lichen diversity values (LDV) were higher in rural sites when compared with urban settings, though disturbances in both environments influenced community composition, with peri-urban and reference sites showing the highest LDV overall [55].

In Malaysia, epiphytic lichen diversity peaked in suburban landscapes with moderate pollution and lower fine particulate levels, while urban areas with greater pollutant loads showed reduced diversity [29]. Interestingly, rural sites in this study sometimes exhibited unexpectedly high pollution levels due to local sources such as open burning, underlining the complexity of rural air quality contexts and the need to consider multiple pollution drivers in diversity assessments [29].

Beyond species richness, urbanization influences functional group composition and spatial patterns of lichen communities. Urban drives toward nitrophilous species, while rural areas maintain a mix of growth forms including crustose, foliose, and fruticose taxa, each with differing sensitivity to pollution and microhabitat conditions. In comparative surveys around Kandy City, Sri Lanka, species exhibiting secondary metabolites associated with stress tolerance were dominant in urban sites, whereas foliose and other growth forms were more abundant in less polluted rural zones, reinforcing that pollutants alter not just presence/absence patterns but also the chemical and adaptive profiles of lichen communities [27]. These spatial trends are corroborated by land-cover analyses demonstrating that habitat structure, tree species composition, and local land use interact with pollution gradients to shape diversity outcomes. Urban landscapes with complex green infrastructure can mitigate some negative impacts, providing refugia where sensitive taxa may survive or recolonize.

Collectively, these studies illustrate that the urban-rural gradient strongly influences lichen diversity through differential exposures to air pollutants and environmental alteration. Urban settings generally favor pollution-tolerant species and result in reduced richness of sensitive taxa, whereas rural landscapes, particularly those with limited pollution inputs, maintain higher overall diversity. However, local factors such as tree species, microhabitat quality, and non-industrial pollution sources can modulate these patterns and sometimes lead to complex outcomes that challenge simple urban / rural dichotomies.

These findings underscore the value of lichens as long-term bioindicators for monitoring habitat quality across land-use types and highlight the importance of integrating ecological, physiological, and atmospheric data to accurately interpret diversity gradients. Future research should further investigate how land management, urban greening, and emission controls influence lichen community resilience and recovery potential.

3.8 Influence of Precipitation and Moisture on Lichen Abundance

Precipitation and moisture availability are among the most influential climatic factors shaping lichen physiology, distribution, and community composition because lichens are poikilohydric organisms, their internal water balance equilibrates passively with ambient environmental moisture rather than being regulated biologically like vascular plants [25, 38]. Consequently, precipitation, humidity, dew, and fog play fundamental roles in determining when and how long lichens can photosynthesize, grow, and reproduce [25].

Research has consistently shown that lichens rely on direct hydration from precipitation or other water sources to fuel metabolic activity. Rainfall events rapidly hydrate thalli, allowing their photosynthetic partners to resume carbon fixation; without sufficient moisture, lichens enter a dormant state that greatly limits growth [8, 9, 10, 11, 38]. Gauslaa (2014) [25] proposed a conceptual model illustrating how rain, dew, and humid air interact with species-specific water-holding traits to influence morphology, function, and spatial distribution in epiphytic lichens. In this model, rainfall provides the most complete hydration, filling external and internal water-holding capacities, especially for cyanolichens, whereas dew often suffices for many chlorolichens due to their lower water requirements [25].

Experimental work with *Lobaria pulmonaria*, a well-studied epiphytic lichen, supports these observations. Controlled studies show that hydration and subsequent growth are not solely controlled by precipitation totals but are also influenced by how long lichens remain hydrated under light conditions (which may be driven by rainfall frequency, dew formation, or low vapor pressure deficit) [11, 32]. These findings underscore precipitation's role as a primary driver of physiological activity in many macrolichens; when precipitation is infrequent or irregular, opportunities for sustained photosynthesis are reduced, constraining growth and carbon gain.

In ecosystems with reliable and frequent rainfall, lichen communities tend to be richer and more diverse. Regions with higher precipitation often support a wider array of species because consistent water input reduces the time lichens spend in desiccated, physiologically inactive states and expands the window for photosynthetic activity [10, 11, 42]. Conversely, in arid and semi-arid environments with limited rainfall, only drought-tolerant or morphologically specialized lichens can persist. Water stress in these landscapes limits metabolic activity to short pulses following precipitation, which constrains growth and may favor crustose forms over macrolichens that require more sustained moist conditions [10, 11, 42].

Studies in high Arctic environments where snow melt and brief summer rainfall provide episodic hydration demonstrate how quickly lichens lose water and become physiologically inactive in the absence of moisture. For example, several lichen species dried to less than 20 % water content within one or two days after rain ceased, significantly reducing photosynthetic performance [10, 11, 16]. These patterns suggest that in cold, low-precipitation climates, rainfall events and meltwater pulses are critical but limited drivers of lichen activity.

Field experiments assessing lichen vitality across environmental gradients also highlight the influence of precipitation and accompanying humidity. In one study examining lichen vitality along altitudinal transects, higher precipitation and humidity were associated with lower electrical conductivity (an indicator of thallus integrity), suggesting better hydration and physiological resilience under wetter conditions [25, 38]. Such relationships indicate that precipitation not only affects lichen distribution but also vitality and stress responses within individuals and populations [8, 9, 10, 11].

While precipitation is a crucial factor, its influence is mediated by other climatic variables. For instance, the effectiveness of rainfall in supporting lichen growth also depends on ambient humidity, temperature, and vapor pressure deficit [8, 9, 10, 11, 25, 32]. Higher temperatures and low humidity can accelerate desiccation following precipitation events, shortening the window for growth even when rain is plentiful. Therefore, precipitation's ecological effects must be understood in the context of broader climatic regimes [8, 9, 10, 11, 25, 38, 42].

Projected changes in precipitation patterns under climate change scenarios may alter lichen communities significantly. Reduced precipitation frequency and extended dry periods could limit hydration opportunities, reduce carbon gain, and ultimately lower species diversity, especially for moisture-dependent taxa [8, 9, 10, 11]. Conversely, increases in precipitation in some regions could enhance conditions for lichen proliferation, though such benefits may be offset by associated changes in temperature or humidity dynamics [8, 9, 10, 11].

In summary, precipitation fundamentally influences lichen hydration, physiological activity, growth rates, vitality, and distribution patterns. Its effects are modified by species-specific traits (e.g., water-holding capacity, photobiont type), interactions with other atmospheric moisture sources (e.g., dew, fog), and climatic contexts. Understanding how precipitation shapes lichen ecology provides insight into how these sensitive organisms respond to current environmental variability and future climate change.

3.9 Lichens as Biological Indicators in Coastal Ecosystems

Lichens are increasingly recognized as effective biological indicators in coastal ecosystems due to their sensitivity to environmental changes and pollutant exposure. As symbiotic organisms that obtain water and nutrients directly from the atmosphere and surrounding surfaces, lichens integrate chemical signals from their environment over time, making them valuable for monitoring coastal pollution, sea-level effects, and ecological change [8, 9, 10, 11, 49, 59].

One of the emerging applications of lichens in coastal environments is the assessment of marine pollution, particularly in intertidal zones. Marine lichenized fungi, such as those studied in the Boston Harbor Islands National Recreation Area, reveal significant associations between pollution levels and lichen community health, including reduced species richness and cover in more polluted areas. These preliminary findings suggest that intertidal lichens could be useful bioindicators of coastal water quality and anthropogenic contamination, although further research is needed to refine species-specific pollution tolerances and bioindicator protocols [52].

The use of lichens to detect coastal pollution builds on extensive work showing that terrestrial lichens accumulate pollutants such as heavy metals and aerosols in their thalli, reflecting ambient environmental conditions over time [49]. In coastal ecosystems, the deposition of pollutants can occur through sea spray, urban runoff, and airborne emissions from maritime traffic or industrial activities, and lichens serve as integrated indicators of these combined stressors [49, 59].

Beyond pollutant detection, coastal lichens also function as indicators of environmental change, such as sea-level rise (SLR). Research conducted along Florida's coastal zones indicates that the presence or absence of salt-sensitive lichen species can reveal areas susceptible to increased saltwater intrusion. In this context, species that are unable to tolerate elevated salt exposure decline or disappear in zones affected by higher sea levels, whereas salt-tolerant species or rapid recolonizers become more prevalent. Based on observed distribution patterns and reproductive traits, using lichen community composition offers a fine-scale indicator of sea-level effects that can inform coastal management and land-use decisions [49, 59].

The value of lichens as indicators of coastal change is further supported by broader ecological research showing that lichen assemblages often reflect historical and ongoing shifts in microhabitat conditions, including salinity gradients, tidal inundation, and substrate exposure [66].

Using lichens as biological indicators in coastal ecosystems offers several practical advantages. Lichens are relatively long-lived, widely distributed, and host a variety of species with different tolerances to stressors, allowing for multi-dimensional assessments of environmental quality. Their sessile nature and reliance on local deposition processes mean that spatial patterns in lichen abundance and diversity often mirror underlying ecological gradients or pollutant distributions, making them useful for spatially explicit monitoring.

However, there are methodological challenges. Marine lichens are often taxonomically complex and can be difficult to identify accurately without specialist expertise; this can hamper large-scale or standardized monitoring efforts [52]. Establishing clear baselines for species-specific tolerances and developing standardized indices or protocols tailored to coastal environments are essential steps for broadening lichen-based bioindication.

Despite these challenges, integrating lichen bioindication into coastal ecosystem monitoring holds promise. Lichens can complement traditional physicochemical monitoring by providing biologically integrated measures of environmental change over time. For instance, variations in coastal lichen communities could be paired with water quality data, salinity measurements, and land-use change analyses to build a more holistic understanding of ecosystem health. Additionally, discerning shifts in lichen community composition in response to climate-driven stressors, such as: rising sea levels, increasing storm frequency, and coastal urbanization, can help target conservation efforts and land-use planning [49, 59]. In summary, lichens have strong potential as biological indicators in coastal ecosystems due to their sensitivity to pollutants and environmental change, integration of atmospheric signals over time, and species-specific responses to stressors. Studies in marine and coastal contexts demonstrate that lichen health, diversity, and community composition can reflect variations in pollution and sea-level influences. To fully harness this potential for environmental assessment and management, future research should refine species tolerance profiles, develop standardized bioindicator protocols for coastal settings, and strengthen the linkage between lichen community patterns and measurable ecological drivers.

3.10 Factors Affecting the Distribution of Lichens in Coastal Ecosystems

The distribution of lichens in coastal ecosystems is shaped by a complex interplay of abiotic and biotic factors that determine where species can establish, grow, and persist. Coastal environments present a suite of physical stresses and gradients, such as tidal inundation, salinity, wave exposure, desiccation, substrate type, and microclimate conditions, that influence lichen zonation and community structure along the shore [8, 9, 10, 11, 30, 67].

One of the most fundamental factors affecting coastal lichens is the frequency and duration of tidal immersion. Marine and littoral lichens occupy distinct vertical zones along rocky shores based on how often they are submerged by tides. For example, upper littoral species such as *Hydropunctaria maura* are adapted to regular wetting and drying cycles, while lower littoral lichens such as *Wahlenbergiella mucosa* are tolerant of longer periods of immersion [30]. Their zonation reflects physiological tolerances: species unable to withstand prolonged desiccation are excluded from upper zones, whereas grazing pressure and other stresses limit the vertical extent of some species [30].

Moisture availability does not depend solely on tides but also on wave splash and sea spray, which influence the extent of the supralittoral zone where lichens rarely get submerged but receive periodic moisture [8, 9, 10, 11, 44, 67]. Salinity and wetting patterns interact with other factors like substrate texture and porosity, which affect how long moisture persists and how lichens adhere to surfaces [8, 9, 10, 11, 44].

Exposure to waves and wind is another key determinant of coastal lichen distribution. High wave exposure can expand the vertical zones available to supralittoral lichens by increasing splash and salt spray height, but it also increases physical stress and abrasion on exposed rocks. Lichens on highly exposed shores may experience enhanced growth in some lower zones due to frequent moisture input, yet species diversity in upper zones may decline where wave action is severe [8, 9, 10, 11, 44].

Salinity gradients also influence lichen distribution in coastal settings [11, 44]. Supralittoral and littoral zones exhibit higher salt exposure than inland ecosystems, which selects for salt-tolerant species and excludes more salt-sensitive taxa. Changes in salinity due to freshwater runoff or estuarine influences, can alter the relative abundance of lichens and terrestrial plants along the shore, enabling terrestrial species to colonize lower zones when salinity decreases [8, 9, 10, 11, 44].

The type and condition of the substrate, such as rock composition, surface roughness, and presence of crevices, influence lichen establishment and persistence [8, 9, 10, 11]. Rough, porous rocks retain moisture and provide microhabitats that buffer lichens against desiccation and extreme temperatures [8, 9, 10, 11]. In contrast, smooth or unstable substrates may limit colonization because they provide fewer niches and are less able to retain moisture or shelter propagules from environmental stressors [8, 9, 10, 11, 44].

Microhabitat variation also arises from aspect and light duration, where south- and southwest-facing surfaces may heat up more and dry out faster, whereas shaded or leeward rock faces may maintain cooler, moister conditions ideal for certain lichens. These microclimatic conditions shape not only species presence but also community composition and functional traits along the shore [44].

Biotic factors such as grazing by invertebrates and competition from algae or other epilithic organisms can also constrain coastal lichen distribution. Some species are unable to survive outside their typical shore level due to increased grazing pressure or competitive exclusion in novel zones [8, 9, 10, 11, 30].

Altogether, research indicates that vertical zonation of coastal lichens emerges from the interplay between abiotic gradients (e.g., tidal frequency, salinity, wave exposure, moisture availability, substrate properties) and biotic pressures (e.g., grazing, competition) [11]. These factors interact to generate distinct lichen communities at different shore heights and exposure regimes. This pattern aligns with trait-based studies showing that physiological adaptations to moisture and salt stress help segregate species along intertidal gradients [67].

Understanding these factors is essential for predicting how climate change and anthropogenic influences (e.g., coastal development, altered hydrology) may reshape coastal lichen distributions. For instance, sea-level rise could compress existing zonation patterns, while changes in storm frequency may alter moisture and physical stresses experienced by lichens.

3.11 Conservation of Lichens in Coastal Ecosystems

Coastal lichens are unique components of coastal biodiversity, often specialized to survive the extreme and fluctuating conditions of the littoral and supralittoral zones such as high salinity, tidal splash, wind exposure, and intense sunlight. Their ecological roles include bioindication of environmental change, contribution to nutrient cycling, and support of invertebrate microhabitats [15, 40]. Unfortunately, these organisms face growing conservation challenges, many of which are rooted in human activities and climate change, prompting increasing scientific attention to their status, threats, and management strategies.

One of the most significant threats facing coastal lichens is sea-level rise (SLR) associated with climate change [40]. Research in the Atlantic Coastal Plain of North America demonstrates that many high-diversity lichen communities occur in low-lying, near-shore habitats that are projected to be inundated under even conservative SLR scenarios. These areas, unrecognized as biodiversity hotspots in traditional assessments, could lose a disproportionate amount of intact lichen-rich habitats this century, highlighting a critical gap in current conservation planning [40].

In addition to climate pressures, direct anthropogenic disturbances also imperil coastal lichens. Terrestrial runoff carrying fertilizers and agrochemicals, trampling by visitors on beaches and rocky shores, and the installation of recreational infrastructure can degrade lichen habitats and alter community composition. For example, studies documenting seashore habitats note that nutrient enrichment from adjacent agricultural land can encourage algal overgrowth on supralittoral rocks, which in turn outcompetes and suppresses sensitive lichen taxa [15].

Moreover, erosion and abrasion, whether from natural processes or human-induced disturbances such as off-road vehicle use, can remove lichen communities entirely or reduce substrate availability. These forms of physical habitat loss may be exacerbated by climate change and coastal development, further shrinking the refugial spaces where lichens can persist [15, 34].

Conservation of coastal lichens calls for both ecological monitoring and proactive management strategies tailored to their unique life histories and habitat requirements. Classical conservation strategies used for terrestrial lichens, such as: establishing protected areas, mitigating pollutants, and conserving critical substrates, have relevance in coastal settings but must be adapted to address coastal dynamics and stresses [33].

One emerging conservation focus has been risk assessment and targeted strategies for rare coastal lichen taxa, particularly those facing rapid habitat change from SLR. McMullin *et al.* (2019) [47] advocate for systematic conservation planning that incorporates lichen occurrences into broader coastal biodiversity assessments, acknowledging that overlooking cryptogam diversity can lead to significant losses of ecological information and heritage without detection.

Efforts to increase public awareness and integrate lichens into broader environmental stewardship efforts are also essential. Studies highlight that lack of awareness about lichen threats impedes effective conservation, as these organisms are often overlooked in policy frameworks and coastal management decision-making. Promoting education and stakeholder engagement can help elevate lichens within conservation agendas and encourage citizen science initiatives that contribute long-term monitoring data [33].

Another key conservation tool is the integration of lichens into coastal management frameworks such as Integrated Coastal Zone Management (ICZM). ICZM emphasizes holistic sustainability in which ecological, social, and economic considerations are balanced. By ensuring that lichens and other cryptogams are factored into habitat protection plans, coastal policymakers can better safeguard biodiversity in the face of competing land-use pressures [33, 40, 53].

In addition, enhancing taxonomic and ecological research, particularly in underrepresented regions and among lesser-studied taxa, will provide the empirical foundation needed for effective conservation. The documented diversity of species and their specific habitat associations, as revealed in regional inventories, underscores how much coastal lichen diversity remains poorly understood, particularly outside well-studied temperate regions [33, 40, 53].

Coastal lichens are valuable yet vulnerable components of shoreline ecosystems, threatened by climate change, habitat alteration, pollution, and direct physical disturbances. Their conservation demands a combination of targeted ecological research, informed monitoring protocols, public engagement, and integration into broader coastal management strategies. Addressing these needs can help ensure that the ecological functions and biodiversity contributions of coastal lichens are preserved in the face of ongoing environmental change.

4. Conclusions

The present study provides an assessment of lichen diversity and abundance on *Azadirachta indica* across three sites along the East Coast of Berbice, Guyana. A total of 6 lichen families, 8 genera, and thirteen species were recorded, with Site 1 (NAREI, Lesbiholden) exhibiting the highest overall abundance and diversity, followed by Site 3 (Line Path ‘C’, Corriverton), while Site 2 (University of Guyana John’s Science Centre) displayed comparatively lower abundance and evenness. This pattern suggests that local environmental factors, such as microclimate, light exposure, and habitat heterogeneity most likely influenced lichen community structure and spatial distribution.

The diversity indices (Shannon H′: 1.99-2.04; Simpson SDI: 0.80-0.84) indicate moderate to high diversity across sites, while species richness was constant (SR = 10), and species evenness was generally high (0.86-0.89). These results demonstrate that although species richness is consistent across sites, differences in relative abundance and evenness contribute to subtle variations in community structure.

Further anslysis of the data revealed that some of the observed lichen species, such as *Flavoparmelia soredians*, *Hypotrachyna laevigata*, *Dirinaria applanata*, *Lecanora muralis*, *Lepraria lobificans*, and *Pertusaria spp*., exhibited a generalist pattern, occurring at all sites and suggesting broad ecological tolerance. In contrast, species such as *Flavoparmelia caperta*, *Parmelia tiliacea*, *Lecanora chlarotera*, *Lecanora conizaeoide*, and *Arthonia spp.* displayed site-specific distributions, implying likely sensitivity to microenvironmental variables, such as moisture availability, light exposure, and local competition. These findings highlight the importance of both species-specific ecological traits and site-specific environmental conditions in shaping lichen assemblages on *A. indica*.

Overall, the study confirms that *Azadirachta indica* serves as a suitable host for corticolous lichens in Guyanese coastal ecosystems and that lichen communities on neem trees may reflect local environmental conditions. The combination of generalist and site-specific lichen species suggests the potential utility of lichens as bioindicators of ecological quality and environmental change in coastal agroecosystems.

5. Compliance with Ethical Standards

1. Acknowledgement

The authors would like to express their sincere gratitude to the University of Guyana for providing this valuable opportunity and for supporting the successful completion of this research. A heartfelt thank you is extended to all authors; whose valuable contributions were instrumental in completing this study.

2. Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

3. Disclosure of conflict of interest

The authors certify that this submission is original work and is not under review at any other publication. The authors hereby declare that this manuscript does not have any conflict of interest.

4. Statement of informed consent

The authors declare that informed consent was obtained from all individual participants included in the study. All work utilized in this study was fully cited and referenced so authors of prior researches are given their due credentials for their work.

5. Data availabity

Data will be made available on request.

6. Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

6. References

1. Aragón G, de Bello F, Mayrhofer H, Giordani P, Prieto M, Aragón JP, *et al*. Contrasting environmental drivers determine biodiversity patterns in epiphytic lichen communities along a European gradient. Microorganisms. 2020;8(12):1913. doi:10.3390/microorganisms8121913.
2. Arya M. Diversity and distribution patterns of lichens in different ecological conditions in the Garhwal Himalaya, Uttarakhand. Nature Environment and Pollution Technology. 2026. doi:10.46488/.
3. Asta J, Erhard W, Ferretti M, Fornasier F, Kirschbaum U, Nimis PL, *et al*. Mapping lichen diversity as an indicator of environmental quality. In: Nimis PL, Scheidegger C, Wolseley PA, editors. Monitoring with Lichens. Dordrecht: Kluwer Academic Publishers; 2002. p.273–279.
4. Bacchus BR, Da Silva PNB. Host plant specificity of corticolous lichens in urban and suburban New Amsterdam, Berbice, Guyana. GSC Biological and Pharmaceutical Sciences. 2021;14(1):101–108. doi:10.30574/gscbps.2021.14.1.0014.
5. Bacchus BR, Da Silva PNB. Corticolous lichen diversity on trees in urban and suburban settings in New Amsterdam, Berbice, Guyana. Advanced Research in Biological Science. 2023;1:75–90. doi:10.9734/bpi/arbs/v1/5931E.
6. Bates ST, Cropsey GWG, Caporaso JG, Knight R, Fierer N. Bacterial communities associated with the lichen symbiosis. Applied and Environmental Microbiology. 2011;77(4):1309–1314. doi:10.1128/AEM.02257-10.
7. Benítez Á, Aragón G, Prieto M. Lichen diversity on tree trunks in tropical dry forests is highly influenced by host tree traits. Biodiversity and Conservation. 2019.
8. Bhagarathi LK, Da Silva PNB, Subramanian G. Lichen-host plant specificity on citrus plant species in coastal agroecosystems at No. 63 Benab, Berbice, Guyana. World Journal of Advanced Research and Reviews. 2024a;21(1):2342–2355. doi:10.30574/wjarr.2024.21.1.0309.
9. Bhagarathi LK, Da Silva PNB, Subramanian G. Lichen inventory and species diversity at coastal ecosystems at No. 63 Benab, Berbice, Guyana. International Journal of Science and Research Archive. 2024b;11(1):737–756. doi:10.30574/ijsra.2024.11.1.0129.
10. Bhagarathi LK, Da Silva PNB, Subramanian G, Maharaj G, Kalika-Singh S, Pestano F, Phillips-Henry Z, Cossiah C. An integrative review of the biology and chemistry of lichens and their ecological, ethnopharmacological, pharmaceutical and therapeutic potential. GSC Biological and Pharmaceutical Sciences. 2023;23(3):92–119. doi:10.30574/gscbps.2023.23.3.0223.
11. Bhagarathi LK, Maharaj G, Da Silva PNB, Subramanian G. A review of the diversity of lichens and factors affecting their distribution in the Neotropics. GSC Biological and Pharmaceutical Sciences. 2022;20(3):27–63. doi:10.30574/gscbps.2022.20.3.0348.
12. Bhagarathi LK, Pestano F, Phillips-Henry Z, Cossiah C, Da Silva PNB, Singh D. A Review on the Properties of Azadirachta indica, Ocimum tenuiflorum, and Cymbopogon citratus. International Journal of Scientific Research and Management. 2021;9(10):96–164. doi: https://doi.org/10.18535/ijsrm/v9i10.b01.
13. Britannica Editors. Lichen. In: Encyclopaedia Britannica. 2025. Available from: https://www.britannica.com/science/lichen.
14. British Lichen Society. What is a lichen? 2025. Available from: https://britishlichensociety.org.uk/learning/what-is-a-lichen.
15. British Lichen Society. Seashore habitats: Management guidelines for seashore lichen communities. n.d. Available from: https://britishlichensociety.org.uk/conservation/seashore-habitats.
16. Brodo IM, Craig B. Identifying mixed hardwood forest lichens. 2001.
17. Caceres MES, Lücking R, Rambold G. Phorophyte specificity and environmental parameters versus stochasticity as determinants for species composition of corticolous crustose lichen communities in the Atlantic Rain Forest of Northeastern Brazil. Mycological Progress. 2007;6:117–136.
18. Cambridge Core review. Lichen algae: the photosynthetic partners in lichen symbioses. The

Lichenologist. 2021,53(5):347–393. doi:10.1017/S0024282921000335.

19. Chandima JPG, Jayalal RGU, Premasiri HDS. Interrelationship between ambient air pollution and lichen diversity urban, semi-urban and rural landscapes in Ratnapura. Proceedings of International Forestry and Environment Symposium. 2019.
20. Chrismas NAM, Allen R, Hollingsworth AL, Taylor JD, Cunliffe M. Complex photobiont diversity in the marine lichen Lichina pygmaea. Journal of the Marine Biological Association of the United Kingdom. 2021;101(4):667–674. doi:10.1017/S002531542100062X.
21. Diekmann M, Heinken T, Becker T, Dörfler I, Heinrichs S, Leuschner C, *et al*. Changes in epiphytic lichen diversity along the urban-rural gradient before, during, and after the acid rain period. Biodiversity and Conservation. 2024,33:2247–2263.
22. España-Puccini P, Gómez JP, Muñoz-Acevedo A, Posada-Echeverría D, Martínez-Habibe MC. Analysis of the diversity of corticolous lichens associated with tree trunks in tropical dry forests of Colombia. Forests. 2024;15(11):2000. doi:10.3390/f15112000.
23. Eversham B. Heathland lichens. 2015.
24. Faisal UM, Saifi MS, Kaish M, Ibrahim M, Shiwani I, Kwakuri SS, Arif, M. Azadirachta indica (neem): An important medicinal plant: A literature review of its chemistry, biological activities, role in COVID-19 management and economic importance. Journal of Pharmacognosy and Phytochemistry, 12(6):59–65. doi: 10.22271/phyto.2023.v12.i6a.14769.
25. Gauslaa Y. Rain, dew, and humid air as drivers of morphology, function and spatial distribution in epiphytic lichens. The Lichenologist. 2014;46(1):1–16.
26. Great Britain Forestry Commission. Lichens in southern woodlands. Forestry Commission Handbook No. 4. Her Majesty’s Stationery Office. 1989.
27. Gunawardana WGDI, Edirisinghe ESM, Abayasekara CL, Athukorala ADSNP. Air pollution affects lichen species richness and metabolite production in Sri Lanka. Ruhuna Journal of Science. 2021;12(2):115–127.
28. Haji, AS, Maurya SR, Shah N. Azadirachta indica A. Juss: Ethnobotanical knowledge, phytochemical studies, pharmacological aspects and future prospects. Plants and Environment. 2023,5(1):1–15. doi:10.22271/2582-3744.2023.may.1.
29. Hakim NSA, Ismail A, Latif MT, Pardi F, Zamzuri R, Khalid S, *et al*. Epiphytic lichen as a bioindicator of air pollution in Malaysia. Journal of Ecology and Environment. 2025;49:33. doi:10.5141/jee.25.033.
30. Higgins NF, Connan S, Stengel, DB. Factors influencing the distribution of coastal lichens Hydropunctaria maura and Wahlenbergiella mucosa. Marine Ecology, 2015,36(4):1400–1414.
31. Hurtado P, Prieto M, de Bello F, Aragón G, López-Angulo J, Giordani P, *et al*. Contrasting environmental drivers determine biodiversity patterns in epiphytic lichen communities along a European gradient. Microorganisms. 2020;8(12):1913. doi:10.3390/microorganisms8121913.
32. Ismail RM., Salman HA, Ibrahim HJ. Study the phytochemical, biological and pharmacological aspects of Azadirachta indica: A review. GSC Biological and Pharmaceutical Sciences. 2024,29(1):33–41. doi:10.30574/gscbps.2024.29.1.0348.
33. Kanyungulu CN. Awareness of lichens and the necessity of their conservation. In: Acta Botanica Hungarica. 2025. Available from: https://akjournals.com/view/journals/034/aop/article-10.1556-034.2025.00573/article-10.1556-034.2025.00573.pdf.
34. Kanyungulu CN. Threats on lichens and their conservation—A review based on a bibliometric analysis. In: Biodiversity (preprint). 2026. Available from: https://www.mdpi.com/1424-2818/18/1/30.
35. Kirika, PM. Diversity, Ecology and altitudinal distribution of corticolous lichens inmount Kenya tropical montane forest. 2012. https://irlibrary.ku.ac.ke/bitstream/handle/123456789/6534/Kirika%20Paul%20Muigai.pdf?sequence=3&isAllowed=y.
36. Komposch H, Hafellner J. Diversity and Vertical Distribution of Lichens in Venezuelan Tropical Lowland Rain Forest. Selbyana. 2000,21(1,2):11–24.
37. Kumar D, Shandilya S, Anuraj. A review on Azadirachta indica (Neem) and its phytochemistry and medicinal potentials. Asian Journal of Research in Botany. 2025. 8(1),131–138. doi:10.9734/ajrib/2025/v8i1249.
38. Lange OL, Green TGA, Meyer A, Zellner H. Rain, dew and fog as drivers of lichen activity and carbon gain. The Lichenologist. 2007.
39. Lättman H, Bergman K, Rapp M, Tälle M, Westerberg L, Milberg P. Decline in lichen biodiversity on oak trunks due to urbanization. Nordic Journal of Botany. 2014;32(4):518–528. doi:10.1111/j.1756-1051.2013.00413.x.
40. Lendemer JC, Allen J. Lichen biodiversity under threat from sea-level rise in the Atlantic Coastal Plain. BioScience. 2014;64(10):923–931. doi:10.1093/biosci/biu136.
41. Lichen Identification Guide. (Identification pamphlet/resource). 2015.
42. Live to Plant Overview. How environmental factors affect lichen diversity. Live to Plant. 2025.
43. Lücking R. Foliicolous lichens and their lichenicolous fungi collected during the Smithsonian International Cryptogamic Expedition to Guyana 1996. Bryophyte Diversity and Evolution. 1998;15(1):45–76.
44. Marine Habitat Classification Centre. Yellow and grey lichens on supralittoral rock. JNCC Marine Habitat Classification. n.d.
45. Maritime Antarctica study. Species composition, diversity and coverage pattern of associated communities of mosses-lichens along a pedoenvironmental gradient in Maritime Antarctica. Anais da Academia Brasileira de Ciências. 2022,94(Suppl. 1).
46. Marshall, N. L. Mosses and lichens: A popular guide to the identification and study of our commoner mosses and lichens, their uses, and methods of preserving. Doubleday, Page & Co. 1919.
47. McMullin RT, *et al*. Risk assessment and conservation strategies for rare lichen species threatened by sea-level rise. Biological Conservation. 2019;235:119–127. doi:10.1016/j.biocon.2019.02.008.
48. Nanda SA, Haq MU, Singh SP, Reshi ZA, Rawal RS, Bisht K, *et al*. Species richness and β-diversity patterns of macrolichens along elevation gradients across the Himalayan Arc. Scientific Reports. 2021;11:20155.

49. National Park Service. Lichens as bioindicators. U.S. National Park Service. 2023.
50. Nave J. Collector’s handy-book: Algae, fungi, diatoms, lichens, desmids, and mosses. G. Routledge. n.d.
51. Nimis PL, Martellos, S. High host preferences in epiphytic lichens across diverse geographic areas. Journal of Lichenology. 2023,85(3), 112–125.
52. Nokes LF, Haelewaters D, Pfister DH. Exploration of marine lichenized fungi as bioindicators of coastal ocean pollution in the Boston Harbor Islands National Recreation Area. Rhodora. 2022,122, 251–273.
53. NY Botanical Garden. Lichen biodiversity of the Mid-Atlantic Coastal Plain. n.d.
54. Ortiz-Álvarez R, de los Ríos A, Fernández-Mendoza F, Torralba-Burrial A, Pérez-Ortega S. Ecological specialization of two photobiont-specific maritime cyanolichen species of the genus Lichina. PLOS ONE. 2015;10(7):e0132718. doi:10.1371/journal.pone.0132718.
55. Ovenseri A, Aigbokhan EI. Diversity of epiphytic lichens in urban, peri-urban and adjoining rural areas of Benin City to monitor ecosystem health. African Scientist Journal. 2019,20(3):113–119.
56. Penn State Ecosystems. What’s to like about lichens? 2023. Available from: https://ecosystems.psu.edu/research/centers/private-forests/news/whats-to-like-about-lichens.
57. Punjani B, Raval J, Nayaka S, Upreti DK. Diversity of saxicolous lichens across the Marine National Park and Sanctuary, Gujarat. Cryptogam Biodiversity and Assessment. 2022;6(2).
58. Rashmi S., Garampalli RH. Diversity of lichens in Southern Karnataka Region and Bio-prospecting fornovel compounds. 2016. Available from: http://shodhganga.inflibnet.ac.in/bitstream/10603/150447/11/11_chapter%203.pdf.
59. Rosentreter R, DeBolt A. Lichens as an indicator of sea-level rise. Evansia, 2023,39(4):162–168.
60. Rosentreter R, DeBolt A, Barger N. Field-oriented keys to the Florida lichens. Florida Museum of Natural History. 2015.
61. Rutgers New Jersey Agricultural Experiment Station (NJ AES). Tree-dwelling lichens. 2025. Available from: https://njaes.rutgers.edu/fs1205/.
62. Sanders WB, Masumoto H. Lichen algae: The photosynthetic partners in lichen symbioses. The Lichenologist. 2021. 53(5):347–393. doi:10.1017/S0024282921000335.
63. Scheidegger C, Groner U, Stofer S. Biodiversity Assessment Tools-Lichens. Nimis, P. L., Scheidegger, C. and Wolseley, P.A. (eds.) Monitoring with Lichens 2002,359-365. Kluwer Academic Publishers, Netherlands.
64. Sequiera M, Kumar A. Lichen substrate host-specificity and diversity considerations in tropical forests. Asian Journal of Plant Sciences and Botany, 2008,5(1), 62–66.
65. Smithsonian Ocean. Seaside lichens [General overview of coastal lichen zonation]. Smithsonian Ocean Portal. 2026.
66. The Bulletin. Can lichens predict sea level rise? The Bulletin. 2023. Available from: https://thebulletin.org/2023/03/can-lichens-predict-sea-level-rise/.
67. Tindall-Jones B, Cunliffe M, Chrismas, N. Lichen zonation on UK rocky seashores: A trait-based approach to delineating marine and maritime lichens. The Lichenologist. 2023,55(2):91–99.
68. van den Boom PPG, Sipman HJM. Foliicolous lichens from Suriname and Guyana: New records and three new species. Folia Cryptogamica Estonica, 2016,53:101–110.
69. Vaz AS, Marques J, Honrado JP. Patterns of lichen diversity in coastal sand-dunes of northern Portugal. Botanica Complutensis. 2014,38, 89–96.
70. Vondrák J. Diversity of the genus Caloplaca on seashore rocks of the Western Black Sea Coast. 2006.
71. Wang X, Song H, Kim KT, Park SY, Lee GW, Choi J, *et al*. Comparative genomic analysis of lichen-forming fungi reveals new insights into fungal lifestyles. Scientific Reports. 2022;12(1):10724. doi:10.1038/s41598-022-14340-5.
72. Wesley T. Lichens: Two lives. (Field guide booklet). 2005.
73. Yadav R, Pednekar A, Avalaskar A, Rathi M, Rewachandani Y. A comprehensive review on Meliaceae family. World Journal of Pharmaceutical Sciences. 2024.

How to Cite This Article
Bhagarathi LK, Da Silva PNB, Subramanian G, Pestano F, Phillips-Henry Z, Ali S, *et al*. Inventory and diversity of corticolous lichens on *Azadirachta indica* (neem) at three sites in Berbice, Guyana: a comparative study. International Journal of Multi Research. 2026; 2(1): 73-86.