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Lichen diversity for environmental stress study: Application of index of atmospheric purity (IAP) and mapping around a paper mill in Barak Valley, Assam, northeast India

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Abstract: The paper discusses the application of lichen diversity in the form of Index of Atmospheric Purity (IAP) for environmental stress study (air pollution) around a paper mill in Assam, India. Seventeen sites were selected within an area of approximately 1800 km² around the mill to prepare a stress zone map using IAP; the values ranged between 17 and 113, delineating the area into five zones. The zones are categorised as zone II (IAP: 1 - 24), zone III (IAP: 25 - 49), zone IV (IAP: 50 - 74), zone V (IAP: 75 - 99), and zone VI (IAP > 99). Zone I, which represents IAP = 0 (or lichen desert) is not found in the study. The resultant map from interpolation of IAP exhibits resilience by lichens to the multiple stress sources like stone crushers, cement industry and urban sprawls. IAP, derived from number of species, frequency of occurrence, coverage, and sensitivity is found to be an efficient and cost effective method depicting long term stress effects on lichens and is one of the most suitable biomonitoring tools for a developing country like India.

Resumen: Este artículo discute la aplicación de la diversidad de líquenes en la forma de un índice de pureza atmosférica (IAP) para el estudio del estrés ambiental (contaminación del aire) en torno a una fábrica de papel en Assam, India. Se seleccionaron 17 sitios dentro de un área de aproximadamente 1800 km² alrededor de la fábrica para elaborar un mapa de zonas de estrés utilizando el IAP; los valores oscilaron entre 17 y 113, permitiendo clasificar el área en cinco zonas. Las zonas fueron clasificadas como zona II (IAP: 1 - 24), zona III (IAP: 25 - 49), zona IV (IAP: 50 - 74), zona V (IAP: 75 - 99) y zona VI (IAP > 99). La zona I, que representa un IAP = 0 (o desprovista de líquenes) no fue hallada en el estudio. El mapa resultante de la interpolación del IAP muestra una resistencia de los líquenes a las numerosas fuentes de estrés como las trituradoras de piedra, la industria del cemento y las aglomeraciones urbanas. Se encontró que el IAP, derivado del número de especies, su frecuencia de aparición, la cobertura y la sensibilidad, es es un método eficaz y rentable que representa los efectos del estrés a largo plazo sobre los líquenes y que es una de las herramientas de biomonitoreo más adecuadas para un país en desarrollo como la India.

Resumo: O artigo discute a aplicação da diversidade de líquenes na forma de índice de pureza atmosférica (IAP) para o estudo do stresse ambiental (poluição do ar) em torno de uma fábrica de papel em Assam, na Índia. Seleccionaram-se 17 estações dentro de uma área de aproximadamente 1800 km² ao redor da fábrica para elaborar um mapa de zonas de stresse utilizando o IAP; os valores variaram entre 17 e os 113, permitindo classificar a área em cinco

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zonas. As zonas foram classificadas como zona II (IAP: 1 - 24), zona III (IAP: 25 - 49), zona IV (IAP: 50 - 74), zona V (IAP: 75 - 99), e zona VI (IAP > 99). A zona I, que representa um IAP = 0 (ou desprovida de líquenes) não foi encontrada no estudo. O mapa resultante da interpolação do IAP exibe uma resistência dos líquenes às numerosas fontes de stresse como as trituradoras de pedra, a indústria de cimento e as aglomerações urbanas. Encontrou-se que o IAP, derivado do número de espécies, da sua frequência de ocorrência, a cobertura e a sensibilidade, é um método eficaz e de baixo custo que representa os efeitos do stresse a longo prazo sobre os líquenes e que é uma das ferramentas de biomonitoramento mais adequado para um país em desenvolvimento como a Índia.

Key words: Epiphytic lichens, ecological index, frequency and coverage, IAP, paper mill, pollution zone map.

Introduction

Lichens are widely used in biomonitoring studies as they provide cost effective tools for mapping spatial and temporal patterns of atmospheric contamination (e.g. Conti & Cecchetti 2001). They are excellent bioindicators of changes in air quality due to their differential sensitivity to various air pollutants (Nash & Egan 1988). Lichens have been used as bioindicators of environmental stress in number of studies, using different techniques including single species distribution maps, analysis of the whole flora (Wetmore 1983), transplant experiments, analysis of morphological injury (Brodo 1961), modification of photosynthetic performance (Christ & Türk 1981), and Indices of Atmospheric Purity (IAP) (LeBlanc & De Sloover 1970). IAP, a quantitative approach, employing a mathematical calculation is best known method to evaluate the level of pollution affecting epiphytic lichen flora (Svoboda 2007). A test carried out by Deruelle (1978) proved the validity of this index to monitor SO_2 pollution in western France. The technique has also been utilized to monitor hydrogen fluoride around an Aluminium refinery in Arvida, Quebec (LeBlanc *et al.* 1972). IAP is frequently used for summarizing information about pollution tolerance of species and their spatial variation of abundance (LeBlanc & De Sloover 1970), and reflects a gradation of lichen species richness from "good" (high diversity) to "worst" (low diversity) (Kricke & Loppi 2002) and sums up the effects of long term environmental conditions.

In the present study IAP method is applied around a paper mill in Assam in north eastern region of India. As very little work has been carried out in Indian subcontinent utilizing IAP, the present work can prove to be efficient, cost-effective and low-tech bioindication method for a developing country like India. Although in Barak Valley, work on lichens is mainly concentrated on diversity (for example, Rout *et al.* 2010), biomonitoring work using IAP is the first of its kind. Objective of the work is to formulate a region specific model to demarcate various zones of pollution around an industrial set up utilizing IAP protocol.

Materials and methods

Study area

The study was conducted around a paper mill situated in Barak Valley in southern Assam in north eastern part of India (Fig. 1). The valley has a subtropical, warm, and humid climate with three seasons - summer, monsoon and winter. Annual rainfall is about 2694.7 mm. Wind speed ranged from 41.7 km h^{-1} during November to 114.6 km h^{-1} during April (Table 1). The topography is undulating and hilly with a general pattern of north-south elongation of hills and hillocks and east-west trending alluvial filled basin. The data on epiphytic lichens were collected at seventeen sites selected within 24 km radius around Cachar paper mill covering an area of around 1800 km^2. The selected sites (Fig. 1) are situated between latitude 24° 42' and 24° 59' N and longitude 92° 22' and 92° 53' E (Table 2). The study sites are selected in a way so that they cover all the directions with the mill in the center. Kalinagar is the nearest site lying 2.4 km away towards east of the mill and Jalalpur is the farthest site lying 24 km towards north west of the mill.

Table 1. Mean monthly temperature, humidity, wind speed, and rainfall observed in the region during the study period.

Months	Temperature (°C)		Humidity (%)		Rainfall (mm)	Wind speed (km h^{-1})
	Maximum	Minimum	Morning	Afternoon		
Jan	25.1	13	93	61.4	2.2	45.7
Feb	28.1	12.9	92	42.3	0	55.9
Mar	32.3	18.7	92	38	20.2	75.7
Apr	29	20.3	96	61	684.2	114.6
May	32.2	23.3	95	61.1	351.1	77.2
Jun	32.2	24.1	95	67	263.9	66.1
Jul	31.2	24.1	96	77	582	78.8
Aug	33.7	25.4	93	66	259.9	92.44
Sep	31	24.3	95	78	387.8	73.59
Oct	30.9	21.8	96	70	134.8	64.38
Nov	29.5	17.2	92	55.9	0	41.7
Dec	27.2	13.7	93	46.6	8.6	44

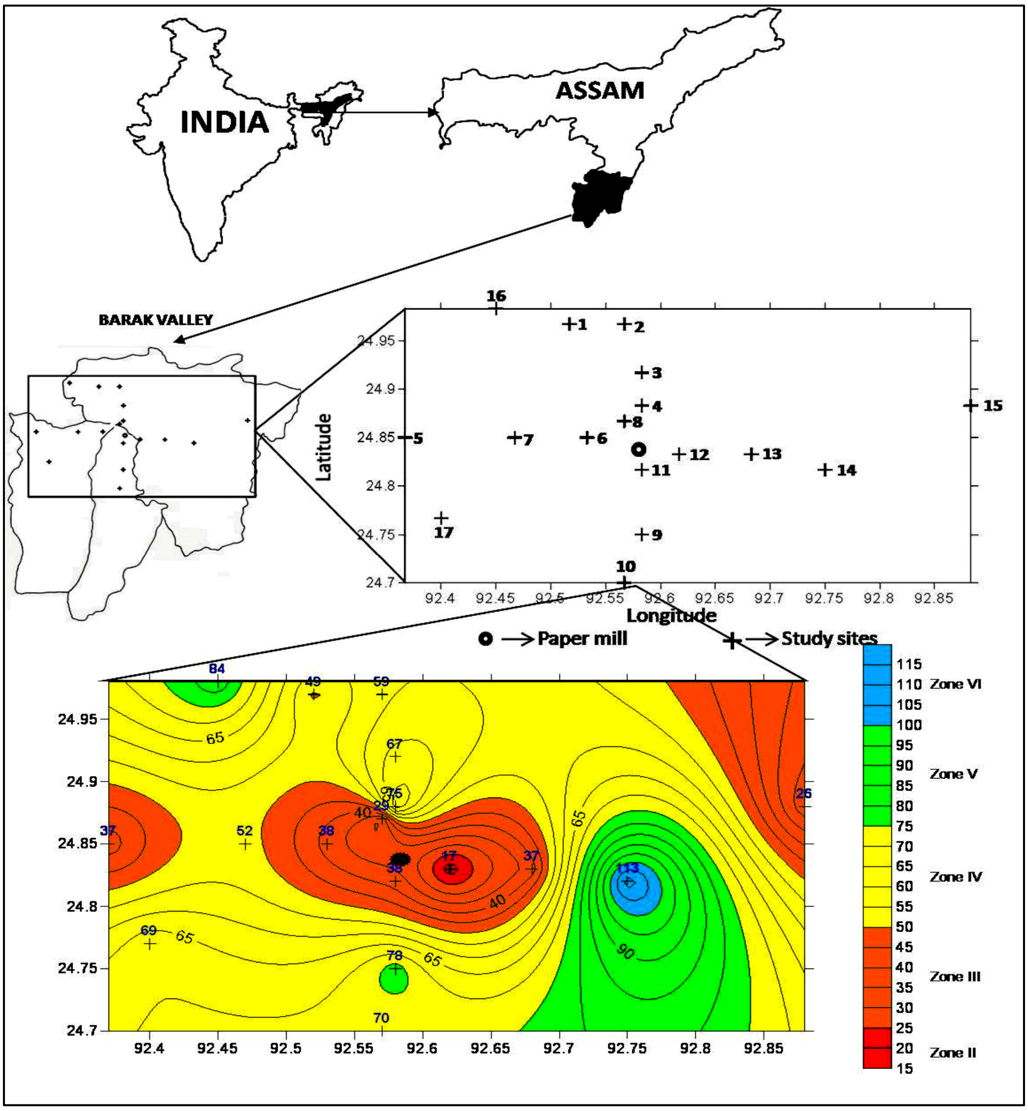

Fig. 1. Pollution zone map around paper mill using IAP protocol.

Table 2. Latitudes and longitudes of all the sites selected for IAP study.

Site number	Site name	Longitude	Latitude	Distance from mill (km)	Direction
1.	Gumra	92° 31′ E	24° 58′ N	16.9	NW
2.	Dumkur	92° 34′ E	24° 58′ N	16.1	N
3.	Baroital	92° 35′ E	24° 55′ N	13.7	N
4.	Mohanpur	92° 35′ E	24° 53′ N	8.8	N
5.	Elongjuri	92° 22′ E	24° 51′ N	19.3	W
6.	Umarpur	92° 32′ E	24° 51′ N	7.2	W
7.	Bhanga	92° 28′ E	24° 51′ N	11.3	W
8.	Devendranagar	92° 34′ E	24° 52′ N	5.6	W
9.	Bornogod	92° 35′ E	24° 45′ N	12.1	S
10.	Lokhirbond	92° 34′ E	24° 42′ N	20.1	S
11.	Uttarkanchanpur	92° 35′ E	24° 49′ N	4.8	S
12.	Kalinagar	92° 37′ E	24° 50′ N	2.4	E
13.	Ghaghrapar	92° 41′ E	24° 50′ N	5.2	E
14.	Sangjurai	92° 45′ E	24° 49′ N	8.4	E
15.	Udharbond	92° 53′ E	24° 53′ N	23.3	NE
16.	Jalalpur	92° 27′ E	24° 59′ N	24.1	NW
17.	Kaliganj	92° 24′ E	24° 46′ N	20.1	SW

Field method and data recording

For studying the epiphytic lichens with respect to stress, a commonly distributed Jackfruit (*Artocarpus heterophyllus*) tree was selected. At each site five large trees exposed to more or less similar environmental conditions were selected. Lichens present on trunks of these trees up to a height of 2 m from the ground were collected and enlisted (Johnson 1979). Frequency of occurrence (Fr) for lichens was calculated as the percentage of trees on which a species was physically present at a given site; while the coverage (Co) was the surface area of the species at that site. Outline of the individual lichen patch was drawn by placing transparent sheet and surface area was measured using graph paper. The coverage of any species was the sum total of surface area of all the individual patches present at that site. The frequency-coverage (f) of each species was estimated by multiplying frequency (Fr) and coverage (Co) and expressed by a number on the scale 1 - 5 (LeBlanc *et al.* 1974).

Data analysis

From the list of lichens occurring on all the seventeen sites, an ecological index (Q) for each species was determined which can be called a unique number of that species. The Q (for any particular species) was calculated by adding together the number of species present (growing) at various sites and then dividing this sum by the total number of sites where that species occurred (LeBlanc *et al.* 1974). In other words, the average number of species concurrently occurring with each lichen species growing on the trunk of *A. heterophyllus* around the paper mill area was determined. The frequency-coverage (f) and the ecological index (Q) data of epiphytes were compiled and tabulated separately for each of the seventeen sites. The IAP for any site was calculated as follows (De Sloover & LeBlanc 1968):

$$IAP = 1/10 \sum_{i=1}^{n} (Qi \times fi)$$

where, n is the total number of species at that site; f is the frequency-coverage scale of each species at that site; Q is the ecological index of a species present at that site. The sum of Q x f is divided by 10 to reduce it to a more manageable figure. IAP for every site was calculated and IAP values were plotted with the help of Kriging interpolation (e.g. Geiser & Neitlich 2007) using geostatistical software, Golden SURFER.

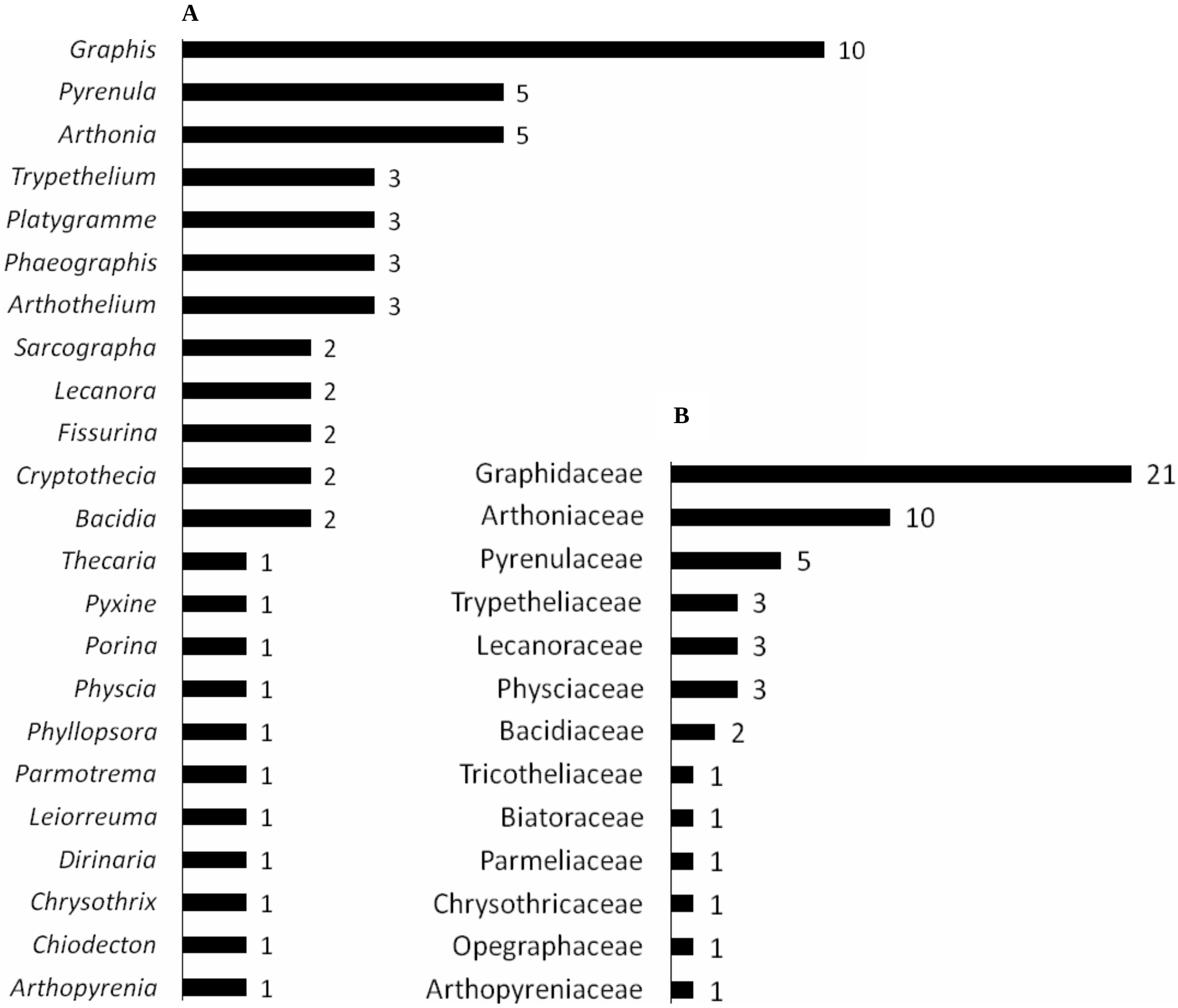

Fig. 2. Number of species of lichens in each genus (A) and each family (B) at different study sites.

Results and discussion

Jackfruit is an abundant tree around the study area and with the choice of a single tree species it is possible to assume that the variations in epiphytic vegetation were due to the changes in the level of pollution and not to dissimilarities in pH, texture, and friability of tree bark (LeBlanc *et al.* 1974). The study revealed a total of 53 species representing 23 genera and 13 families from seventeen sites (Fig. 2). The Ecological Index (Q) representing the tolerance or sensitivity ('low Q, High tolerance' and 'high Q, low tolerance'); LeBlanc & De Sloover (1970)) ranged from 8 (*Graphis subassimilis*) to 38 (*Cryptothecia lunulata*) (Table 3). Ecological index for foliose lichens ranged from 9 (*Phyllopsora corallina*) to 19 (*Physcia dilatata*). The f value ranged from 10 (sites 8 and 14) to 812300 (site 14) and classes ranged as: class 1: 10-100, class 2: 100 - 1000, class 3: 1000 - 10000, class 4: 10000 - 100000 and class 5: > 100000. The suspended particulate matter (SPM), sulphur dioxide (SO_2), and nitrogen dioxide (NO_2) concentrations, measured inside the paper mill (from Assam State Pollution Control Board, Silchar) ranged from 80-188.2 µg m^{-3}, 22.2 - 66 µg m^{-3}, and 24.4 - 66 µg m^{-3}, respectively (Das 2008).

Frequency of the species varied between different sites. The lowest IAP value was 17 at site 12 representing only 5 species. This site is situated at about 2.4 km from the mill towards east direction (Fig. 1). It is to be noted that except for *Cryptothecia lunulata* which had a high Q value of 38, all the other species had values ≤ 20. Some of the species showed definite trend in accordance to the distance of locations from pollution source.

Table 3. List of lichens found in the study area on the basis of sensitivity (ecological index) (Q).

Species	Q	Species	Q
Graphis subassimilis	8	*Lecanora achroa*	15
Arthonia recedens	9	*Phaeographis albolabiata*	15
Fissurina columbina	9	*Trypethelium albopruinosum*	15
Phyllopsora corallina	9	*Trypethelium macrosporum*	15
Phaeographis sp.	10	*Arthonia arctata*	16
Graphis scripta	12	*Arthonia impolitella*	16
Platygramme wattiana	12	*Arthothelium abnorme*	16
Sarcographa subtricosa	12	*Arthothelium nigrodiscum*	16
Arthopyrenia indusiata	13	*Bacidia medialis*	16
Chrysothrix candelaris	13	*Graphis intermediella*	16
Graphis chloroalba	13	*Platygramme caesiopruinosa*	16
Graphis persulcata	13	*Pyrenula brunnea*	16
Graphis subasahinae	13	*Thecaria austroindica*	16
Porina subhibernica	13	*Fissurina comparilis*	17
Pyrenula oxisporiza	13	*Parmotrema saccatilobum*	17
Sarcographa leprieurii	13	*Phaeographis dendritica*	17
Arthothelium chiodectoides	14	*Pyrenula defossa*	17
Cryptothecia effusa	14	*Graphis assamensis*	18
Dirinaria aegialita	14	*Graphis inamoena*	18
Graphis nigroglauca	14	*Arthonia tumidula*	19
Platygramme pudica	14	*Leiorreuma* sp.	19
Pyrenula fuscoolivaceae	14	*Physcia dilatata*	19
Pyxine cocoes	14	*Pyrenula costaricensis*	19
Trypethelium endosulphurium	14	*Arthonia catenatula*	20
Bacidia inundata	15	*Lecanora leprosa*	21
Chiodecton leptosporum	15	*Cryptothecia lunulata*	38
Graphis capillaceae	15		

Bacidia medialis, Dirinaria aegialita, Graphis inamoena, Phaeographis dendritica, Platygramme caesiopruinosa, and *Sarcographa subtricosa* showed a gradual increase in their frequency with distance from paper mill in contrast to *Graphis capillaceae, G. subasahinae, Pyrenula fuscoolivaceae*, which showed a decrease in their frequency, with the increase in distance from paper mill. The highest IAP value was 113 at site 14 (Table 4) with 24 species situated at about 8.5 km from the mill towards east direction. The IAP values are categorized (Table 4) according to different ranges: 1 - 24, 25 - 49, 50 -74, 75 - 99 and > 99. These ranges are designated as different IAP or pollution zones from II to VI. In the present study no site was found with IAP value zero (i.e. no lichens; zone I), hence sites have started from zone II (IAP range: 1 - 24). The first zone (designated as zone II) with lowest IAP value of 17 and the last zone (designated as zone VI) with highest IAP value of 113 corresponded with the lowest and highest number of lichen species present at that site (Table 4). Correlation of IAP with number of species is found to be positive and statistically significant ($r = 0.95$, $P < 0.05$). Correlation between IAP and distance from mill is although positive, but statistically not significant ($r = 0.26$).

The average number of species per tree showed a gradual increase from 1.8 in zone II to 9 in zone VI (Fig. 3). The highest, two-fold, increase in species number was noticed from zone II to III followed by 1.7-fold increase from zone III to VI. From zone IV to V and V to VI, an almost constant increase of 1.2-fold in lichen species was recorded.

Table 4. Lichen numbers, IAP value, range and zones around the mill.

Site No.	Distance from mill (km)	Number of lichens	IAP value	IAP range	IAP zone
12	2.4 E	5	17	1-24	II
1	16.9 NW	12	49	25-49	III
5	19.3 W	11	37	25-49	III
6	7.2 W	10	38	25-49	III
8	5.6 W	10	29	25-49	III
11	4.8 S	11	38	25-49	III
13	5.2 E	10	37	25-49	III
15	23.3 NE	9	26	25-49	III
2	16.1 N	13	59	50-74	IV
3	13.7 N	20	67	50-74	IV
7	11.3 W	12	52	50-74	IV
10	20.1 S	15	70	50-74	IV
17	20.1 SW	16	69	50-74	IV
4	8.8 N	18	75	75-99	V
9	12.1 S	18	78	75-99	V
16	24.1 NW	17	84	75-99	V
14	8.4 E	24	113	>99	VI

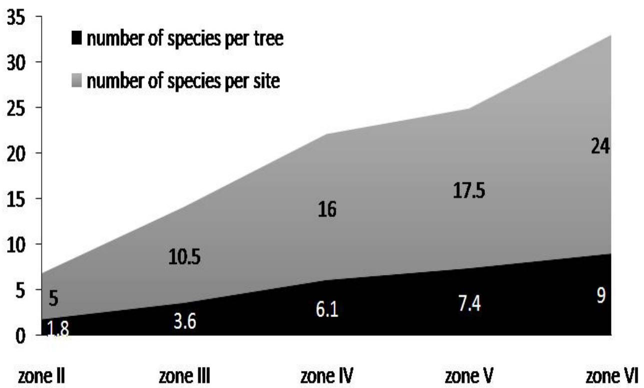

Fig. 3. Average number of species per tree and per site across different zones.

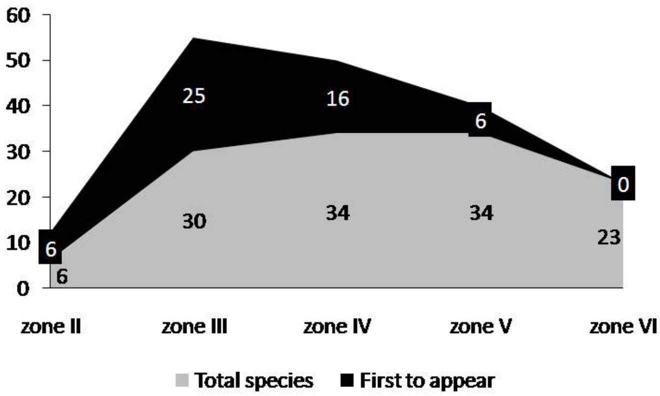

Fig. 4. Total number of lichen species across different zones.

An overall increase of about 5-times was observed from zone II to VI. The number of species per site also showed an increasing trend from 5 species in zone II to 24 species in zone VI (an increase of about 4.8-times) (Fig. 3). Out of five zones, the zones IV and V had the maximum diversity of lichens (34 species each), followed by zone III (30 species), VI (23 species), and II (6 species) (Fig. 4). The study area comprised lichens of only two growth forms, crustose and foliose, that showed inverse trend in their occurrence from zone II to VI (Fig. 5). The crustose growth form was 100 % in zone II, which gradually decreased to about 83 % in zone VI, although zone V exhibited a nominal increase in percentage. Similarly foliose growth form which was zero in zone II increased to over 16 % in zone VI. The first appearance of macrolichen (*Dirinaria aegialita*) was at a distance of about 4.8 km from the paper mill in zone III. *Dirinaria aegialita* with low Q value has been shown to have very high tolerance (LeBlanc & De Sloover 1970) and reported to be present with high abundance near pollution sources. Increase in number of species per tree and number of species per site from lower to higher zone is comparable to the values reported in the review of Will-Wolf (1988), where it was suggested that quantitative approaches to air quality indices rely on overall linear declines of species in communities affected by air pollutants.

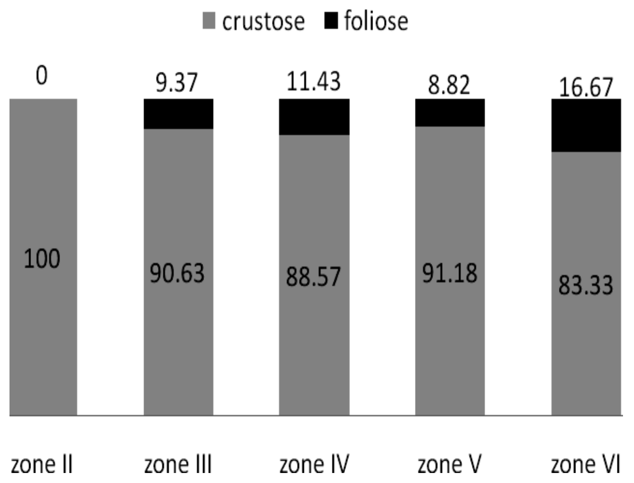

Fig. 5. Lichen growth forms across different zones.

From the IAP zone map (Fig. 1) it is clear that the highest stress zone is in the vicinity of the mill. The site-12 (Kalinagar) nearest to the paper mill exhibited the lowest IAP value of 17 (zone II) and was represented by only crustose lichens such as *Graphis subasahinae, G. persulcata, G. chloroalba*, *Sarcographa subtricosa* and *Porina subhibernica*. At Wawa, Ontario, Rao & LeBlanc (1967) reported that the first epiphytic lichens (*Bacidia chlorococca*, *Cladonia coniocraea*) near an iron smelter appeared on tree bases at 10 km and on tree boles at 30 km, however, in the present study the epiphytic lichens were found within one kilometer from the paper mill. Site 5 (Elongjuri) and site 15 (Udharbond) exhibited a different trend compared to the variations in the zone. The site Elongjuri, which is just adjacent to a township, is likely to be affected by the urban influence. The lichens found there mainly are crustose belonging to the genera *Graphis* (4 species), *Sarcographa* (2 species), *Trypethelium, Pyrenula* and *Lecanora* (1 species each). The site 15 (Udharbond area) exhibited a different trend may be due to number of small stone crushing industries. *Graphis* (4 species), *Trypethelium*, *Sarcographa*, *Arthonia*, *Arthopyrenia* (1 species each) together with a single foliose species (*Pyxine cocoes),* were recorded at site 15. Mosses and lichens can respond rapidly to environmental changes through both reductions and increments in cover (Belnap *et al.* 2006) and exhibiting increase in abundance because of induced resistance to any particular type of pollutant (Hawksworth & Rose 1970).

In the present study, the lichen 'desert' (area with no lichens/IAP=0), which is a common zone reported in and around many pollution sources even extending up to 25 km (Barkman 1958; Hawksworth & Rose 1970; Herzig *et al.* 1989; LeBlanc *et al.* 1974) did not exist, similar to the study conducted by Paoli *et al.* (2006). The highest IAP value (113) is observed at site 14 (Sangjurai) lying at a distance of 8.5 km towards east of the paper mill. The site is represented by 10 families. Lichen family Graphidaceae dominated the site with 9 species and accompanied by Physciaceae, Arthoniaceae (3 species each) and 4 foliose lichen species belonging to 2 families and 4 genera. Interestingly both the highest and the lowest IAP values were observed in the east of the pollution source. The lowest IAP value was recorded in the direction of frequent wind flow from the paper mill (Bhagavathi Ana Labs. 2010).The wind rose of the area also showed that for maximum time during the study period, the wind blew from west direction. Site 14, where the highest IAP was recorded, is situated just across a hilly tract of Srikona region having its elongation towards north-north east direction, which may act as a barrier for polluted air, and hence the change in zone is observed.

The high positive correlation between the IAP value and the number of species recorded in the present study is similar to the result obtained by Giordano *et al.* (2004) and LeBlanc *et al.* (1974). But unlike LeBlanc *et al.* (1974) where IAP value and distance from the pollution source was highly correlated, present study showed a nonsignificant correlation. Possible reasons for this may be the undulating topography, wind pattern, and presence of two other significant pollution sources (town area and stone crushing industries) in addition to the paper mill within the study area. Lichen taxa *Graphis chloroalba*, *G. persulcata*, *G. subasahinae*, and *Porina subhibernica* existing in all the five zones of the study area indicated their ability towards adapting in environment from highest to lowest pollution level; interestingly all the species had Q value of 13. Some of the lichen species exhibited their restricted distribution in a particular zone and are the possible indicator species which will help in determining high pollution level in similar climatic and physiographic conditions. *Arthonia recedens, Fissurina columbina, Graphis subassimilis, Phyllopsora corallina* and *Platygramme wattiana* are restricted to zone III. *Arthothelium abnorme, A. nigrodiscum,* *Fissurina comparilis, Pyrenula defossa* and *Thecaria austroindica* are sensitive species with respect to air quality as they had restricted distribution in relatively cleaner environment of zone V. *Arthonia tumidula, Bacidia inundata, Chiodecton leptosporum* and *Leiorreuma* species were recorded only from the intermediate zone i.e. from zone IV.

Unlike the IAP zones demarcated by LeBlanc *et al.* (1974), which actually represented concentric lines around the pollution source due to hand plotting of IAP values, the zone map in the present study (Fig. 1) depicts a better visual presentation due to use of interpolation with the help of geostatistical software. The interpolated map shows similarity with the land use pattern of the region as described by Johnson (1979). The zone II in the present study is a small area adjacent to the paper mill. The bean shaped zone III represents an area with a cumulative effect of the paper mill and a cement industry operating at a distance of 2 km towards southwest direction from the paper mill. A small part in the west direction of zone III is close to the Karimganj town area, one of the major urban areas in Barak Valley region. The north and north-eastern part of zone map (zone III) corresponds with an area where numerous stone crushers are operating and have their impact on the micro environment of the lichens. These local sources of pollution have significant role in the overall shape of the zone map. Proximity to local source of pollution such as farms, roads, and small factories have been found to significantly change lichen biodiversity of an area (Carvalho *et al.* 2002; Fos 1998; van Herk 2001), creating artifacts in large scale studies (Pinho *et al.* 2004). Another distinct land use depicted in the lichen map (zone V) towards north-west direction is a part of a vegetated hillock which is an unpolluted village area with lush green cover. A contradiction however, is observed towards the south, as site 10 (Lokhirbond) is adjacent to an urban area (Hailakandi town) which is also the next bigger town in the region after Karimganj. This site represents zone IV lying within zone III. Such types of contradictions are also reported by Gombert *et al.* (2004) and Svoboda (2007), where the cause is attributed to complex affinities of lichen assemblages with any particular type of pollutant.

Conclusions

Present study attempted to delineate an area around a paper mill into different zones (zones II to VI) with the help of lichen based mapping method known as Index of Atmospheric Purity of the lichen flora away from an idealized state. The 'desert zone' (IAP=0) is not found in the present study. In our study the IAP method is manifested into a two dimensional zone map with the help of Kriging interpolation. The IAP zone map is correlated with the land use pattern of the area which contributed towards a change in the local environment such as urban areas, stone crushers, cement industry and a paper mill. The index-based mapping techniques have played an important role in urban planning in some parts of Europe (Richardson 1975). This method has been applied very scarcely in the tropical countries till now. It is suggested that using interpolation, IAP zonification can be used successfully to see the effect of environmental pollution. These maps can also be used in long temporal scales to track changes in the local environment.

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