The Lichenologist **37**(4): 345–356 (2005)
doi:10.1017/S0024282905014994 *Printed in the United Kingdom*

Epiphytic lichens as indicators of environmental health in the vicinity of Chiang Mai city, Thailand

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Abstract: Epiphytic lichens were sampled on selected trees in 19 sites radiating from Chiang Mai city including the adjacent mountain Doi Suthep in Northern Thailand using the VDI method (Verein Deutscher Ingenieure) to obtain frequency of occurrence in 10 area units per sampled tree. Sites selected included highly polluted sites in urban and adjacent industrial areas of Chiang Mai city, disturbed rural sites and undisturbed forest on Doi Suthep mountain, with altitudes varying from 260–1450 m. Lichen diversity was highest in upland sites and lowest in urban and agricultural sites. Analysis of lichen taxa at generic and at macrolichen species level and environmental data using PRIMER showed that upland and lowland sites were distinguished in the first division at both levels and correlated with altitude and vegetation type. Analysis of all taxa at generic level showed no separation of lowland sites but at macrolichen species level a better separation was obtained, suggesting that lichen diversity alone cannot be used for biomonitoring of air pollution. The relationship of epiphytic lichens to climate and pollution data available for Chiang Mai city and Doi Suthep is discussed and results compared with data from other studies in SE Asia.

Key words: bioindicators, lichens, northern Thailand, pollution

Introduction

Lichens have long been known to include species that are highly sensitive to environmental changes especially to pollution caused by sulphur dioxide arising from industrial and domestic fuel burning. A variety of methods combining diversity, frequency and toxiphoby have been used to demonstrate correlation of lichen diversity, frequency and sensitivity to levels of SO_2 deposition (de Sloover & LeBlanc 1968). The scale produced by Hawksworth and Rose (1970) and Gilbert (1974) in Britain was adapted for use in Hong Kong by Thrower (1980) using sensitive and tolerant species: Zone 6—presence of foliose *Parmotrema tinctorum*, Zone 5—presence of fruticose species of *Usnea*, Zone 4—presence of crustose species of *Graphidaceae* and *Dirinaria picta*, Zones 3 & 2—presence of *Pyxine cocoes* and *Lepraria* respectively, Zone 1—too polluted for the survival of lichens. Thrower (1980) showed that lichen deserts in Zone 1 corresponded to areas in the vicinity of power stations or of industry in Hong Kong and that clean air zones 5 and 6 with *Parmotrema tinctorum* and *Usnea* spp. were further from the city and at higher altitudes. Around Osaka in Japan size and frequency of *Parmotrema tinctorum* has been monitored and correlated with SO_2 deposition (Sugiyama *et al.* 1976) while Hamada *et al.* (1995) correlated the distribution of *Phaeophyscia limbata* and *Lecanora pulverulenta* with atmospheric pollutants SO_2 and NO_2.

In Germany, the VDI (Verein Deutscher Ingenieure—German Association of Engineers) adopted a bioindication method using frequency of selected lichens to produce an index (LGW [=Luftgütewert]) of air

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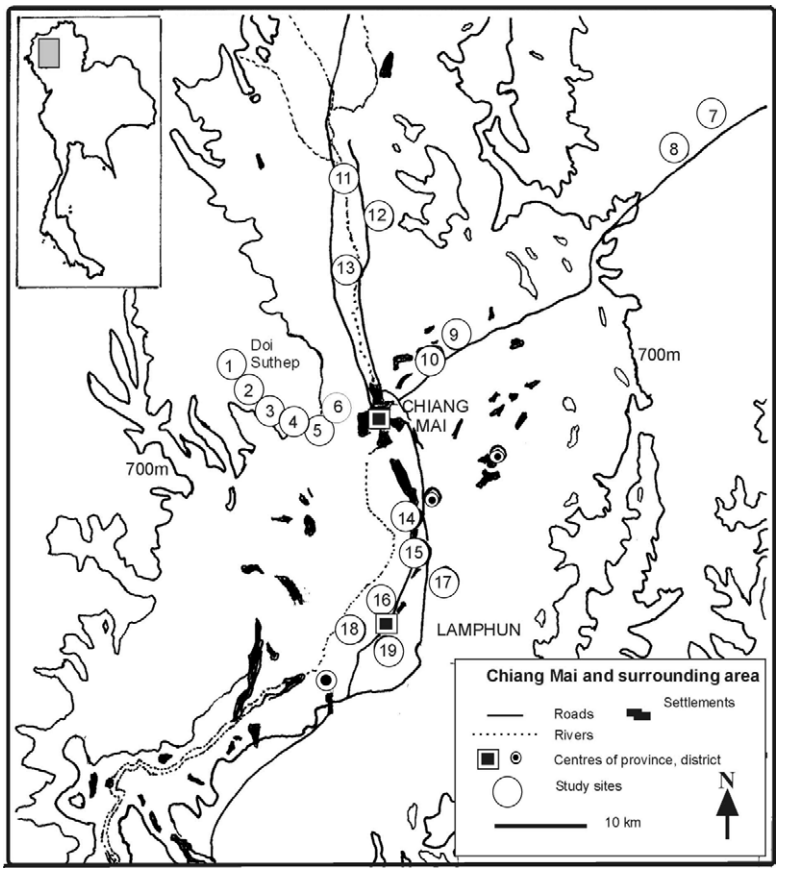

FIG. 1. Location of study sites in the provinces of Chiang Mai, Chiang Rai, Lampang and Lamphun (Northern Thailand) listed in Table 1.

quality for each land unit sampled based on the standard deviation across a defined study (VDI 1995). Selected lichens included foliose and crustose lichens that were widely distributed in Europe (Kirschbaum 1995; Kirschbaum *et al.* 1996; Kirschbaum & Hanewald 1998; Dilg 1999; Windisch 1999; Nobel *et al.*, 1999; Kricke & Loppi 2002). Preliminary investigations suggested that lichens could be used as biomonitors of air quality in areas where population and industry were rapidly expanding in tropical conditions in Northern Thailand (Saipunkaew 2000).

The objectives of this paper were to apply standard European sampling methods of epiphytic lichens in and around Chiang Mai city in Northern Thailand in order to detect taxa that can be used as biomonitors of urban pollution in tropical conditions, and to determine environmental factors influencing distribution of epiphytic lichens in a range of altitudes and vegetation types from natural forest to agricultural and urban habitats.

Materials and Methods

The study area

Chiang Mai city (18°47′N, 88°59′E) is the capital of Chiang Mai Province lying in the basin of the Mae Ping river at about 300 m elevation. It has expanded rapidly to 171594 inhabitants in 1998 (National Statistic Office of Thailand 2004). The city is situated at the foot of Doi Suthep mountain which rises steeply to 1685 m west of the city (Fig. 1). To the east, there is another ridge of mountains separating provinces Chiang Mai and

https://doi.org/10.1017/S0024282905014994 Published online by Cambridge University Press

Chiang Rai. In the plain to the north and south of the city there is irrigated agricultural land with rice and other crops. Large scale industrial activities in the Northern Region Industrial Estate have been developed recently in the river basin to the south of the city in Lamphun province.

The climate consists of a cool dry season caused by continental airflows from the north-east, with temperatures of 20–25°C from November to February. The hottest season of the year from March to May, when daytime temperatures may be as high as 45°C, is followed by a switch to the rain-bearing south westerlies which last from June to October. Below 500 m, rainfall averages between 600 and 1000 mm per annum, but the rainfall on Doi Suthep is *c.* 1200 mm per annum and the temperature drops by *c.* 0.6°C per 100 m altitude, so that the mountain-top is cooler and wetter with high relative humidity for a large part of the year (Ogawa *et al.* 1961).

Vegetation

Doi Suthep-Pui mountain is a National Park of high conservation importance. It represents the most natural and least disturbed vegetation of the area ranging from dry dipterocarp forest (DDF) on the lower slopes dominated by deciduous species of *Dipterocarpus* and *Shorea*, through seasonal-evergreen forest (SEF) with a high proportion of emergent leguminous trees, to the evergreen forest (EF) dominated by fagaceous species of *Castanopsis*, *Quercus* and *Lithocarpus* together with other evergreen species of *Anneslea*, *Phoebe* and *Terminalia* (Wolseley & Aguirre-Hudson 1997). Evergreen forest is found above 1000 m and SEF may be found in a mosaic with DDF where the DDF occupies the drier slopes and SEF the moister valleys. Increasing use of fire in all sites has allowed the fire-tolerant DDF to expand at the expense of other forest types (Wolseley 1997). The lowland forests were logged a long time ago and vegetation in the lowland areas is mainly determined by surrounding land use and the availability of the selected phorophyte *Mangifera indica*. In the lowland areas sites are distinguished as agricultural (A) and urban (U).

Selection of sites

The study sites lay in radiating directions from Chiang Mai city, and include the industrial area south of the city, agricultural areas to the north and south, and the hill areas to the west and east (Fig. 1). This allowed the collection of lichen data from sites in a range of conditions including different altitudes, different vegetation types and upwind or downwind of sources of pollution. Nineteen sites were selected for investigation: 6 sites on the west of the city towards Doi Suthep mountain with altitudes ranging from 420 to 1450 m; 4 sites across lowland areas to hills up to 1100 m to the north-east; and in the lowland and agricultural areas to the north and south, 3 and 6 sites, respectively, were chosen where accessible *Mangifera indica* trees occurred at altitudes between 260–360 m (Table 1). Sites were assigned to one of 5 categories of disturbance; category 1 represented sites in undisturbed forest on Doi Suthep. Category 2 included sites adjacent to roads where there was obvious damage to natural forests. Category 3 included sites with considerable fire damage. Village and agricultural areas were in category 4 and industrial and urban sites in category 5. In industrial and urban sites where it was difficult to locate suitable trees, the nearest suitable area was selected, for example sites 16 and 17 located up- and down-wind of the Northern Region Industrial Estate (Table 1. Fig. 1).

Sampling method

The sampling method used is outlined in the VDI guideline (VDI 1995), based on the frequency of occurrence of lichen species on the bark of defined tree species. In order to accommodate tropical conditions and vegetation it was modified as follows. Where possible the widespread mango tree (*Mangifera indica* L.) was selected and in forest margins where *Mangifera* species were absent other exposed trees with healthy lichen communities were selected. The area defined for sampling was 0·5 × 0·5 km. Exposed trees with a ± straight trunk were selected and the aspect of the trunk where lichen cover was highest was chosen for sampling using a 20 × 50 cm grid frame with 10 sampling units of 10 × 10 cm. This was fixed to the trunk between 1–1·50 m above ground level. Girth at 1·50 m and quadrat aspect were recorded and all lichen species occurring in the grid-frame were recorded and their frequency in 10 units noted. Lichen species in the vicinity of the grid frame were also recorded. Samples of all species were collected and labelled for later identification. The sampling was carried out between May and July 1998.

Identification of materials

The preliminary study (Saipunkaew 2000) used lichen diversity of a few easily identifiable species or genera for air quality mapping. However in order to detect species that could be used as pollution indicators in tropical areas identification of all specimens was essential. Specimens were sorted to genus using light microscopy and spot tests. Macrolichens were determined to species level using other techniques where appropriate, such as High Performance Thin Layer Chromatography. This was essential in order to identify species of *Parmeliaceae* by their characteristic secondary compounds (S. H. J. J. Louwhoff *et al.* unpublished). Crustose taxa were identified to genus, where possible to species, and preliminary investigations begun to distinguish taxa that were new to science in genera of *Arthoniaceae* and *Parmeliaceae*. Specimens of the crustose families *Graphidaceae*, *Lecanoraceae* and sterile crusts were excluded from the investigation. Specimens are deposited at the Natural History Museum, London (BM) and the Herbarium of Department of Biology, Chiang Mai University (CMU) Thailand.

TABLE 1. *Study sites in Chiang Mai and surrounding area*

Site number and name		Longitude–latitude	Altitude (m)	Vegetation*	Disturbance†	Distance from urban centre (km)	Direction from urban centre
1	Sanku, Doi Suthep	98°54′E, 18°49′N	1450	EF	1	18	W
2	Phuping Palace, Doi Suthep	98°54′E, 18°48′N	1350	EF	2	15	W
3	St Louis temple, Doi Suthep	98°55′E, 18°48′N	1000	EF	2	13	W
4	CMU observation station, Doi Suthep	98°55′E, 18°47′N	840	SEF	3	10	W
5	Wat Palad temple, Doi Suthep	98°56′E, 18°48′N	600	DDF	3	7	W
6	Chiang Mai Zoo	98°57′E, 18°48′N	420	DDF	2	5	W
7	Ban Khun Lao	99°23′E, 19°10′N	1100	EF	2	53	E
8	Ban Pang Aun	99°03′E, 19°20′N	900	SEF	3	47	E
9	Ban Bo Hin	99°06′E, 18°52′N	360	A	4	13	NE
10	Ban Mae Kuang	99°04′E, 18°50′N	330	A	4	8	NE
11	Ban Lom Luang	98°58′E, 19°03′N	330	A	4	27	N
12	Ban Mae Fang Mai	98°59′E, 18°59′N	360	A	4	22	N
13	Ban Pa Bong	98°59′E, 18°55′N	350	A	4	17	N
14	Saraphi	99°03′E, 18°43′N	330	U	5	0	C
15	Ban Umong	99°04′E, 18°40′N	320	A	4	3, 17	N&S
16	Industrial area 1	99°05′E, 18°35′N	260	U	4	0	C
17	Industrial area 2	99°02′E, 18°37′N	270	U	4	0	C
18	Lamphun city	99°01′E, 18°34′N	260	U	5	0	C
19	Sri Muang Yoo	99°00′E, 18°34′N	260	A	4	3	S

*Vegetation type: evergreen forest (EF), semi-evergreen forest (SEF), dry dipterocarp forest (DDF), agriculture (A) and urban area (U).
†Disturbance rating: 1—undisturbed forest of native species, 2—disturbed forest but native species present, 3—sparse fire-damaged forest, 4—agriculture and domestic and 5—urban, traffic and industrial.

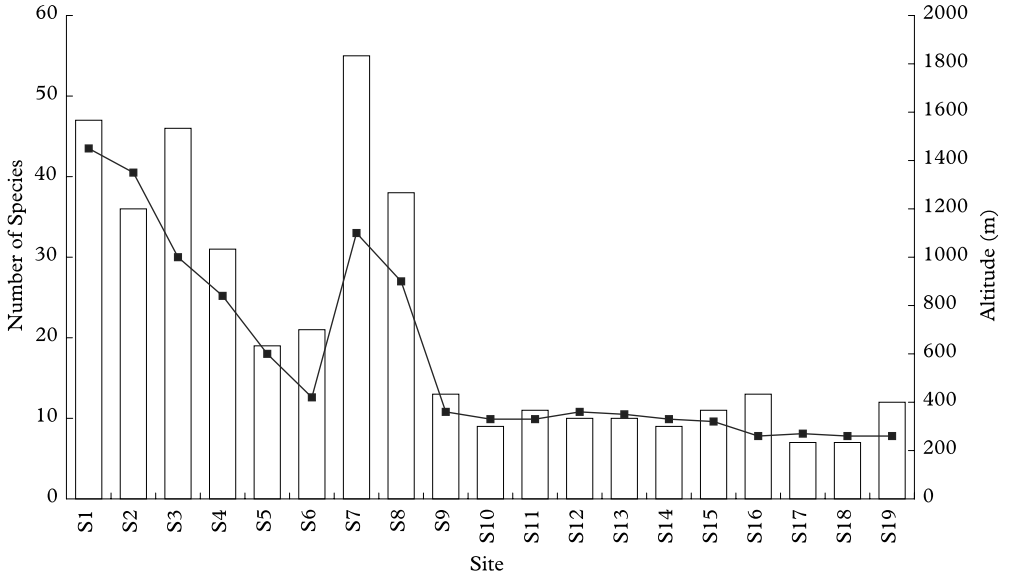

FIG. 2. Total species diversity (□) on all trees sampled in each site and altitude of each site (■).

Data entry and processing

All data were entered in a database. Following preliminary sorting of environmental factors, multivariate analysis was carried out using PRIMER 5 Principal Components Analysis (PCA), Non-Metric Multi Dimensional Scaling (MDS), and Cluster Analysis (CA) were used to establish similarities and differences between lichen components and sites. Site similarity was estimated based on average frequency of all genera on all trees in each site, and in macrolichens by average frequency of all species. In MDS and Cluster Analysis, the Bray-Curtis coefficient of similarity was used. The species compositions involved in site relationships were elucidated using the SIMPER (SIMilarity PERcentage contribution) routine in PRIMER. Factors used in the analysis include altitude, forest type, girth of tree and disturbance categories 1-5 where 1 represented 'low' and 5 represented 'high'.

Results

Total lichen diversity on trunks within each site (Fig. 2) showed that lichen diversity was highest in the montane forest zones above 600 m and lowest in agricultural and urban areas below 400 m. The highest diversity was found in EF forest in site 7 at 1100 m where 55 species were recorded (Table 2) and the lowest diversity of 7 species was found in sites 17 at 270 m and 18 at 260 m (Fig. 2). Cluster Analysis also distinguished upland (>400m) from lowland (<400m) sites, except for site 8 at 900 m which had been highly disturbed by fire (Fig. 3A). However, lowland trees sampled were all *Mangifera* in artificial sites whereas trees sampled in upland sites were forest trees in natural to disturbed sites. The distribution of upland sites followed an altitudinal gradient that was also associated with changes in forest type from EF in sites above 1000 m to DDF in sites 5 and 6 (Fig. 3).

Correlation was highest between the combined factors of altitude and vegetation type (Spearman's rank correlation r=0·84, P<0·01) followed by the combined factors of altitude with disturbance categories (r=0·83) and by altitude (r=0·81). Individually and in combination with each other, vegetation type and category of disturbance gave lower, more moderate correlations (r=0·71–0·79).

The SEF and EF sites were distinguished by both geographical location (sites 7 and 8 being on another range of mountains) and type of disturbance; the most fire-damaged site 8 being more similar to the urban and agricultural group (Fig. 3). Analysis of data from all taxa at generic level did not

TABLE 2. *Species diversity at each site and % contribution of lichen taxa to each site. Species with % contribution below 1 are omitted.*

	Forest sites								Agricultural and urban sites										
Species	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19
Species diversity per site	47	36	46	31	19	21	55	38	13	9	11	10	10	9	11	13	7	7	12
Arthonia cinnabarina	—	—	—	—	—	—	—	2·7	—	—	—	—	—	—	—	—	—	—	—
Arthonia spp.	—	—	—	—	4·3	9·7	—	—	2·3	14·3	2·0	—	3·3	8·7	8·7	39·4	15·3	2·4	6·4
Arthonia subgyrosa	—	—	—	—	—	27·3	—	—	—	—	—	—	—	—	—	—	—	—	—
Bacidia spp.	—	—	1·9	—	—	—	0·9	8·5	—	—	0·7	—	—	—	0·9	—	—	—	—
Phyllopsora spp.	4·5	—	—	—	—	—	—	10·3	—	—	—	—	—	—	—	—	—	—	—
Chrysothrix xanthina	—	—	1·6	—	3·2	12·1	1·1	—	0·9	6·6	4·4	12·6	—	3·2	2·1	0·9	0·9	7·6	6·3
Dimerella lutea	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0·6	—	—	—	—
Haematomma flexuosum	—	—	—	—	—	—	1·2	—	—	—	—	—	—	—	—	—	—	—	—
H. cf. *puniceum*	—	—	—	2·8	—	—	3·2	—	—	—	—	—	—	—	—	—	—	—	—
H. collatum	—	6·7	22·4	8·2	—	—	6·6	—	—	—	—	—	—	—	—	—	—	—	—
H. wattii	—	3·0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Lecidea spp.	—	—	8·9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Bulbothrix goebelii[⋆1]	—	—	4·7	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
B. isidiza[⋆1]	—	8·7	19·5	2·8	10·1	—	16·6	6·5	—	—	—	—	—	—	—	—	—	—	—
B. pigmentacea[⋆1]	—	—	1·6	12·2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
B. setschwanensis[⋆1]	—	—	—	9·7	—	—	0·9	—	—	—	—	—	—	—	—	—	—	—	—
Everniastrum nepalense[⋆1]	2·4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
E. scabridum[⋆1]	—	1·0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Hypogymnia pseudobitteriana[⋆1]	2·5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Hypotrachyna exsecta[⋆1]	2·4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Parmelinella wallichiana[⋆1]	39·4	—	—	6·1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Parmelinopsis expallida[⋆1]	—	—	1·4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Parmotrema nilgherrense[⋆1]	—	—	—	—	—	—	—	7·4	—	—	—	—	—	—	—	—	—	—	—
P. poolii[⋆1]	—	—	—	—	—	—	—	14·5	—	—	—	—	—	—	—	—	—	—	—
P. saccatilobum[⋆1]	—	—	—	—	—	6·8	—	—	—	—	—	—	—	—	—	—	—	—	—
P. sancti-angeli[⋆1]	—	1·2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
P. tinctorum[⋆1]	15·0	7·0	6·8	25·3	5·4	—	15·5	—	—	—	—	—	—	—	—	—	—	—	—
Relicinopsis rahengensis[⋆1]	—	—	—	7·1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Rimelia reticulata[⋆1]	—	22.0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Usnea spp.	7·5	9·7	—	—	—	—	14·3	—	—	—	—	—	—	—	—	—	—	—	—
Pertusaria spp.	2·2	4·0	2·2	8·0	9·0	25·5	0·9	—	—	—	—	—	—	—	—	—	—	—	—
P. pertusa	—	—	—	—	—	—	1·0	—	—	—	—	—	—	—	—	—	—	—	—

TABLE 2. *Continued*

Species	Forest sites								Agricultural and urban sites										
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19
Species diversity per site	47	36	46	31	19	21	55	38	13	9	11	10	10	9	11	13	7	7	12
Pertusaria dehiscens	—	—	—	—	—	—	1·2	—	—	—	—	—	—	—	—	—	—	—	—
P. pertusella	—	—	—	—	17·8	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Buellia spp.*[2]	8·1	—	3·6	—	9·0	—	—	—	—	—	—	—	—	—	—	—	—	—	—
*Diplotomma alboatrior**[2]	—	—	—	—	—	9·7	—	—	—	—	—	—	—	—	—	—	—	—	—
*Dirinaria aegialita**[2]	—	—	4·8	5·6	9·0	—	—	—	—	—	—	—	—	—	—	—	—	—	—
*D. applanata**[2]	—	—	—	—	—	—	10·6	—	—	—	—	3·5	—	—	—	—	—	—	—
*D. confluens**[2]	2·7	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
*D. picta**[2]	—	—	—	—	—	—	—	16·7	79·2	0·5	15·5	21·4	62·8	40·4	39·4	12·7	8·6	—	21·9
Heterodermia spp.*[2]	10·8	35·3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
*Heterodermia obscurata**[2]	—	—	—	—	—	—	20·3	11·0	—	—	—	—	—	—	—	—	—	—	—
*Hyperphyscia adglutinata**[2]	—	—	—	—	—	—	—	—	—	23·9	9·5	—	—	2·1	2·4	8·8	35·5	18·3	5·2
*Pyxine berteriana**[2]	—	—	—	—	—	—	1·2	—	—	—	—	—	—	—	—	—	—	—	—
*P. coccifera**[2]	—	—	—	12·4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
*P. cocoes**[2]	—	—	—	—	—	—	—	—	12·5	54·3	65·0	62·5	32·7	44·3	33·2	29·6	39·7	71·7	59·1
*P. consocians**[2]	—	—	—	—	15·2	—	—	—	—	—	—	—	—	—	—	—	—	—	—
*P. coralligera**[2]	—	—	—	—	12·8	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Melanotheca spp.	—	—	—	—	—	—	—	—	1·4	—	—	—	—	—	—	—	—	—	1·2
Pyrenula spp.	—	1·5	5·5	—	—	9·0	0·9	18·3	0·7	—	0·7	—	—	—	—	3·1	—	—	—
Bactrospora spp.	—	—	—	—	—	—	—	—	—	—	2·1	—	—	—	—	—	—	—	—
Graphidastra spp.	—	—	2·4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Lecanographa sp.	—	—	—	—	—	—	—	—	1·5	0·6	—	—	1·3	1·3	12·8	—	—	—	—
Caloplaca sp.	—	—	—	—	—	—	3·6	—	—	—	—	—	—	—	—	—	—	—	—
Porina spp.	—	—	—	—	4·3	—	—	4·1	—	—	—	—	—	—	—	—	—	—	—
Laurera spp.	2·6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Trypetheliaceae	—	—	—	—	—	—	—	—	0·8	—	—	—	—	—	—	5·5	—	—	—
Trypethelium eluteriae	—	—	—	—	—	—	—	—	0·7	—	—	—	—	—	—	—	—	—	—

*Species used in macrolichen analysis, [1]*Parmeliaceae*, [2]*Physciaceae*.

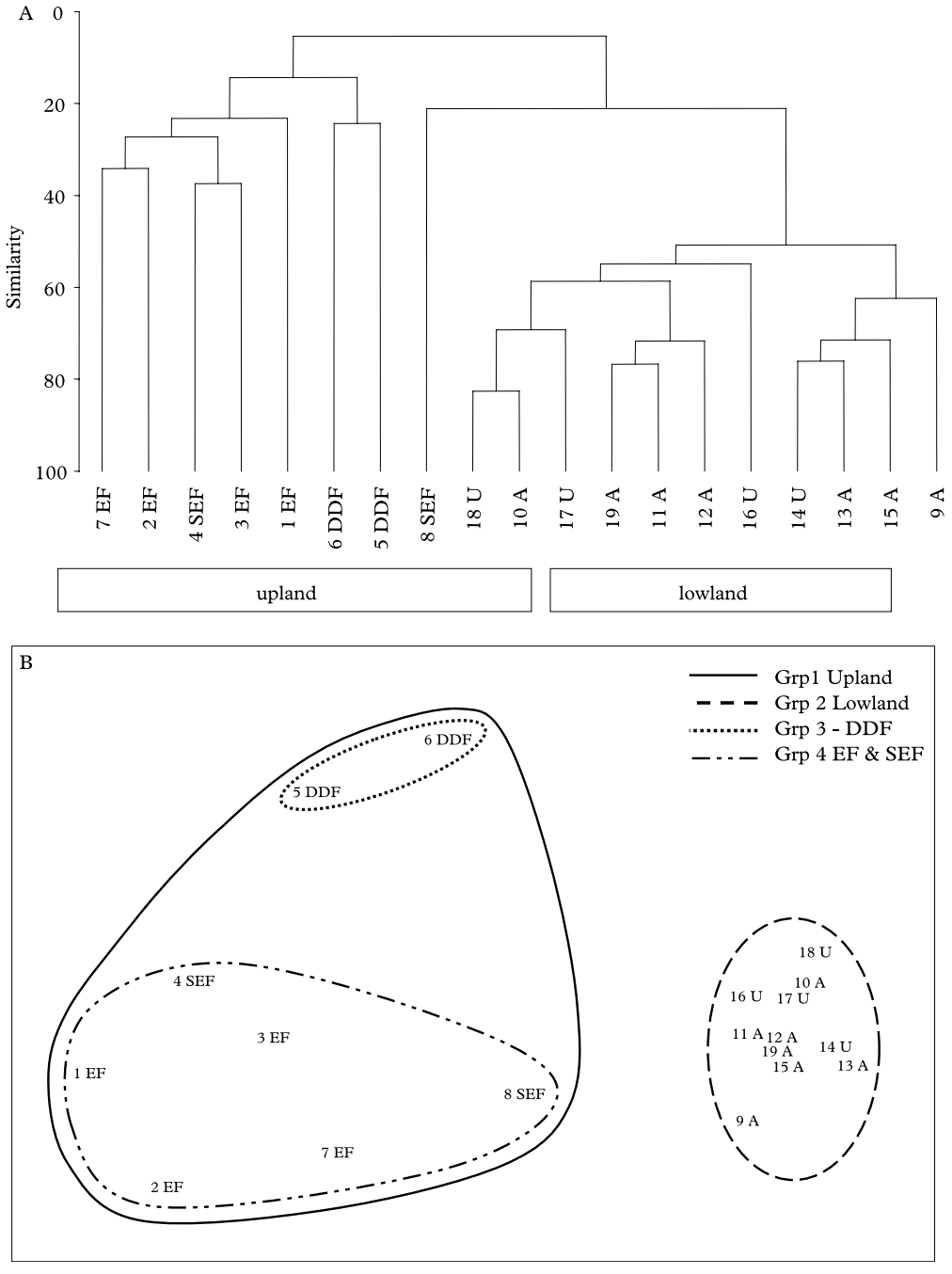

FIG. 3. A, dendrogram from Cluster Analysis using PRIMER based on average frequency of all genera per site showing separation of upland from lowland sites at the first level except site 8, that urban and agricultural sites in the lowland are not clearly distinguished and that upland DDF sites are distinguished from EF sites; B, site similarity based on data from 3A showing separation of lowland and upland sites, within upland sites separation of forest type and altitude and poor separation of agricultural and urban sites in the lowlands.

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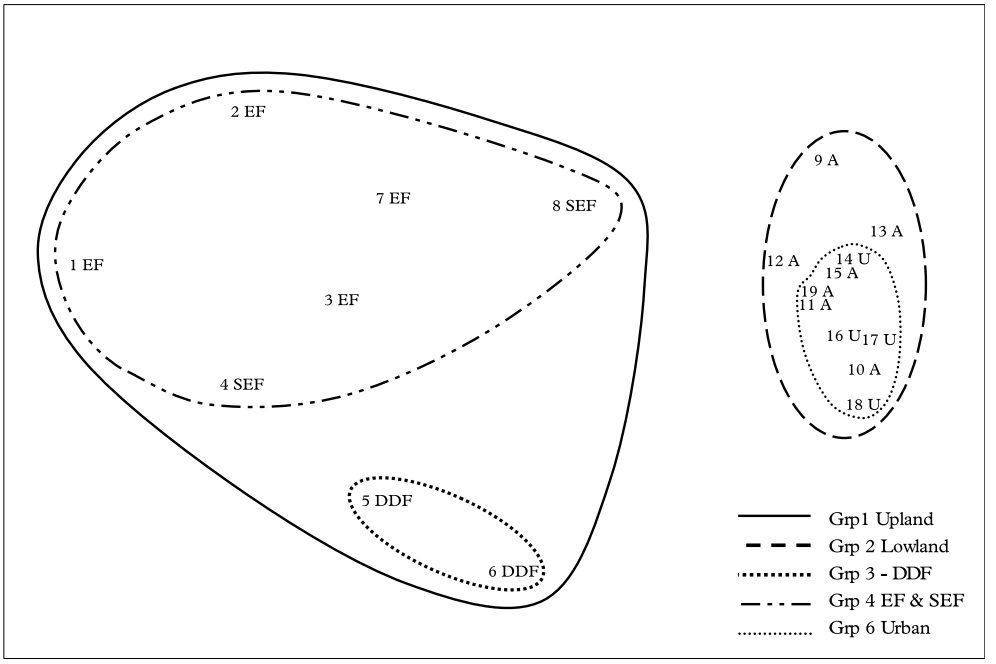

FIG. 4. Site similarity based on average frequency of species of macrolichens showing a similar grouping of upland and lowland sites as the analysis at generic level, and better definition of urban and agricultural sites. Group 1 coinciding with upland forest sites, group 2 with lowland sites where *Dirinaria picta* and *Pyxine cocoes* are present, group 3 with DDF sites, group 4 with EF and SEF sites, group 6 with sites where *Hyperphyscia adglutinata* is present.

distinguish urban from agricultural sites where macrolichens were infrequent and crustose taxa more frequent. In order to avoid the problem caused by unidentified crustose species and to test whether macrolichen species would allow further differentiation of the sites, analysis of macrolichen data at species level was undertaken using average frequency on trees in all sites (Fig. 4). This analysis showed a similar pattern in separating upland and lowland sites, but also provided clusters within the lowland sites that showed a better correlation with urban and agricultural sites.

The species components of the sites are shown in Table 2 using frequency of all species to estimate percentage contribution of each species to the sampled lichen community in each site (contributions below 1% are omitted). This table shows that the separation was based on the differing composition of the lichen flora in the upland and lowland regions. Species of *Parmeliaceae* belonging to genera *Bulbothrix*, *Everniastrum*, *Hypogymnia*, *Hypotrachyna*, *Parmelinella*, *Parmelinopsis*, *Parmotrema*, *Relicinopsis* and *Rimelia* were found only in the upland forests at 420 m and above. Species of *Physciaceae*, including *Dirinaria picta*, *Hyperphyscia adglutinata*, and *Pyxine cocoes*, are widespread in the lowland sites. Other species of *Pyxine* and *Dirinaria* are associated with natural forest sites at and below 1000 m (Table 2). There are very few species that are found in both upland and lowland clusters except *Chrysothrix xanthina* which is frequent in fire damaged forests and occurs in both DDF forest and in EF sites 3 and 7, which are regularly burned.

At the macrolichen level the lowland sites were distinguished by the presence of *Dirinaria picta* and *Pyxine cocoes* occurring in both agricultural and urban areas (Fig. 4). Within this group, urban/industrial sites and

https://doi.org/10.1017/S0024282905014994 Published online by Cambridge University Press

adjacent NE areas were distinguished by the presence of *Hyperphyscia adglutinata* with a gradient in the % contribution from sites with <10% (11, 14, 15, 16, 19) to sites with >18% (10, 17, 18). The latter corresponded to urban and industrial areas and site 10 lying to the NE of Chiang Mai city where atmospheric pollutants are deposited by the wet south-westerly monsoon. In these sites, diversity was also very low with 7–9 species (Fig. 2) compared to 13 species in site 16 which is in the northern part of the city.

Discussion

The difference in climate between the uplands and the lowlands in the tropics is associated with rapid shifts in temperature and humidity (Wolseley 1991). In hot climates this has been shown to cause a strong gradient in lichen communities (Loppi *et al.* 1997; Pirintsos *et al.* 1995). This difference is exacerbated in Thailand by the loss of forest in the lowlands causing increasing atmospheric dryness and higher average temperatures (Wolseley & Aguirre-Hudson 1997). In this paper, lowland and upland lichen floras were distinguished in analyses of all species at generic level and at macrolichen species level, lichen communities showing a good correlation with altitude, forest type and disturbance. This was apparent at the generic and family level where *Parmeliaceae* dominated the upland community and *Physciaceae* the lowland community (Table 2). The widespread occurrence of the macrolichen *Parmotrema tinctorum* on the trunks sampled in the uplands and its absence from the trunks in the lowlands suggests that this species may be restricted by factors other than pollution. A global increase in members of the *Physciaceae* (including species of *Dirinaria* and *Pyxine*) has been linked to climate change (van Herk *et al.* 2002) and also to an increase in dust (Loppi & Pirintsos 2000), the latter being a characteristic condition of urban and agricultural lowlands in the tropics. *Dirinaria picta* and *Pyxine cocoes* are associated with the lowland climate where forest loss has already occurred but are also tolerant of pollution in urban sites. The high percentage contribution of *Dirinaria picta* at site 8 at 900 m altitude was associated with a high disturbance level from repeated burning causing a shift towards the lowland group (Fig. 4). However, fire is of widespread occurrence in the DDF forest in Thailand (Wolseley 1997) and this forest has few species in common with the lowland forest, other than *Chrysothrix xanthina* and several species of *Pyxine* that are not found on lowland *Mangifera* trees where fire is a rare occurrence.

The distribution of clusters in the lowlands is difficult to interpret without data on atmospheric pollutants. *Hyperphyscia adglutinata* is associated with nutrient-enriched bark in Europe (Purvis *et al.* 1992) but is now becoming widespread in urban areas across the world including SE Asia, in Japan (Kashiwadani 1985), Hong Kong (Aptroot & Seaward 1999) and Taiwan (Aptroot *et al.* 2002). In Thailand in the Chiang Mai area, this species is absent from the upland forests and present in all lowland sites except sites 9, 12 & 13, which are situated to the north of Chiang Mai city (Fig. 4). The percentage contribution was highest in urban and industrial centres i.e. sites 10, 17 and 18 where total diversity was also very low.

Pollution data from a monitoring station of the Pollution Control Department (PCD) at Yupparat School in the centre of Chiang Mai city and from a provincial area outside the city are available for the years 1998 and 1999. This shows that SO_2 levels are relatively low being 2·8 and 1·1 ppb annual mean concentrations inside and outside the city respectively, whereas NO_2 is 5·9 and 8 ppb annual mean concentration respectively and PM10s are 71·1 and 48·2 $\mu g\ m^{-3}$ respectively. Sulphur dioxide and NO_2 mean annual concentrations are considerably lower than those reported for Osaka city by Hamada *et al.* (1995). However Chiang Mai city is not the main source of industrial pollution and the absence of data from the industrial area does not permit comparison with other sites in the tropics. Recent work using modelling of atmospheric sulphur in

Thailand at a 50 km resolution shows the Chiang Mai square with monthly means above 15 ppb(v) and adjacent squares with >10 ppb(v) to the north and east in July and to the south and west in December (M. Engardt, pers comm.). Although the 50 km grid square in Chiang Mai includes all our sites except 7 and 8, our results suggest a similar effect on lichen communities to the NE of urban sites due to wet deposition during the monsoon season and less effect during the dry season.

The occurrence of natural and semi-natural vegetation in the uplands is associated with higher humidity and lower temperatures than in the lowland areas, where the natural vegetation has long ago been destroyed (Wolseley & Aguirre-Hudson 1997) hence the correlation between lichen communities and altitude and forest type. Although there is no separation of agricultural and urban lichen communities in the generic analysis of all taxa, analysis of macrolichen species provides a separation of sites that correspond to expected atmospheric deposition of pollutants from urban and industrial areas. *Hyperphyscia adglutinata* is usually associated with nutrient-enriched substrata so that its association with industrial/urban and adjacent areas of Chiang Mai suggests that acidification is not the main factor affecting urban lichen communities in the vicinity of Chiang Mai. Recent research in London has demonstrated a rapid increase in lichens characteristic of nutrient enrichment (nitrophytes) and a decrease in acidophytes (Davies *et al.* 2004; Larsen *et al.* 2005), associated with falling SO_2 levels.

We are now assessing the use of epiphytic lichens as bioindicators of pollution in the lowlands of northern Thailand in eight provinces. This will provide information from a wider geographic area on factors influencing lichen distribution in the lowland tropics.

Conclusions

An essential part of developing lichens as bioindicators in the tropics is the identification of species that are sensitive to, or tolerant of, changes in atmospheric conditions. Within the Chiang Mai area lichen communities of natural forests with a high frequency of *Parmeliaceae* of the uplands are clearly separated from those of anthropogenically altered habitats of the lowlands with a high frequency of *Physciaceae*. This can be clearly seen at both generic and species levels of analysis.

Macrolichen species of epiphytic communities in the lowlands can be used to distinguish urban and industrial sites from agricultural and rural sites. The acquisition of more lichen data over a wider area of northern provinces together with atmospheric monitoring or modelled pollution data will allow further elaboration of lichens as bioindicators in the tropics.

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Accepted for publication 17 *March* 2005