

Mapping Lichen Diversity Around Bongaigaon Refinery, Assam, Northeast India

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ABSTRACT

The present study assesses the spatial pattern of lichen diversity around Bongaigaon Refinery. Sampling was conducted from 20 sites located in four directions at distances of 2, 4, 6, 8 and 10 km from the refinery. A total of 84 lichen species belonging to 30 genera and 17 families were recorded. Graphidaceae was the most abundant family, while crustose lichens represented the major growth form (76%), followed by foliose (22%) and leprose forms (2%). Species richness increased with distance from the refinery,

from 21 species at 2 km to 64 species at 10 km. The chi-square analysis showed significant variation in species richness among distances ($\chi^2 = 30.25$, $df = 4$, $p < 0.01$). Sørensen similarity value was highest between the 8 km and 10 km sites (0.75), suggesting greater species similarity and stability at farther distances from the pollution source. *Pyxine cocolosae* showed the highest frequency (100%), whereas *Chrysothrix chlorina*, *Cryptothecia striata* and *Dirinaria consimilis* were also widely distributed (95%). The study provides baseline information on lichen diversity around a point source and supports its use for future biomonitoring around refinery areas.

Keywords Bongaigaon refinery, Epiphytic lichen, Lichen diversity, Species richness, North-East India.

INTRODUCTION

Lichens are ubiquitous organisms that exhibit a unique symbiotic association between algae and fungi. They are well-recognised bioindicators of air quality due to their unique physiology and sensitivity to atmospheric pollutants. Due to the lack of roots and protective cuticles, lichens absorb nutrients and contaminants directly from the atmosphere, making them ideal organisms for monitoring pollutant loads in terrestrial ecosystems. Variation in lichen species richness and composition can thus reflect spatial and temporal patterns of air pollution, particularly in industrial and urban environments. The differential sensitivity of lichen growth forms - with crustose lichens generally more tolerant, foliose forms moderate to sensitive and

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fruticose as the most sensitive- provides a basis for assessing pollution gradients (Conti and Cecchetti 2001, Nimis and Purvis 2002, Budzyńska-Lipka *et al.* 2022, Morillas 2024). Industrial activities, especially those associated with petroleum refining, release a complex mixture of pollutants including particulate matter, heavy metals and volatile organic compounds. The dispersion of these pollutants is largely influenced by meteorological factors, with wind direction and speed as the primary determining factors for the spatial pattern of contaminant dispersion and deposition (Jindamanee *et al.* 2025, Michael and Joepen 2021, Mikulec *et al.* 2025). Consequently, areas downwind or in proximity to such industrial complexes often experience elevated levels of atmospheric deposition, which directly impacts sensitive bioindicators like lichens (Bajpai *et al.* 2016).

The lichen zone concept is a technique for indicating pollution levels in relation to lichen diversity and distance from pollution sources. Systematic mapping of lichens around cities resulted in distinct zones with varying lichen diversity and disappearance of sensitive species from the core zone (Upreti *et al.* 2015). Based on the species richness and detailed physiological analysis of lichen species surrounding pollution sources from different biogeographic regions, five major zones are being identified, viz. lichen desert (critical air pollution) ; inner struggle zone (higher air pollution) ; outer struggle zone (medium air pollution) ; transition zone (lower air pollution) ; and normal zone (very low air pollution) (Herzig *et al.* 1989, Lisowska 2011, Shukla and Upreti 2010, Loppi 2019; Correa-Ochoa *et al.* 2021, Niepsch *et al.* 2021, Rani *et al.* 2024). Northeast India, in particular, represents a biodiversity hotspot with rich lichen flora due to its humid, subtropical climate and extensive forest cover. However, this region has witnessed rapid industrialization in recent decades, with petroleum refineries, coal mines, and other industries posing potential threats to its biological communities (Rout *et al.* 2010, Singh *et al.* 2015, Manas *et al.* 2016, Behera *et al.* 2021, Thangjam *et al.* 2022, Bajpai *et al.* 2022, Hajong *et al.* 2025). Bongaigaon Refinery in Assam is one of the largest petroleum processing units in Northeast India, established amidst a mosaic of rural, semi-urban, and forested landscapes. The refinery represents a significant point source of

atmospheric emissions. The radial distance sampling approach, combined with directional transects, allows systematic assessment of pollution gradients around point sources (Gagić-Serdar *et al.* 2023, Mikulec *et al.* 2025). This approach has been successfully employed in various industrial settings to map pollution zones and identify tolerant indicator species (Lucadamo *et al.* 2021, Gagić-Serdar *et al.* 2023, Mikulec *et al.* 2025). Despite the ecological importance of the region and its vulnerability to industrial impacts, no systematic assessment of lichen diversity around Bongaigaon Refinery has been conducted to date. Understanding the spatial distribution of lichens in relation to the refinery provides valuable insights into the extent of atmospheric pollution and its ecological consequences, while establishing a baseline for long-term biomonitoring. This study involves a systematic assessment to document lichen species richness, diversity, growth form, and spatial distribution around the refinery ; evaluate distance-dependent patterns in lichen diversity ; identify pollution zones based on community structure and identify tolerant species that can be employed as bioindicators for air quality monitoring in refinery-affected areas.

MATERIALS AND METHODS

Study area

The study was conducted in the fringe areas of Bongaigaon Refinery located at Dhaligaon in Chirang district, Assam, India. The refinery was considered as the point source for this study. It is situated approximately 10 km from the Bongaigaon District office and about 200 km from Guwahati, at approximately 26°31'00.81" N and 90°31'53.85" E, at an elevation of 63 m. The surrounding landscape consists of rural settlements, agricultural fields, and patches of rubber gardens, and the National Highway 27 passes through the area (Fig. 1).

Sampling method

Lichen sampling was carried out at approximately 2, 4, 6, 8 and 10 km from the refinery within four general directions (North, South, East and West) (Fig. 1. D). Sampling locations were selected considering

Table 1. List of lichen species recorded in the study area and their occurrence across different distances.

Sl. No.	Species	Family	GF	2 km	4 km	6 km	8 km	10 km	Freq (%)
1	<i>Allographa xanthospora</i>	Graphidaceae	Cr	0	0	0	0	1	10
2	<i>Arthonia inconspicua</i>	Arthoniaceae	Cr	1	1	0	1	1	35
3	<i>Arthopyrenia punctiformis</i>	Arthopyreniaceae	Cr	0	0	0	1	0	5
4	<i>Arthothelium abnorme</i>	Arthoniaceae	Cr	0	0	0	1	1	10
5	<i>Bactrospora</i> sp.	incertae sedis under Arthoniales	Cr	0	0	0	0	1	10
6	<i>Buellia</i> sp.	Caliciaceae	Cr	0	0	0	1	0	5
7	<i>B. morehensis</i>	Caliciaceae	Cr	0	0	0	1	1	10
8	<i>Chrysotrrix candelaris</i>	Chrysotrichaceae	Le	0	1	1	1	1	30
9	<i>C. chlorina</i>	Chrysotrichaceae	Le	1	1	1	1	1	95
10	<i>Coccocarpia palmicola</i>	Coccocarpiaceae	Fo	0	0	0	1	0	5
11	<i>Coenogonium pineti</i>	Coenogoniaceae	Cr	0	0	0	1	0	5
12	<i>Coniocarpon cinnabarinum</i>	Arthoniaceae	Cr	1	1	1	1	1	75
13	<i>Cryptothecia striata</i>	Arthoniaceae	Cr	1	1	1	1	1	95
14	<i>Diorygma soozanum</i>	Graphidaceae	Cr	0	0	0	1	0	5
15	<i>D. junghuhnii</i>	Graphidaceae	Cr	0	0	0	1	1	45
16	<i>Dirinaria applanata</i>	Physciaceae	Fo	0	0	1	1	1	45
17	<i>D. consimilis</i>	Physciaceae	Fo	1	1	1	1	1	95
18	<i>D. picta</i>	Physciaceae	Fo	1	0	1	1	1	25
19	<i>Fissurina capsulata</i>	Graphidaceae	Cr	0	1	0	0	0	5
20	<i>F. insignis</i>	Graphidaceae	Cr	0	1	0	0	0	5
21	<i>F. subnitidula</i>	Graphidaceae	Cr	0	1	1	1	1	30
22	<i>Glyphis cicatricosa</i>	Graphidaceae	Cr	0	1	1	1	1	65
23	<i>G. confluens</i>	Graphidaceae	Cr	0	1	0	1	1	20
24	<i>G. duriuscula</i>	Graphidaceae	Cr	1	0	0	1	1	20
25	<i>Graphis</i> sp.	Graphidaceae	Cr	0	0	0	1	1	15
26	<i>G. ajarekarii</i>	Graphidaceae	Cr	0	0	0	0	1	5
27	<i>G. argentea</i>	Graphidaceae	Cr	1	1	1	1	1	40
28	<i>G. assimilis</i>	Graphidaceae	Cr	1	1	0	0	1	15
29	<i>G. aurita</i>	Graphidaceae	Cr	0	0	0	1	1	20
30	<i>G. caesiella</i>	Graphidaceae	Cr	0	0	0	1	0	5
31	<i>G. capillacea</i>	Graphidaceae	Cr	1	1	1	1	1	40
32	<i>G. cincta</i>	Graphidaceae	Cr	0	0	0	0	1	5
33	<i>G. conferta</i>	Graphidaceae	Cr	0	0	0	1	1	20
34	<i>G. dendrogramma</i>	Graphidaceae	Cr	1	1	0	0	1	15
35	<i>G. dracaenae</i>	Graphidaceae	Cr	0	0	0	1	1	10
36	<i>G. epimelaena</i>	Graphidaceae	Cr	0	0	0	1	1	15
37	<i>G. furcata</i>	Graphidaceae	Cr	0	1	1	1	0	20
38	<i>G. glaucescens</i>	Graphidaceae	Cr	1	1	0	0	1	20
39	<i>G. handelii</i>	Graphidaceae	Cr	1	1	1	1	1	40
40	<i>G. leptocarpa</i>	Graphidaceae	Cr	1	0	0	0	1	10
41	<i>G. librata</i>	Graphidaceae	Cr	0	0	1	1	1	25
42	<i>G. lineola</i>	Graphidaceae	Cr	1	0	0	0	1	15
43	<i>G. pinicola</i>	Graphidaceae	Cr	1	1	1	1	1	25
44	<i>G. pyrrohocheiloides</i>	Graphidaceae	Cr	1	0	1	1	1	45
45	<i>G. scripta</i>	Graphidaceae	Cr	0	1	1	1	1	25
46	<i>G. subasahinae</i>	Graphidaceae	Cr	0	1	1	0	0	10
47	<i>G. submarginata</i>	Graphidaceae	Cr	0	0	0	0	1	10
48	<i>G. sundarbanensis</i>	Graphidaceae	Cr	1	0	0	1	1	15
49	<i>Herpothallon minutum</i>	Arthoniaceae	Cr	0	1	1	1	1	50
50	<i>Heterodermia diademata</i>	Physciaceae	Fo	0	0	0	0	1	5
51	<i>Lecanora andina</i>	Lecanoraceae	Cr	0	0	1	1	0	20
52	<i>L. chlarotera</i>	Lecanoraceae	Cr	0	1	1	0	1	30
53	<i>L. helva</i>	Lecanoraceae	Cr	0	1	1	1	1	20
54	<i>L. insignis</i>	Lecanoraceae	Cr	0	0	1	1	1	20
55	<i>Leptogium denticulatum</i>	Collembataceae	Fo	0	0	0	0	1	5

Table 1. Continued..

Sl. No.	Species	Family	GF	2 km	4 km	6 km	8 km	10 km	Freq (%)
56	<i>Lopadium coorgianum</i>	Lopadiaceae	Cr	0	0	1	0	0	5
57	<i>Malmidea gyalectoides</i>	Malmideaceae	Cr	0	1	0	0	0	5
58	<i>M. leptoloma</i>	Malmideaceae	Cr	0	0	0	0	1	5
59	<i>M. perplexa</i>	Malmideaceae	Cr	0	0	0	0	1	5
60	<i>Parmotrema crinitoides</i>	Parmeliaceae	Fo	0	0	1	1	1	25
61	<i>P. praesorediosum</i>	Parmeliaceae	Fo	0	1	0	1	1	20
62	<i>P. reticulatum</i>	Parmeliaceae	Fo	0	0	0	1	1	25
63	<i>P. saccatilobum</i>	Parmeliaceae	Fo	0	0	1	1	1	15
64	<i>P. tinctorum</i>	Parmeliaceae	Fo	0	0	1	1	1	35
65	<i>P. tsavoense</i>	Parmeliaceae	Fo	0	1	1	1	1	50
66	<i>Phaeophyscia kairamoi</i>	Physciaceae	Fo	0	0	1	0	1	20
67	<i>Physcia abuensis</i>	Physciaceae	Fo	0	0	0	1	1	40
68	<i>P. tribacioides</i>	Physciaceae	Fo	0	1	1	1	1	20
69	<i>Pseudopyrenula pupula*</i>	Trypetheliaceae	Cr	0	0	1	0	0	5
70	<i>Pyrenula acutalis</i>	Pyrenulaceae	Cr	0	0	0	1	0	5
71	<i>P. aggregata</i>	Pyrenulaceae	Cr	0	1	1	1	1	35
72	<i>P. glabrescens</i>	Pyrenulaceae	Cr	0	0	1	1	1	20
73	<i>P. minor</i>	Pyrenulaceae	Cr	0	1	0	1	0	10
74	<i>P. quassiaecola</i>	Pyrenulaceae	Cr	0	0	1	0	1	10
75	<i>P. subacutalis</i>	Pyrenulaceae	Cr	0	0	0	1	0	5
76	<i>P. subducta</i>	Pyrenulaceae	Cr	0	0	0	1	0	5
77	<i>Pyxine cocoos</i>	Caliciaceae	Fo	1	1	1	1	1	100
78	<i>P. meissnerina</i>	Caliciaceae	Fo	0	0	0	1	1	10
79	<i>P. reticulata</i>	Caliciaceae	Fo	1	1	1	1	1	30
80	<i>Sarcographa intricans</i>	Graphidaceae	Cr	0	1	0	1	1	30
81	<i>S. labyrinthica</i>	Graphidaceae	Cr	0	1	0	1	0	15
82	<i>S. subtriosa</i>	Graphidaceae	Cr	0	1	1	1	1	45
83	<i>S. triosa</i>	Graphidaceae	Cr	1	1	1	1	1	30
84	<i>Trypethelium eluteriae</i>	Trypetheliaceae	Cr	0	0	0	1	0	5
Species richness				21	36	38	61	64	

GF = growth form; Cr = crustose; Fo = foliose; Le = leprose. Values 1 and 0 indicate presence and absence, respectively. Frequency is based on occurrence across the 20 surveyed sites.

site accessibility, availability of suitable trees and the occurrence of lichens. At each distance, four sam-

pling sites representing four directions were selected. At each site, five suitable trees within an accessible

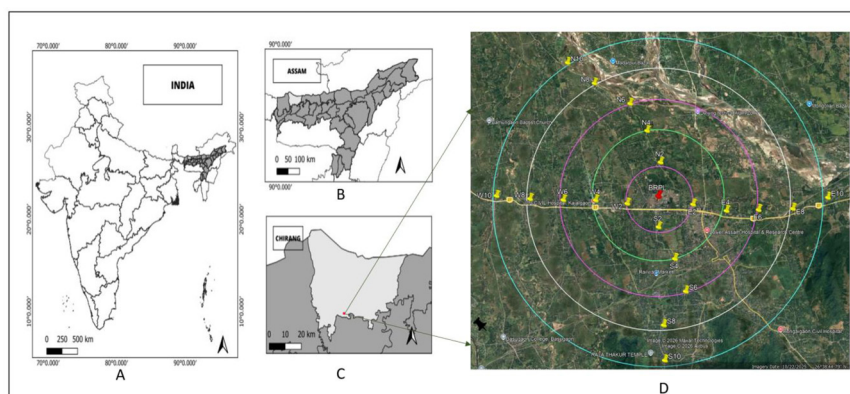


Fig. 1. Map of the study area showing A: Country- India. B: State-Assam. C: District-Chirang and D: Sampling sites around Bongaigaon Refinery located in Chirang District.

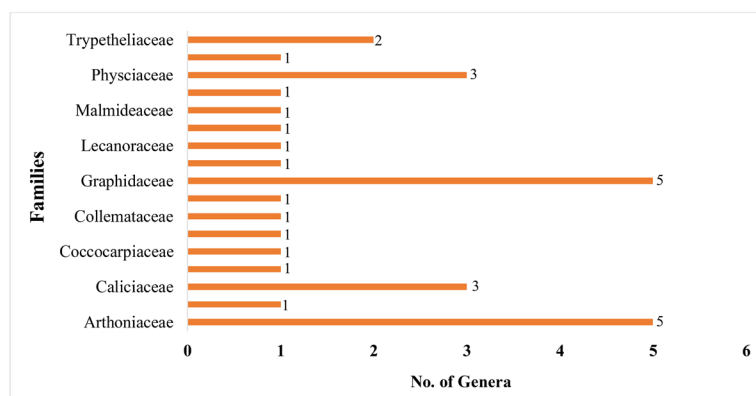


Fig. 2. Distribution of genera among lichen families.

area of approximately 100-200 m were selected for the collection of epiphytic lichens. Thus, a total of 20 sampling sites and 100 trees were surveyed.

Collection and identification

Specimens were collected during 2022- 2024 from

tree trunks at a height of 1.5 – 2.0 m above the ground using a hammer and chisel, while avoiding visible contamination. Samples were air-dried and stored in herbarium packets. Identification was performed by studying morphological characters (under stereo-zoom microscope Leica EZ4W) and anatomical characters (under compound microscope Leica DM

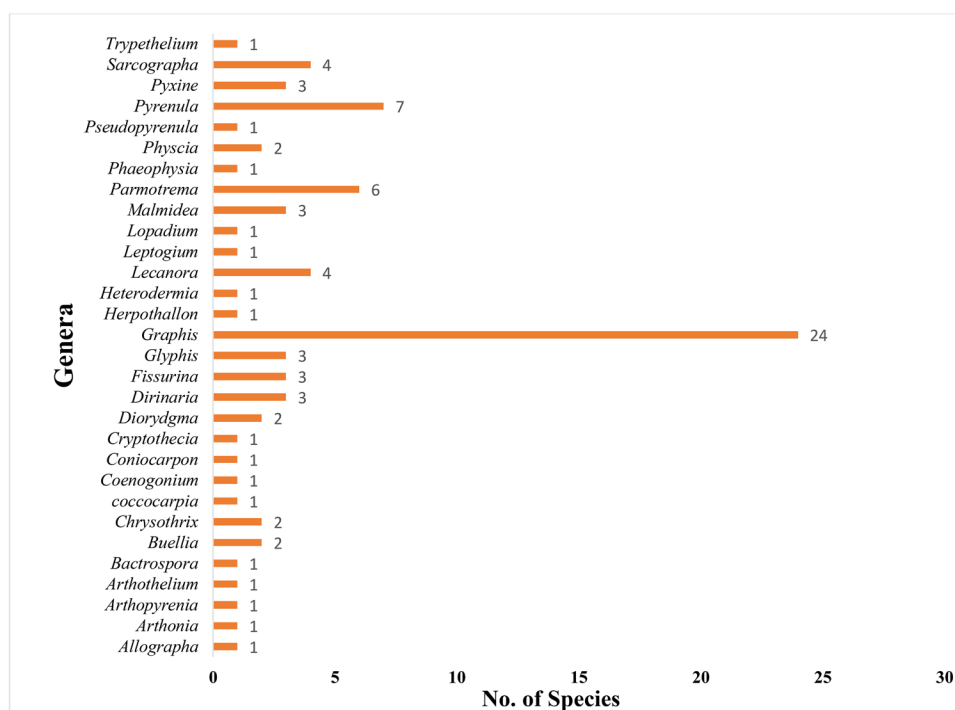


Fig. 3. Distribution of species among different genera.

750), fluorescence was observed under UV lamp at (254 nm), and chemical test (spot test and thin layer chromatography using solvent system A, [Toluene (180): 1,4-Dioxane (45): Acetic acid (5)] following Orange *et al.* 2001. The nomenclature and families of the identified lichen species, by referencing relevant published literature (Awasthi 1991; Awasthi 2007; Nayaka 2005), were updated according to Index Fungorum (2026) and Wijayawardene *et al.* 2020.

Data analysis

The occurrence of each species was further analyzed for species richness and distribution patterns, and frequency of occurrence. Species Richness (S) was calculated as the total number of species present at each distance. Frequency (%) = No. of sites where the species occurred / Total number of sites surveyed $\times 100$. A Chi-square test (χ^2) was used to check for significant differences in species richness among the different distances. Sørensen similarity index (S) was used to assess pairwise compositional similarity among distances using the formula:

$$S = 2C / (A+B)$$

Where, A and B are the number of species in site A and B, respectively, and C is the number of species common to both sites.

RESULTS

Lichen diversity and growth forms

A total of 84 lichen species, representing 30 genera and 17 families, were recorded from the study area (Table 1). Graphidaceae (40%) was the most dominant family with 5 genera and 34 species (Fig. 2 and Fig. 3). The lichen assemblage was dominated by crustose forms (76%), followed by foliose (22%) and leprose forms (2%) (Fig. 4).

Distance-wise distribution

Species richness varied among the sampling distances and showed a clear increasing trend with distance from the refinery. The distance-wise distribution of

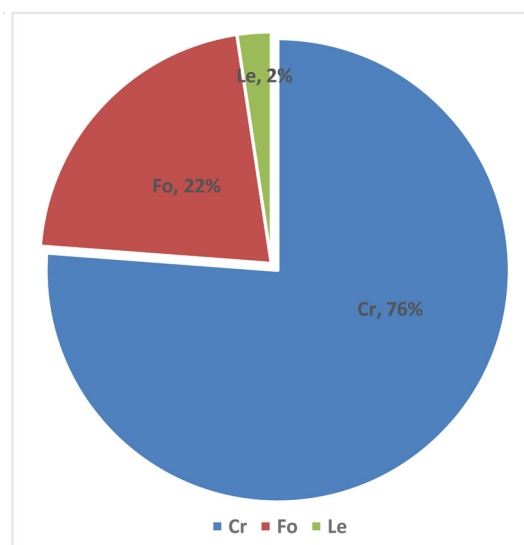


Fig. 4. Overall growth forms of lichen species from the study sites.

lichen species richness was in the order: 10 km (64 species) > 8 km (61 species) > 6 km (38 species) > 4 km (36 species) > 2 km (21 species). The reduced species richness at 2 km indicates that sites closer to the refinery were comparatively less favorable for lichen colonization, whereas the species richness recorded at 8 km and 10 km suggests better environmental conditions away from the refinery. This pattern indicates that the environmental condition becomes increasingly conducive for lichen growth with increasing distance from the pollution source (Fig. 5). Crustose lichens were the dominant growth form across all sampling sites reflecting their tolerance to atmospheric pollutants, whereas the foliose growth form of lichens showed a gradual increase with dis-

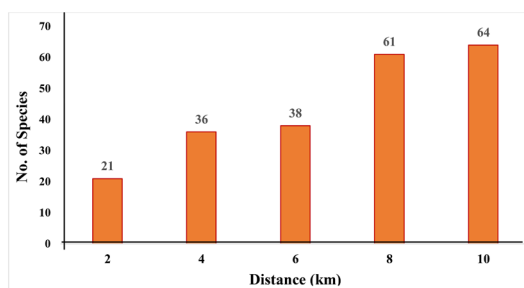


Fig. 5. Graph showing the Species richness Vs. Distance from the refinery.

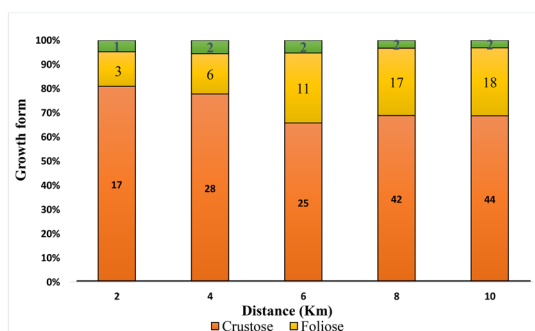


Fig. 6. Growth forms of lichen species across different distances.

tance from the refinery (Fig. 6). The distance-wise distribution of foliose lichen species followed the order: 10 km (18) > 8 km (17 species) > 6 km (11 species) > 4 km (6 species) > 2 km (3 species). This increasing pattern indicates their preference for reduced environmental stress. Among the recorded species *Pyxine cocola* showed highest frequency (100%) and was recorded across all sites. *Chrysothrix chlorina*, *Cryptothecia striata*, *Coniocarpon cinnabarinum*, *Dirinaria consimilis* were widely distributed in all sites, each showing frequency (95%). These species may be considered tolerant.

Data analysis

Chi-square test revealed a significant relationship between distance and lichen diversity. It showed a notable difference in species richness among the various distances ($\chi^2 = 30.25$, $df = 4$, $p < 0.01$), which confirmed that the refinery has a considerable impact on lichen distribution. Sørensen similarity values demonstrated variation in species composition along the distance gradient (Table 2). The highest similarity was observed between 8 km and 10 km (0.75), followed by similar values of 0.65 between 6 km and 8 km and between 6 km and 10 km distances, indicating stable and similar communities at greater distances.

DISCUSSION

The present study offers valuable insights into lichen diversity near a refinery in the Chirang district of Assam, highlighting their growth forms and distributions in the area. Research conducted in industrial zones of Northeast India indicates that the distribution of

Table 2. Sørensen similarity index showing compositional similarity among different distances.

Distance	2 km	4 km	6 km	8 km	10 km
2 km	1	0.53	0.44	0.39	0.49
4 km		1	0.65	0.58	0.58
6 km			1	0.65	0.65
8 km				1	0.75
10 km					1

lichen communities and the accumulation of heavy metals are significantly influenced by local industrial activities, such as oil refining and coal mining (Hajong *et al.* 2025). *Crustose lichens* like *Cryptothecia scripta* and *C. striata* were dominant in the refinery. Similarly, in the present study, *Cryptothecia striata*, *Chrysothrix chlorina* and *Dirinaria consimilis* were also found to thrive well in the sites studied with a frequency of 95% each, while *Pyxine cocola* was the most widespread taxon with 100% frequency across all the sites. Higher frequency confirms its status as a robust, pollution-tolerant bioindicator that can withstand significant anthropogenic stress (Bajpai *et al.* 2022) and can be used for pollution monitoring studies. In the present study, it is notable that the richness of epiphytic lichen species increased with distance from the refinery. The increase in lichen richness with distance from the refinery indicates a clear pollution gradient with its greater impact near the refinery, suggesting environmental stress from industrial emissions along with other anthropogenic activities. This trend aligns with the “lichen zonation”, observed near other industrial facilities, where species diversity was inversely proportional to the proximity of the pollution source (Jakučionytė 2017, Taufikurrahman *et al.* 2024, Mikulec *et al.* 2025). Results of the Sørensen similarity Index further support higher similarity among distant sites and reflect ecological stability, indicating the prevalence of a pollution gradient. The variation in species frequency with distance suggests that the dispersal of emissions from the refinery creates a specific corridor of impact that shapes the community composition at different distances. Studies from other refinery areas in the region, such as Guwahati and Digboi, have also shown significant impacts on lichen community composition and heavy metal accumulation in lichen thalli (Daimari *et al.* 2013, Hajong *et al.* 2025).

CONCLUSION

The study recorded 84 lichen species and demonstrated a significant increase in species richness with increasing distances from the refinery. Crustose lichens dominated the assemblage, while foliose lichen increased with distance from the point source. Higher similarity between 8 and 10 km sites indicates more common and stable lichen species at far distances. The widespread occurrence of *Pyxine cocolos*, *Chrysothrix chlorina*, *Cryptothecia striata* and *Dirinaria consimilis* can be useful for future biomonitoring studies near industrial sites, including refineries. Overall, the findings provide a baseline for future monitoring and contribute to our understanding of the ecological impact of industrial emissions in the region.

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