

# FINAL REPORT



FR1570

Grant No. RG/2004/BM/01 & RG/2008/EB/02



**Section 1**

**Information regarding Project/Project Personnel:**

- i) Contract Number- RG/2004/BM/01 and RG/2008/EB/02
  - ii) Title of the Project- Study of diversity and taxonomy of lichens in the Horton Plains National Park with a view to biomonitor the ecosystem health.
  - iii) Principal Investigator- Prof. V. Karunaratne
  - iv) Co-Investigators- Dr. D.S.A. Wijesundara
  - v) Institute(s) where research was being carried out- National Herbarium, Royal Botanic Gardens, Peradeniya and Department of Chemistry, University of Peradeniya, Peradeniya.
  - vi) Date of award- RG/2004/BM/01-30/09/2004  
RG/2008/EB/02-01/05/2008
  - vii) Date of completion of Project-30/04/2009
  - viii) Total allocation of funds (Rs)- RG/2004/BM/01-Rs. 524,500.00  
RG/2008/EB/02-Rs.300,000.00
  - ix) Total spent (Rs)-All the amount recieved
  - x) Number of Research Students employed-One
  - xi) Post graduate degree completed with dates-Ph.D.
  - xii) Number of Technical Assistants and/or labourers employed and period of service-None
  - xiii) Publications/Communications arising from the project during the reporting period-
- Jayalal, R.G.U., Wijesundara, D.S.A. and Karunaratne, V. (2005). Preliminary survey of lichen flora of Horton Plains. Proceeding of the Peradeniya University Research Sessions *Vol. 10*. Pp. 107.
  - Jayalal, R.G.U., Wijesundara, D.S.A. and Karunaratne, V. (2006). Preliminary Survey of Macrolichen flora of the Horton Plains National Park. 10<sup>th</sup> Anniversary International Symposium of the Sabaragamuwa University of Sri Lanka. Pp.265.
  - Jayalal, R.G.U., Illeperuma, O.A., Wijesundara, D.S.A. and Karunaratne, V. (2006). Monitoring air pollution levels in the Horton Plains National Park using passive gas sampling technique. Sri Lanka Association for the Advancement of Science. Proceeding of the 62<sup>nd</sup> Annual Sessions. Pp. 124.

- Jayalal, R.G.U., Wijesundara, D.S.A. and Karunaratne, V. (2006). Preliminary survey on the lichen–host species diversity in the Horton Plains National Park. Proceeding of the Peradeniya University Research Sessions. *Vol. 11*. Pp. 132.
- Jayalal, R.G.U., Wolseley, P., Wijesundara, D.S.A. and Karunaratne, V.(2007). New record of *Anzia* (Lichenized ascomycotina, parmeliaceae) from Horton Plains National Park. Proceeding of the Peradeniya University Research Sessions. *Vol. 12*, Pp. 60.
- Jayalal, R.G.U., Wijesundara, D.S.A. and Karunaratne, V.(2007). Distribution of Lobariaceae (a lichen family) within the Horton Plains National Park Sri Lanka. Proceedings of the 63<sup>rd</sup> annual sessions, Association for the Advancement of Science. Pp. 59-60.
- Jayalal, R.G.U., Wolseley, P., Wijesundra, S. and Karunaratne, V. (2008). Macrolichen diversity as an indicator of environmental changes in montane forest of Horton Plains National Park, Sri Lanka. The 6<sup>th</sup> IAL symposium and annual ABLIS meetings, California, USA. Pp.140.
- Jayalal, R.G.U., Wolseley, P., Wijesundra, S. and Karunaratne, V. (2008). Distribution of lichens with respect to pH variation of the host trees within the Horton Plains National Park, Sri Lanka. 64<sup>th</sup> annual sessions, Sri Lanka Association for the Advancement of Science. Pp. 104.
- Jayalal, R.G.U., Wijesundara, D.S.A. and Karunaratne, V.(2008).Lichenological works in Sri Lanka. 13<sup>th</sup> International Forestry and Environment Symposium 2008.Pp.69-70.
- Jayalal, R.G.U., Wolseley, P., Wijesundra, S. and Karunaratne, V. (2008).Sterile crust lichens as indicators of forest health in Horton Plains National Park, Sri Lanka. Peradeniya University Research Sessions 13, 309-311.

## **Section 2**

### **Executive Summary of the Project:**

Although lichens are a conspicuous component of many tropical environments, the taxonomy and description of these are little studied. In the tropics, environmental techniques using lichens are less developed, owing to a lack of knowledge of the taxonomy and the ecology of the organisms. In Sri Lanka, there is a paucity of knowledge of its lichen flora. Hence, an essential part of the current project was to produce baseline taxonomic data.

Prior to this study, taxonomic work on lichens of Sri Lanka had been conducted entirely by overseas scientist commencing in 1849 and leading to the Hale's collection (1976-1978). These studies have documented 659 species in 122 genera. Information on their natural history is completely lacking and only a few specimens have been deposited in Sri Lanka. In the present study, lichens from 18 sampling sites within continuous forest and forest islands were selected using remote sensing map of Horton Plains National Park (HPNP). Types of lichens and their diversity in relation to light intensity, temperature, tree species, density, height, diameter and the distribution pattern of trees within the transect were recorded. At the same time air quality monitoring in the HPNP was carried out to determine the lichen species sensitivity to the disturbance or air pollution in HPNP.

A total 379 lichen species belonging to 67 genera and 24 families were identified. This study documented several new lichen taxa for Sri Lanka that consist of 12 genera and 102 species. The 12 new genera were composed of 7 foliuses (*Fuscopannaria*, *Leioderma*, *Anzia*, *Canomaculina*, *Cetrelia*, *Canoparmelia*, *Menegazzia*), 4 crustoses (*Punctelia*, *Pleurotrema*, *Parathelium*, *Pleurotheliopsis*) and 01 fruticose (*Polichidium*) lichen genera. Similarly the 102 species were composed of 11 species of crustose, 89 species of foliose and 03 species of fruticose. A principal co-ordinate analysis (PCA) of site data, tree data and lichen cover shows that most of the lichens are highly correlated with the bark pH and light demanding crustoses such as Thelotremataceae, Pyrenulaceae are positively correlated with the high light intensities. Most of the lichens present in the study plots preferred relatively high pH range (5.0-6.0). The most dominant lichen species (314 species) within this pH range were macrolichens like *Lobaria retigera*, *Pseudocyphellaria beccarii*, *Heterodermia microphylla* and microlichens like *Graphis sp.* *Myriotrema sp.* like microlichens. The number of lichen colonies increase with increase diameter class from 5-10 cm to 11-20 cm. The highest number of lichen colonies was found on hosts of 11-20 cm diameter class in both forest types. It was clearly observed that the number of lichen colonies decrease with increasing diameter size of the lichen host species. According to the observations smooth bark type had the highest diversity of lichens in both forest types and this was followed by smooth to rough bark type. The least lichen diversity was observed on deeply furrowed bark type in the continuous forest, while in the forest islands, the least diversity was observed on flaky bark type.

The data revealed that the concentrations of ambient NO<sub>2</sub> and SO<sub>2</sub> were very low in HPNP. The variations of ambient NO<sub>2</sub> and SO<sub>2</sub> concentration during the study period showed insignificant positive correlation ( $p \geq 0.05$ ) with the rainfall pattern. Considering the variations of two pollutants with RH and number of vehicles visited HPNP, both pollutants had insignificant positive correlation. The IAP value obtained for the whole area of the HPNP was 54.22. This value belonged to the quality level 5 which represent the 'very low' pollution level (Kommission Reinhaltung der Luft in VDI and DIN, 1995). The results

including lichen data and air quality data could confirm that the ambient air quality at HPNP is very high.

### **Section 3**

#### **Report in detail:**

##### I) Introduction/background

### **Part I**

#### **Lichen species in the tropical region**

The knowledge of diversity of the larger organisms is properly studied, but it is less studied for fungi and their lichenized counterparts in the tropical forests (Coppins and Wolseley, 2002). Aptroot and Sipman (1997) shows that the tropical forests lichens represented about between one-third and one-half of the world's lichen diversity. Due to the lack of suitable checklists, it is difficult to make more accurate figures or estimates regarding tropical lichen diversity. According to the database (<http://www.checklists.de>) which prepared by Feuerer, presently contains 18,882 species (Feuerer and Hawksworth, 2007), including about 1560 lichenicolous fungi in the world (Lawrey and Diederich 2003).

Due to the lack of modern lichen checklist available in the tropical countries, their analysis is rather difficult (Coppins and Wolseley, 2002). The Hong Kong lichen checklist is the only available checklist from tropics since 1997 and it was included 261 species, of them 176 were new to Hong Kong, 132 were new to China and 43 were new to East Asia (Aptroot and Seaward, 1999). However, Thailand, Colombia and Ecuador are preparing their checklists (Filson, 1996). According to the Aptroot and Sipmans (1997), 50 % of the tropical lichens have been identified so far.

#### **Lichenological studies in Sri Lanka**

Sri Lanka has very rich plant diversity and includes plants that belong a variety of taxonomic groups. Out of these, lichens are a highly specialized and ubiquitous group as they have the ability to adapt to extreme environmental conditions, which enabled them to become pioneers of vegetation. However, little work has been done on lichens in Sri Lanka and thus knowledge with regard to diversity and distribution in Sri Lanka is rather incomplete.

G.H.K. Thwaites, superintendent and later director at the Botanical Garden at Peradeniya, who made the first collection of lichens in central highlands of Sri Lanka between 1849 to 1880. This collection was studied and described by Leighton (1869) and he was able to identify 196 lichen species. Of them 44 species were new to science including many Graphidaceae and Thelotremaaceae. Then Almquist, the famous Swedish explorer collected lichens at Peradeniya area in 1879. This collection was sent to Nylander for identification on the basis of "Lichens Ceylonenses" in 1900.

A.G.H. Alston collected few lichens in 1926 to 1931. He wrote a Kandy flora, a supplement to Trimen's handbook, and unpublished taxonomic treatments of Ceylon Bryophytes, Algae and Lichens.

Kurokawa and Mineta collected mainly in montane forest in 1966/68 contributing to *Anaptychia* (Kurokawa, 1973) and family Parmeliaceae (Kurokawa & Mineta, 1973). Another lichen collection has been done incidentally under the Smithsonian Institution Flora of Ceylon Project from 1970 to 1976, mostly by the Louis Wheeler in drier lowland

areas. Then Rolf Santesson and Roland Moberg visited Sri Lanka in 1975, and who together collected about 10 specimens of Thelotremaaceae, mostly in the Horton Plains area.

During 1976 to 1978, Hale collected lichens from canopies of virgin Dipterocarp trees being logged in Sinharaja forest. At that time he was able to add 76 species to the family Thelotremaaceae and 4 additional species of *Relicina*.

Following a botanical excursion from the University of Vienna in 1984, Brunbauer was compiled an account of the literature on lichens in Sri Lanka in 15 articles (Brunbauer 1984–1987), including 546 species and their synonymy at that time. This includes 550 species belonging to 122 genera and 48 families.

In 1986, Moberg describe a new lichen genus *Rolfidium* in the family Bacidiaceae. Further publications by Singh (1990), Awasthi (1991), Makhil and Patwaradhan (1992), described some microlichen genera including *Buellia* and *Diplotomma*, *Macolichens* and *Trypethelium* species respectively.

In 1997, O. Breuß described 54 new lichen species reporting from central and Southern part of Sri Lanka. In the same year, Vezda described 53 folicolous lichens from Sri Lanka. Among them, 32 species were new to Sri Lanka. Above all the literatures have brought the lichen number up to 659 species recorded to Sri Lanka.

Then in 1999, preliminary survey of lichen conducted during first lichen workshop at Peradeniya University and participants were able to collect 98 of different types of lichen specimens (unpublished data). All these specimens are kept in the National Herbarium, Peradeniya. Other than that Jayasooriya recorded 17 species of lichen during his study of the flora of Ritigala and those specimens also kept at the National herbarium (Jayasooriya, 1984).

During 1999 to 2003, Chandrani Wijerathne surveyed lichens flora at Ritigala Mountains and its vicinity. During their survey, they were able to describe 35 new lichen species to Sri Lanka (unpublished data–NSF report 2004). In 2001, Orange *et al.* described two new additional lepraoid lichens to Sri Lankan lichen flora. Jørgensen, described a new genus *Kroswia*, in 2002. In 2003, Nayanakantha and Gajameragedara described about 50 lichen species collected from Kandy municipal region.

In 2006, M.K. Karunarathne carried out a survey in five ecoregions in Sri Lanka and they were able to find out 23 genera of lichens. In our survey at Horton Plains National park Sri Lanka during 2004 to 2006, total of 1515 specimens of macrolichens belonging to 13 families 48 genera and 293 species were identified. Amongst them, 4 genera were new to Sri Lankan lichen flora. According to the literature regarding the Sri Lankan lichens, 696 species are already recorded in Sri Lanka. However, this number should be exceeding 1500 according to the unpublished data and ongoing research findings.

## Part II

### Air pollution monitoring in Sri Lanka

Sri Lanka has four automated air quality monitoring stations; with 3 of them belong to Central Environment Authority (CEA) and the other at the Faculty of Engineering, University of Peradeniya. Since 2000, air quality in Sri Lanka has been monitored randomly by several research organizations using three sampling methods: active, passive and automatic analyzer method (Abeyratne, 2005). The Chemistry department of the university of Colombo carried out first formal monitoring of Pb in air in Colombo in 1983 (Mathes and Gunawardene, 1995).

The environmental division of National Building Research Organization (NBRO) carried out a continuous air-monitoring programme in Colombo from March 1989 to August 1991, named as CAMP Phase 01, using low cost semi quantitative methods for the monitoring of SO<sub>2</sub> and dust at 49 locations within the Colombo city (<http://www.nbro.gov.lk/sub/air.html>).

During 1991 to 1992, CEA have analyzed the air quality at 6 roadside locations in Colombo and revealed a direct relationship between the volume of traffic and pollutant levels. Industrial Technology Institute (ITI) also carried out a research to monitor the vehicular exhaust emissions during the period of August 1991 to October 1993 (Bennett and Buchen, 1995).

Then ambient air pollution levels were measured at the upper Gampola road near the Faculty of Engineering, using online CO, SO<sub>2</sub> and NO<sub>2</sub> detection sensors (Herath, 2002). The first record of passive sampling monitoring in Sri Lanka was recorded in October 2001, while NBRO had started it for Colombo in November 2001 (Abeyratne, 2001).

Case study on roadside air quality at Galaha junction using low cost techniques was carried out from December 2003 to May 2004 (Illeperuma and Dissanayake, 2004). Ambient air quality at 20 locations in rural areas of Kitulgala, Puttalam and Matara and 15 locations at Colombo city (Samarakkody *et al.*, 2004) and Sapugaskanda area (Perera *et al.*, 2004) using passive sampling were measured by the NBRO in 2004.

NBRO is presently conducting a passive sampling network at 50 sampling locations within the Colombo metropolitan area since 2003. Another passive sampling monitoring station is located at Dutuwewa in the Anuradhapura district. It is implemented in collaboration and partnership with a monitoring stations network under the Malé Declaration programme (Abeyratne, 2005).

During 2002 to 2004, Abeyratne (2005) carried out an active and passive sampler method at Kandy and Anuradhapur area. The data reveals that NO<sub>2</sub>, SO<sub>2</sub> and O<sub>3</sub> analyzed exceed the recommended air quality standards in Sri Lanka on about 14 %, 41 % and 28 % occasions respectively for Kandy while the corresponding exceedences at Anuradhapura were 0 %, 21 % and 27 % respectively.

Hardly any work has been done to identify the bioindicating plants or animals in Sri Lanka except the attempt carried out to assess the air quality using lichens in Colombo, Ritigala and Ambuluwawa area (Wijeratna and Attanayake, 2004).

## II) Scientific scope of the project (overall and specific objectives)

The overall objective was to carry out a survey on lichen flora in different forest communities within Horton Plains National Park.

The Specific Objectives are:

1. Taxonomic description of lichens and documentation associated with forest types of Horton Plains
2. Correlate the distribution of lichens with forest community types.
3. Determination the quality of ambient air at HPNP, since polluted air can seriously affects the forest health and correlate the lichen diversity data with the air quality at HPNP.

### III) Materials and methods (including statistical methods)

#### Methodology

##### Part I

##### Study site

Study was carried out in HPNP during 2004 to 2005. HPNP is a cloud forest in the central highland of Sri Lanka and is located between N 6° 47' – 6° 50' latitude and E 80° 46' – 80° 51' longitude. Altitude ranges from 2100 m to 2300 m above mean sea level. HPNP covers 3160 ha or 9% of the upper montane forest in the country. Eighteen plots (50x 20m) were selected using a remote sensing map (Fig 1A, B) of HPNP.

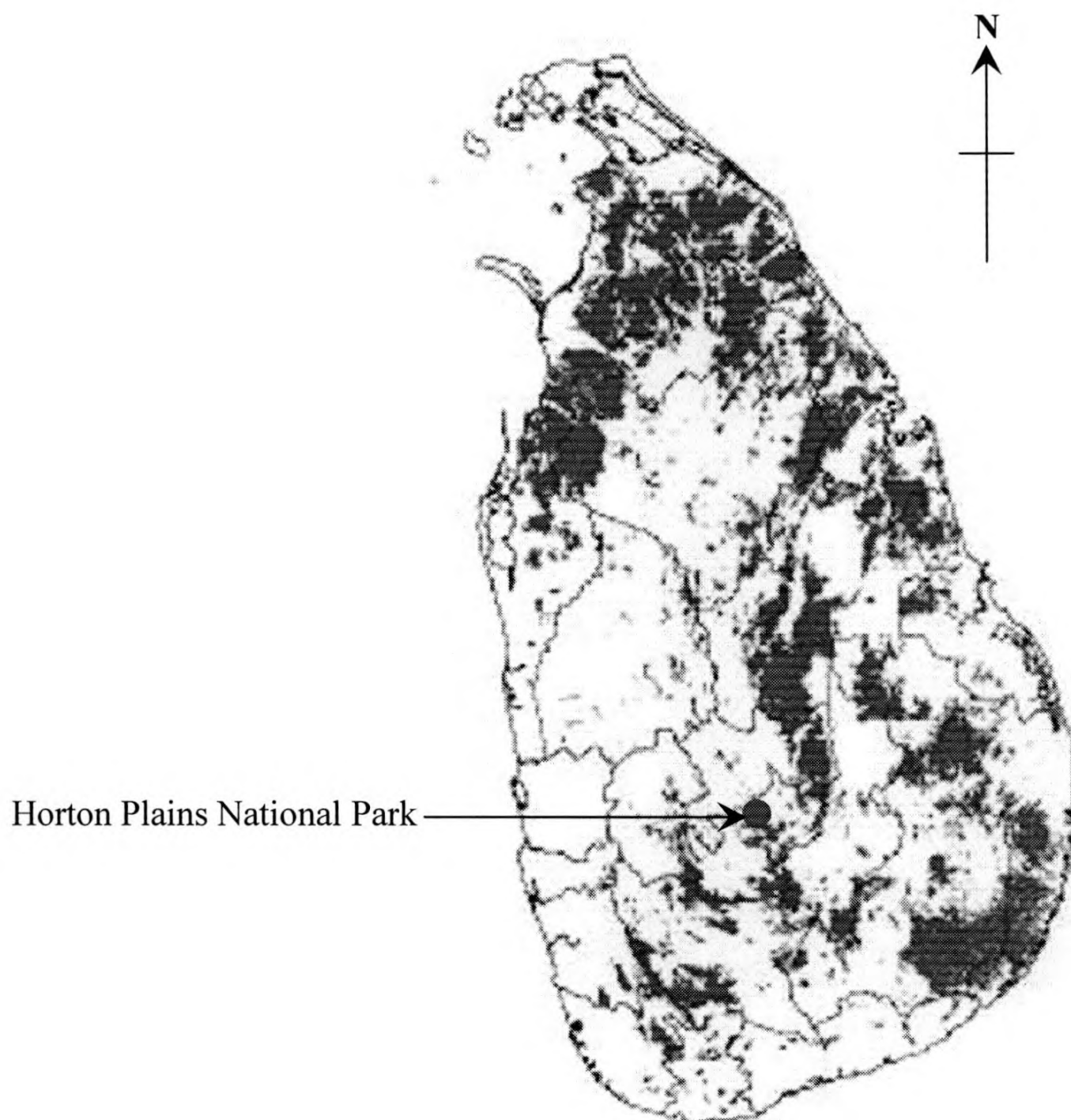


Figure 1.A: Map showing the situation of HPNP in Sri Lankan map (Source: [www.climate.lk](http://www.climate.lk) ).

# Land Cover Types and Forest Diebacks in Horton Plains

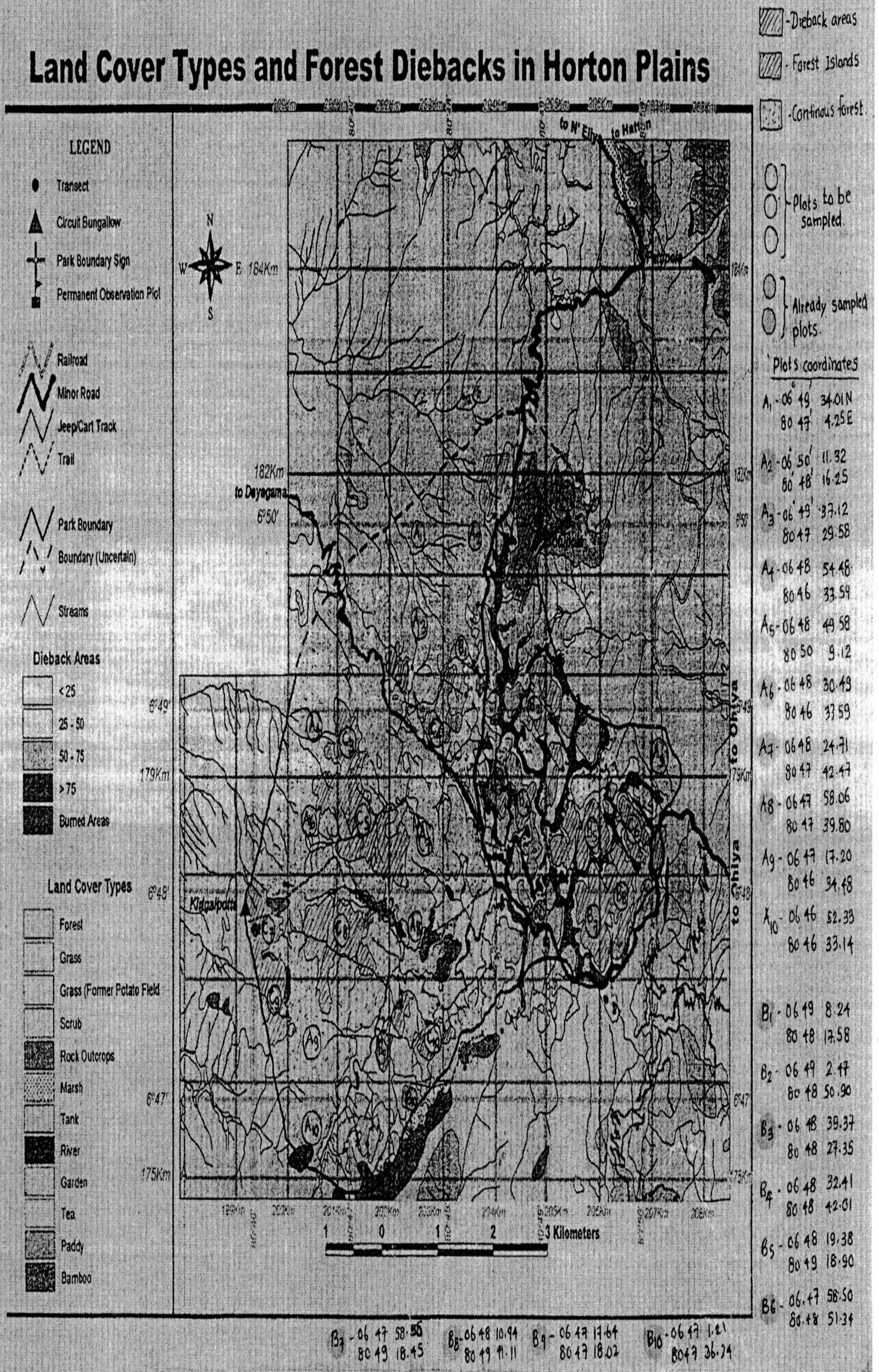


Figure 1B: Horton Plains map showing the distribution of continuous forest and forest islands plots.

## Fieldwork

### Establishment of a transect

Area to be studied was marked in the field using Global Positioning System (Garmin, GPS 76) and the aspects were noted down from a compass. A 50 m rope was firmly tied up without any slackening. Twenty meter ropes were tied up at the ends as well as at a mid point of the 50 m rope and they were taken in the same direction perpendicular to the 50 m rope. Another 50 m rope was tied up to the second end of the first 20 m rope and ran it parallel to the first 50 m rope touching other two 20 m ropes. The 50 x 20 m transect thus marked was segmentalised in to five 10 x 20 m areas with the help of 20 m ropes (Figure 2).

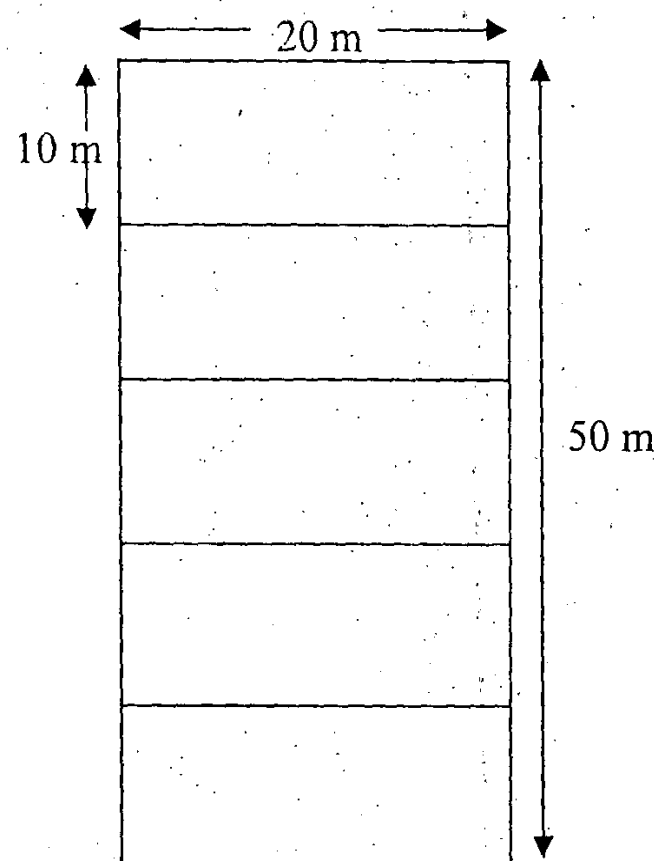


Figure 2: A transect

### Quantifying the structures

The number of individual trees whose girth at 1.50 m is  $\geq 10$  cm and were marked in site and tree data sheets by assigning each individual a number. For each individual tree the tree height was measured using graduated perches. The tree diameter was measured using a 5 m metal scale. The badly damaged and dead trees were marked as "set of the past". The light intensity at 1.50 m was measured using a Lux meter (model SKP 200) at 2000 range. The presence (L) or absence (N) of lichens at the same height was noted in the tree data sheet. The individual was located with its number on the Basal Area Graph. The number of economically important plants in the grids in each segment was noted down on the Site Data sheet.

## **Quantifying lichen diversity and its microhabitat preferences**

Lichen samples from 1/3 number of the individuals (trees whose girth at 1.50 m is  $\geq 10$  cm) were quantified occurred in each segment i.e. for convenience and uniform data collection, for each 3 individual trees studied, quantified lichen data from one of them. Quantification of lichens was done by placing the transparency lichen grid (20x20 cm) on the tree at 1.50 m  $\pm$  30 cm from ground level depending on the lichen availability. With the help of a hand lens lichen colonies behind the grid were carefully observed and located. Each colony was assigned a number while recording the area of each lichen. Each specimen was carefully collected in a separate sealed polythene bag. The lichen cover graph as well as lichen specimen bag were marked using a special code. The code used was as follows. **1:4:3(9): 2.**

1– Indicates the transect number

4– Indicates the segment number (1–2–3–4–5)

3(9) – 3 Indicates the lichen sample tree number and (9) indicates the tree number in the Tree data sheet under that segment

2– Indicates the colony/ species number noted in the lichen graph

The date, aspect, lux, bark nature were marked on the top of lichen cover graph and also on the lichen specimen bag. In order to measure bark pH 2 x 2 cm bark chips were removed from the bark and those samples were marked the same way and “pH” was noted in place of lichen number on the specimen bag.

## **Laboratory studies**

### **Lichen identification**

First the lichen specimen was observed under the dissecting microscope for morphological data. The cross sections of thallus and ascomata were taken using a sharp razor blade and observed under the compound microscope. Observations were used to fill up the lichen data sheet. Lichens were identified using the identification keys and other literature.

#### *External morphology*

The external morphology of the thallus was studied under the dissecting binocular microscope with magnifications of 10 to 30  $\times$ . The surface of thallus, areoles, margin of lobes, presence/absence of isidia, soredia, external cephalodia, cyphellae, pseudocyphellae, cilia, rhizines were examined and measurements were taken.

#### *Internal morphology (Anatomy)*

Thin sections of lichen thallus and reproductive structures were cut using a razor blade. Each section was mounted on a glass slide using water or glycerin. Then a cover slip was placed over the mounted specimen and observed under the trinocular light microscope. All observations on the nature and dimension of thallus, structure of ascocarp (hymenium, hypothecium, epithecium, paraphyses, paraphysoids), asci and ascospores were noted on a slip pad and the slip paper later placed inside the packet of the specimen as a permanent

record of one's observation with name and date. Photographs of some selected specimens were taken by a Canon S80 digital camera fitted with the microscope.

### *Chemical data*

#### Spot test

Following spot test reagents were used to test the color changers of the thallus and medulla of the lichen.

#### 10% KOH in distilled water (**K**)

Many keys depend on the spot reactions given by potassium hydroxide (K). An easily obtained alternative for this chemical is therefore needed. A good substitute may be found in a solution of caustic soda (sodium hydroxide). The strength is not critical but about 10 % caustic soda to 90 % water by volume works well. If too strong a solution is made the reaction is very slow and it is difficult to get it to wet the lichen tissue. The solution was tested on *Xanthoria* or an orange *Caloplaca*, if there is an almost instant crimson reaction, the strength was considered.

#### Sodium hypochloride (**C**)

Sodium hypochlorite is a chemical compound with the formula NaClO. Sodium hypochlorite solution, commonly known as bleach, is frequently used as a disinfectant or a bleaching agent.

#### 5% *p*-Phenyldiamine in ethyl alcohol (**P**)

The use of *para*-phenylenediamine (Pd) is probably best avoided in the early stages of lichenology due to its possible health risks. Over the past few years there has been much discussion amongst lichenologists concerning the dangers inherent in the use of *para*-phenylenediamine. It is known to be carcinogenic but recent evidence seemed to suggest that the dangers were remote and that it was only a very weak carcinogen (<http://www.thebls.org.uk/content/chemical.html>).

- Small fragment of lichen was removed from the specimen.
- The sample was placed on a white filter paper.
- A minute amount of spot test reagent was added onto the thallus using a dissecting needle.
- Then the color change was observed quickly. But it was checked again after a 3 minutes.
- Finally small part of the upper cortex of the thallus was removed using razor blade and above same procedure was repeated.

Other than those solutions, **IKI** solution (I25g of Iodine (I<sub>2</sub>) crystals and 1.5 g of KI<sub>2</sub> in 100 ml of distilled H<sub>2</sub>O) was used to observe the color changers of the following structure.

1. Ascomatal wall
2. Epithecium

3. Paraphysis
4. Ascus apex

#### Micro crystal test

First a small part of the thallus was taken onto a glass slide. Then specimen was crushed using needle with the help of forceps and the dissecting microscope. Then crushed particles were collected to one place of the glass slide. Then 2 to 3 drops of acetone solution was added using dropper or a glass rod. After few times the residue was removed from the slide and it was gently held over the flame of the spirit lamp. Then a few drops of recrystallization agent such as GAW (H<sub>2</sub>O: Glycerol: Ethanol=1:1:1) or GE (Acetic Acid: Glycerol=1:3) was added onto the remaining particles of the glass slide. After the formation of crystals, they were covered with a glass, slide. Then the slide was observed under the microscope.

#### *TLC method*

Lichen fragments (very small quantities) were soaked in 1 ml of acetone for 5 min in a small test tube and the resultant acetone solution was boiled to reduce the volume to 0.1 ml. This concentrated solution was analyzed by Thin Layer Chromatography (TLC) on silica gel plates using the following solvent systems:

- A: toluene/dioxane/acetic acid (180:45:5)
- B: hexane/diethyl ether/formic acid (130:80:20)
- C: toluene/acetic acid (170:30)
- E: cyclohexane/ethyl acetate (75:25)
- F: cyclohexane/ethyl acetate (50:50)
- G: toluene/ethyl acetate/formic acid (139:83:8)

Then the TLC plate was examined in the following manner:

- (a) Under UV light and spots marked.
- (b) Colour of the TLC spots after spraying with H<sub>2</sub>SO<sub>4</sub> and charring.

The identity of the unknown substance was confirmed by comparative TLC in at least three solvent systems described above (a lichen extract was run adjacent to a pure known standard compound).

#### **Bark pH estimation**

Segment of bark (2 × 2 cm<sup>2</sup>) was removed from each sampled tree using a knife. Bark segments were collected at about 1-5 m height on the tree trunk. Samples were collected from 451 trees representing both forest types in HPNP. Each sample was stored in separate sealed plastic bags until brought to the laboratory.

In order to measure the bark pH, the upper surface of the bark chip was cleaned free of debris. Then the surface of the bark segment was wetted with a 25 mM solution of KCl and after 5 min the pH on the surface was measured using a flat ended digital pH meter TPS

Aqua Version 01(Farmer *et al*, 1990). Each bark pH determination was based on the mean of two such estimations per tree.

### Identification of host plant species

Host plant specimens (higher plant) were collected from each tree species and tagged in the field itself. Those live specimens were taken to the laboratory and wrapped with news papers and blotted with methylated spirit to prevent the falling off of leaves and flower parts. Then these specimens were tightly pressed using cardboard paper and aluminum sheets. After that, these tightly packed specimens were oven dried for few days to get dry specimens. After drying the specimen identification was carried out using the reference herbarium specimens in the National Herbarium, Peradeniya.

### Preparation of lichen herbarium specimens

Lichen specimens were thoroughly air dried and they were sealed in polythene bags, and were exposed to temperatures of  $-18^{\circ}\text{C}$  for 7 days. The lichen specimens were removed from the polythene bags after they have returned to room temperature. After drying the lichen specimens, they were wrapped in fresh dry tissue paper and placed in a butter-paper bag (10 x 13 cm), affixed to a thick paperboard (10 x 10 cm), which were further placed in green wrapping paper (35 x 25 cm) (Figure 3) and given a proper label. These were then preserved in a herbarium. A suiTable label was inscribed with requisite details of locality, altitude, type of substratum, name of collector, date of collection, specimen number, thallus colour out side of the packet. Then these lichen packets were stored vertically in cardboard boxes and placed inside the steel cabinets. Finally, naphthalene balls were kept where lichens were stored.

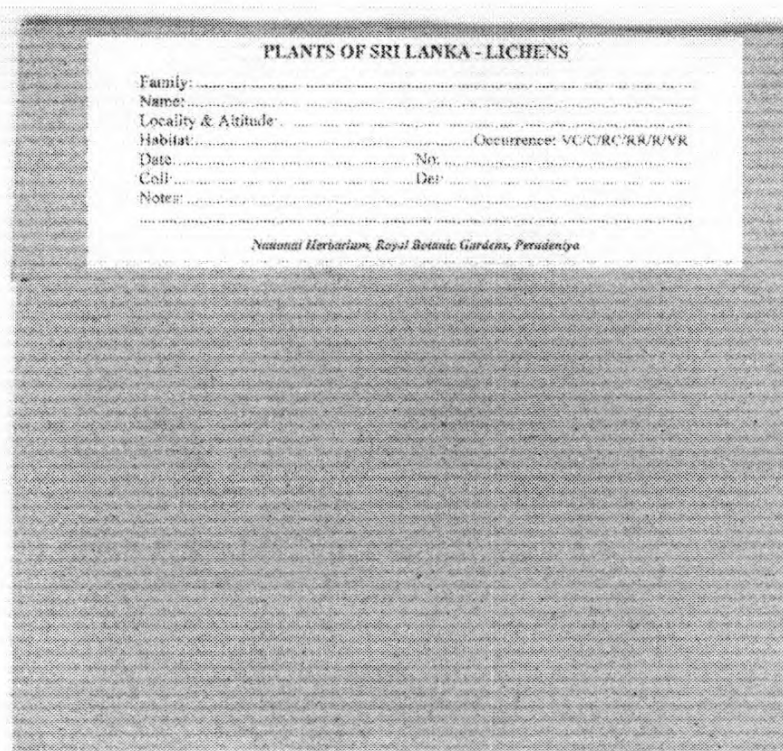


Figure 3: Lichen Herbarium packet

## Data Analysis

Field data were recorded in customized Microsoft Excel data sheets. Cluster analysis was performed to separate 12 plots into continuous forest plots and forest island plots according to the cover and frequency values using SAS software (version 6.12). Correlation analysis was carried out to check the distribution of lichens in relation to bark pH, light intensity, tree height and tree diameter using SAS software (version 6.12). *t*-Test was performed to compare the pH, light intensity, tree height and tree diameter values of the continuous forest and forest islands using Minitab 14 software.

The Shannon Diversity Index (H) and Simpson Index (D) (Magurran, 1988) were calculated. H was calculated using the formula:  $H = -\sum p_i \ln p_i$ , where  $p_i$  is the proportion of species  $x$ , and  $\ln$  is the natural logarithm. Simpson index was calculated using the formula:  $D = \sum [n_i(n_i-1)/N(N-1)]$ , where  $n_i$  is the number of individuals in the  $i^{\text{th}}$  species and  $N$  is the total number of individuals.

## Part II

### METHODOLOGY

#### Sampling sites

Sampling sites were selected using remote sense map of Horton Plains National Park (Figure 5). All the five sites were situated facing the North West and South East wind directions. The longitude, latitude and altitude of all the sampling sites were given in the Table 1.

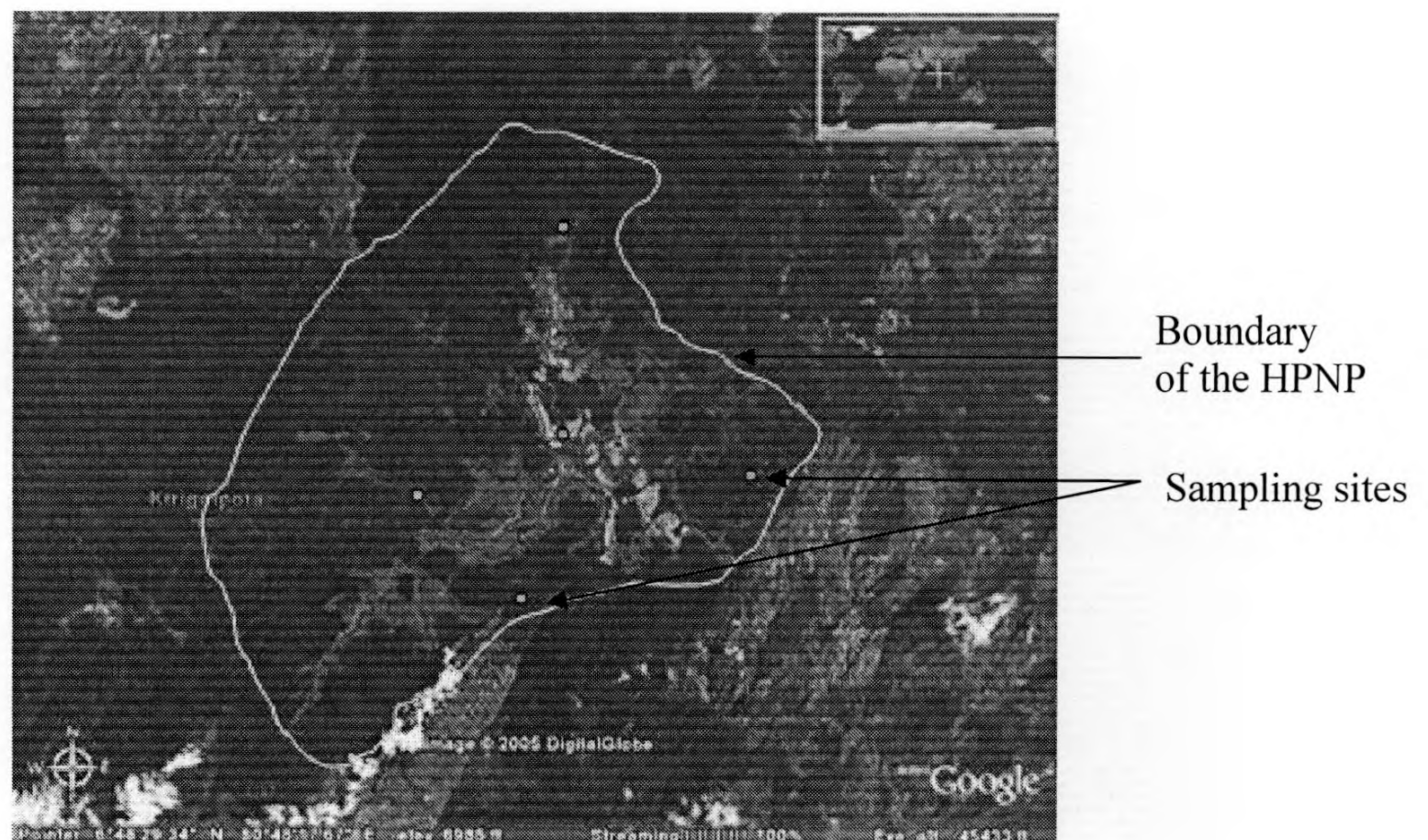


Figure 5: Map of Horton Plains National Park showing sampling sites.

Table 1: Latitude, Longitude and Altitude of the 5 air sampling plots in HPNP.

Sampling Site	Latitude	Longitude	Altitude (m)
1. Pattipola Road	06 <sup>0</sup> 50' 30.4" N	80 <sup>0</sup> 48' 45.7" E	2172
2. Ohiya Road	06 <sup>0</sup> 48' 45.7" N	80 <sup>0</sup> 90' 11.0" E	2161
3. Worlds' End	06 <sup>0</sup> 47' 08.1" N	80 <sup>0</sup> 47' 59.8" E	2080
4. Middle	06 <sup>0</sup> 48' 10.0" N	80 <sup>0</sup> 48' 26.4" E	2190
5. Kirigalpotta	06 <sup>0</sup> 47' 55.0" N	80 <sup>0</sup> 47' 46.3" E	2145

### Preparation of air samplers and sampler stands

During preparation and analysis with trace amounts, contamination can result in serious errors in the analysis. Therefore special attention was paid during the experiment to minimize such errors. High purity chemicals were used to prepare every solution. De-ionized water was always used even for the rinsing of apparatus and glass wares. Teflon coated tweezers and needles were used when handling the sampler components. Small glass vials and test tubes were used for every analysis. All reagents were prepared in small vials immediately prior to use. All the samplers were locally assembled using 25 mm diameter Teflon rods. All the sampler stands were also prepared locally using PVC tubes and plastic plates (Figure 4). All sampler components and glass vials used were first soaked in Teepol, rinsed thoroughly and dried in an oven and stored in a clean environment.



Figure 4: Air samplers and stand in the Horton Plains National Park.

Climatic parameters during the research period were obtained on a daily basis from the Seetha Eliya meteorological station which is located about 10 km distance from the sampling sites. Meteorological data including rainfall, maximum and minimum daily temperatures, wind direction and relative humidity were obtained from the station.

## **Sample storage**

After exposure the samplers are removed and seal in its container and taken to the laboratory for further analysis. In laboratory, sorbent filter is removed and sealed in a small polythene bag. These are then marked with an identifying code indicating the pollutant, site and sample number and store at 4 °C until analysis. At the same time a set of samplers is prepared in an identical manner and keep unexposed to be used as blanks for each pollutant type.

## **Analytical techniques**

### *Analysis of NO<sub>2</sub>*

Before analysis filters, which trapped pollutant are transferred in to small clean glass vials with the help of Teflon covered tweezers. Pollutant is then extracted in to 5 ml of de-ionized water after sonicated for 10 minutes in a shaker. Same procedure is carried out to the blank. The solution is then analyzed for nitrite by colouri metric technique.

### Preparation of the colour reagent

25 ml of 85 %phosphoric acid and 2.5 g sulfanilamide is added in to 200 ml of de-ionized water in a 250 ml volumetric flask. After dissolving sulfanilamide completely, 0.25 g of N-(1-naphthyl)-ethylenediamine dihydrochloride is added and mixed to dissolve. It is then diluted to 250 ml with water.

### Measurement of absorbance

0.2 ml of colour reagent is added to 5 ml sample and mixed. After 10 minutes, the absorbance is measured using a colourimeter (Janway-6050) at a wavelength of 540 nm against a blank, which is treated with the same qualities of the reagent employed for colour development.

### Preparation of calibration curve for nitrite

Using the stock solution of 400 ppm NaNO<sub>2</sub> a series of 50 ml of 1, 3, 4, 5, 6, 7, 8, 9 and 10 ppm are prepared in volumetric flasks. 5 ml of each solution are taken in to small test tube and 0.2 ml of colour reagent is added to each solution. Absorbance of each solution is measured at a wavelength of 540 nm against de- ionized water blank added with equal amount of colour reagent. Values are plotted in a graph of nitrite concentration versus absorbance. Concentration of samples is calculated with the help of this calibration curve.

### *Analysis of SO<sub>2</sub>*

### Preparation of reagents

Following reagents are prepared in volumetric flasks using high purity chemicals.

1. Bufer Solution: 3 g of Mg Cl<sub>2</sub>. 6 H<sub>2</sub>O, 0.5 g CH<sub>3</sub>COONa. 3 H<sub>2</sub>O, 0.1 g KNO<sub>3</sub> and 2 ml acetic acid (99%) are dissolved in 50 ml of distilled water and made up to 100 ml.
2. Standard sulphate solution: 0.0148 g anhydrous Na<sub>2</sub>SO<sub>4</sub>is dissolved in de-ionized water and is diluted to 100 ml in a volumetric flask.

### Measurement of turbidity

20 ml of the sample is filtered and placed in a 25 ml conical flask. 4 ml of buffer solution is added and mixed it with the use of a magnetic stirrer. While stirring 1 g of BaCl<sub>2</sub> crystals are added and begin timing immediately for 1 minute at speed 8. After that the solution is poured in to the cell of the turbidity meter (DRT- 15CE) and the reading of the absorbance is taken after 5 minutes.

### Preparation of calibration curve for sulphate

Using the stock solution of 400 ppm Na<sub>2</sub>SO<sub>4</sub>, concentration of 0.5, 2, 3, 4, and 5 ppm solution of 25ml are prepared in reagent bottles. De-ionized water is used as the blank. 20 ml of each solution is taken in 25 ml conical flasks and 4 ml buffer solution is added, and mixed using a magnetic stirrer. While stirring spoon full (5 g) of BaCl<sub>2</sub> is added and begin timing immediately for 1 minute at speed 8. The solution is poured in to turbidity cell and the turbidity is measured after 5 minutes.

Calibration for the concentration of sulphate versus turbidity units is prepared and concentrations of samples are calculated using the calibration curve.

### **IAP calculation**

The IAP formula uses the occurrence and frequency of lichens at the study sites and an ecological index for each species. The formula is

$$IAP = \sum_i^n \frac{Q \times f}{10}$$

Where,  $n$  is the number of species found at a given station;  $Q$  the ecological index of a species or the average species richness;  $f$  the number of sampled trees on which this lichen species was found at the site. The value for  $Q \times f$  is divided by 10 to give a more manageable number (Kricke and Loppi, 2002).

The concentration of each pollutant was calculated in nM M<sup>-3</sup> as follows.

$$\text{Pollutant (g)} = \frac{L \times Ev \times [X]}{T \times Dc}$$

Where,  $L$  = Total air resistant (41.2 m<sup>-1</sup>)  
 $Ev$  = Extraction volume (ml)  
 $T$  = Sampling time (s)  
 $DC$  = Diffusion coefficient (m<sup>2</sup> sec<sup>-1</sup>)  
 $NO_2 = 1.54 \times 10^{-5}$  m<sup>2</sup> sec<sup>-1</sup>  
 $SO_2 = 1.32 \times 10^{-5}$  m<sup>2</sup> sec<sup>-1</sup>  
 $[X]$  = Pollutant anion concentration (μM)

This Figure can be converted to ppbv using,

$$P = \frac{n \times R \times T}{V}$$

Where, n = Number of moles (in a m<sup>3</sup>)  
R = Gas constant (0.082061 atm mol<sup>-1</sup> K<sup>-1</sup>)  
T = Temperature during sampling (K)  
V = Air volume (1000 L)

#### IV) Results/outputs

##### Part I

##### i) Lichen taxa recorded in HPNP

Lichens collected from the 12 plots of HPNP were observed and were identified using different lichen keys. A total of 379 lichen species belonging to 67 genera and 24 families were identified from the 12 collecting plots at Horton Plains National Park. The number of genera and species included in each of the 24 families are given in the Table 2.

Table 2: The number of genera and species included in each of the 24 families recorded in the Horton Plains National Park (HPNP).

Family	Genera	Species
Bacidiaceae	02	09
Chrysothricaceae	01	01
Cladoniaceae	01	05
Coccocarpiaceae	01	03
Collemataceae	02	16
Graphidaceae	05	19
Gyalectaceae	01	03
Lecanoraceae	03	14
Lobariaceae	03	48
Megalosporaceae	01	02
Nephromataceae	01	01
Pannariaceae	05	12
Parmeliaceae	16	67
Pertusariaceae	02	18
Physiaceae	04	31
Placynthiaceae	01	01
Pyrenulaceae	05	29
Ramalinaceae	01	01
Sphaeroporaceae	01	04
Teloschistaceae	02	02
Thelotremaaceae	04	52

Trichotheliaceae	03	08
Uncertain	02	03
Unknown	-	30

Family Parmeliaceae included the largest number of genera (16) as well as the largest number of species (67). The second highest number of species (52) was represented by family Thelotremaaceae in 4 genera. There were 9 families which were represented by only single genus. These families were Chrysothricaceae, Cladoniaceae, Coccocarpiaceae, Gyalectaceae, Megalosporaceae, Nephromataceae, Placynthiaceae, Ramalinaceae and Sphaeroporaceae. Of the 67 identified genera in HPNP, *Heterodermia* and *Sticta* included 27 and 23 species respectively followed by *Thelotrema*, which was represented by 22 species of lichens. *Pseudocyphellaria*, *Parmotrema* and *Pertusaria* were represented by 17 species in each. Amongst the 67 genera of lichens, 24 of the lichen genera were represented by a single species.

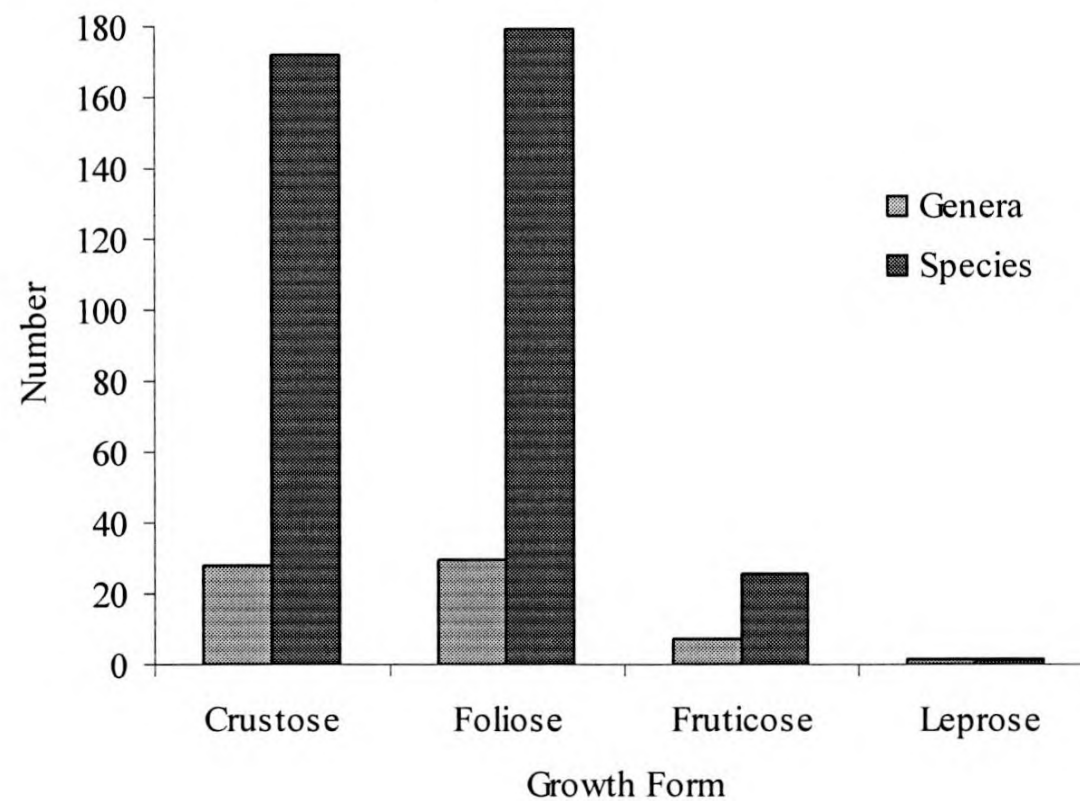


Figure 6: Number of genera and species of different types of growth forms of lichens recorded in HPNP.

In addition to the taxonomic diversity, distinct differences in the habit (growth forms) of the collected lichen were also observed (Figure 6). According to the Figure 01, 30 (44.7 %) and 28 (41.8 %) genera were represented by foliose and crustose lichens respectively. However, 7 (10.4 %) types of genera were found as fruticose lichens and the least number of genera (2) represented by leprose type of lichens. At the species level, 179 species (47.3 %) of the collected lichens were folioses and 172 species (45.4 %) were crustoses. Apart from that 26 species (6.86 %) of fruticose and 2 species (1.11 %) of leprose lichens were collected during this survey.

## List of lichens collected during the survey at HPNP

The list of lichen species (379 species) documented during the study is given below, where family, genera and species following the classification of Tehler (1996).

### Family Basidiaceae W. Watson

- 1) *BACIDIA* de Not.
  - 1) *Bacidia* sp. 01
  - 2) *Bacidia* sp. 02
  - 3) *Bacidia* sp. 03
  - 4) *Bacidia* sp. 04
  - 5) *Bacidia* sp. 05
  
- 2) *PHYLLOPSORA* Müll. Arg.
  - 6) *Phyllopsora buettneri* Müll. Arg. (New Record)
  - 7) *Phyllopsora* sp. 01
  - 8) *Phyllopsora* sp. 03
  - 9) *Phyllopsora* sp. 04

### Family Chrysothricaceae Zahlbr

- 3) *CHRYSOTHRIX* Mont.
  - 10) *Chrysothrix* sp. 01

### Family Cladoniaceae Zenker

- 4) *CLADONIA* Browne
  - 11) *Cladonia cf. cartilaginea* Müll. Arg.
  - 12) *Cladonia cf. didyma*(Fée) Vainio
  - 13) *Cladonia cf. macilenta* Hoffm.
  - 14) *Cladonia cf. ramulosa*(With.)Laundon
  - 15) *Cladonia chlorophaea*(Sommerf.)Sprengel.(New Record)

### Family Coccocarpiaceae (Mont.ex K. Müller) Henssen

- 5) *COCCOCARPIA* Pers.
  - 16) *Coccocarpia erythroxyli* (Spreng.) Swinscow & Krog
  - 17) *Coccocarpia palmicola* (Spreng.) Arv. & D.J. Galloway
  - 18) *Coccocarpia* sp. 01

### Family Collemataceae Zenker

- 6) *COLLEMA* Wigg.
  - 19) *Collema cf. subflaccidum* Degel.
  - 20) *Collema* sp. 01

21) *Collema* sp. 02

7) **LEPTOGIUM** (Ach.) Gray

22) *Leptogium azureum* (Ach.) Mont.

23) *Leptogium burgessii* (L.) Mont. (New Record)

24) *Leptogium cf. adpressum* Nyl.

25) *Leptogium cf. californicum* Tuck.

26) *Leptogium cf. hibernicum* P. M. Jørg.

27) *Leptogium cf. juressianum* Tavares, Port.

28) *Leptogium cyanescens* (Rabenh.) Körb.

29) *Leptogium denticulatum* (New Record)

30) *Leptogium ulvaceum* (New Record)

31) *Leptogium* sp. 01

32) *Leptogium* sp. 02

33) *Leptogium* sp. 03

34) *Leptogium* sp. 04

**Family Uncertain**

8) **LEPROCAULON** Nyl.

35) *Leprocaulon arbuscula* (Nyl.) Nyl. (New Record)

36) *Leprocaulon cf. pseudoarbuscula* (Asah.) Lamb & Ward.

**Family Graphidaceae Dumorber**

9) **FISSURINA** Fée

37) *Fissurina* sp.

10) **GRAPHINA** Müll. Arg.

38) *Graphina* sp.

11) **GRAPHIS** Adanson

39) *Graphis* sp.

12) **SARCHOGRAPHA** (Fée)

40) *Sarchographa* sp. 01

41) *Sarchographa* sp. 02

42) *Sarchographa* sp. 03

43) *Sarchographa* sp. 04

44) *Sarchographa* sp. 05

45) *Sarchographa* sp. 06

46) *Sarchographa* sp. 07

13) **Unknown Genera**

47) Graphidaceae sp. 01

48) Graphidaceae sp. 02

49) Graphidaceae sp. 03

50) Graphidaceae sp. 04

51) Graphidaceae sp. 05

52) Graphidaceae sp. 06

53) Graphidaceae sp. 07

- 54) Graphidaceae sp. 08
- 55) Graphidaceae sp. 09

**Family Gyalectaceae (A. Massal.) Stizenb**

14) *DIMERELLA* Trevisan

- 56) *Dimerella lutea* (Dicks.) Trevis.
- 57) *Dimerella pineti* (New Record)
- 58) *Dimerella* sp. 01

**Family Lecanoraceae**

15) *HAEMATOMMA* Massal.

- 59) *Haematomma cf. africanum*

16) *LECANORA* Ach.

- 60) *Lecanora* sp. 01
- 61) *Lecanora* sp. 02
- 62) *Lecanora* sp. 03
- 63) *Lecanora* sp. 04
- 64) *Lecanora* sp. 05
- 65) *Lecanora* sp. 06
- 66) *Lecanora* sp. 07
- 67) *Lecanora* sp. 08
- 68) *Lecanora* sp. 09
- 69) *Lecanora* sp. 10

17) *LECIDELLA* Körber

- 70) *Lecidella cf. euphorea*
- 71) *cf. Lecidella* sp. 01
- 72) *Lecidella* sp. 01

**Family Lobariaceae Chev.**

18) *LOBARIA* (Schreber) Hoffm.

- 73) *Lobaria cf. pseudopulmonaria* Gyeln.
- 74) *Lobaria discolor* (Delise) Hue, Nouv.
- 75) *Lobaria isidiosa* (Müll. Arg.) Vain.
- 76) *Lobaria kurokawae* Yoshom. (New Record)
- 77) *Lobaria retigera* (Bory) Trevisan.
- 78) *Lobaria* sp. 02
- 79) *Lobaria* sp. 03
- 80) *Lobaria* sp. 05

19) *PSEUDOCYPHELLARIA* Vainio

- 81) *Pseudocyphellaria argyracea* (Delise) Vainio.
- 82) *Pseudocyphellaria beccarii* (Kremp.) (New Record)

- 83) *Pseudocyphellaria cf. brattii* D.J. Galloway & Kantvilas
- 84) *Pseudocyphellaria cf. crocatoides* D.J. Galloway
- 85) *Pseudocyphellaria cf. dissimilis* (Nyl.) D.J. Galloway & P. James
- 86) *Pseudocyphellaria cf. jamesii* D.J. Galloway
- 87) *Pseudocyphellaria cf. rigida* (Müll.Arg.) D.J. Galloway  
*Pseudocyphellaria crocata* (L.) Vainio.
- 88) *Pseudocyphellaria desfontainii* (Delise) Vain. (New Record)
- 89) *Pseudocyphellaria dissimilis* (Nyl.) D.J. Galloway & P. James (New Record)
- 90) *Pseudocyphellaria insculpta* (Stizenb.) D.J. Galloway (New Record)
- 91) *Pseudocyphellaria intricata* (Delise) Vainio.
- 92) *Pseudocyphellaria sayeri* D.J. Galloway (New Record)
- 93) *Pseudocyphellaria sulphurea* (Schaer.) D.J. Galloway (New Record)
- 94) *Pseudocyphellaria* sp. 01
- 95) *Pseudocyphellaria* sp. 02
- 96) *Pseudocyphellaria* sp. 03

20) *STICTA* (Schreber) DC.

- 97) *Sticta cf. marginifera* Mont.
- 98) *Sticta cf. brevipes* (Müll. Arg.) Zahlbr
- 99) *Sticta cf. cyphellulata* (Müll.Arg.) Hue
- 100) *Sticta cf. duplolumbata* (Hue) Vain.
- 101) *Sticta cf. filicina* Ach.
- 102) *Sticta cf. subtomentella* (C.Knight ex Shirley) Zahlbr
- 103) *Sticta cyphellulata* (Müll.Arg.) Hue (New Record)
- 104) *Sticta duplolumbata* (Hue) Vain.
- 105) *Sticta marginifera* Mont.
- 106) *Sticta subtomentella* (C.Knight ex Shirley) Zahlbr
- 107) *Sticta* sp. 01
- 108) *Sticta* sp. 02
- 109) *Sticta* sp. 03
- 110) *Sticta* sp. 04
- 111) *Sticta* sp. 05
- 112) *Sticta* sp. 06
- 113) *Sticta* sp. 07
- 114) *Sticta* sp. 08
- 115) *Sticta* sp. 09
- 116) *Sticta* sp. 10
- 117) *Sticta* sp. 11
- 118) *Sticta* sp. 12
- 119) *Sticta weigellii* (Ach.) Vainio

**Family Megalosporaceae Vezda ex Hafellmer & Bellem**

21) *MEGALOSPORA* Meyen in Meyen & Flotow

- 120) *Megalospora tuberculosa* (Fée) Sipman
- 121) *Megalospora sulphurata* Meyen

**Family Nephromataceae Wetm.**

22) *NEPHROMA* (Ach.)

122) *Nephroma cf. tropicum* (Müll. Arg.) Zahlbr.

**Family Pannariaceae Tuck.**

23) *FUSCOPANNARIA* P.M. Jørg. (New Record)

123) *Fuscopannaria coerulescens* P. M. Jørg (New Record)

24) *KROSWIA* P. M. Jørg. gen. nov.

124) *Kroswia cf. crystallifera* P. M. Jørg. sp. nov.

25) *LEIODERMA* Nyl. (New Record)

125) *Leioderma solediatum* G. Galloway & P. Jørgensen

26) *PANNARIA* Delise

126) *Pannaria complanata* P. Jørg. (New Record)

127) *Pannaria* sp. 01

27) *PARMELIELLA* Müll. Arg.

128) *Parmeliella leistroma* (Nyl.) P.M. Jørg. (New Record)

129) *Parmeliella cf. mariana*

130) *Parmeliella cf. papillata* P.M. Jørg.

131) *Parmeliella philippina* (Vain.) P.M. Jørg. (New Record)

132) *Parmeliella zeylanica* P.M. Jørg.

133) *Parmeliella* sp. 01

134) *Parmeliella* sp. 02

**Family Parmeliaceae Zenker**

28) *ANZIA* Stizenb (New Record)

135) *Anzia* sp. 01 (New Record)

136) *Anzia* sp. 02 (New Record)

29) *CANOMACULINA* Elix & Hale (New Record)

137) *Canomaculina* sp. 01 (New Record)

30) *CETRELIA* Culb. & C. Culb. (New Record)

138) *Cetrelia braunsiana* (Müll. Arg.) (New Record)

31) *CANOPARMELIA* Elix & Hale (New Record)

139) *Canoparmelia* sp. 01 (New Record)

32) *HYPOGYMNA* (Nyl.) Nyl.

140) *Hypogymnia cf. vittata* (Ach.) Parr.

- 141) *Hypogymnia zeylanica* (R. Sant.) D.D. Awasthi & Kr.P. Singh  
 142) *Hypogymnia vittata*(New Record)

33) *HYPOTRACHYNA* (Vainio) Hale

- 143) *Hypotrachyna cf. crenata* (Kurok.) Hale  
 144) *Hypotrachyna cf. exsecta* (Taylor) Hale  
 145) *Hypotrachyna cf. imbricatula* (Zahlbr.) Hale  
 146) *Hypotrachyna cf. osseoalba* (Vainio) Park & Hale  
 147) *Hypotrachyna cf. subpustulifera* Elix  
 148) *Hypotrachyna costaricensis* (Nyl.) Hale(New Record)  
 149) *Hypotrachyna crenata*(New Record)  
 150) *Hypotrachyna densirhizinata* (Kurok.) Hale(New Record)  
 151) *Hypotrachyna endochlora* (Leighton) Hale  
 152) *Hypotrachyna exsecta* (Taylor) Hale  
 153) *Hypotrachyna immaculate* (Kurok.) Hale(New Record)  
 154) *Hypotrachyna mason-halei*(New Record)  
 155) *Hypotrachyna sublaevigata* (Nyl.) Hale(New Record)

34) *MENEGAZZIA* Massal. (New Record)

- 156) *Menegazzia terebrata* (Hoffm.)Massal.(New Record)  
 157) *Menegazzia capitata*(New Record)  
 158) *Menegazzia monospora*(New Record)  
 159) *Menegazzia subsimilis*(New Record)

35) *MYELOCHROA* (Asah.) Elix & Hale

- 160) *Myelochroa cf. xantholepis* (Mont. & Bosch) Elix & Hale  
 161) *Myelochroa entotheiochroa*(Hue) Elix & Hale(New Record)  
 162) *Myelochroa* sp. 01

36) *PARMELINA* Hale

- 163) *Parmelina* sp. 01

37) *PARMELINELLA* Elix & Hale

- 164) *Parmelinella wallichiana* (Taylor) Elix & Hale

38) *PARMELINOPSIS* Elix & Hale

- 165) *Parmelinopsis expallida*(New Record)

39) *PARMOTREMA* Massl.

- 166) *Parmotrema cf. abessinicum* (Krempelh.) Hale  
 167) *Parmotrema cf. chinense* (Osbeck) Hale & Ahti  
 168) *Parmotrema cf. crinitum* (Ach.) M. Choisy  
 169) *Parmotrema cf. direagens* (Hale) Hale  
 170) *Parmotrema cf. gardneri* (Dodge) Sérus.  
 171) *Parmotrema cf. grayanum* (Hue) Hale  
 172) *Parmotrema cf. melanothrix* (Mont.) Hale  
 173) *Parmotrema cf. mellissii* (Dodge) Hale  
 174) *Parmotrema cf. robustum* (Degel.) Hale  
 175) *Parmotrema cf. subsidiosum* (Müll. Arg.) Hale  
 176) *Parmotrema cf. zollingeri* (Hepp) Hale

- 177) *Parmotrema stuppeum* (Taylor) Hale (New Record)
- 178) *Parmotrema* sp. 01
- 179) *Parmotrema* sp. 02
- 180) *Parmotrema* sp. 03
- 181) *Parmotrema* sp. 04
- 182) *Parmotrema* sp. 05

40) *PUNCTELIA* Krog (New Record)

- 183) *Punctelia* cf. *neutralis* (Hale) Krog

41) *RIMELIA* Hale & Fletcher

- 184) *Rimelia cetrata* (Ach.) Hale & Fletcher (New Record)
- 185) *Rimelia* cf. *austrocetrata* Elix & J. Johnst
- 186) *Rimelia* cf. *reticulata* (Taylor) Hale & Fletcher
- 187) *Rimelia reticulata* (Taylor) Hale & Fletcher (New Record)

42) *USNEA* Adans.

- 188) *Usnea barbata* (L.) Weber ex F.H. Wigg. emend. Jørgensen *et al.*
- 189) *Usnea* cf. *complanata* (Müll. Arg.) Mot.
- 190) *Usnea* cf. *corallina* Mot.
- 191) *Usnea* cf. *mutabilis* Stirton
- 192) *Usnea* cf. *stigmatoides* G. Awasthi sp. nov.
- 193) *Usnea* cf. *subflorida* (zahlbr.) Mot.
- 194) *Usnea* cf. *undulate* Stirton
- 195) *Usnea* sp. 01
- 196) *Usnea* sp. 02
- 197) *Usnea* sp. 03
- 198) *Usnea* sp. 04

43) Unknown Genera

- 199) Parmeliaceae sp. 01
- 200) Parmeliaceae sp. 02
- 201) Parmeliaceae sp. 03

**Family Pertusariaceae Körber**

44) *PERTUSARIA* DC in Lam. & DC.

- 202) *Pertusaria acuta* (New Record)
- 203) *Pertusaria* cf. *granulata* (Ach.) Müll. Arg.
- 204) *Pertusaria* cf. *hemispherica*
- 205) *Pertusaria melastomella* Nyl.
- 206) *Pertusaria* sp. 01
- 207) *Pertusaria* sp. 02
- 208) *Pertusaria* sp. 03
- 209) *Pertusaria* sp. 04
- 210) *Pertusaria* sp. 06
- 211) *Pertusaria* sp. 07
- 212) *Pertusaria* sp. 08
- 213) *Pertusaria* sp. 09

- 214) *Pertusaria* sp. 10
- 215) *Pertusaria* sp. 11
- 216) *Pertusaria* sp. 12
- 217) *Pertusaria* sp. 13
- 218) *Pertusaria* sp. 14

45) *OCHROLECHIA* Massal

- 219) *Ochrolechia subpallescens* (New Record)

**Family Physciaceae Tuck.**

46) *HETERODERMIA* Trevisan

- 220) *Heterodermia cf. angustiloba* (Müll.Arg.) Awasthi
- 221) *Heterodermia cf. comosa* (Eschw.) Follmann & Rédon
- 222) *Heterodermia cf. congoensis* (Kurok.) Swinscow & Krog
- 223) *Heterodermia cf. incana* (Stirton) Awas.
- 224) *Heterodermia cf. japonica* (M. Satô) Swinscow & Krog
- 225) *Heterodermia cf. pseudospeciosa*
- 226) *Heterodermia cf. speciosa* (Wulfen) Trevis.
- 227) *Heterodermia diademata* (Taylor) Awasthi
- 228) *Heterodermia dissecta* (Kurok.) Awasthi(New Record)
- 229) *Heterodermia flabellata* (Fée)Awasthi
- 230) *Heterodermia hypocaesia* (Yasuda) Awas.(New Record)
- 231) *Heterodermia hypoleuca* (Ach.) Trevisan.
- 232) *Heterodermia isidiophora* (Vainio) Awasthi(New Record)
- 233) *Heterodermia leucomelos* (L.) Poelt
- 234) *Heterodermia leucomelos* sub sp. boryi (Fée) Swinscow & Krog
- 235) *Heterodermia microphylla* (Kurok.) Skorepa
- 236) *Heterodermia obscurata* (Nyl.) Trevisan(New Record)
- 237) *Heterodermia pseudospeciosa* (Kurok.) W. Culb.(New Record)
- 238) *Heterodermia rubescens* (Räs.) Awasthi(New Record)
- 239) *Heterodermia speciosa* (Wulfen) Trevis.
- 240) *Heterodermia* sp. 01
- 241) *Heterodermia* sp. 02
- 242) *Heterodermia* sp. 03
- 243) *Heterodermia* sp. 04
- 244) *Heterodermia* sp. 05
- 245) *Heterodermia* sp. 06
- 246) *Heterodermia* sp. 07

47) *PHYSCIA* (Schreber) Michaux

- 247) *Physcia cf. verrucosa* Moberg
- 248) *Physcia* sp. 01

48) *BUELLIA* de Not.

- 249) *Buellia* sp. 01

49) *DIPLATOMMA* Flotow

- 250) *Diplotomma* sp. 01

**Family Placynthiaceae A.E. Dahl**

- 50) *POLICHIDIUM* (Ach.) Gray (New Record)  
251) *Polichidium* sp. (New Record)

**Family Pyrenulaceae Rabenh**

51) *PYRENULA* (Ach.)

- 252) *Pyrenula* sp. 01  
253) *Pyrenula* sp. 02  
254) *Pyrenula* sp. 03  
255) *Pyrenula* sp. 04  
256) *Pyrenula* sp. 05  
257) *Pyrenula* sp. 06  
258) *Pyrenula* sp. 07  
259) *Pyrenula* sp. 08  
260) *Pyrenula* sp. 09  
261) *Pyrenula* sp. 10  
262) *Pyrenula* sp. 11  
263) *Pyrenula* sp. 12  
264) *Pyrenula* sp. 13  
265) *Pyrenula* sp. 14  
266) *Pyrenula* sp. 15

52) *ARTHOPYRENIA* Massal.

- 267) *Arthopyrenia* sp. 01

53) *PLEUROTREMA* Müll. Arg. (New Record)

- 268) *Pleurotrema* cf. *verrucosum*

54) *PARATHELIUM* (Nyl.) (New Record)

- 269) *Parathelium* sp. 01 (New Record)

55) Unknown Genera

- 270) Pyrenulaceae sp. 01  
271) Pyrenulaceae sp. 02  
272) Pyrenulaceae sp. 03  
273) Pyrenulaceae sp. 04  
274) Pyrenulaceae sp. 05  
275) Pyrenulaceae sp. 06  
276) Pyrenulaceae sp. 07  
277) Pyrenulaceae sp. 08  
278) Pyrenulaceae sp. 09  
279) Pyrenulaceae sp. 10  
280) Pyrenulaceae sp. 11

**Family Ramalinaceae Ag.**

56) *RAMALINA* Ach.

- 281) *Ramalina disparata* Krog & Swinscow (New Record)

**Family Sphaerophoraceae Fr.**

57) *BUNODOPHORON*

- 282) *Bunodophoron formosanum* (Zahlbr.) Wedin(New Record)
- 283) *Bunodophoron diplotypum* (Vain.) Wedin(New Record)
- 284) *Bunodophoron* sp. 03
- 285) cf.*Bunodophoron*

**Family Telochistaceae Zahlbr.**

58) *TELOSCHISTES* Norman

- 286) *Teloschistes flavicans* (Swartz) Norman

59) *CALOPLACA* Th. Fr.

- 287) *Caloplaca* sp. 01

**Family Thelotremaaceae (Nyl.) Stizenb**

60) *MYRIOTREMA* (Fée)

- 288) *Myriotrema* cf. *fissurinum* Hale
- 289) *Myriotrema* cf. *hartii* (Müll. Arg.) Hale
- 290) *Myriotrema* cf. *microstomum* (Müll. Arg.) Hale
- 291) *Myriotrema nuwarensense* Hale
- 292) *Myriotrema* sp. 01
- 293) *Myriotrema* sp. 02
- 294) *Myriotrema* sp. 03
- 295) *Myriotrema* sp. 04
- 296) *Myriotrema* sp. 05
- 297) *Myriotrema* sp. 06
- 298) *Myriotrema* sp. 07
- 299) *Myriotrema* sp. 08
- 300) *Myriotrema* sp. 09
- 301) *Myriotrema* sp. 10
- 302) *Myriotrema* sp. 11

61) *OCELLULARIA* Meyer

- 303) *Ocellularia mahabalei*(New Record)
- 304) *Ocellularia leucomelaena* (Nyl.) Hale
- 305) *Ocellularia pertusariaeformis* (Leight.) Zahlbr.
- 306) *Ocellularia subsimilis* (Hale) Hale
- 307) *Ocellularia* sp. 01
- 308) *Ocellularia* sp. 02
- 309) *Ocellularia* sp. 03
- 310) *Ocellularia* sp. 04
- 311) *Ocellularia* sp. 05
- 312) *Ocellularia* sp. 06
- 313) *Ocellularia* sp. 07
- 314) *Ocellularia* sp. 08
- 315) *Ocellularia* sp. 09
- 316) *Ocellularia* sp. 10

62) *THELOTREMA* Ach.

- 317) *Thelotrema cf. aggregatum* (Hale) Hale
- 318) *Thelotrema cf. kamatii* (Patw. & C.R. Kulk.) Hale
- 319) *Thelotrema cf. nostalgicum* G. Salisb.
- 320) *Thelotrema cf. novae-zelandiae* Szatala
- 321) *Thelotrema cf. piluliferum* Tuck.
- 322) *Thelotrema cf. weberi* Hale
- 323) *Thelotrema kamatii* (Patw. & C.R. Kulk.) Hale
- 324) *Thelotrema patens* Nyl.
- 325) *Thelotrema* sp. 01
- 326) *Thelotrema* sp. 02
- 327) *Thelotrema* sp. 03
- 328) *Thelotrema* sp. 04
- 329) *Thelotrema* sp. 05
- 330) *Thelotrema* sp. 06
- 331) *Thelotrema* sp. 07
- 332) *Thelotrema* sp. 08
- 333) *Thelotrema* sp. 09
- 334) *Thelotrema* sp. 10
- 335) *Thelotrema* sp. 11
- 336) *Thelotrema* sp. 12
- 337) *Thelotrema* sp. 13
- 338) *Thelotrema* sp. 14

63) Unknown Genera

- 339) *Thelotremataceae* sp. 01

**Family Trichotheliaceae (Müll. Arg.) Bitter & Schilling**

64) *PORINA* Müll. Arg.

- 340) *Porina desquamescens* Fée
- 341) *Porina cf. subcutanea*
- 342) *Porina* sp. 01
- 343) *Porina* sp. 02
- 344) *Porina* sp. 03

**Family Trypetheliaceae Zenker**

65) *PSEUDOPYRENULA* Müll. Arg.

- 345) *Pseudopyrenula* sp. 01
- 346) *Pseudopyrenula* sp. 02

66) *PLEUROTHELIOPSIS* Zahlbr. (New Record)

- 347) *Pleurotheliopsis* sp. 01 (New Record)

**Uncertain Family**

67) *LEPRARIA* Ach.

- 348) *Lepraria cf. pulchellum*

68) Unknown crustose

- 349) Crustose sp. 01
- 350) Crustose sp. 02
- 351) Crustose sp. 03
- 352) Crustose sp. 04
- 353) Crustose sp. 05
- 354) Crustose sp. 06
- 355) Crustose sp. 07
- 356) Crustose sp. 08
- 357) Crustose sp. 09
- 358) Crustose sp. 10
- 359) Crustose sp. 11
- 360) Crustose sp. 12
- 361) Crustose sp. 13
- 362) Crustose sp. 14
- 363) Crustose sp. 15
- 364) Crustose sp. 16
- 365) Crustose sp. 17
- 366) Crustose sp. 18
- 367) Crustose sp. 19
- 368) Crustose sp. 20

69) Unknown foliose

- 369) Foliose sp. 01
- 370) Foliose sp. 02
- 371) Foliose sp. 03
- 372) Foliose sp. 04
- 373) Foliose sp. 05
- 374) Foliose sp. 06
- 375) Foliose sp. 07
- 376) Foliose sp. 08
- 377) Foliose sp. 09

70) Unknown fruticose

- 378) fruticose sp. 01

**ii) New records of lichens for Sri Lanka**

The current study documented several new lichen taxa for Sri Lanka that consist of 11 genera and 102 species. The 12 new genera composed of 7 folioses (*Fuscopannaria*, *Leioderma*, *Anzia*, *Canomaculina*, *Cetrelia*, *Canoparmelia*, *Menegazzia*), 4 crustoses (*Punctelia*, *Pleurotrema*, *Parathelium*, *Pleurotheliopsis*) and 01 fruticose (*Polichidium*). Similarly the 102 species were composed of 11 species of crustose, 89 species of foliose and 03 species of fruticose (New records were indicated within brackets in the list).

In the family Parmeliaceae, two genera *Parmotrema* and *Hypotrachyna* each with a nine species are new to Sri Lanka. In the family Physciaceae, the genera *Heterodermia* with 9 species is new to Sri Lanka. In the genus *Menegazzia* 4 of the species collected have not been recorded from Sri Lanka previously. However, 42 specimens were kept as unidentified species. It includes 29 species of crustose, 12 species of foliose and 01 species of fruticose. Many species found in the family Graphidaceae were pooled together as species of either *Graphis* or *Graphina*. Some times several new species or new records may be contained within these pooled sets of lichens. Thus, a total of 11 genera (16.41 %) and 102 species (26.91 %) of lichens new to Sri Lanka were recorded from the present study.

### iii) Diversity Statistics

Comparison of different types of diversity statistics of the whole HPNP, continuous forest and forest islands are shown in the Table 3. Shannon Diversity Index, evenness and Log Series Index ( $\alpha$ ) are higher in the whole area of the HPNP. Number of lichen individuals, lichen families genera and species are rich in the forest islands than the continuous forest. Other diversity statistics such as Shannon Diversity Index, Simpson's Index (1/D), Log Series Index ( $\alpha$ ) and evenness are higher in the continuous forest than the forest islands.

Table 3: Diversity of lichens in the continuous forest and forest islands in HPNP calculated using a variety of diversity statistics (A) and the pattern of species abundance in the two forest types (B).

	Whole HPNP	Continuous Forest	Forest Islands
A) Diversity			
Number of Families	24	20	22
Number of Genera	67	48	51
No. of Species	379	249	264
No. of Individuals	2371	956	1415
Shannon Diversity Index (H)	4.97	4.89	4.73
Simpson's Index (1/D)	98.75	129.46	79.53
Evenness	0.87	0.74	0.66
Log Series Index ( $\alpha$ )	114.54	112.40	79.53
B) Fit of model			
Log Series	Yes	Yes	Yes

*iv) Correlation analysis*

The correlation of lichen diversity with tree diameter, bark pH, light intensity, No. of colonies and host tree diversity were analysed using SAS statistical software. The Pearson correlation analysis showed that, tree height, tree diameter, number of lichen colonies and host tree diversity were positively correlated with lichen diversity in the continuous forest. As opposed to this bark pH and light intensity were negatively correlated with the lichen diversity. A significant relationship was observed only with number of colonies and host tree diversity (Table 4 A). In the forest islands, tree diameter, bark pH, number of colonies and host tree diversity were positively correlated with lichen diversity and tree height and light intensity showed a negative correlation. However, a significant relationship was observed only with number of colonies (Table 4 B).

Table 4: Pearson correlation analysis of lichen diversity of crustose and foliose lichens with tree height, tree diameter, bark pH, light intensity and host tree diversity in the continuous forest (A) and forest islands (B) of HPNP. The second value in each cell indicating the p value of each coefficient index and significant correlations ( $p < 0.05$ ) were indicated as bold numbers.

A	Tree Diameter	Bark pH	Light Intensity	No. of Colonies	Host Tree Diversity	Lichen Diversity
Tree Height	0.0764 <i>0.6936</i>	0.4783 <b>0.0087</b>	-0.2708 <i>0.1553</i>	0.1272 <i>0.5107</i>	0.1826 <i>0.3430</i>	0.1198 <i>0.5357</i>
Tree Diameter		-0.1758 <i>0.3616</i>	0.2381 <i>0.2135</i>	0.2179 <i>0.2561</i>	-0.0555 <i>0.7748</i>	0.2385 <i>0.2126</i>
Bark pH			-0.0274 <i>0.8877</i>	-0.0093 <i>0.9614</i>	0.0972 <i>0.6159</i>	-0.1530 <i>0.4279</i>
Light Intensity				-0.1839 <i>0.3394</i>	0.0025 <i>0.9897</i>	-0.0245 <i>0.8992</i>
No. of Colonies					0.4390 <b>0.0172</b>	0.7084 <b>0.0001</b>
Host Tree Diversity						0.5694 <b>0.0013</b>

<b>B</b>	Tree Diameter	Bark pH	Light Intensity	No. of Colonies	Host Tree Diversity	Lichen Diversity
Tree Height	0.5261 <b>0.0034</b>	0.0190 <i>0.9220</i>	-0.1683 <i>0.3827</i>	-0.2090 0.2764	-0.0536 <i>0.7821</i>	-0.1760 <i>0.3609</i>
Tree Diameter		0.2021 <i>0.2930</i>	-0.0819 <i>0.6728</i>	0.3383 0.0726	-0.2206 <i>0.2501</i>	0.2683 <i>0.1593</i>
Bark pH			-0.2886 <i>0.1289</i>	0.3273 0.0831	-0.4090 <b>0.0276</b>	0.2686 <i>0.1588</i>
Light Intensity				-0.1754 0.3626	0.2554 <i>0.1810</i>	-0.0052 <i>0.9784</i>
No. of Colonies					-0.1295 0.5032	0.8189 <b>0.0001</b>
Host Tree Diversity						0.0695 <i>0.7202</i>

A principal co-ordinate analysis (PCA) of site data, tree data and lichen cover (Figure 7) shows that most of the lichens are highly correlated with the bark pH and light demanding crustosoles such as Thelotremaaceae, Pyrenulaceae are positively correlated with the high light intensities. Both foliose and crustose lichens were found on the highest positive scale of the axis 1 and few of them being found on the negative section of the axis 1.



Figure 7: PCA of site data, tree data and lichen cover.

#### v) Dominant and rarity of lichens in HPNP

The rarity and dominance of lichens were determined by the frequency (Table 5). They were classified as very rare, rare, common, dominant and predominant. 42 % genera found to be very rare, 19.40 % rare, 17.91 % common, 10.44 % dominant and 10.44 % predominant. *Sticta*, *Pseudocyphellaria*, *Lobaria*, *Heterodermia*, *Bunodoporon*, *Leptogium* like macrolichens and *Graphis* like microlichen were predominant and *Buellia*, *Caloplaca*, *Cetrelia*, *Diplotomma*, *Pleurotheliopsis*, *Arthopyrenia*, *Haemmatoma* like microlichens and *Nephroma*, *Pannaria*, *Parmelina*, *Parmelinella*, *Myelochroa* like macrolichens were very rare lichens. *Graphina*, *Lepraria*, *Rimelia*, *Fissurina*, *Hypogymnia*, *Parmotrema*, *Megalospora*, *Usnea*, *Leprocaulon*, *Phyllopsora*, *Ocellularia* and *Myriotrema* were found as common lichen genera.

Table 5: Dominance and rarity among lichens of HPNP

Colony class	Categories	No. of Genera
1 to 5	Very rare	28
6 to 20	Rare	13
21 to 50	Common	12
51 to 100	Dominant	07
> 101	Predominant	07
	Total	67

According to the graph obtained for % Frequency Vs total cover values of the foliose lichens *Pseudocyphellaria*, *Heterodermia*, *Sticta*, *Leptogium*, *Lobaria* were found as a predominant genera. Lichens genera other than these were found as a rare or very rare (Figure 8).

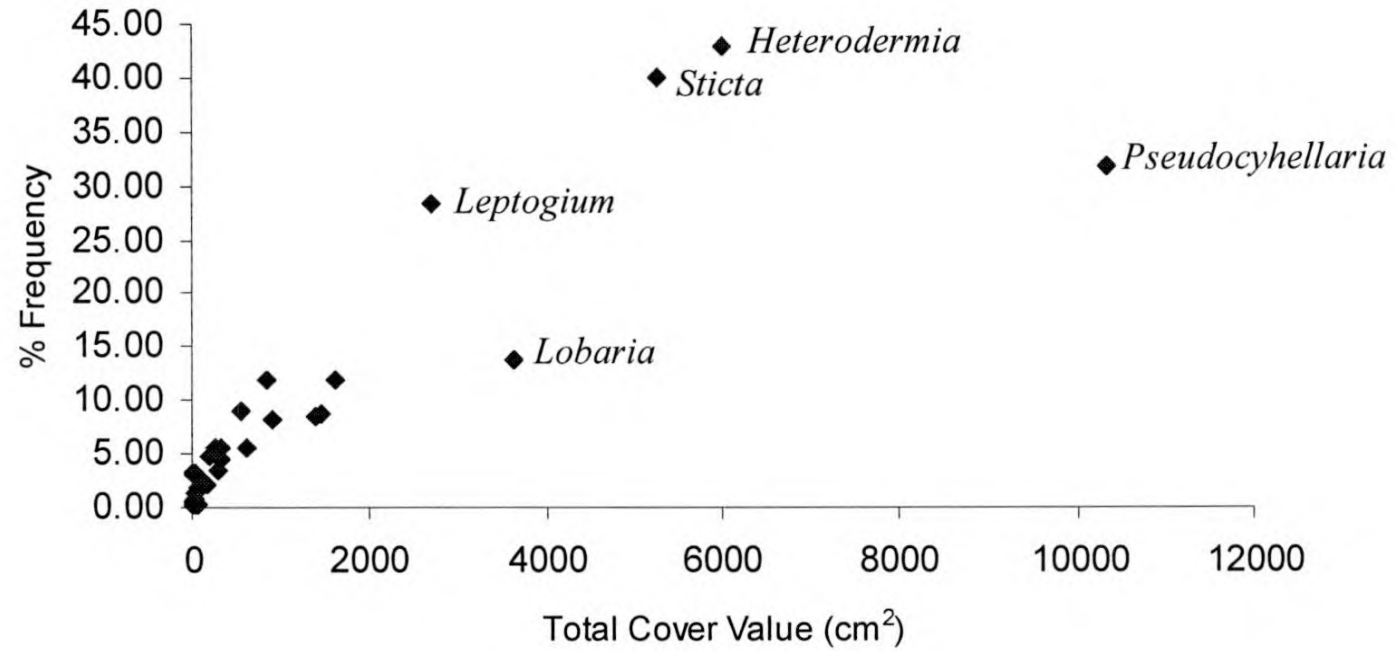


Figure 8: Dominant and rarity of macrolichens (Foliose and Fruticose) in HPNP

According to the graph obtained for % Frequency Vs total cover values of the crustose lichens, *Graphis*, *Thelotrema*, *Ocellularia*, *Myriotrema* and *Pyrenula* were present as predominant genera. All the other crustose genera were found as rare or very rare (Figure 9).

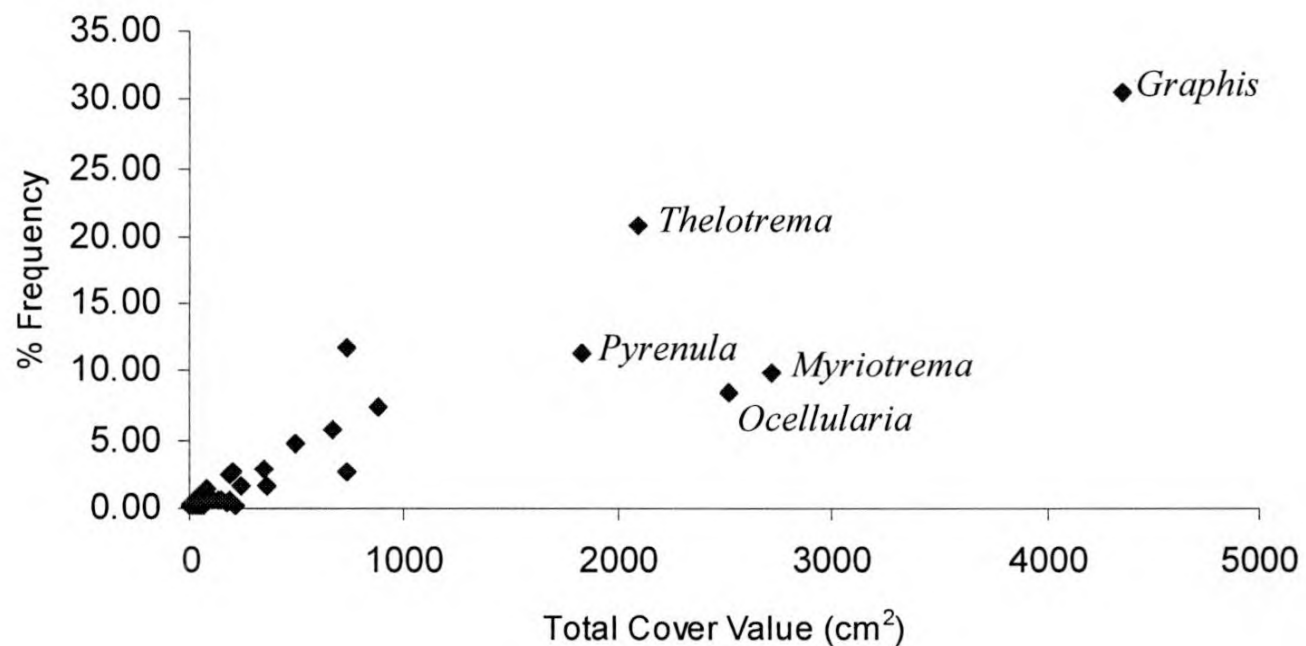


Figure 9: Dominant and rarity of microlichens (Crustose) in HPNP

**vi) Distribution of lichens in relation to host bark pH variations**

Most of the lichens present in the study plots preferred relatively high pH range (5.0-6.0). The most dominant lichen species (314 species) within this pH range were macrolichens like *Lobaria retigera*, *Pseudocyphellaria beccarii*, *Heterodermia microphylla* and microlichens like *Graphis sp.* *Myriotrema sp.*. It was observed that few lichens (45 species) preferred extremely low pH range (3.00 - 3.99) and extremely high pH (8.00 - 8.99) range (Figure 10). A similar pattern also observed with crustose and foliose lichens (Figure 11).

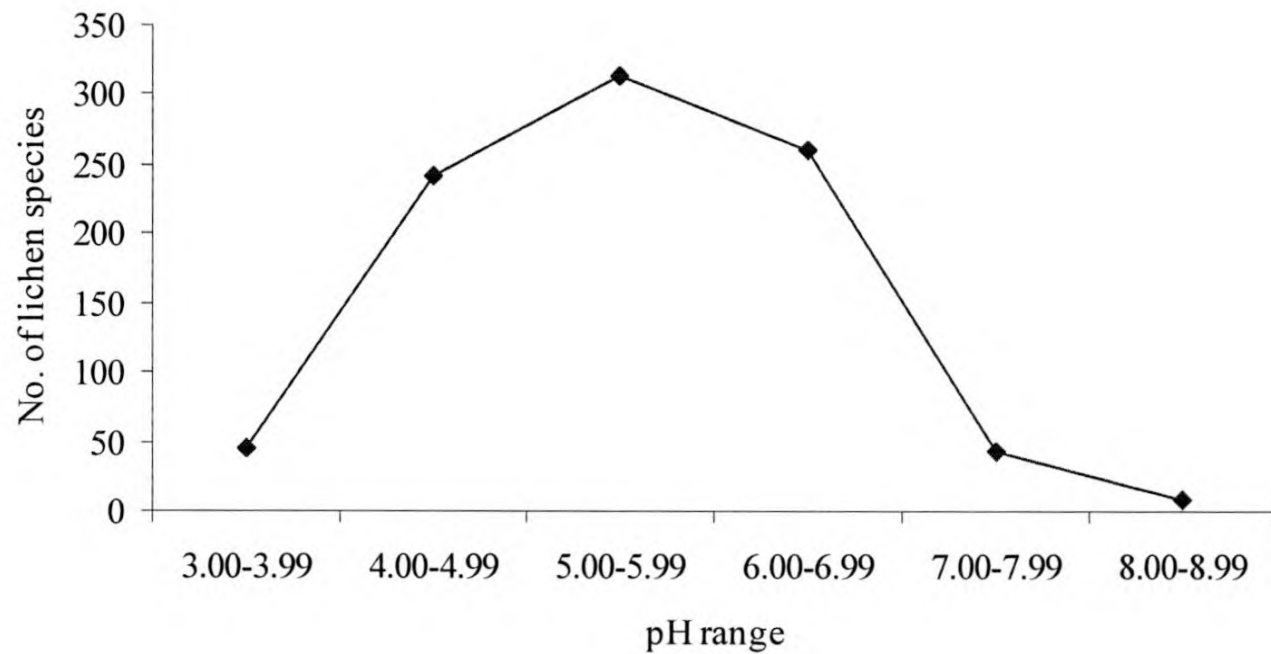


Figure 10: Distribution of all types of lichens in relation to pH variation in the HPNP.

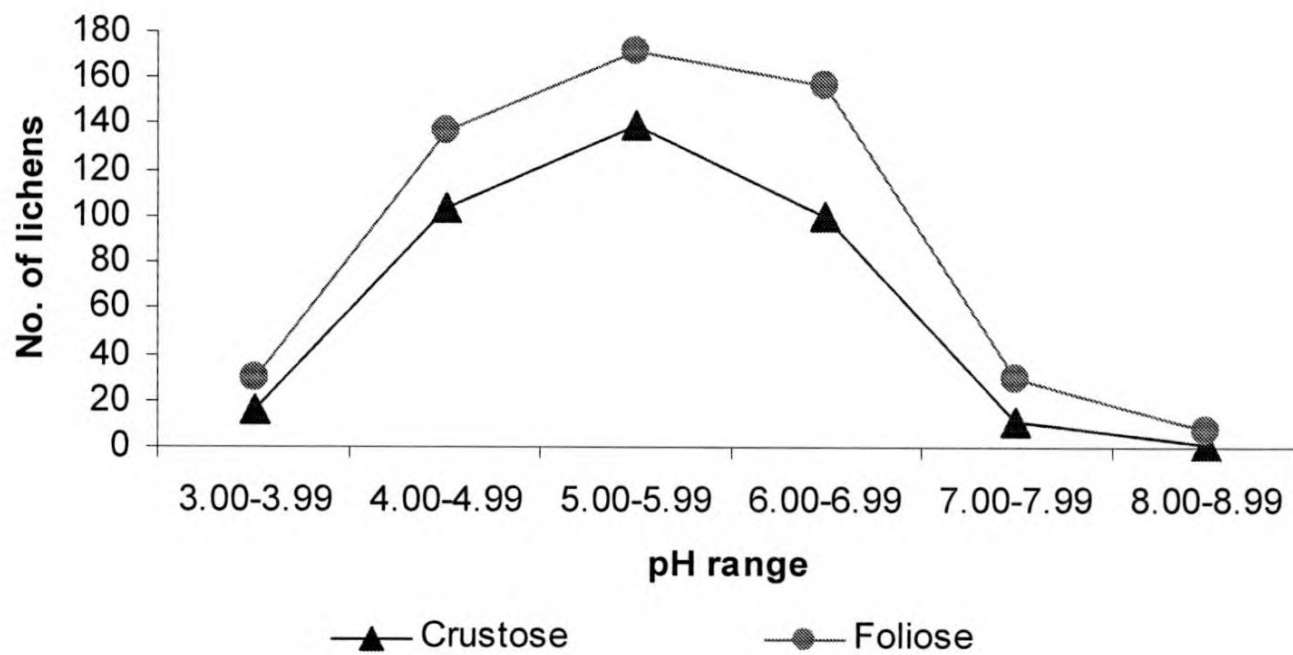


Figure 11: Distribution of crustose and foliose types of lichens in relation to pH variation in the HPNP.

Comparing the distribution of lichens (both crustoses and folioses) with respect to bark pH in the forest islands and in continuous forest, the highest number (122) of lichen species (*H. leucomelos*, *P. beccarii*, *Graphis sp.*) preferred a low pH range (4.0-6.0) in the continuous forest while lichens (*L. retigera*, *P. intricata*, *Thelotrema sp.*) in the forest islands preferred a higher pH range (5.0-7.0) (Figure 12 and 13).

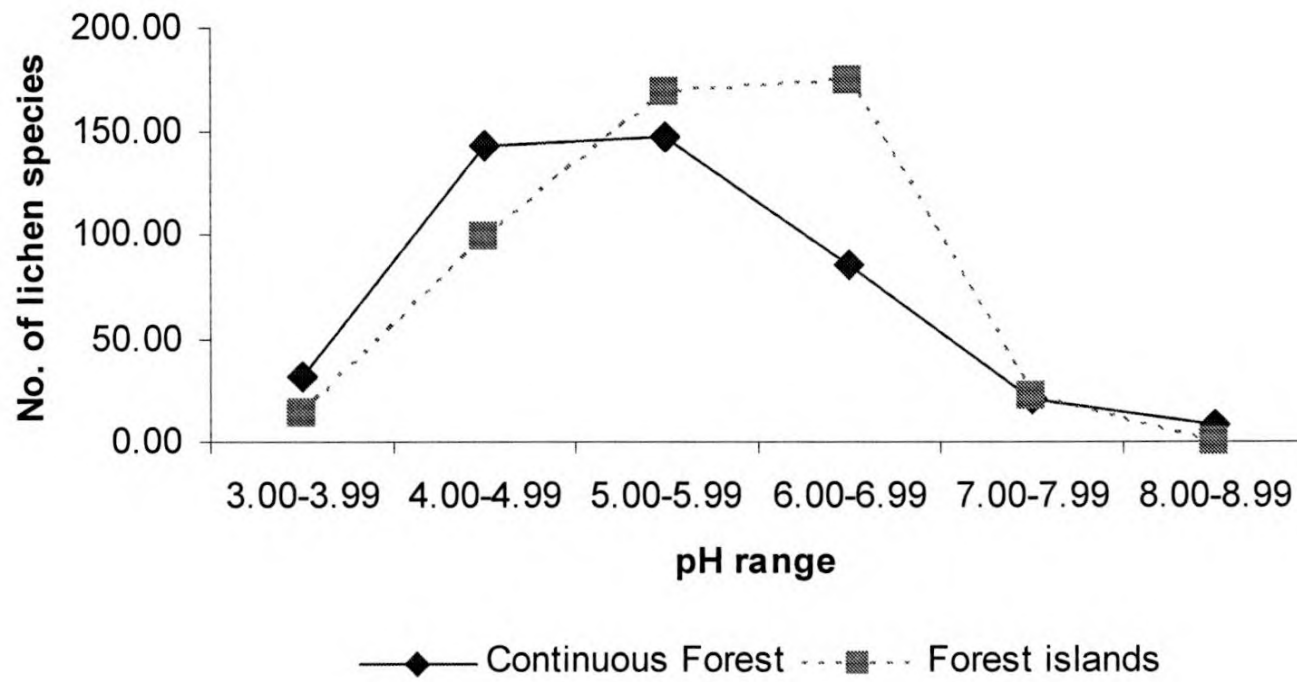


Figure 12: Occurrence of lichen species with different pH ranges in continuous forest and forest patches of HPNP

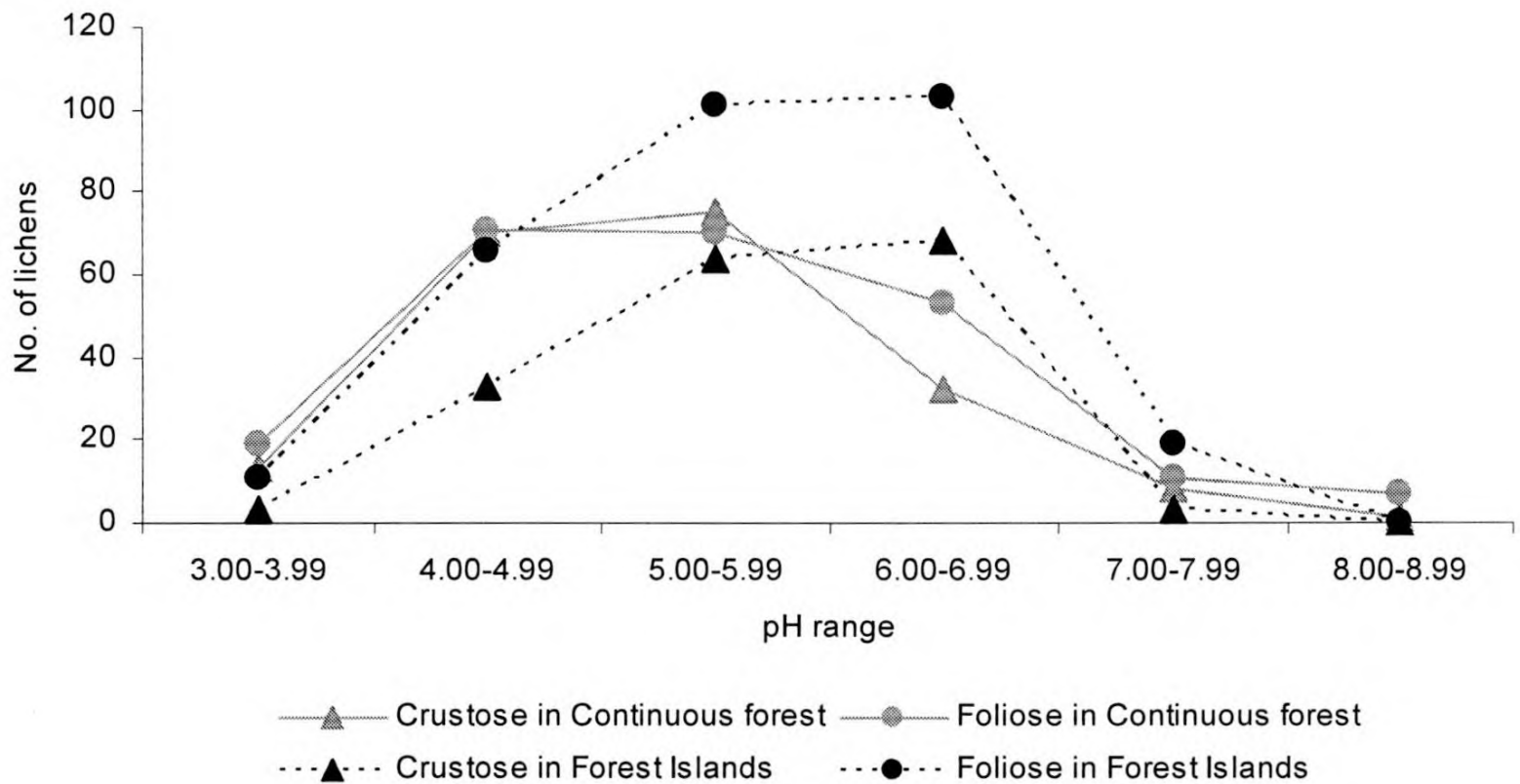


Figure 13: Occurrence of foliose and fruticose lichens with different pH ranges in continuous forest and forest patches of HPNP

According to the statistical analysis (correlation analysis, MNITAB 14.0,  $p=0.05$ ), a positive correlation was observed between host tree diameter and the bark pH (Figure 14). Trees having larger diameter classes such as *Calophyllum walkeri*, *Eugenia maboeides* possessed high bark pH values (5-7) while smaller trees such as *Symplocos cochinchinensis*, *Actinodaphne speciosa* possessed slightly low pH values (5-6). A similar trend was observed with tree height, where bark of taller trees having basic bark conditions and shorter trees having acidic bark conditions. Furthermore, it was observed that high number of lichen species was observed in trees with smaller diameter when compared to the trees with larger diameter (Figure 14).

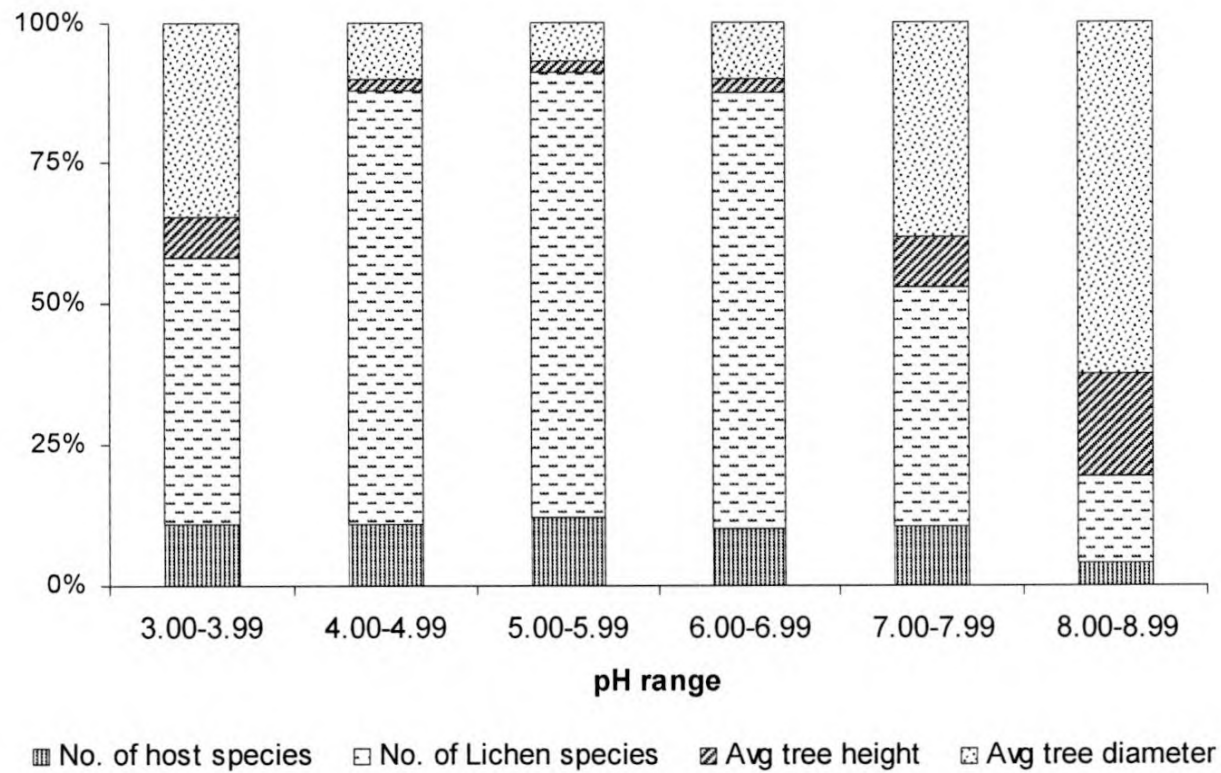


Figure 14: The variation of No. of lichen species and No: of host species and their height and diameter within different pH ranges.

Furthermore, it was observed that, the dominance of acidophytic lichen taxa (*Bunodophoron sp.*, *Leprocaulon pseudoarbuscula* and *Cladonia sp.*) in the general epiphytic lichen flora at HPNP, clearly reflects the acidic character of the bark of the tree within HPNP. However, in forest patches most lichens preferred slightly less acidic conditions.

When compared the average pH of some host plant species, the highest average bark pH (7.46) was observed on one unidentified tree species and the lowest average bark pH (4.13) was observed on *Vaccinium symplocifolium*. The bark pH of most of the host tree species ranged between pH 5-6 (Figure 15).

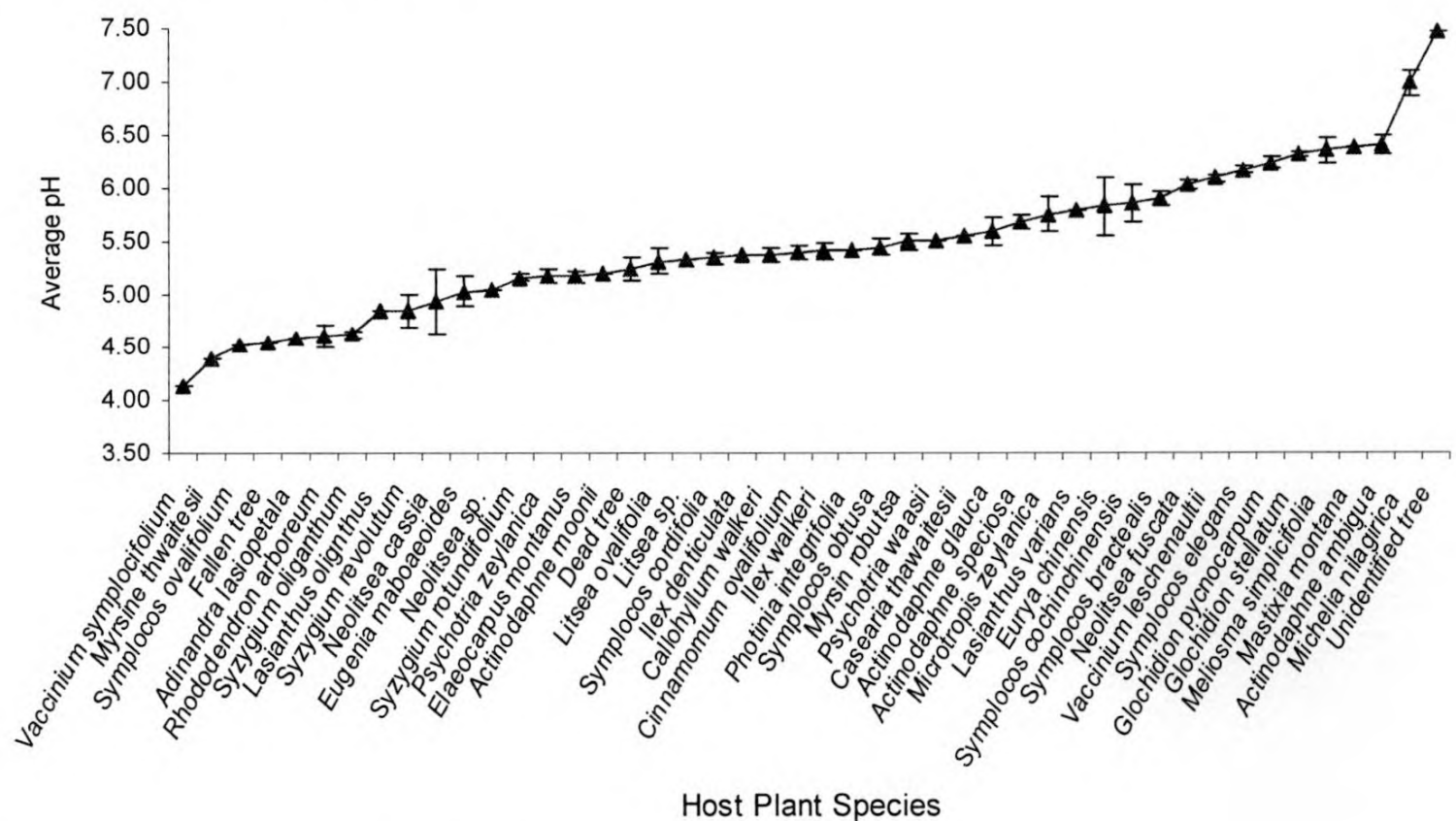


Figure 15: Bark pH variations of host tree species in HPNP.

*Eugenia maboaoides* showed the lowest bark pH (4.01) in forest islands and *Cinnamomum ovalifolium* showed the lowest bark pH (4.94) in continuous forest. *Michelia nilagirica* showed the highest bark pH in both continuous forest (6.73) and forest islands (7.21). *Ilex walkeri*, *Litsea ovalifolia*, *Meliosma simplicifolia*, *Michelia nilagirica*, *Microtropis zeylanica* and *Neolitsea fuscata* were showed similar arrangement of pH variation in both forest types. However, all the above species present in continuous forest showed the lower pH values than the forest islands. Some trees showed large pH variations in both forest types. *Eugenia maboaoides* showed higher pH (6.06) in continuous forest and lower pH (4.01) in forest islands (Figure 16).

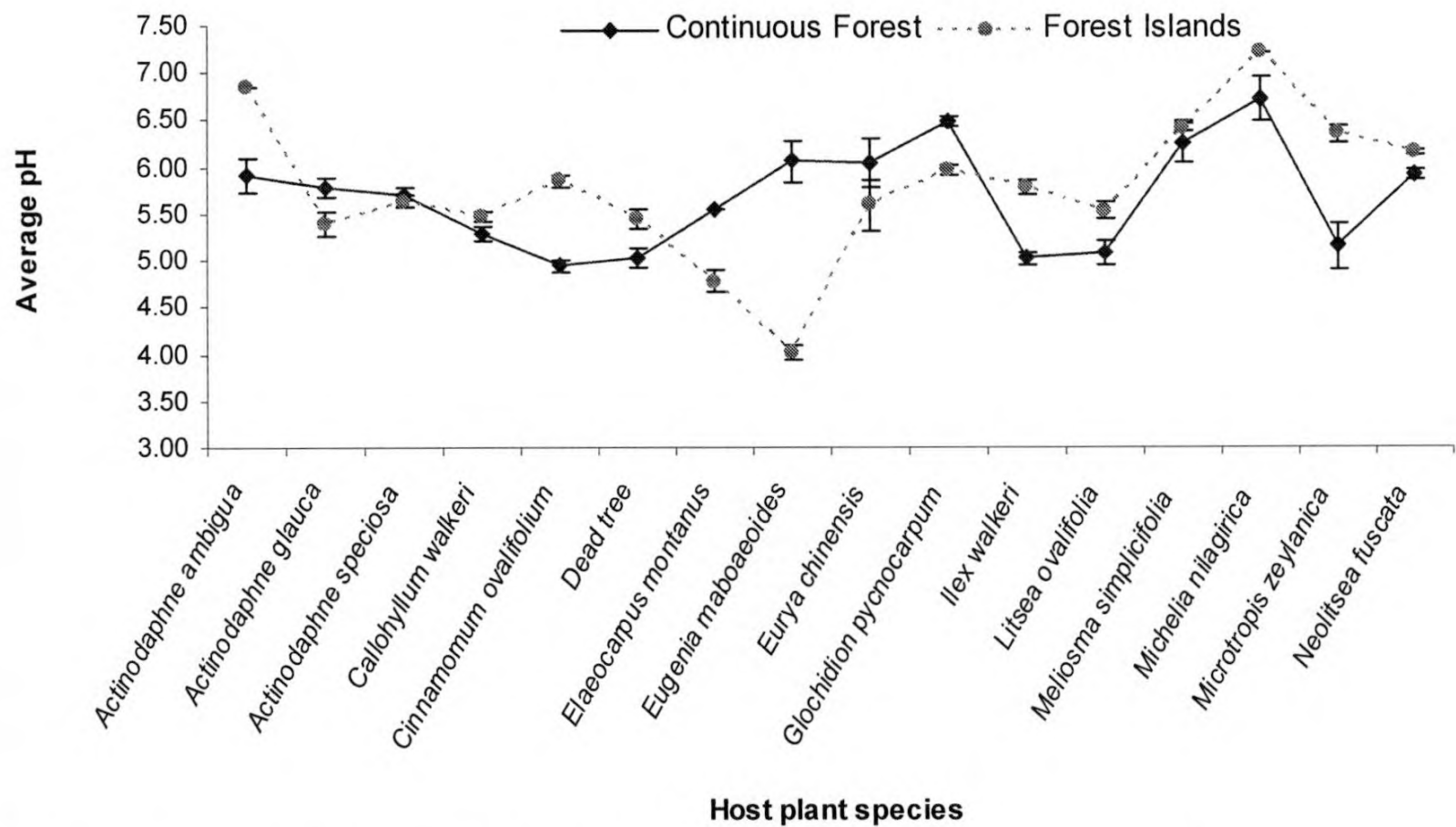


Figure 16: Variation of average pH of host trees in continuous forest and forest islands.

### vii) Distribution of lichens in relation to host species

Floristic analysis revealed the presence of 450 individual trees (recorded lichen host trees) in 12 plots. Those trees consist of 42 tree species belonging to 24 genera and 11 families. Of them Lauraceae was the dominant flowering plant family, while Rubiaceae, Myrtaceae and Symplocaceae were the other leading families. More than 95 % of the tree species recorded in 12 plots were endemic to Sri Lanka. Host plants in continuous forest are more diverse than the forest islands (Table 6). Species richness was higher in forest islands, where as evenness of the host species was higher in continuous forest (Table 6).

Table 6: The diversity of lichens in the continuous forest and forest islands in the HPNP calculated using a variety of diversity statistics and B) the pattern of species abundance in the forest types.

	Continuous Forest	Forest Islands
Number of Families	11	11
Number of Genera	21	21
No. of Species	36	31
No. of Individuals	213	237
Shannon Diversity Index (H)	3.151	2.824
Evenness	0.587	0.516

In the continuous forest, the highest diversity (42 species) and the second highest diversity (29 species) of crustose lichens were observed on *Ilex walkeri* and *Syzygium rotundifolium* respectively. In the same forest type the highest and the second highest foliose lichens diversity were observed on *Neolitsea fuscata* (35 species) and *Ilex walkeri* (34 species) respectively (Figure 17). In the forest Islands the highest diversity of crustose (29 species) and foliose (85 species) lichens were found on *Neolitsea fuscata* and the second highest crustose (19 species) and foliose (49 species) were found on *Ilex walkeri* and *Cinnamomum ovalifolium* respectively (Figure 18). Dead trees were also contained higher number of foliose species (66) than crustose species (29) in both forest types (Figure 17 and 18).

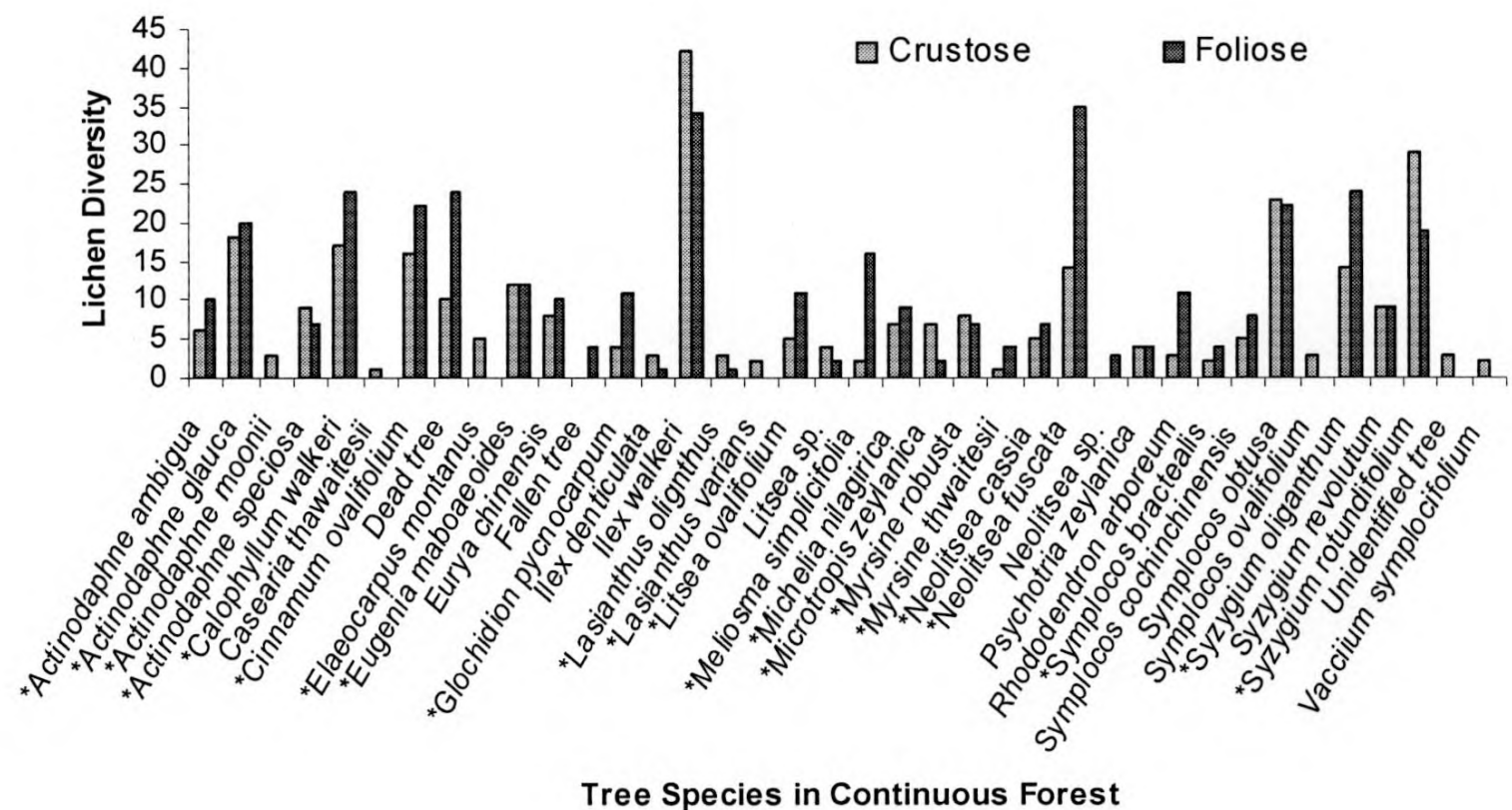


Figure 17: Diversity of crustose and foliose lichens on different host tree species in continuous forest of HPNP. (\* mark indicated trees are endemic to Sri Lanka).

Some tree species found in the continuous forest, such as *Actinodaphne mooni*, *Elaeocarpus montanus*, *Lasianthus varians*, *Symplocos ovalifolium*, *Vaccinium symplocifolium* were found to be associated only with the crustose species. A fallen tree and a *Neolitsea* species in this forest type contained only foliose species (Figure 17).

Similarly trees such as *Eugenia maboaeoides*, *Photinia integrifolia* and *Psychotria waasii* provided the substrate only for the foliose species in the forest islands (Figure 18). Most of the trees found in both forest types hosted more foliose lichens than crustose lichens.

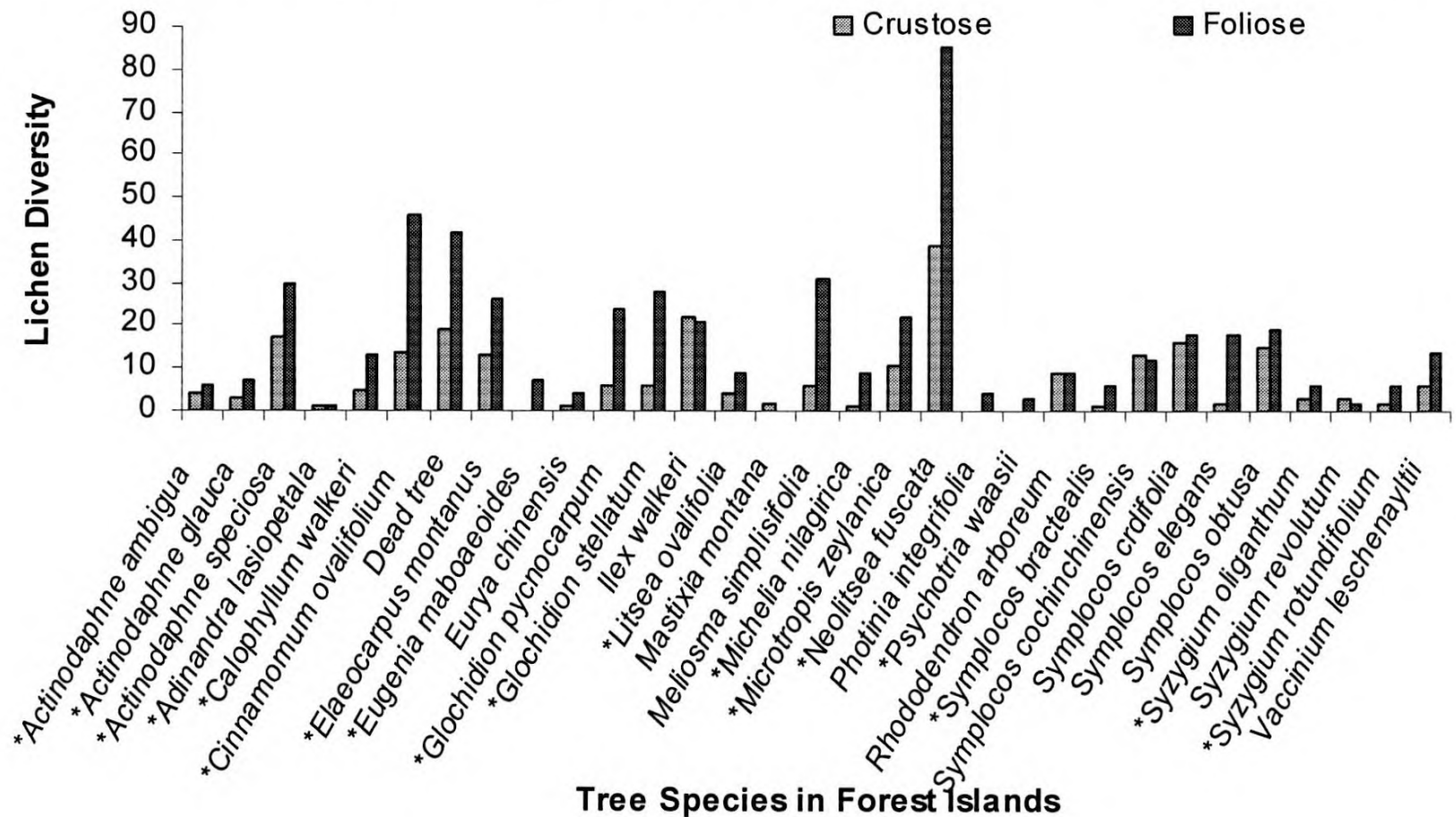


Figure 18: Diversity of crustose and foliose lichens on host tree species in forest islands of HPNP. (\* mark indicated trees are endemic to Sri Lanka).

*Graphis* sp. is the most frequently found crustose genus on the barks of host trees in both continuous forest and forest Islands. It was found on 26 (16.5 %) host species in the continuous forest and 19 (14.5 %) host species in the forest islands. *Thelotrema* sp. was found from 15 (10.4 %) host species in both forest types. *Myriotrema* sp., *Ocellularia* sp., *Pertusaria* sp. and *Pyrenula* were the other leading crustose genera found on the host trees in both forest types. Above crustose genera other than *Myriorema* sp. found on host tree species are higher in the continuous forest than the forest islands. Some lichen genera were found only on one tree species in the continuous forest and these include *Buellia* sp., *Caloplaca* sp., *Lecidella* sp. and *Pseudopyrenula* sp.. Similarly *Chrysothrix* sp. and *Heamatomma* sp. found from single tree species in the forest islands (Figure 19).

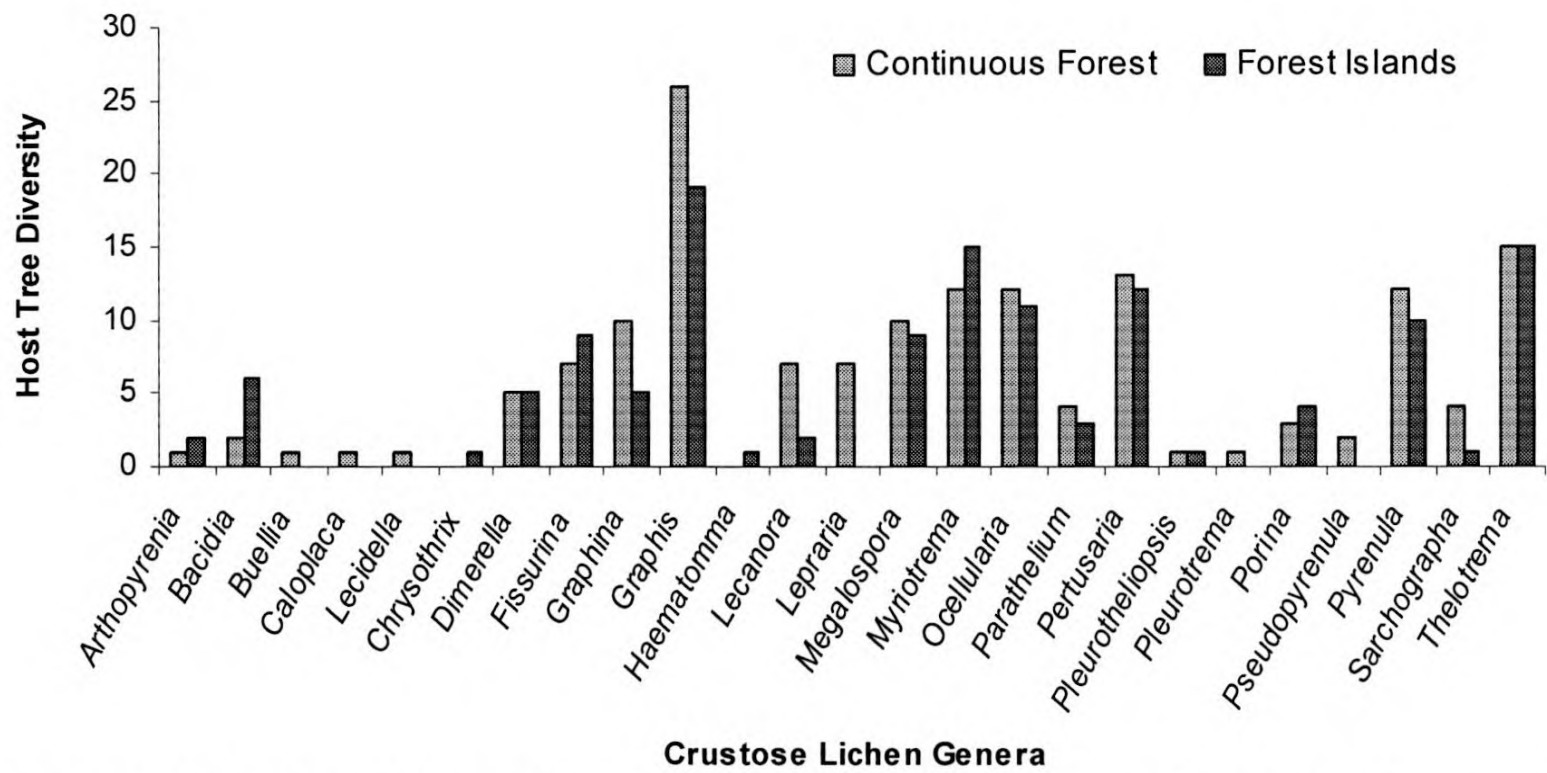


Figure 19: Distribution of crustose lichen genera on host trees in continuous forest and the forest islands of HPNP.

The genus *Heterodermia* and *Pseudocyphellaria* were recorded from more than 25 host species in the continuous forest (11.8 %) and forest islands (10.7 %) respectively. Genus *Sticta* was found on 23 (10 %) host species in both forest types. The other leading genera found in both forest types include *Bunodophoron*, *Cladonia*, *Coccocarpia*, *Hypotrachyna*, *Lobaria*, *Parmeliella*, *Phyllopsora* and *Usnea*. Foliose genera such as *Canomaculina*, *Cetrelia*, *Canoparmelia*, *Leioderma*, *Nephroma*, *Punctelia*, *Ramalina* and *Teloschistes* found on a single tree species in the forest islands. Similarly, *Parmelinella* and *Parmelinopsis* were found on single host species in the continuous forest (Figure 20).

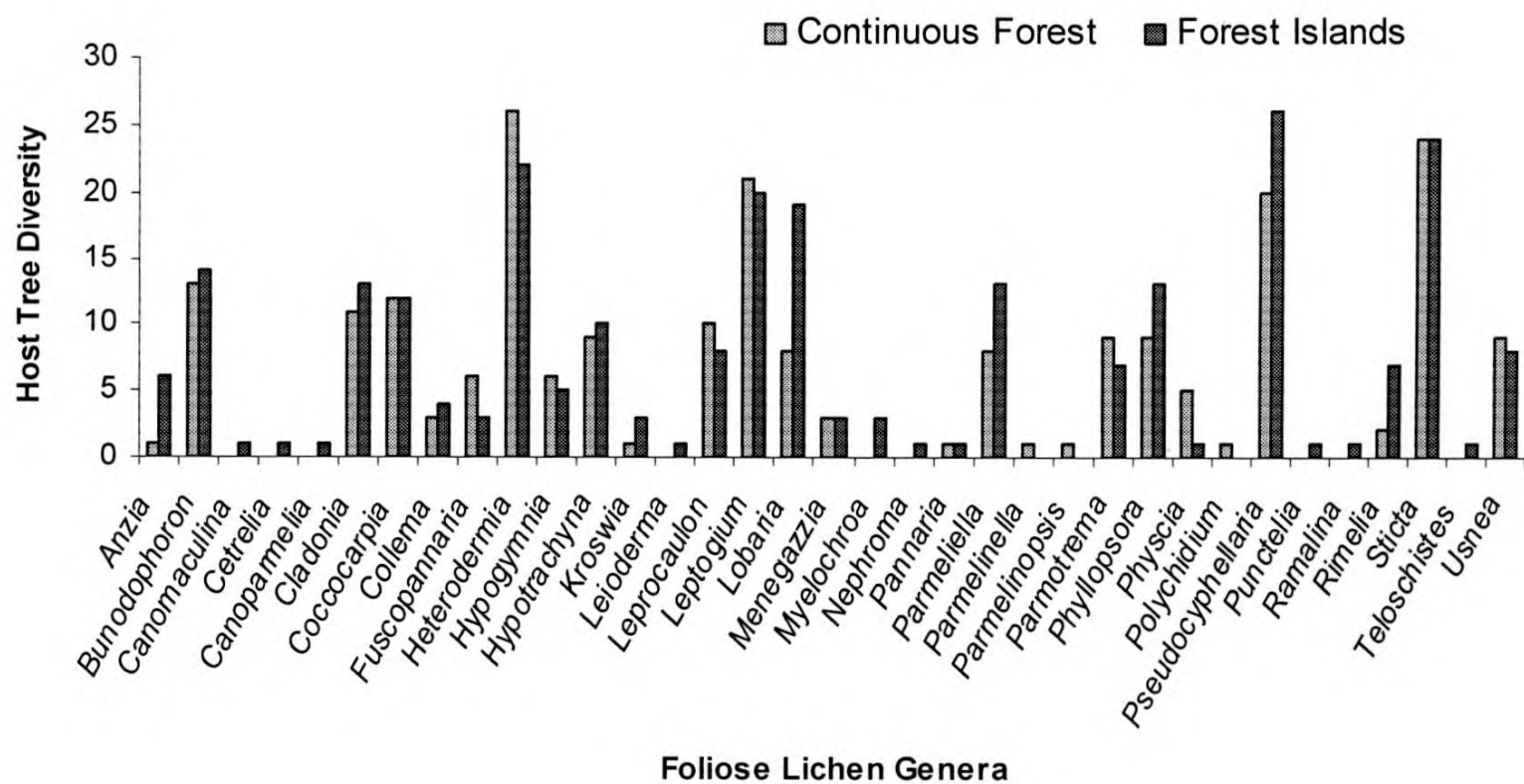


Figure 20: Distribution of foliose genera on different host trees in continuous forest and forest islands of HPNP.

viii) **Distribution of lichens in relation to diameter of host trees**

Figure 21A records the distribution of host species within each diameter class. The highest number of host species was found in 11-20 cm diameter class in the continuous forest while in the forest islands the highest number of host species found in 21-30 cm diameter class. It was observed that the number of host tree species increased with increasing diameter up to 11-20 cm diameter class in both forest types. A decrease in number of host species in higher diameter classes above 20 cm was observed in both forest types. Also 29.21 % of lichen host species represented in 11-20 cm diameter class in the continuous forest and 25.00 % of host species represented in the 21-30 cm diameter class in the forest islands. *Calophyllum walkeri* represented on all diameter classes except the diameter class 5-10 in continuous forest, while *Neolitsea fuscata* represented on all diameter classes in forest islands.

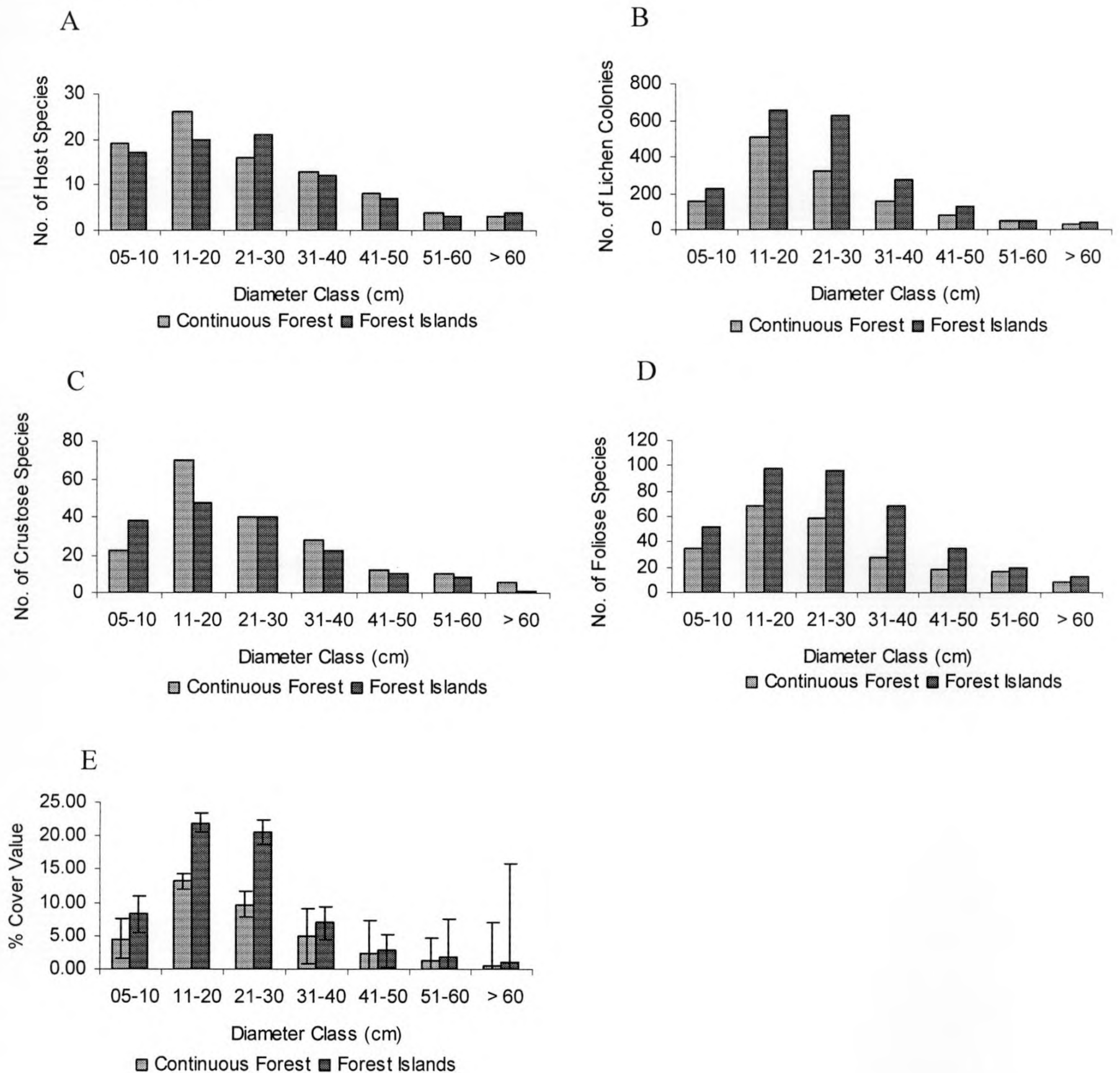


Figure 21: A. No. of host species, B. No. of lichen colonies, C. No. of crustose species, D. No. of foliose species, E. % cover Value on seven tree diameter classes in the continuous forest and forest islands of HPNP.

The number of lichen colonies increased with increase in diameter class from 5-10 cm to 11-20 cm. The highest number of lichen colonies was found on hosts of 11-20 cm diameter class in both forest types. It was clearly observed that the number of lichen colonies decrease with further increasing diameter size of the lichen host species. The number of lichen colonies in continuous forest was lower than that of forest islands in all diameter classes (Figure 21B).

The diameter class 11-20 cm possessed the highest number of crustose species in both forest types. The number of crustose species increased with increasing diameter from 5-10 cm to 11-20 cm. However, the number of crustose species were decreased with further increasing diameter size from 11-20 cm onward (Figure 21C). Similar observation was made with foliose lichens in both forest types. However, the number of foliose lichens in the continuous forest was always less than that of the forest islands in all the diameter classes (Figure 21D). The crustose lichens like *Thelotrema* sp. and *Myriotrema* species were found in all the diameter classes in continuous forest. Species like *Megolospora sulphurata*, *Graphis* sp. and *Haematomma africanum* were specific to 21-30 cm in forest islands while *Arthopyrenia* sp. and *Myriotrema cf. fissurinum* were specific to diameter class 5-10 cm and > 60 cm respectively in continuous forest.

The foliose lichens, *Leptogium denticulatum* and *Sticta* sp. were recorded on all the diameter classes in continuous forest while *Bunodophoron* sp. and *Sticta cyphellulata* were recorded on all the diameter classes in forest islands. *Anzia* sp. was specific to 51-60 cm while *Parmeliella leiostroma* specific to 5-10 cm diameter class in continuous forest. *Heterodermia rubescens* and *Hypogymnia vitata* was specific to 31-40 cm while *Parmotrema gardneri* specific to diameter class 11-20 cm in forest islands (Figure 21D).

Figure 21E revealed the variations in cover values of lichens in forest islands and continuous forest. The highest % cover values were obtained on 11-20 cm diameter class in both forest types. Beyond the diameter class 11-20 cm, the % cover values of lichens decreased with increasing diameter size. The % cover value of continuous forest was less than that of forest islands in all the diameter classes. This was significant in ( $p < 0.05$ , *t*-test) diameter classes 11-20 cm and 21-30 cm.

The host tree species *Actinodaphne glauca*, *Actinodaphne speciosa*, *Cinnamomum ovalifolium*, *Ilex walkeri*, *Neolitsea fuscata*, *Symplocos cochinchinensis*, *Symplocos obtuse* and *Rhododendron arboretum* represented the diameter class 11-20 cm in both continuous forest and forest islands. However, in continuous forest only *Actinodaphne ambigua*, *Litsea ovalifolia* and *Syzygium revolutum* represented the diameter class 11-20 cm. While in the forest islands the same diameter class was occupied by *Glochidion stelatum*, *Meliosma simplicifolia* and *Symplocos elegans*. The diameter class > 60 cm was represented by *Calophyllum walkeri*, *Ilex denticulate* and *Michelia nilagirica* in continuous forest and *Eugenia maboaeoides*, *Mastrixia Montana* and *Neolitsea fuscata* in forest islands.

#### ix) Disstribution of lichens in relation to bark type

The lichen diversity was compared with the host bark types in both continuous forest and forest islands in HPNP. According to the observations smooth bark type had the highest diversity of lichens in both forest types and this was followed by smooth to rough bark

type. The least lichen diversity was observed on deeply furrowed bark type in the continuous forest, while in the forest islands, the least diversity was observed on flaky bark type (Figure 22). The foliose lichen diversity was higher in all the bark types of the forest islands. However, the same pattern of lichen diversity was not observed in the bark types of continuous forest. Instead a higher diversity of foliose lichens were observed in smooth to rough and fissured bark types while a higher crustose lichen diversity was observed with smooth and flaky barks.

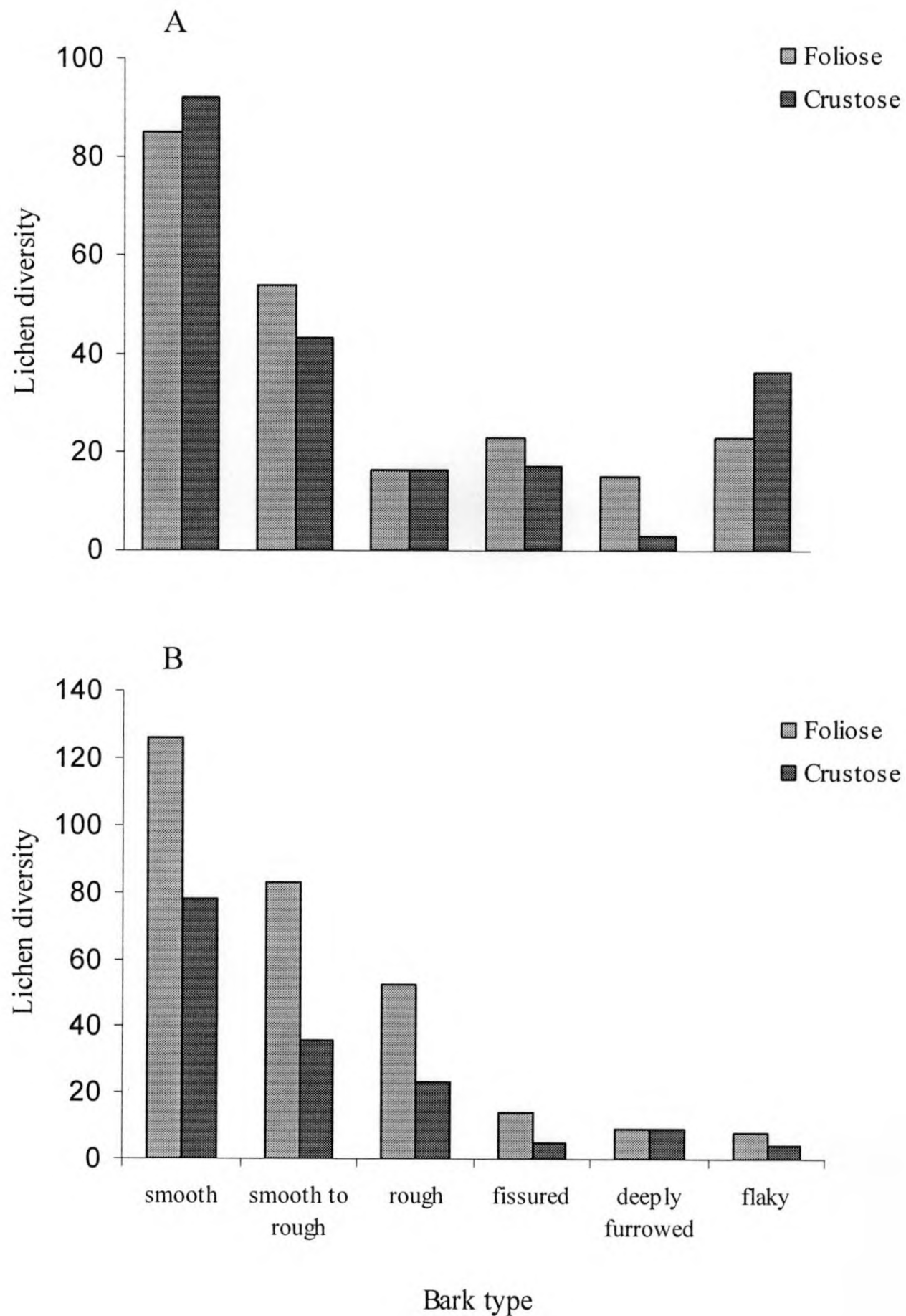
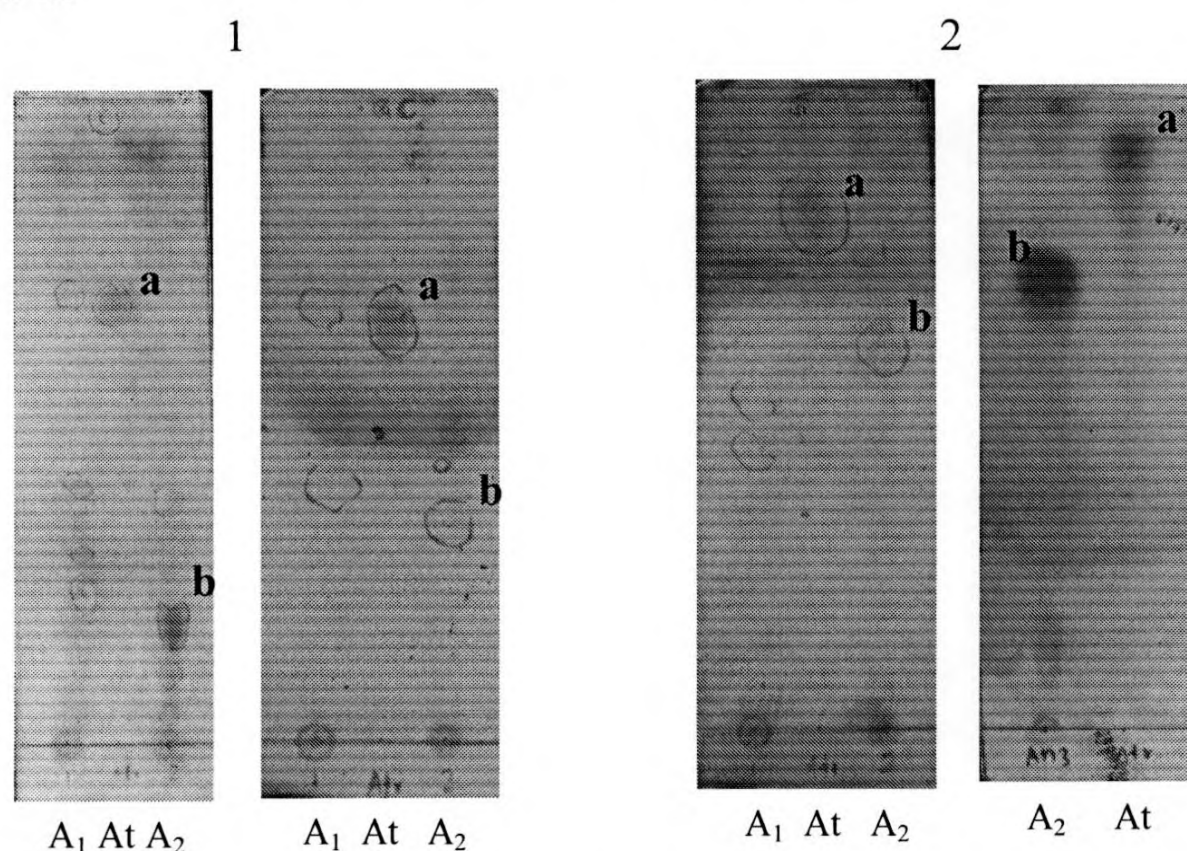


Figure 22: Foliose and crustose lichen diversity in relation to host bark types in the (A) continuous forest and (B) forest islands of the HPNP.

x) Species differentiation using lichen chemistry - Thin Layer Chromatography (TLC) analysis

*Anzia* spp.

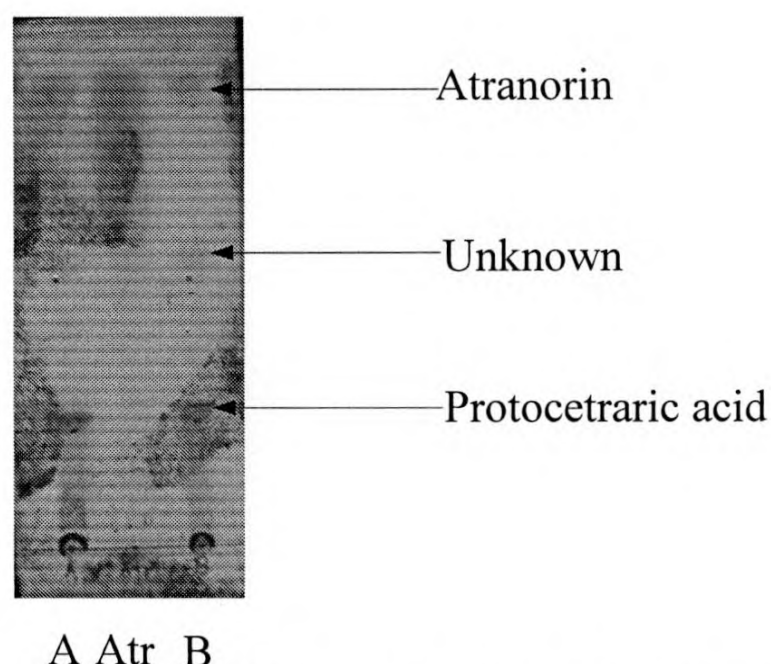
The presence of major chemicals between *Anzia* species 1 and 2 were visualized in Figure 23. Major spot (orange red-a) of *Anzia* species 1 was observed at  $R_f=0.75$  with solvent system C (toluene 170: acetic acid 30) and  $R_f=0.89$  with that of G (toluene 139: ethylacetate 83: formic acid 8). Those spots coincided with the reference sample atranorin. A red spot (b) was observed for the *Anzia* species 2 at  $R_f=0.33$  with solvent system C and  $R_f=0.66$  with that of G.



**Figure 23:** Thin layer chromatogram developed with the solvent system C- toluene 170: acetic acid 30 (1) and G-toluene 139: ethylacetate 83: formic acid 8 (2) of the acetone extract of *Anzia* unidentified 1 (A<sub>1</sub>), *Anzia* unidentified 2 (A<sub>2</sub>) and Atranorin (At) after spraying with 10 % H<sub>2</sub>SO<sub>4</sub> in ethanol followed by heating at 100 °C. a-Atranorin, b- Unknown compound.

*Parmotrema* species

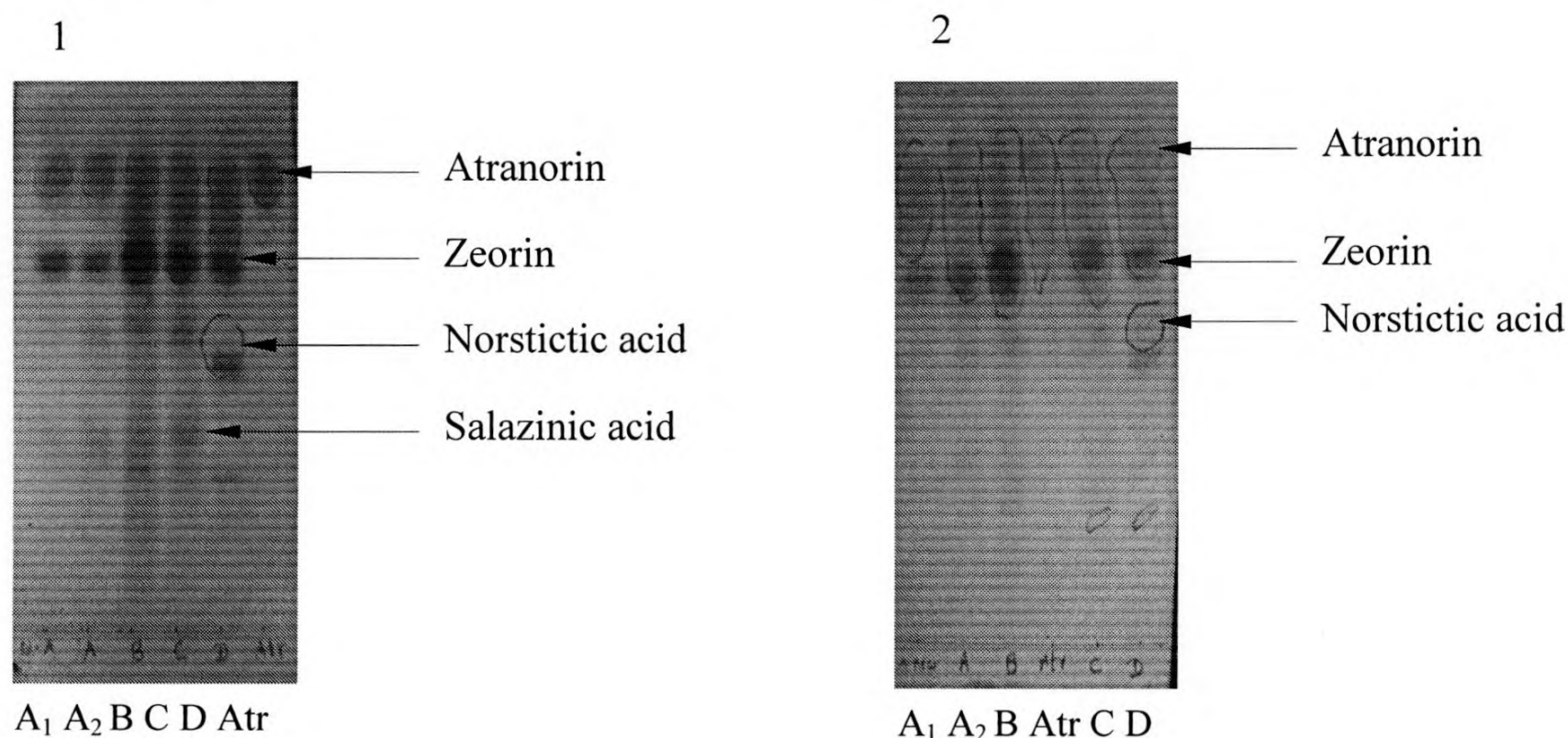
Three spots were observed with both A and B samples eluted with the G (Figure 24). The upper most spot ( $R_f=0.90$ ) was coincided with the reference sample atranorin. Another light grey spot was observed at  $R_f=0.56$  and resulted chemical was not identified. The lowest spot was in grey colour at  $R_f=0.27$  and it was identified as protocetraric acid.  $R_f$  values of three spots of both samples were similar. Therefore the both specimens were represented the lichen *Parmotrema cf. gardneri*.



**Figure 24:** Thin layer chromatogram developed with the solvent system G (toluene 139: ethylacetate 83: formic acid 8) of the acetone extract of *Parmotrema cf. gardneri* (A,B) and Atranorin (Atr) after spraying with 10 % H<sub>2</sub>SO<sub>4</sub> in ethanol followed by heating at 100 °C.

### *Heterodermia* species

The presence of major chemical spots in five *Heterodermia* species was visualized in Figure 25. Atranorin ( $R_f = 0.90$ ), Zeorin ( $R_f = 0.72$ ) and salazinic acid ( $R_f = 0.27$ ) were presented in all the samples. Zeorin was violet with anisaldehyde and pink to purple with 10 % H<sub>2</sub>SO<sub>4</sub> in ethanol. Yellow colour spot of norstictic acid was observed at  $R_f = 0.58$  and the specimen was labeled as *Heterodermia* unidentified 7. According to the pattern of spots appeared in the chromatogram, remaining specimens of *Heterodermia* were separated in to four species.



**Figure 25:** Thin layer chromatogram developed with the solvent system G (toluene 139: ethylacetate 83: formic acid 8) of the acetone extract of *Heterodermia* unidentified 2 (A<sub>1</sub>), *H. cf. incana* (A<sub>2</sub>), *H. cf. japonica* (B), *Heterodermia* unidentified 3 (C), *Heterodermia* unidentified 7 (D) and Atranorin (Atr) after spraying with anisaldehyde (1) and 10 % H<sub>2</sub>SO<sub>4</sub> in ethanol (2) followed by heating at 100 °C.

## Part II

### Variations of ambient NO<sub>2</sub> concentrations in selected plots of HPNP

Data used for passive sampling in this study was the average values of 15-30 days. As there are no standards available for this period the data analyzed were compared with 24 h standards. Ambient air quality standards for Sri Lanka are given in the Table 7.

Table 7: Ambient air quality standards for Sri Lanka (Gazette Extraordinary No. 850/4 of December 1994).

Pollutant	Averaging Time (h)	Unit	Standard
SO <sub>2</sub>	1	μg/m <sup>3</sup> (ppm)	200 (0.08)
	8		120 (0.05)
	24		80 (0.03)
NO <sub>2</sub>	1	μg/m <sup>3</sup> (ppm)	250 (0.13)
	8		150 (0.08)
	24		100 (0.05)
O <sub>3</sub>	1	μg/m <sup>3</sup> (ppm)	200 (0.01)
CO	1	μg/m <sup>3</sup> (ppm)	30 (26.1)
	8		10 (8.7)
Lead	Anytime	μg/m <sup>3</sup>	58 (50)
	24		2.0
	Annual		0.5
Suspended Particulate Matter	1	μg/m <sup>3</sup>	500
	3		450
	8		350
	24		300
	Annual		100

Variations of 24 h average ambient NO<sub>2</sub> concentration of five sites (Pattipola road, Ohiya road, World's end, middle and Kirigalpotta) at HPNP during August 2005 to September 2006 are given in Figure 26. Amongst the sampling points, World's End showed comparatively low concentrations of NO<sub>2</sub> through out the studied period. Comparatively higher concentrations were observed during the whole period at Pattipola road and Middle point. However the variation pattern of NO<sub>2</sub> concentrations in each month was almost similar at five sampling points throughout the studied period. The average concentration of NO<sub>2</sub> was comparatively low in September 2005 to March 2006 and began to increase after March 2006 till September 2006. The lowest average NO<sub>2</sub> concentration (0.0001 ppm) was observed in October 2005 and the highest average concentration (0.00048 ppm) was observed in August 2006 (Figure 27). The average concentrations of NO<sub>2</sub> during the study period at each sampling point showed considerable variations (Figure 28). The highest concentration of NO<sub>2</sub> (0.00033 ppm) was observed at Pattipola sampling point and the

second highest (0.00031 ppm) was observed at Middle sampling point, which was situated close to the vehicle park of HPNP. The lowest concentration of NO<sub>2</sub> (0.00018 ppm) was observed at World's end sampling point.

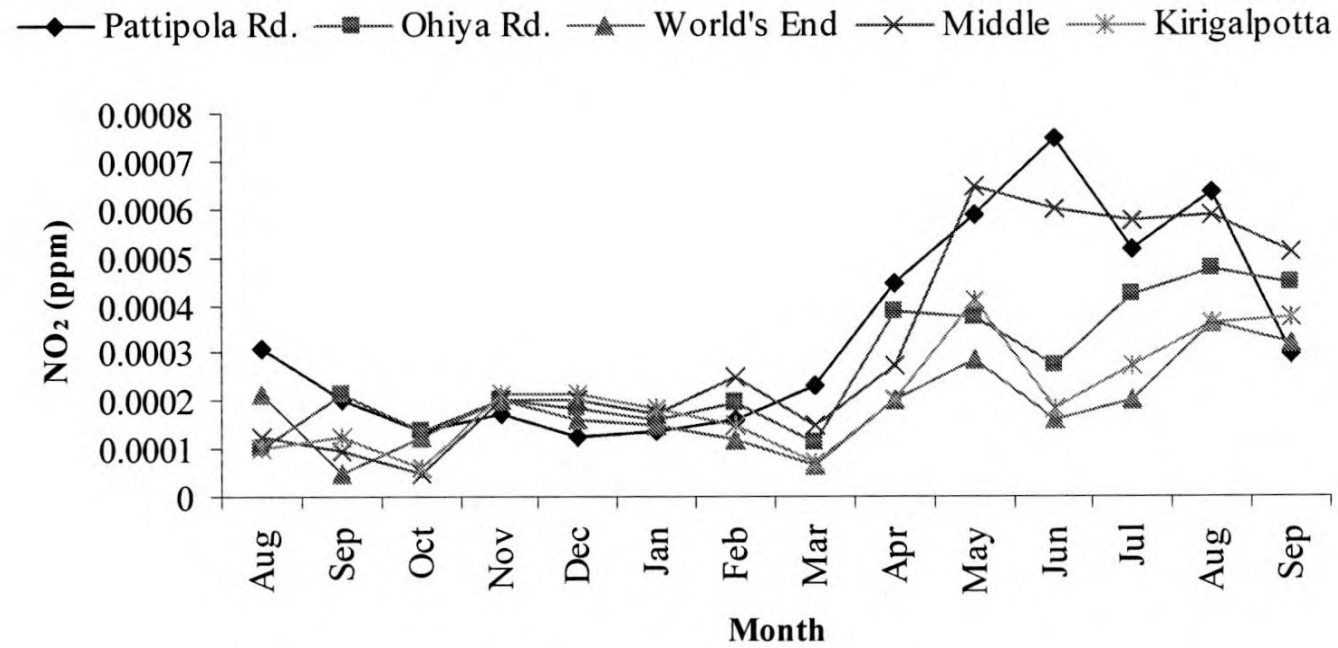


Figure 26: Variations of 24 h average ambient NO<sub>2</sub> concentration of each site at HPNP during August 2005 to September 2006

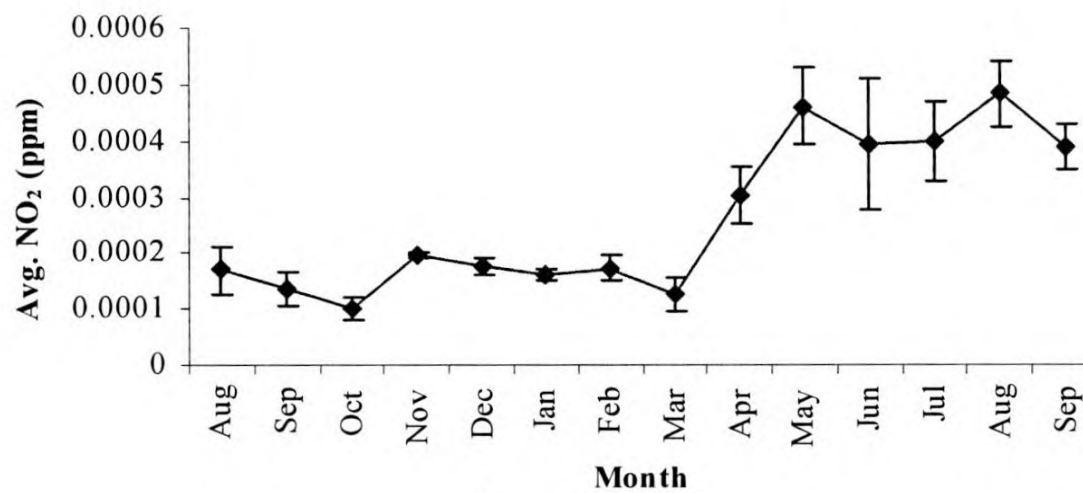


Figure 27: Variations of 24 h average ambient NO<sub>2</sub> concentration at HPNP during August 2005 to September 2006

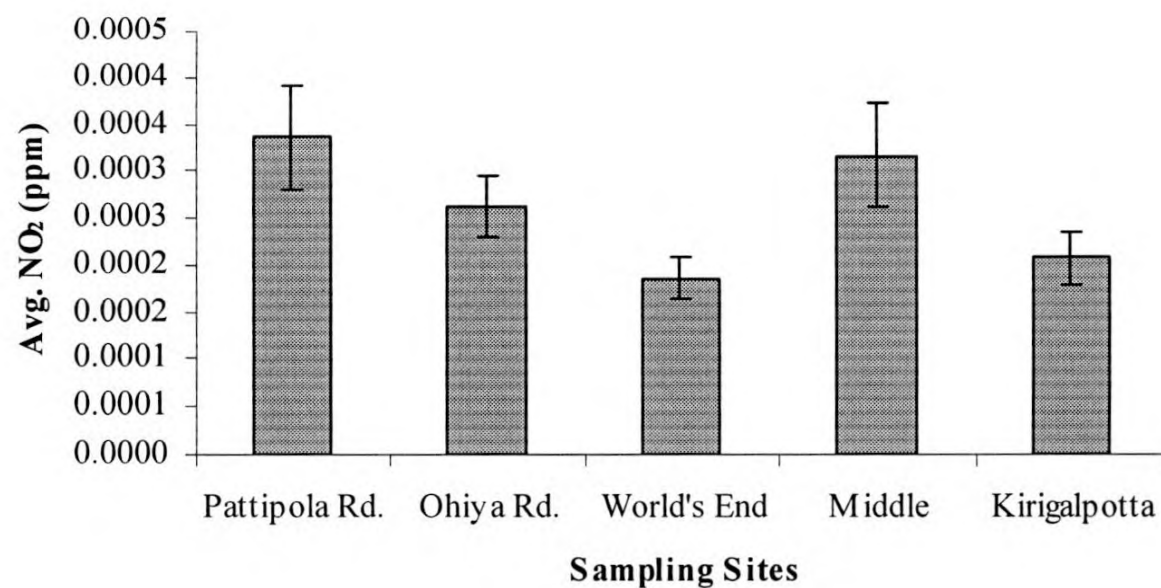


Figure 28: Variations of average ambient NO<sub>2</sub> concentration of five sites at HPNP during August 2005 to September 2006

### Variations of ambient SO<sub>2</sub> concentrations in selected plots of HPNP

Variations of 24 h average ambient SO<sub>2</sub> concentration of five sites (Pattipola road, Ohiya road, World's end, Middle and Kirigalpotta) at HPNP during August 2005 to September 2006 are given in Figure 29. Amongst the sampling points, World's End showed comparatively low concentrations of SO<sub>2</sub> through out the studied period. Comparatively higher concentrations were observed during the whole period at Pattipola road and at Middle point. However, the variation pattern of SO<sub>2</sub> concentrations in each month was almost similar at five sampling points throughout the study period. The average concentration of SO<sub>2</sub> was comparatively low in September 2005 to March 2006 and began to increase after March 2006 till September 2006. The lowest average SO<sub>2</sub> concentration (0.0022 ppm) was observed in February 2006 and the highest average concentration (0.014 ppm) was observed in August 2006 (Figure 30). The average concentrations of SO<sub>2</sub> during the study period at each sampling point showed considerable variations (Figure 31). The highest concentration of SO<sub>2</sub> (0.0063 ppm) was observed at Pattipola sampling point and the second highest value (0.0061 ppm) was observed at the Middle sampling point which was situated close to the vehicle park of HPNP. The lowest concentration of SO<sub>2</sub> (0.0042 ppm) was observed at the World's end sampling point.

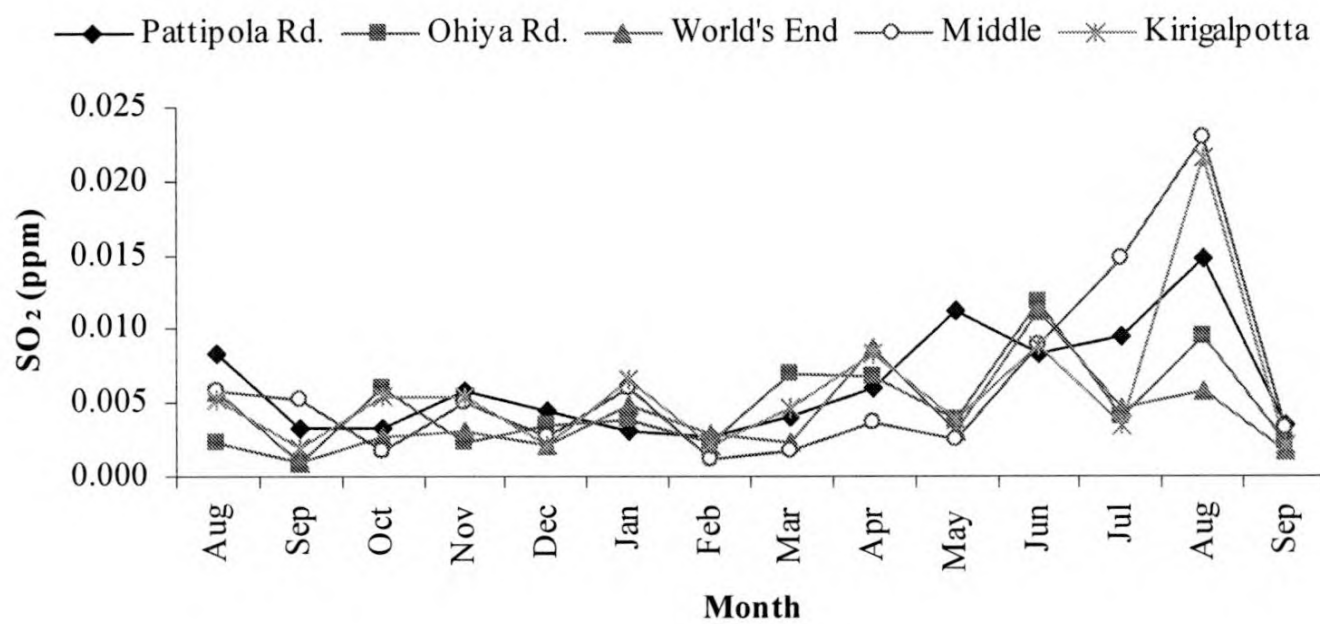


Figure 29: Variations of 24 h average ambient SO<sub>2</sub> concentration of each site at HPNP during August 2005 to September 2006

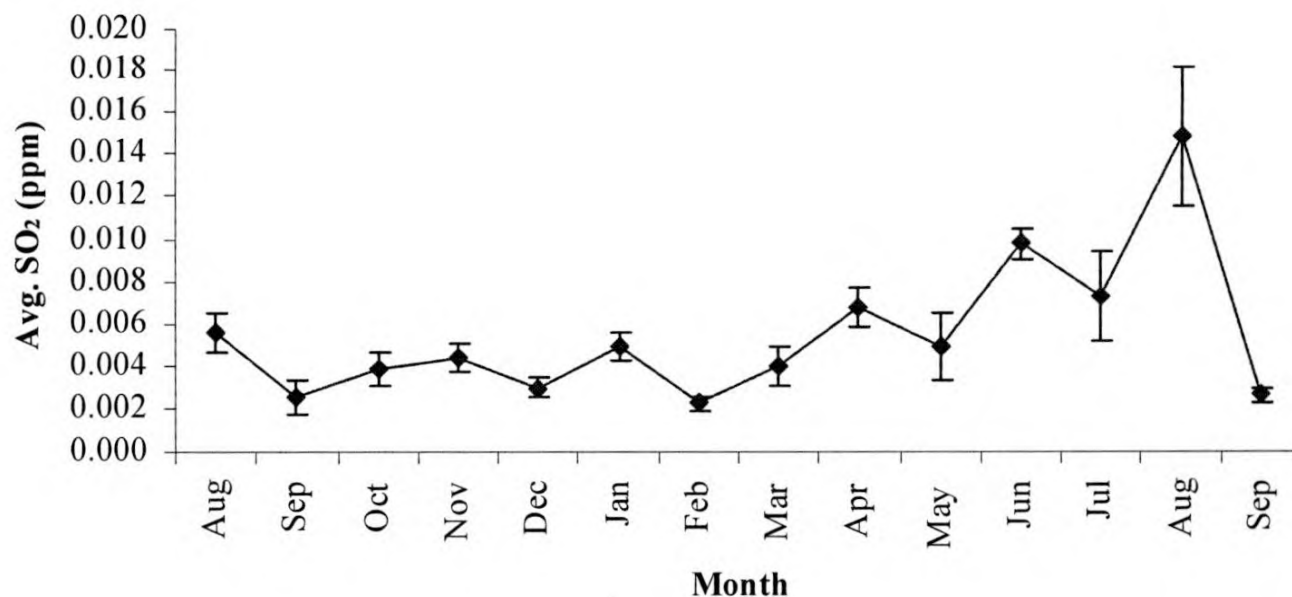


Figure 30: Variations of 24 h average ambient SO<sub>2</sub> concentration at HPNP during August 2005 to September 2006.

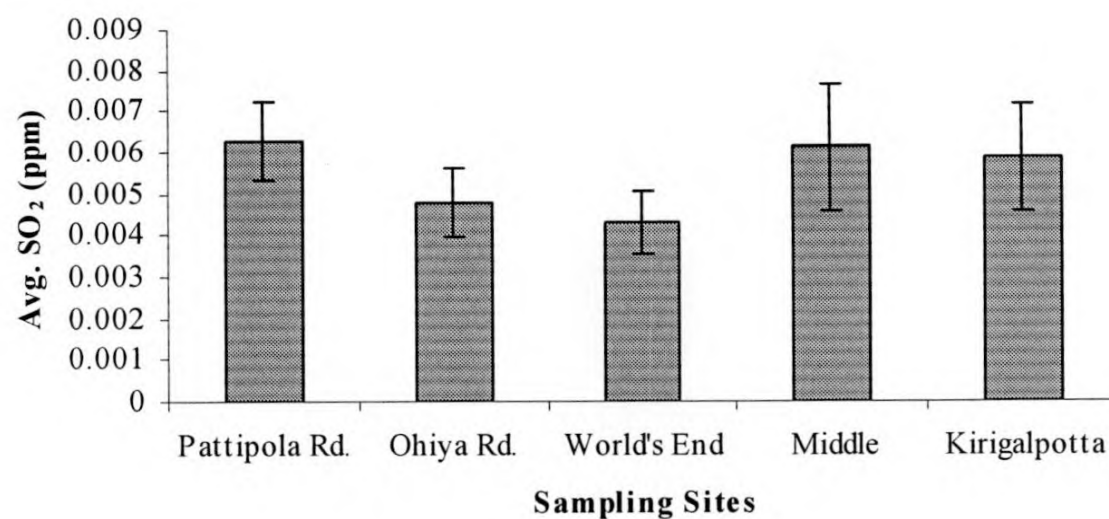


Figure 31: Variations of average ambient SO<sub>2</sub> concentration of five sites at HPNP during August 2005 to September 2006.

The variations of average NO<sub>2</sub> and SO<sub>2</sub> concentrations, was almost similar through out the study period (Figure 32). When statistically analyzed, a significant positive correlation was observed between the two at  $p \leq 0.05$  (Pearson correlation of NO<sub>2</sub> and SO<sub>2</sub> = 0.649, P-Value = 0.012) (Figure 33). Average concentrations of the two pollutants showed similar variations at each sampling sites (Figure 34) but with an insignificant positive correlation at  $p \leq 0.05$  (Pearson correlation of NO<sub>2</sub> and SO<sub>2</sub> = 0.714, P-Value = 0.176) (Figure 35).

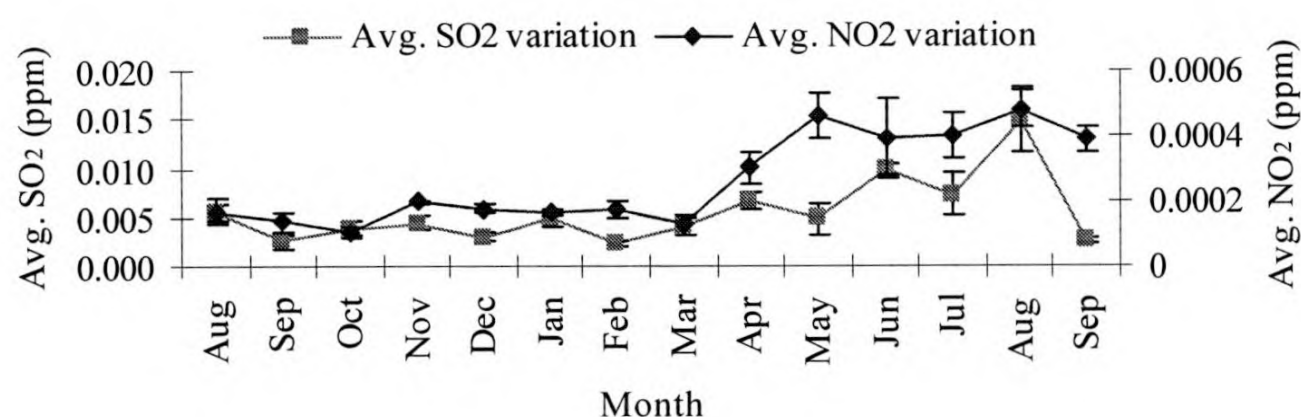


Figure 32: Comparison of variations of average ambient SO<sub>2</sub> and NO<sub>2</sub> concentration at HPNP August 2005 to September 2006

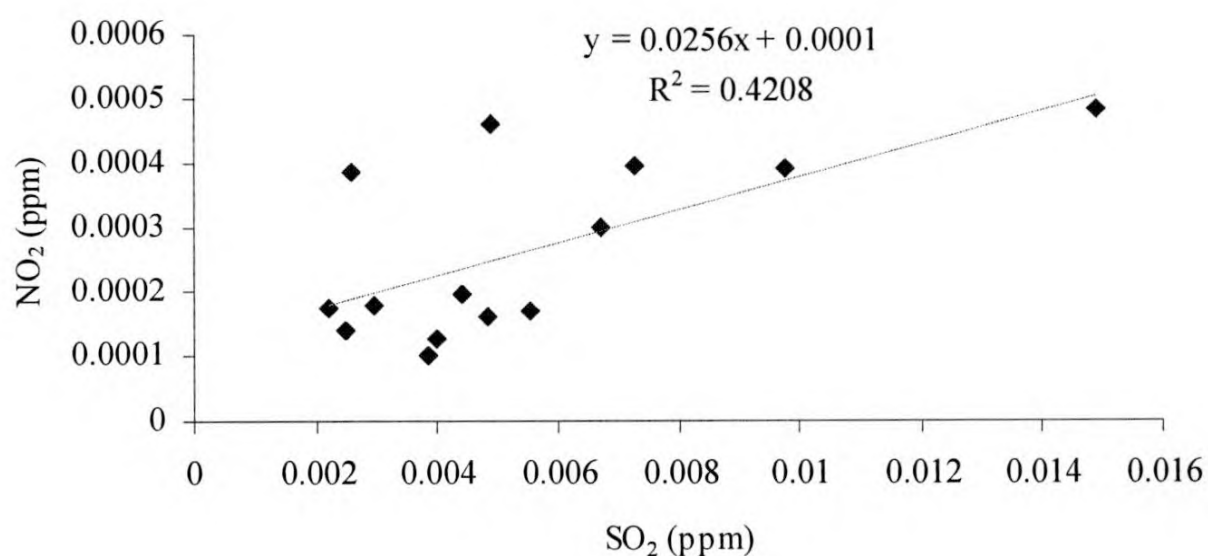


Figure 33: Correlation between ambient NO<sub>2</sub> concentration and ambient SO<sub>2</sub> concentration

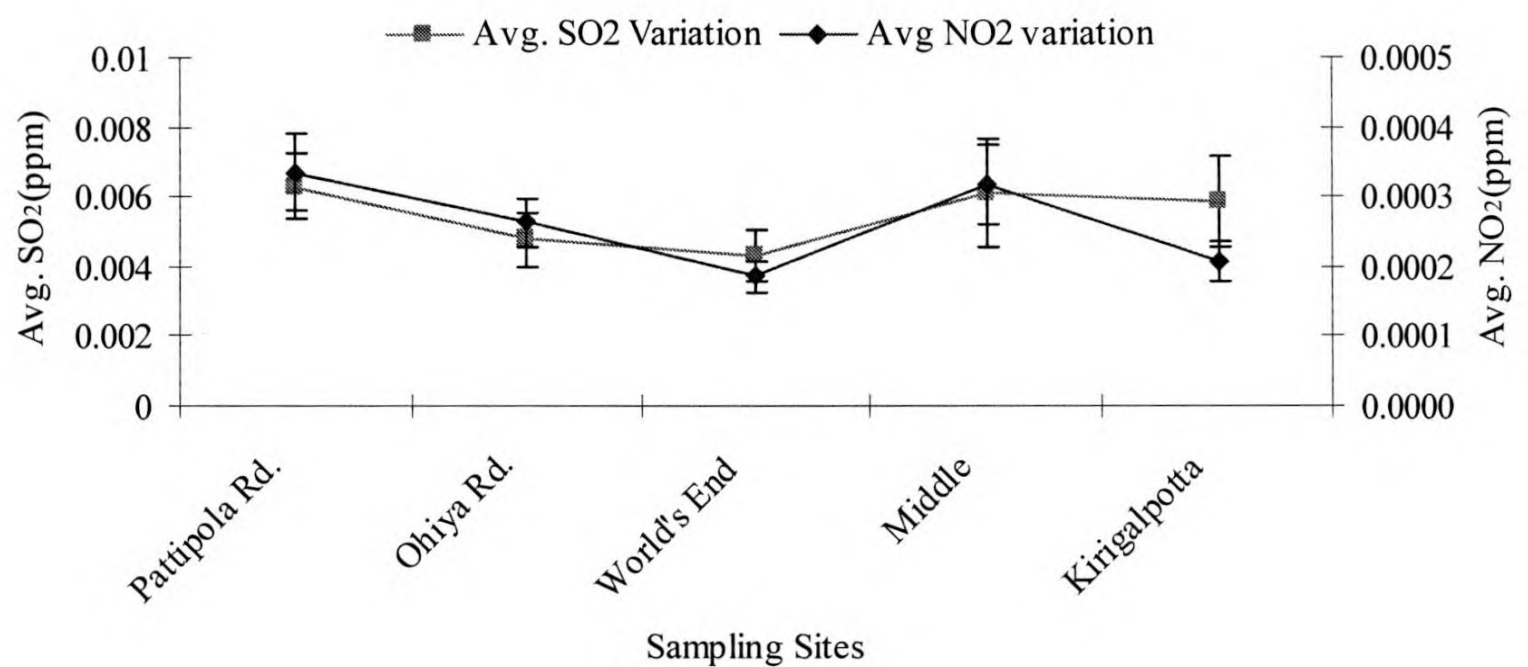


Figure 34: Comparison of variations of average ambient SO<sub>2</sub> and NO<sub>2</sub> concentration of each sampling point at HPNP August 2005 to September 2006

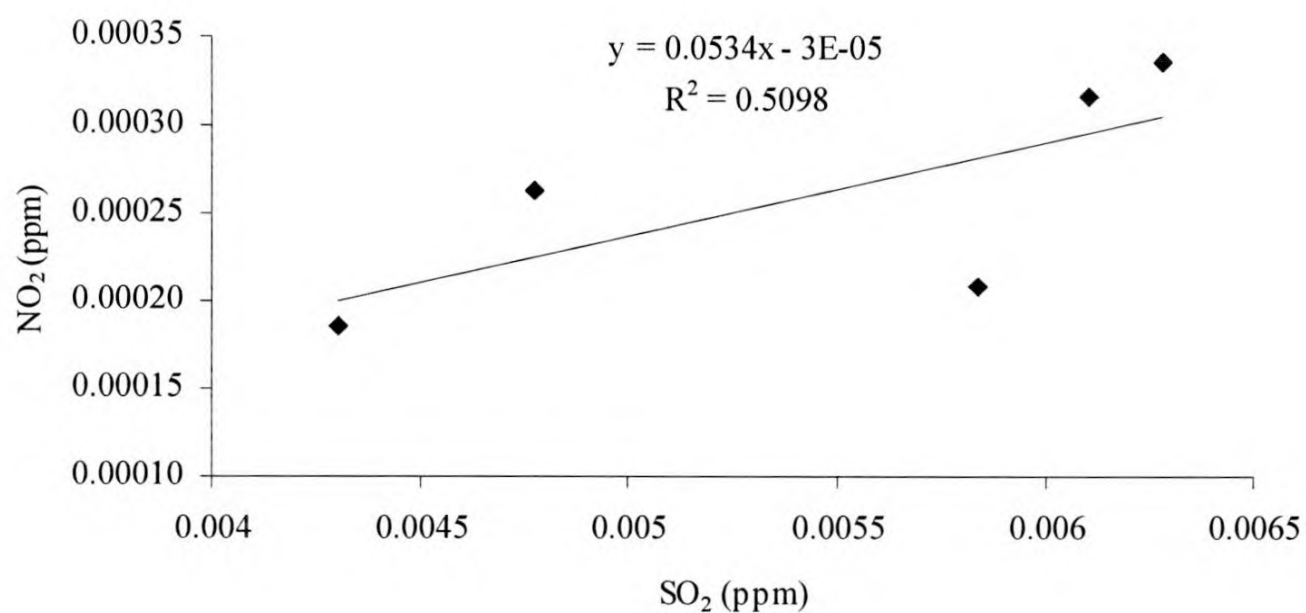


Figure 35: Correlation between avg. NO<sub>2</sub> concentration and avg. SO<sub>2</sub> concentration at five sampling points

### Variation of ambient NO<sub>2</sub> concentration with environmental and vehicular factors

Variations of ambient NO<sub>2</sub> concentration with respect to rainfall, wind velocity, average temperature, relative humidity, bright sunshine and total no. of vehicles visited to HPNP are given in the Figure 36. During the sampling period, rainfall fluctuated throughout the year (Figure 36 A). A higher rainfall was observed in January (316.2 mm) and May (333.5 mm) 2006. The lowest rainfall was observed in December 2005 and it was about 75.6 mm. The variations in ambient NO<sub>2</sub> concentration during the study period showed insignificant positive correlation ( $p \geq 0.05$ ) with the rainfall pattern (Table 8).

Variation of monthly average wind velocities are given in the Figure 36 B. According to this, the highest wind velocity was recorded as 18.2 km/h in July 2006 and the lowest was recorded as 5.3 km/h in April 2006. Comparatively lower wind velocities were observed from November 2005 to April 2006. Variations of both ambient NO<sub>2</sub> concentration and

wind velocity shows insignificant positive correlation ( $p \leq 0.05$ ) throughout the study period (Table 8).

Variations of monthly average ambient temperatures are given in the Figure 36 C. The highest temperature was recorded as  $16.95^{\circ}\text{C}$  in April 2006 and the lowest temperature was recorded as  $14.6^{\circ}\text{C}$  in January 2006. The lower temperature values were recorded during December 2005 and February 2006. Positive significant correlation ( $p \leq 0.05$ ) was observed between variation of ambient  $\text{NO}_2$  concentration and ambient temperature (Table 8).

Comparatively higher RH was observed at HPNP during the sampling period. The highest RH was observed as 91 % in May 2006 and the lowest was recorded as 78.3 % in January 2006. Comparatively lower values were recorded from January 2006 to March 2006 (Figure 36 D). However there was insignificant ( $p \leq 0.05$ ) positive correlation was observed between variation of ambient  $\text{NO}_2$  concentration and RH (Table 8).

Considering the bright sunshine hours during the study period, the highest bright sunshine hours were recorded as 6.7 h in April 2006 and the lowest were recorded as 3.3 h in October 2005. Most of the time bright sunshine hours were lower than 6 h during the sampling period (Figure 36 E). Although the bright sunshine hours were positively correlated with ambient  $\text{NO}_2$  concentration, the relationship was not significant ( $p \leq 0.05$ ) (Table 8).

Number of vehicles visited to HPNP during study period was given in Figure 36 F. These vehicles included petrol and diesel vehicles such as cars, jeeps, busses and motor bicycles. The highest no. of vehicles visited was recorded in August 2006. Considerably higher no. of vehicles was recorded in August 2005 and April 2006 too. The variation of ambient  $\text{NO}_2$  concentration with no. of vehicles visited to HPNP during studied period was observed to be an insignificant ( $p \leq 0.05$ ) positive correlation.

#### **Variation of ambient $\text{SO}_2$ concentration with environmental and vehicular factors**

Variations of ambient  $\text{SO}_2$  concentration with respect to rainfall, wind velocity, average temperature, relative humidity, bright sunshine and total no. of vehicles visited in HPNP were studied and results are given in the Figure 37. All the meteorological parameters and vehicular parameters were similar as description under the variation of ambient  $\text{NO}_2$  concentration. However the correlations of variations of ambient  $\text{SO}_2$  concentration with above parameters were different from ambient  $\text{NO}_2$  concentrations.

The variation of ambient  $\text{SO}_2$  concentration was positively correlated with rainfall, wind velocity, ambient temperature, RH and no. of vehicles visited at HPNP during the study period. Positive correlation was higher with wind velocity and the no. of visited vehicles, while correlation was less with rainfall, ambient temperature and RH. These all correlations were insignificant at  $p \leq 0.05$  (Table 8). Variation of ambient  $\text{SO}_2$  concentration with rainfall data showed opposite variations in most of the months (Figure 37 A). However, the variation of ambient  $\text{SO}_2$  concentration was negatively correlated only with the bright sunshine in insignificantly (Table 8).

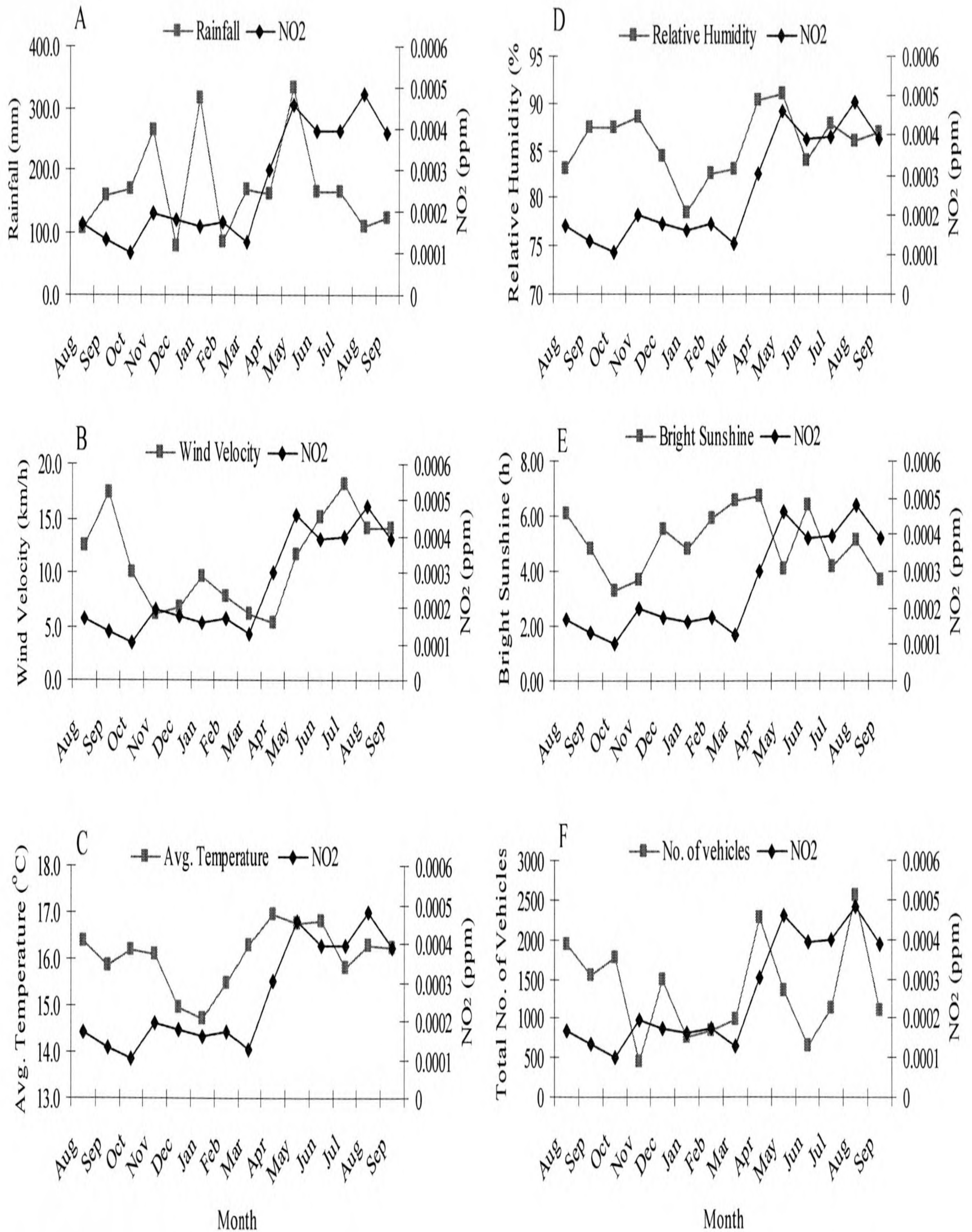


Figure 36: Variation of NO<sub>2</sub> with A) rainfall B) wind velocity C) average temperature D) relative humidity E) bright sunshine and F) Total No. of visited vehicles in HPNP.

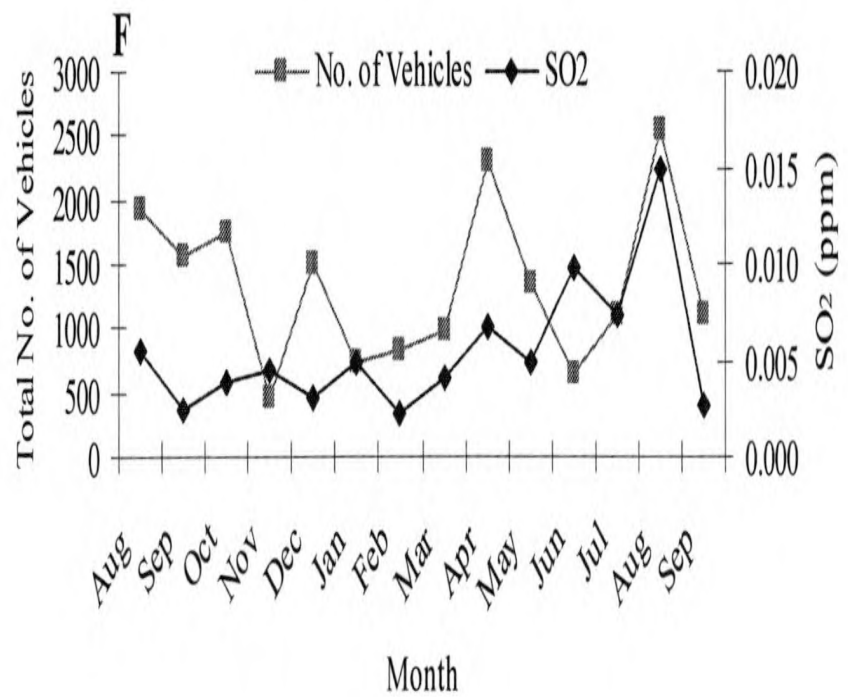
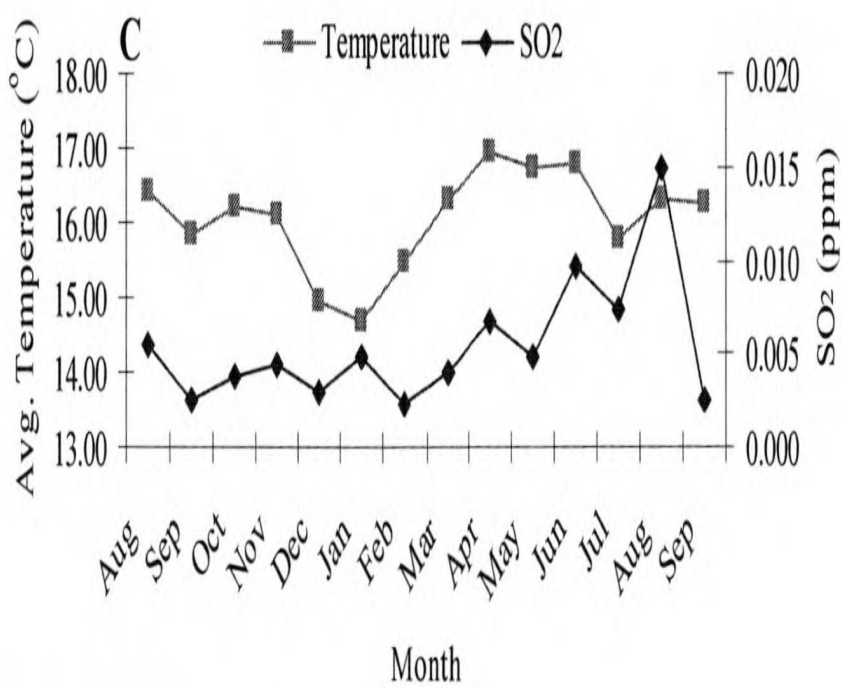
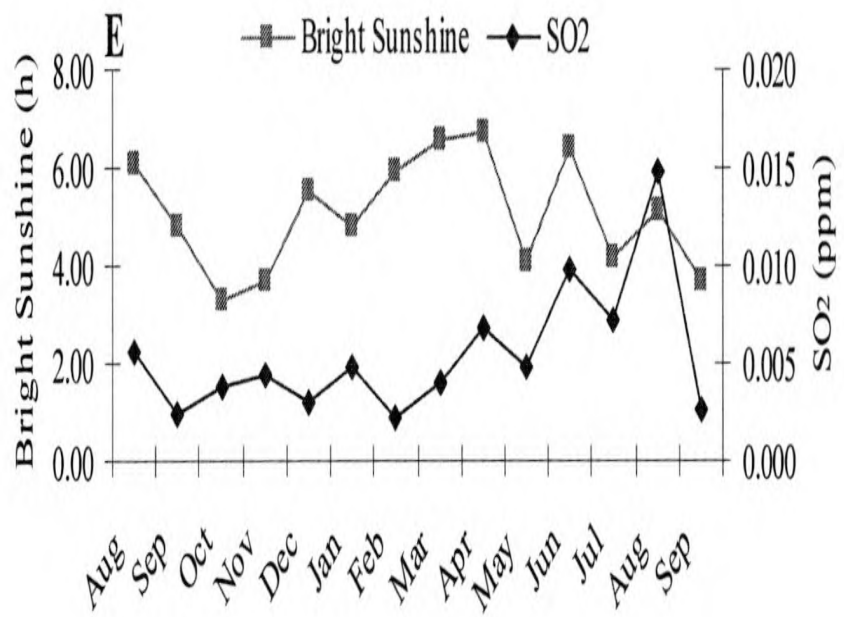
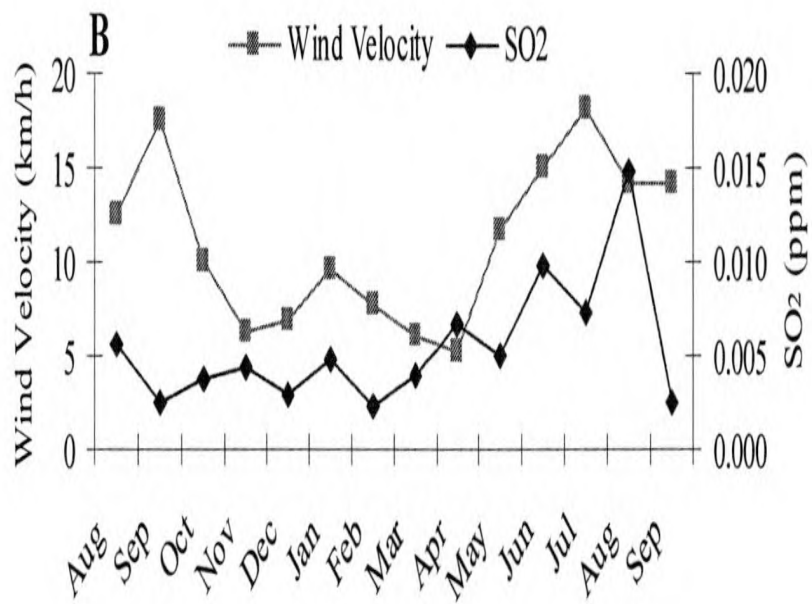
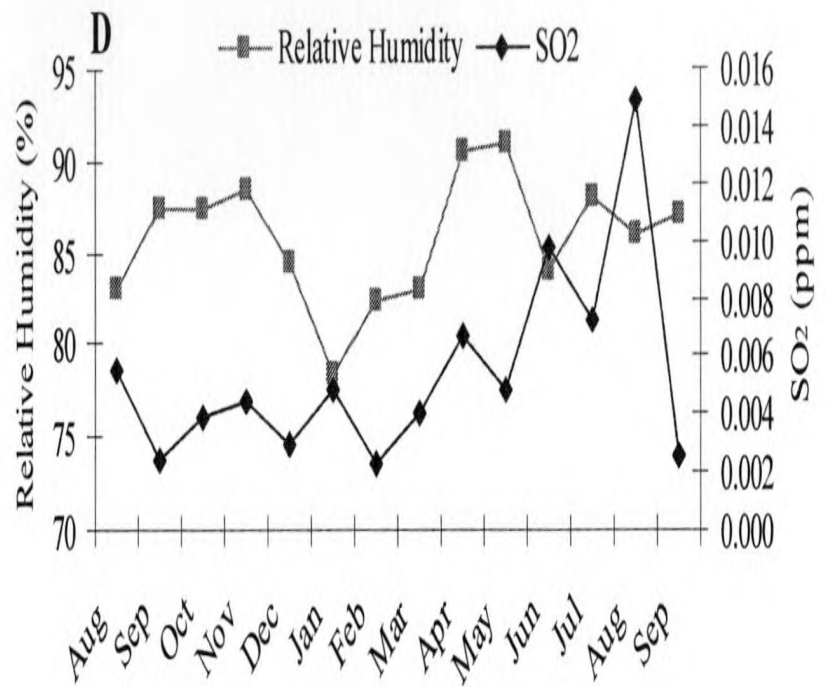
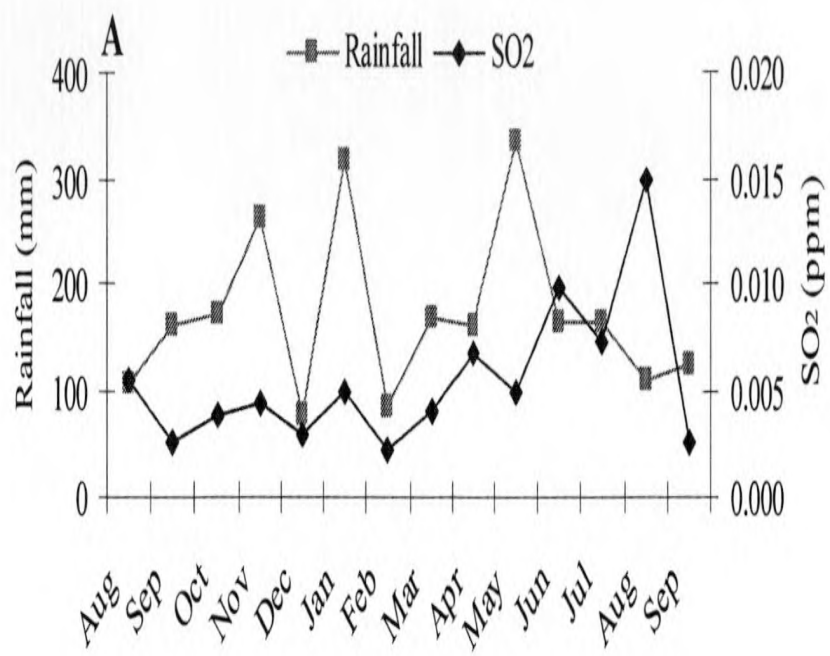


Figure 37: Variation of SO<sub>2</sub> with A) rainfall B) wind velocity C) average temperature D) relative humidity E) bright sunshine and F) total no. of vehicles in HPNP.

Table 8: Results of correlation analysis (MINITAB 14) amongst NO<sub>2</sub>, SO<sub>2</sub>, bright sunshine, temperature, wind velocity, rainfall and No. of vehicles

Variables	SO <sub>2</sub> (ppm)	Rainfall (mm)	Wind Velocity (km/h)	Temperature (°C)	Relative Humidity (%)	Bright Sunshine (h)	No. of Vehicles
NO <sub>2</sub> (ppm)	0.641* 0.013**	0.158* 0.590**	0.100* 0.734**	0.566* 0.035**	0.425* 0.129**	0.192* 0.511**	0.181* 0.537**
SO <sub>2</sub> (ppm)	-	0.122* 0.677**	0.382* 0.178**	0.169* 0.564**	0.056* 0.849**	-0.149* 0.611**	0.448* 0.108**
Pearson correlation*							
P-Value**							

### Index of Atmospheric Purity (IAP) in HPNP

The IAP value obtained for the whole area of the HPNP was 54.22. This value was calculated using 379 lichen species spread in 12 quadrates which were situated in forest islands and in continuous forest of HPNP.

## V) Discussion

### Part I

Many species of lichens have been described from Sri Lanka by the foreign scientists; however, this information is not available in the country. While the taxonomic information is scattered in the literature, some of the material is held several herbaria (Helsinki in Stockholm, Kew in Austria), museums (British Museum) and institutions (Smithsonian in US, Uppsala in Sweden) of the world. Apart from that, few specimens are kept in the National Herbarium at Peradeniya Botanical Gardens. According to the lichen list of Brunnbauer (1984) compiled by field survey and the taxonomic literature, 550 species belonging to 122 genera and 48 families were recorded. Then Moberg (1986) describe a new lichen genus *Rolfidium* in the family Bacidiaceae. Further publications by Singh (1990), Awasthi (1991), Makhil and Patwaradhan (1992), described some microlichen genera including *Buellia* and *Diplotomma*, Macrolichens and *Trypethelium* species respectively. In 1997, O. Breuß described 54 new lichen species reporting from Central and Southern part of Sri Lanka. In the same year, Vezda described 53 folicolous lichens from Sri Lanka. Among them, 32 species were new to Sri Lanka. All of the above literature have brought the lichen number up to 659 species recorded to Sri Lanka. During the present study conducted in the HPNP, 379 species in 24 families were recorded. Based on the current taxonomic knowledge of lichens, 43.53 % (165 spp.) of the collected lichens were identified to species level. The rest (56.47 %) were identified only to the genus level. Some were not identified even up to genus level. It was 8.97 % of the total collection. The main problem is the lack of recent revision for the different lichen taxa in the region and the lack of sufficient lichens materials for the observations. During present lichen survey, 102 lichen species were recorded as new to Sri Lanka. The remaining lichen species found in this survey had been recorded in research papers and some monographs by foreign scientists.

### Diversity

According to the lichen diversity indices, HPNP showed a highly diverse area. Furthermore, it revealed that continuous forest was more diverse than the forest islands. Lichen richness was higher in forest islands than the continuous forest. These observations were derived from the indices which incorporate information on the proportional abundances of species, the Shannon index ( $H'$ ), the Simpson index ( $D$ ) and the log series index ( $\alpha$ ). Evenness is greater in continuous forest and hence the lichen flora here is more diverse than that of forest islands. Species abundant data in both forest types confirms to a log series distribution. This evidence suggests that a small number of abundant species and a large proportion of rare species occurred in both forest types (Magurran, 1988). This could be due to one or more environmental factors dominate the lichen distribution in both forest types. Support for this hypothesis comes from evidence that a combination of bark pH, light, humidity, tree diameter, tree height and distribution is important in determining the level of species richness (Kotelko *et al*, 2008). All diversity statistics confirmed that quality of the continuous forest is higher than that of the forest islands. Since lichen diversity can be taken as estimates of environmental quality, where high values correspond to good quality and low values indicate poor quality (Asta *et al.*, 2002a, 2002b).

According to the Shannon Diversity Index, highest Diversity Index ( $H'= 4.2522$ ) was obtained for site B9 in the forest islands (where 106 lichen species were collected). The second highest Diversity Index ( $H'= 4.2108$ ) was for site B1 located as the forest island (where 107 lichen species were collected). Therefore, the lichen diversity is higher in B9 than in B1. Correlation

analysis showed that, light intensity and trunk diameter were positively correlated with lichen diversity in both plots. However, bark pH is positively correlated with lichen diversity in B1, where as bark pH is negatively correlated with lichen diversity in B9 where bark pH was highly affected on the lichen diversity. Plot B9 was mainly represented by *Sticta*, *Pseudocyphellaria* and *Lobaria* species, where as B1 was mainly represented by *Cladonia*, *Thelotrema* and *Pyrenula* species. Although in B1 has high number of lichen species, it does not affect to the lichen diversity within this plot. Plot A7 showed the highest Diversity Index ( $H' = 4.1619$ ) amongst the continuous forest plots (where 78 lichen species were collected). The least Diversity Index ( $H' = 3.6919$ ) was obtained for site A8 (where 50 lichen species were collected). This means that A7 has higher lichen diversity than A8. When compare the sites A8 and A7, both trunk size and pH were negatively correlated with lichen diversity in A8 and A7. However, light intensity was negatively and positively correlated with lichen diversity in A7 and A8 respectively. Because, lichen diversity in both A7 and A8 were highly depended on light intensities of the area. Most of the shade loving species such as *Sticta* sp. and *Leptogium* sp. were found in A7, where as Graphidaceae species and Thelotremataceae species were found in A8. According to the observations made during this study the Shannon diversity index ranged from 3 - 4.3 in all plots studied. Lichen diversity values in boreal jack pine forest in Central Canada ranged from 2-3 (Kotelko *et al.*, 2008) and it was 4.298 in Guindy National Park, in Chennai (Balaji and Hariharan, 2004). Although the forest types of above countries are completely different from HPNP, the higher values of Shannon diversity index were highly associated with strength of lichen diversity.

With regards to species evenness, the highest value of 0.9570 was obtained for the site A2, indicating that lichen species recorded from this site are equally abundant and stress factors such as disturbances by the animals against the forest in this area were minimal. Hence the lichen population in this area is under stable condition. The least value of 0.8828 was obtained for the site B7 indicating that recorded lichen species are not equally abundant. This may due to the fact that B7 has suffered from stress conditions such as Sambar grazing.

The Pearson correlation analysis showed that, tree height, tree diameter, number of lichen colonies or host tree diversity were positively correlated with lichen diversity in the continuous forest. Where as, bark pH and light intensity were negatively correlated with the lichen diversity. A significant relationship was observed only with the number of lichen colonies and host tree diversity. In the forest islands, tree diameter, bark pH, number of colonies or the host tree diversity were positively correlated with lichen diversity while tree height and light intensity were negatively correlated. However, a significant relationship was observed only with the number of lichen colonies. Light intensity plays an important role with lichen diversity because, altering light intensities within a forest (e.g. through fragmentation or selective deforestation) may alter lichen community composition if the change in the light regime is sufficiently dramatic (Waring, 2008). Bark type also play an important role in lichen diversity. The highest diversity of lichens in both forest types was observed on smooth bark type whereas the least diversity of lichens was observed on deeply furrowed bark type in continuous forest and flaky bark type in forest islands. Similarly, Wolseley and Aguirre-Hudson (1997) observed high diversity of lichens on smooth thin-barked evergreen species in Thailand. These data suggest that lichen species diversity/richness in continuous forest and forest islands mainly depends on the availability of host, bark pH and light intensity. Pinokiyo *et al.*, in 2008 found that great availability of habitat directly responsible to corticolous lichen diversity in the Ghauri camp area. Further they suggested that not only the habitat availability, but tree species composition and tree diversity also play an important role in the distribution and abundance of

lichens. Although, the moisture availability may become critical, both for colonization, establishment and growth of lichen thalli (Wolseley and Aguirre-Hudson, 1997) we were unable to measure the moisture level within plots in this study.

There are several factors that affect the distribution and diversity of lichens. The composition of the epiphytic lichen flora is strongly influenced by the variation of microclimate, which not only vary vertically along the trunk, but also between tree fractions, such as trunk and branches (Coxson and Coyle, 2003). Microclimate is determined by the interactions between regional climate, tree architecture and bark properties, such as chemistry, texture and moisture holding capacity (Coxson and Coyle, 2003). Not only that, the diversity of corticolous lichens may change due to characteristics such as tree age or tree species (Jüriado, *et al.*, 2003) and correspondent bark pH (van Herk, 2001), or even due to tree health status (Hauck and Runge, 2002). Variations in microclimatic conditions, particularly light, water and nutrients, driven by local sources of disturbance, such as roads or farms, different land uses or habitat fragmentation can influence lichen diversity. Apart from above factors resource availability (nutrients) is another abiotic predictor of lichen cover and richness (Dyer and Letourneau, 2007). The present study suggests that distribution of lichen species in the HPNP is also influenced by many of the above factors.

The rarity and dominance of lichens were determined by the frequency. They were classified as very rare, rare, common, dominant and predominant. This classification was based on the lichen survey carried out by the Balaji and Hariharan (2004) in Guindy National Park India. According to the lichen survey at HPNP, 42 % of genera found to be very rare, 19.40 % were rare, 17.91 % were common, 10.44 % were dominant and 10.44 % were predominant. These results emphasized that nearly 50 % of the lichens recorded in HPNP are very rare species. Macrolichens like *Sticta*, *Pseudocyphellaria*, *Lobaria*, *Heterodermia*, *Bunodophoron*, *Leptogium* like and microlichen like *Graphis* were predominant. Microlichens like *Buellia*, *Caloplaca*, *Cetrelia*, *Diplotomma*, *Pleurotheliopsis*, *Arthopyrenia*, *Haemmatoma* and Macrolichens like *Nephroma*, *Pannaria*, *Parmelina*, *Parmelinella*, *Myelochroa*, *Teloschistes* were very rare lichens. *Graphina*, *Lepraria*, *Rimelia*, *Fissurina*, *Hypogymnia*, *Parmotrema*, *Megalospora*, *Usnea*, *Leprocaulon*, *Phyllopsora*, *Ocellularia* and *Myriotrema* were found as common lichen genera. According to the IUCN Global Red List of Lichens, 26 of lichen species are categorized as highly threaten endangered species ([http://www. botany.hawaii.edu/cpsu/endlich.html](http://www.botany.hawaii.edu/cpsu/endlich.html), 2006). *Heterodermia leucomelos* and *Teloschistes flavicans* are also among the list. These are distinct species assemblages at different sites, showing restrictive species distribution, and signifying a need for protection of large areas for lichen conservation.

The graphs showing the % Frequency Vs total cover values of the foliose and fruticose lichens reconfirm the dominancy and rarity of the lichens. Since lichens *Pseudocyphellaria*, *Heterodermia*, *Sticta*, *Leptogium*, *Lobaria* were again categorized as a predominant foliose genera and the lichens such as *Graphis*, *Thelotrema*, *Ocellularia*, *Myriotrema* and *Pyrenula* were categorized as predominant crustose genera.

The lichen flora of HPNP is mostly composed of foliose lichens followed by crustoses. This is a result of the influence of micro environmental factors. According to the observations in HPNP the highest cover values and frequencies are recorded from the lichens of family Lobariaceae, which includes the genera *Pseudocyphellaria*, *Lobaria* and *Sticta*. These genera are frequent in montane forests of the tropics, and are also found in Europe associated with Western Oceanic Oak forests, where they are intolerant to changes to the forest structure (Wolseley, 1991). These

lichens, which are associated with a cyanobacterial or blue green algae partners always prefer high humid and low light level microenvironments (Wolseley and Aguirre-Hudson 1997). The climatic conditions of HPNP are strongly favorable for the distribution of such lichens. The observations made in this study can be further supported by various other works in other countries. In the montane forest of Thailand, a greater number of foliose and fruticose lichens were observed above 1500 m, while between 350 and 900 m crustose species were observed in higher numbers (Wolseley and Aguirre-Hudson 1997). It has been observed that foliose species were more numerous than crustose species at Nanda Devi Biosphere Reserve and Meghamalai Wildlife Sanctuary in India (Upreti and Negi, 1995). In panama, Büdel *et al.* (2000) reported that almost half of the species found were foliose cyanolichens. Most of them grew in shaded habitats (e.g. *Leptogium*), whereas others (*Sticta* and *Dictyonema*) also occurred in sunny, exposed habitats.

### **Distribution of lichens in relation to pH variations and tree diameter**

It is well known that the pH of bark has a strong influence on epiphytic lichen development (Kricke 2002). Results in HPNP revealed that, most of the lichens present in the study sites preferred relatively high pH range (5.0-6.0). The dominant lichen species (314 species) within this pH range were macrolichens like *Lobaria retigera*, *Pseudocyphellaria beccarii*, *Heterodermia microphylla* and microlichens like *Graphis sp.* *Myriotrema sp.*. It was observed that only a few lichens (45 species) preferred extremely low pH range (3.00 - 3.99) and extremely high pH (8.00 - 8.99) range. *Bunodophoron spp.*, *Sticta cyphellulata*, *Hypotrachyna exsecta*, *Thelotrema patens*, *Cladonia spp.* were few lichens represented in extremely low pH range. *Leptogium denticulatum*, *Sticta cf. subtomentella*, *Phyllopsora sp.* were found in extremely high pH range. The pH variations of both crustose and foliose types were equally varied in both forest types. Bark pH will vary with species and age in cool temperate climates, where trees with a high pH being associated with richer lichen communities, particularly in fagaceous forests (Rose, 1992). Similar observations were reported from Thailand, where the tree species with higher bark pH have more species-rich lichen communities than species with a low pH (Wolseley and Aguirre-Hudson, 1997a). In Estonia, where the mean bark pH of the studied trees was usually subneutral and decrease of lichen species richness with increasing bark pH was reported (Jüriado *et al.*, 2009). Bark pH is varied with Nitrogen (N) and Sulphur (S) containing pollutants (Wolseley *et al.*, 2006) and the tree species (van Herk, 1999). Bark pH may also be influenced by calcareous dust, as well as by geology, rainfall and age of the bark surface. In regions of high rainfall the bark is leached of basic ions so that the bark tends to be more acidic (Bates 1992).

Comparing the distribution of lichens with respect to bark pH variations in the forest islands and continuous forest, the highest number of lichen species (*H. leucomelos*, *P. beccarii*, *Graphis sp.*) preferred a low pH range (4.0-6.0) in the continuous forest while lichens (*L. retigera*, *P. intricata*, *Thelotrema sp.*) in the forest islands preferred a higher pH range (5.0-7.0). The same pattern of distribution was observed with the crustose and foliose groups in the continuous forest and forest islands too. This type of distribution may be due to the higher percentage of acid tolerant lichen genera (Acidophytes) such as *Usnea sp.*, *Cladonia sp.*, *Hypogymnia sp.* and *Ochrolechia sp.* (Wolseley *et al.*, 2006) in the continuous forest and base tolerant species (Nitrophytes) such as *Physia sp.* (Wolseley *et al.*, 2006) in the forest islands.

Considering the average pH of some host plant species, the highest average bark pH (7.46) was observed in unidentified tree species and the lowest average bark pH (4.13) was observed in *Vaccinium symplocifolium*. Most of the tree species had their bark pH vary between 5 to 6.

Trees with bark pH from 4.3 to 6.3 were observed in the Krasnoyarsk district in Siberia (Otunyukova and Sekretenko, 2008), 3.16 to 5.82 in northern Thailand, where Wolseley and Aguirre-Hudson (1997a) suggest that bark pH will vary between tree species. This tree specimen-specific variation in bark pH of canopy twigs can probably be explained by different mineral uptake through tree roots situated in different soils along a gradient from more raised and leached topographic positions to the lower portions of brook ravines with upwelling mineral-rich ground water (Kermit and Gauslaa, 2001).

There was a positive correlation between tree diameter and the bark pH. Trees having larger diameter classes such as *Calophyllum walkeri*, *Eugenia maboaeides* possessed high bark pH values while smaller trees such as *Symplocos cochinchinensis*, *Actinodaphne speciosa* was having slightly low pH values. The similar results were obtained with tree height, where bark of taller trees having basic bark pH and shorter trees having acidic bark pH. This may be a result of less amount of leaching experienced by trees with large diameter having larger crowns. When the crown is large, it facilitates draining the rain away from main trunk (Kermit *et al.*, 2001). Then the outer parts of the branches are flushed with much drained rainwater, the trunk remains dry even after prolonged rainfall. Due to the less leaching effect on the bark at dry conditions, high amount of calcium ions remains on the bark. So that the bark pH is eventually increased, because Farmer *et al.* (1991) and Bates (1992) have demonstrated that increasing bark pH is associated with increasing base ions particularly calcium.

Most of the trees within HPNP occurred between 11-20 cm diameter class. Therefore we can assume that most of the trees within that diameter class were experienced to relatively high leaching effect due to the acid rain. Because average pH of the rain water and cloud water of the HPNP had been recorded to be between 5.37-7.47 and 3.88-5.59 respectively (Gunawardena *et al.*, 1998).

### **Lichen diversity in relation to host species**

Floristic analysis revealed the presence of 450 individual trees from which lichen were in 12 sites. Those consisted of 42 tree species belonging to 24 genera and 11 families. Of them, Lauraceae was the dominant flowering plant family, while Rubiaceae, Myrtaceae and Symplocaceae were the other leading families. Balasubramaniam *et al.*, (1993) also recorded that some selected sites of the HPNP were represented by 57 of vascular plants, which belonged to 44 genera and 31 families and the most dominant family was Lauraceae. There is an argument that the species of the family Lauraceae are secondary species that have established in the forest after the primary vegetation has been disturbed or removed. The dominance of the family Lauraceae reveals a very important fact that the HPNP has been under some kind of disturbance to a considerable extent (D.S.A. Wijesundara, Personal communication). In 2007 Ranawana *et al.* reported that family Lauraceae is having the highest relative density (12.76) followed by family Symplocaceae, which had of relative density 10.32.

More than 95 % of the tree species recorded in the 12 plots were endemic to Sri Lanka. Sri Lanka after getting detached from the Indian subcontinent in the late Miocene has evolved to give approximately 850 (27 %) endemic angiosperm flora that has been specially confined to the higher altitude of the Wet Zone. Sri Lanka being an island, the evolution of its endemic flora can lead to the endemic lichen flora that depends on them. Host plants in the continuous forest are more diverse than the forest islands. Similarly, lichen diversity also highest in the continuous forest (Table 3). Jürriado *et al.* in 2003 reported that the tree species diversity is also important for creating the conditions necessary for a diverse epiphytic lichen community.

Host species richness was higher in the forest islands, while evenness of the host species was higher in the continuous forest. Although the host species richness is less, they are equally distributed in the forest islands. The rank abundance plots in both forest types fit to the log normal distribution. This evidence emphasizes that tree species in both forest types are in stable stage in the succession process.

The diversity of lichens on the host tree species reveals that, crustose and foliose were considerably higher on *Ilex walkeri*, *Syzygium rotundifolium*, *Neolitsea fuscata* and *Cinnamomum ovalifolium* in both forest types. Considering the nature of the bark of the above species, *Syzygium rotundifolium* has a patchy flaky bark and all the other species have smooth bark. Due to the presence of rough bark and lack of other competitive epiphytes such as mosses with *Syzygium rotundifolium*, it facilitates the high abundance of crustose lichens. Although the moisture level of smooth barks is less, trees with such bark types are associated with high abundance of crustose and foliose lichens. *Grphis* sp. is the most frequently found crustose genera in both forest types. It was found on 26 host species in the continuous forest and 19 host species in the forest islands. *Thelotrema* sp. was found from 17 host species in both forest types. *Myriotrema* sp., *Ocellularia* sp., *Pertusaria* sp. and *Pyrenula* were the other prominent crustose genera found on the host trees in both forest types. All crustose genera mentioned above other than *Myriorema* sp. are found higher in the continuous forest than in the forest islands. The genus *Heterodermia* sp. and *Pseudocyphellaria* sp. were found from more than 25 host species in the continuous forest and forest islands respectively. Genus *Sticta* sp. was found from 23 host species in both forest types. The other leading genera found in both forest types include *Bunodophoron* sp., *Cladonia* sp., *Coccocarpia* sp., *Hypotrachyna* sp., *Lobaria* sp., *Parmeliella* sp., *Phyllopsora* sp. and *Usnea* sp. Brodeková *et al.* in 2006 have shown that the nature of the substrate on which lichens grow has considerable influence on the diversity and abundance of lichen species that arise in a woodland. Rough bark surface with consequently a greater potential to hold moisture when compared with the smoother bark and this moisture promotes development of other epiphytes especially mosses and climbing ivy in greater abundance and some lichens in less abundance. However, in smooth bark surfaces where moisture holding ability is less and leads to less abundance of mosses and climbing ivy and greater abundance of crustose lichens. It is also recognized that rougher bark, as found on the oak trees, provides a better habitat for the development of a wider spectrum of lichen species. In another study, Ellis and Coppins (2007) found that habitat quality for crustose lichens within a site is determining by tree age because, tree age as a factor controlling micro-habitat or site occupancy by lichen species. Tree age may thus comprise the genetically occupied factors such as bark chemistry, texture and moisture (Kantivilas and Minchin, 1989), which change during the phases of an individual tree's life-span. Dead trees were also contained higher number of foliose species (66) than crustose species (29) in both forest types. Because, dead trees in various stages of decay offer a wider range of different microhabitats in terms of chemistry, structure, and microclimate compared to living, healthy trees (Hauck, 2000).

Some lichen genera found only on one tree species in the continuous forest and these include *Buellia* sp., *Caloplaca* sp., *Lecidella* sp. and *Pseudopyrenula* sp.. Similarly *Chrysothrix* sp. and *Heamatomma* sp. were found from single tree species in the forest islands. Each of the following foliose genera such as *Canomaculina* sp., *Cetrelia* sp., *Canoparmelia* sp., *Leioderma* sp., *Nephroma* sp., *Punctelia* sp., *Ramalina* sp. and *Teloschistes* sp. were found on a single tree species in the forest islands. Similarly, *Parmelinella* sp. and *Parmelinopsis* were found on single host species in the continuous forest. It could be that one or few of the above genera present as a host specific species. However, it is difficult to predict such species due to the lack of details of

lichens which are present at the upper part of the trunk and canopy of host species. Especially light demanding foliose and fruticose taxa are dominant in the canopy and shade-tolerant crusts dominant on the trunks (Wolseley and Aguirre-Hudson, 1997a).

Diversity and distribution of lichens with respect to the host diameter classes in both forest types showed the highest number of host species, the highest number of lichen colonies, the highest number of crustose and foliose lichen species and highest % cover values were in 11-20 cm diameter class. Especially the diameter class distribution of the live individuals was an inverted J curve with high densities of individuals in the lower diameter classes which is typical of mature tropical rain forests (Whitmore, 1984). The pH and light intensities of each diameter classes in both forest types were not significantly different (One Way ANOVA,  $p=0.05$ ).

TLC analyses were carried out to identify some of the lichen specimens up to their species level. According to the TLC analysis, several chemicals were identified in each *Anzia* sp., *Heterodermia* sp. and *Parmotrema* sp. Amongst the identified chemicals atranorin, zeorin, salazinic acid, norstictic acid, protocetraric acid and few unknown compounds were present. Atranorin was present in all the examined lichen species and others were unique to genera or species. The grey colour of the lichen thallus is associated with the presence of atranorin in thallus (Divakar and Upreti, 2005). Especially all most all the species of *Heterodermia* were consisted of atranorin and zeorin. The genus *Parmotrema* found to contain the chemicals atranorin, Protocetraric acid and an unknown compound. However Divakar and Upreti, (2005) mentioned that, usnic acid containing species also present in the genus *Parmotrema*. The major problem encountered in TLC analysis was the absence of relevant authentic chemicals.

According to the observations it can be concluded that HPNP has a remarkably high diversity of corticolous lichens. The diversity of lichens within HPNP found to be varied with environmental, microclimatic and host tree factors. The current study was able to identify 102 lichens as new records. However, further studies should be needed to explore the diversity of lichens present in whole tree including crown, leaves and other lichen dominating substrates such as stones, soil.

## Part II

Due to the adverse effects caused by air pollution, investigations, analysis and predicting of air quality parameters are important topics of atmospheric and environmental research today (Ghazali *et al.*, 2009). Those adverse effects have direct and indirect contacts on ecosystems and the environment. Such effects can include visible injury on vegetation and adverse impacts on growth, productivity, nutritive quality and community structure and biological diversity, with or without symptoms of injury to the plant foliage (Legge, 2009). Air pollution in Sri Lanka is primarily due to the combustion of commercial energy and the biggest contributor of pollutants to the environment is by the transport sector (Senarath, 2003).

The average concentration of both  $\text{NO}_2$  and  $\text{SO}_2$  were comparatively low in September 2005 to March 2006 and began to increase after March 2006 till September 2006. These variations are highly correlated with the wind velocities at HPNP during the above periods. Different wind velocities are due to seasonal wind patterns occurring in Sri Lanka. Since Sri Lanka is situated close to the equator within an altitude of  $6^\circ$  to  $10^\circ$  N, it experiences a typical tropical climate which is somewhat modified by the seasonal wind reversal of the Asiatic monsoons. Southwest monsoon (May-September), first inter monsoon followed by the Southwest monsoon (October-November), Northeast monsoon (November-February), second inter monsoon followed by

Northeast monsoon (March- May) could be considered as the major climatic monsoons (Domroes, 1974). The lower concentrations of NO<sub>2</sub> and SO<sub>2</sub> are resulted during the intermediate and Northeast monsoonal period and the higher concentrations are resulted during the Southwest monsoonal period. This could be due to relatively low wind speed experienced during inter monsoons and Northeast monsoons. When the year as a whole is considered, southwest winds towards the inland are regular and as a result the central part of the country could also be affected due to the air pollution load from Colombo and other industrialized areas in the western province. Zubair (2001) stated that Southwest monsoon comes from west, Northwest-West and Southwest-West. According to Ileperuma (2000), air pollution in big cities such as Colombo and Kandy is mainly due to the increasing traffic congestion, overload buses and trucks. Romero *et al.*, (1999) investigated that the air pollution levels in various regions of Santiago and determined that in some regions wind decreases the pollution. According to Abeyratne (2005), the highest concentration of ambient NO<sub>2</sub> and SO<sub>2</sub> resulted at Kandy and Anuradhapura during Northeast monsoonal period in 2001. These results could be due to the South and Southeast Asian emissions that cause considerable air quality degradation over an area in excess of 10 million km<sup>2</sup> (Lelieveld *et al.*, 2001).

The observed higher concentrations of ambient NO<sub>2</sub> and SO<sub>2</sub> after March 2006 were correlated with number of vehicles visited to HPNP as well. Especially festival seasons and school vacations are overlapped with this period and as a result higher number of visitors and vehicles come to HPNP. The highest number of vehicles visited was recorded in August 2006. Therefore, the pollutants emissions from the vehicles due to fuel combustion also could increase. According to Abeyratne (2005), in Kandy concentrations of both NO<sub>2</sub> and SO<sub>2</sub> recorded relatively low values during school vacations, where vehicular traffic in the city observed was comparatively low. However, sudden increases of these pollutants were observed for the samples in Kandy during festival seasons such as Christmas, Sinhalese New Year and Kandy Esala perahera. Shankar (2002) in India stated that, the possible reasons for increase in the levels of NO<sub>2</sub> is due to tremendous growth in the number of petrol and diesel vehicles in the Mumbai city, which are contributing to this increasing level of NO<sub>2</sub> in the atmosphere. Apart from the number of vehicles in urban areas, other reasons for increasing vehicular pollution are the types of engines used, age of vehicles, congested traffic, poor road conditions, and outdated automotive technologies and traffic management systems (MoEF 1997).

The lowest average NO<sub>2</sub> concentration (0.0001 ppm) was observed in October 2005 and the lowest average SO<sub>2</sub> concentration (0.0022 ppm) was observed in February 2006. The highest average concentrations of both NO<sub>2</sub> (0.00048 ppm) and SO<sub>2</sub> (0.014 ppm) were observed in August 2006. The recommended Sri Lankan air quality standards for the 24 h average of SO<sub>2</sub> and NO<sub>2</sub> are 0.03 and 0.05 respectively. Both SO<sub>2</sub> and NO<sub>2</sub> concentrations in HPNP were much lower compared to the standard levels of air quality in Sri Lanka. When compared the above results with comparatively polluted Kandy and Anuradhapura cities, pollutant concentrations during the study from February 2002 to December 2004 in Kandy city using the passive sampler method were in the range of 0.002-0.081 ppm for NO<sub>2</sub>, 0.001-0.133 ppm for SO<sub>2</sub>. During the same period, values obtain in the Anuradhapura city were in the range of 0.001-0.081 ppm NO<sub>2</sub>, 0.001-0.133 ppm SO<sub>2</sub>. The data reveal that NO<sub>2</sub> and SO<sub>2</sub> analyzed during the sampling period in Kandy exceeded the recommended Sri Lankan standard on about 14% and 41% occasions respectively. SO<sub>2</sub> analyzed during the sampling period in Anuradhapura exceeded the recommended Sri Lankan air quality standard on about 21% occasion. However, data analyzed for NO<sub>2</sub> in Anuradhapura had no exceeding throughout the research period (Abeyratne, 2005). In another study at Galaha junction in Peradeniya using the same passive sampling technique recorded high values for the same two pollutants where maximum values recorded were 0.063

ppm (NO<sub>2</sub>) and 0.048 ppm (SO<sub>2</sub>). During the 20 sampling occasions at this site, both pollutants exceeded the Sri Lankan standard on 60 % occasions (Ileperuma and Dissanayake, 2004). Average concentration of NO<sub>2</sub> and SO<sub>2</sub> for a period of 14 months gave very low values indicating that the air quality in Horton Plains National Park is very high.

During the study it was observed that the concentrations of ambient NO<sub>2</sub> and SO<sub>2</sub> were very low in HPNP. This could be due to the conversion of ambient NO<sub>2</sub> and SO<sub>2</sub> into nitric and sulfuric acid with the presence of moisture. The U.S. EPA report (1998) and Martin (1989) stated that, SO<sub>2</sub> and NO<sub>x</sub> oxidize in the atmosphere to form sulfuric acid and nitric acid, respectively. These acids may be deposited to the earth's surface in dry form as gases or aerosols or in wet form as acid rain. Wet deposition is determined by the amount, duration, and location of precipitation and changes in the total acid levels, which are in turn determined by atmospheric chemistry and precipitation patterns. In a related study (Gunawardane and Nandasena, 1998), rain and fog analysis at Horton Plains indicated that the pH of rain water varied from 5.37 to 7.47 with sulphate concentrations of 0-3.39 mg/l and nitrate concentrations ranging from 0-3.54 mg/l. The fog analysis indicated much higher acidities with pH values as low as 3.88 recorded during the dry season of April to May. Furthermore, all the air samplers were situated amongst the trees in the forest of HPNP. Hence considerable amount of ambient NO<sub>2</sub> and SO<sub>2</sub> might be uptaken by the foliage of plants. Lenzian (1984) found that foliar uptake of SO<sub>2</sub> is via the stomata due to the cuticle impermeability against such gas. According to Rondon and Granat (1994), NO<sub>2</sub> also enters via the cuticles of leaves without an internal resistance. The lower NO<sub>2</sub> concentrations at the HPNP might be due to the conversion process, in which ambient NO<sub>2</sub> converts into O<sub>3</sub> with the presence of sunlight (Ghazali *et al.*, 2009). However, since HPNP is a remote, undisturbed, reserved forest the pollution could be anyway modest. As a result the amount of pollutants could also be low.

The average concentrations of NO<sub>2</sub> and SO<sub>2</sub> during the studied period at each sampling point were shown considerable variations. The highest concentration of both NO<sub>2</sub> (0.00033 ppm) and SO<sub>2</sub> (0.0063 ppm) were observed at Pattipola sampling point and the second highest value of NO<sub>2</sub> (0.00031 ppm) and SO<sub>2</sub> (0.0061 ppm) were observed at Middle sampling point which was situated near the vehicle park. The lowest concentration of both NO<sub>2</sub> (0.00018 ppm) and SO<sub>2</sub> (0.0042 ppm) were observed at World's end sampling point. There were many reasons to obtain the highest ambient concentration of both NO<sub>2</sub> and SO<sub>2</sub> at Pattipola sampling point. It was situated in a hilly terrain closed to the Pattipola road. Pattipola road is the main entrance to the HPNP and more than 90 % of vehicles are coming along this road. Therefore, the emission of fuel-burned pollutants including NO<sub>2</sub> and SO<sub>2</sub> is also high. According to Senarath (2003), 12.5 % of the air pollution in Sri Lanka is due to vehicular transportation. Not only that this area is directly facing Nuwara Eliya and Pattipola areas where large-scale farm lands and agricultural lands are situated with high levels of organic matter. Ammonia and hydrogen sulphide (H<sub>2</sub>S) are generated during the anaerobic decomposition of such organic matter (Ileperuma, 2001). H<sub>2</sub>S reacts to form SO<sub>2</sub> under atmospheric conditions within a few hours (Jacobson, 1999). Therefore, there could be a possibility for such pollutants from farmlands and agricultural lands to reach these sampling areas due to wind effect.

Middle sampling point was situated very close to the vehicle park at HPNP. All the vehicles visiting HPNP were gathered at this place. Therefore, highest concentrations of pollutants could be observed at this place. Aberatne (2005) also mentioned that the sampling sites closer to city centers recorded higher pollutant levels in both Kandy and Anuradhapura cities. Not only the vehicles, some garbage cylinders were also kept around this sampling point. Therefore, it could be a reason to produce little amount of H<sub>2</sub>S which then transferred to SO<sub>2</sub>.

The lowest ambient NO<sub>2</sub> and SO<sub>2</sub> were recorded at the World's End sampling point. Considering the location of this point which was directly faced to the windward direction of small world's End. High wind velocities are occurring at the small World's End due to the lack of wind barriers such as mountains, large trees opposite to this place. High speed winds are able to carry pollutants away from the collecting point. Therefore, pollutant concentrations observed at this point were low. Çelik and Kadi (2007) mentioned that the high hills and mountains make slower wind speeds, causing higher pollutant concentration around the Karabük city in Turkey. According to the Ileperuma (2001), the air quality in Kandy, was very serious due to the location of the city in a valley and calm weather conditions. Considering the Kirigalpotta sampling point, this was situated at the base of the mountain and far away from the trail of HPNP. The obtained concentrations of ambient NO<sub>2</sub> and SO<sub>2</sub> were higher than the World's End data and smaller than the Pattipola and middle point's data. The Kirigalpotta mountain could be affected as a wind barrier and as a result intermediate pollutant concentrations were obtained. Ohiya road is another entrance to HPNP from Nuwara Eliya. However, vehicles transport from this road is very few when compare with the Pattipola road. Therefore, the resulted lower ambient concentrations of NO<sub>2</sub> and SO<sub>2</sub> at Ohiya road sampling point could be due to the lower vehicular emissions at this location.

Variations of both ambient concentrations of NO<sub>2</sub> and SO<sub>2</sub> were significantly correlated with each other in all the months of the study period. According to the Aberatne (2005), similar variations pattern of such pollutants were recorded at Kandy and Anuradhapura during 2002 to 2004.

Penner *et al.* (1989) has shown that the atmospheric chemical reactions were influenced by local weather pattern such as temperature, precipitation, clouds, atmospheric water vapor, wind speed, and wind direction. Not only that these weather patterns also involve to atmospheric transport processes and the rate of pollutant export from urban and regional environments to the global-scale environments.

The variations of ambient NO<sub>2</sub> and SO<sub>2</sub> concentration during the study period showed insignificant positive correlation ( $p \geq 0.05$ ) with the rainfall pattern. According to Aberatne (2005) lower concentrations of ambient NO<sub>2</sub> and SO<sub>2</sub> were resulted at high rainfall periods because such gasses are dissolved in rainwater. A positive significant correlation ( $p \leq 0.05$ ) was observed between variation of ambient NO<sub>2</sub> concentration and ambient temperature. However, insignificant positive correlation was observed with ambient SO<sub>2</sub> concentration and temperature. According to the Salem (2009), insignificant positive effects for temperature on NO<sub>2</sub> concentrations while as significant positive effects on SO<sub>2</sub> concentrations were observed. Çelik and Kadi (2007) also found that SO<sub>2</sub> concentrations increased with the temperature at Karabük City in Turkey. Aberatne (2005) found that negative relationship between NO<sub>2</sub> concentration and ambient temperature while no relationship between SO<sub>2</sub> and ambient temperature.

Considering the variations of two pollutants with RH and no. of vehicles visited HPNP, both pollutants had insignificant positive correlation. Salem in 2009 found that insignificant positive effects for humidity and wind speed on NO<sub>2</sub>, SO<sub>2</sub> concentrations at in United Arab Emirates. According to the Sánchez-Ccoyllo and Andrade (2002), high values of pollution concentrations prevailed due to weak ventilation, low relative humidity and an absence of precipitation. However, bright sunshine hours were positively correlated with the variations of ambient NO<sub>2</sub> concentration and negatively correlated with SO<sub>2</sub> concentrations. These correlations were

insignificant at 95 % confidence intervals. Although the ambient NO<sub>2</sub> and hours of bright sunshine were positively correlated with each other, Thompson (1992) and Ghazali *et al.*, (2009) have shown that considerable amount of NO<sub>2</sub> convert in to O<sub>3</sub> through photochemical reactions in the presence of sunlight.

The IAP value obtained for the whole area of the HPNP was 54.22. This value belonged to the quality level 5 which represent the 'very low' pollution level. This value was calculated using 379 lichen species spread in 12 quadrates which were situated in forest islands and continuous forest of HPNP. IAP values are highly correlated with species diversity. Therefore, high and low IAP values indicate the places having high and low species diversity respectively. The IAP method has the capability to provide a quantitative measure of the differential between urban and rural lichen communities as well. Although IAP values are resultants of the indicators of air pollution, differences in IAP or lichen species richness can also arise due to habitat disturbance (DeSloover & Leblanc, 1968; Kricke & Loppi, 2002). According to ter Braak (1998) many lichen species respond negatively to high SO<sub>2</sub> concentrations while the direct effects of ozone (O<sub>3</sub>) and nitrogen dioxide (NO<sub>2</sub>) on lichen communities are not well understood. The results including lichen data and air quality data could confirm that the ambient air quality at HPNP is very high. However, the fluctuations observed in air quality could be due to different environmental factors.

## VI) Conclusions

### Part I

- HPNP has a remarkably high number of corticolous lichens taxa. More than 50 % of lichen taxa were added to the Sri Lankan lichen flora so far identified and current study was able to identify 49 lichens as new records.
- Apart from these records no quantitative or qualitative studies have been carried out in HPNP regarding its lichen flora. Therefore the results obtained for the taxonomy of lichens will be useful in different ways in the future.
- A principal component analysis (PCA) of site data, tree data and lichen cover shows that most lichens are highly correlated with the bark pH and light intensities.
- Most of the lichens present in the study plots preferred relatively high pH range (5.0-6.0). The most dominant lichen species (314 species) within this pH range were macrolichens like *Lobaria retigera*, *Pseudocyphellaria beccarii*, *Heterodermia microphylla* and microlichens like *Graphis* sp. *Myriotrema* sp.
- The number of lichen colonies increased with increasing diameter class from 5-10 cm up to 11-20 cm and they decreased with increasing diameter size of the lichen host species. The highest number of lichen colonies was found on hosts of 11-20 cm diameter class in both forest types.
- Smooth bark type had the highest diversity of lichens in both forest types and this was followed by smooth to rough bark type. The least lichen diversity was observed on deeply furrowed bark type in the continuous forest, while in the forest islands, this was observed on flaky bark type.

- However, further studies should be carried out to explore the diversity of lichens present in whole trees including crown, leaves and other lichen dominating substrates such as stones and soil.

## Part II

- The data revealed that neither NO<sub>2</sub> nor SO<sub>2</sub> concentrations reach the maximum permissible levels at HPNP revealing ambient air quality is very high in HPNP.
- The variations of ambient NO<sub>2</sub> and SO<sub>2</sub> concentration during the study period showed insignificant positive correlation ( $p \geq 0.05$ ) with the rainfall pattern.
- Considering the variations of two pollutants with RH and number of vehicles visiting HPNP, both pollutants had insignificant positive correlation.
- The IAP value obtained for the whole area of the HPNP was 54.22. This value belonged to the quality level 5 which represent the 'very low' pollution level.
- The high diversity of lichens and the minimal levels of air pollutants suggested that the forest health at HPNP is highly conserved.
- Long term study of air quality followed by floristic studies may give more information regarding air quality & its effects on forest dieback.

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VIII) Problems if any, encountered during the implementation of the project

Due to the unexpected weather conditions and financial problems, we were unable to complete the project within decided time frame.

#### **Section 4**

##### **Impact of Research results:**

- i) Relevance of results achieved to scientific advancement
  - ii) Relevance of results achieved to national/socio-economic development
  - iii) Dissemination/application of research output
- The identified some indicator lichen species of air pollution, may provide a better understanding of air pollution in the particular environment. And this will reduce the high expenditure needed for chemicals and instruments if monitored otherwise.
  - Furthermore the results obtained from the research will be used in preparing the proposed “Lichen Flora of Sri Lanka”. And that will ultimately be a major source of information of lichen for those who are interested in the study of lichens. Moreover this will be the first publication in Sri Lanka that will include complete description of lichens.
  - The results of the project will be used to popularise lichen studies and to emphasise their important in schools and other institutes.
  - This research is the first step in the establishment of further studies of lichens. Moreover this will be a good foundation for the other institutes who are interested in the study of lichens.
  - There is no adverse impact of the proposed project on the environment.

#### **Section 5**

##### **Miscellaneous**

- i) List of major equipment acquired during the project period and their functionality

Kruzz Trinocular microscope-still functioning  
UV lamp- still functioning

Canon (S80) Digital Camera- still functioning

Hand Microtome- still functioning

- ii) List of publications/communications arising from the project and/or presentations made at seminars, workshops etc. (Please attach copies)

**Section 6**

**Summary Statement of Expenditure** (indicate under Personnel, Equipment, Consumables, Travel and Subsistence and Miscellaneous)



# POSTGRADUATE INSTITUTE OF SCIENCE (PGIS)

UNIVERSITY OF PERADENIYA  
P. O. Box 25, Peradeniya  
SRI LANKA

03.12.2009

Our ref. No. 6062

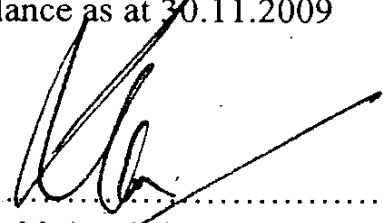
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National Science Foundation  
No. 47/5, Maitland Place  
Colombo 07.

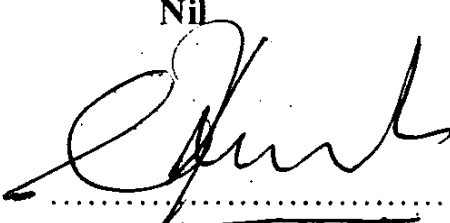
## Financial Statement for the period of 08.02. 2005 to 30.11.2009

The financial position of grant no. RG/2004/BM/01 awarded to Prof. N L V V Karunaratne by National Science Foundation is as follows:

		Funds Received by the Uni./ Institution	Total Expenditure Rs.	Balance available Rs.
Personal	Research Assistant	524,500.00	524,500.00	-
	Technical Assistant	--	--	
Equipment	Foreign	--	--	
	Local	--	--	
Consumables	Foreign	--	--	
	Local	--	--	
Travel & Subsistences		--	--	
Miscellaneous		--	--	
	<b>Total</b>	<b>524,500.00</b>	<b>524,500.00</b>	<b>Nil</b>
Funds Received 15.03.2005		Rs.	72,000.00	
29.06.2005		Rs.	36,000.00	
27.10.2005		Rs.	72,000.00	
02.01.2006		Rs.	36,000.00	
28.06.2006		Rs.	45,000.00	
31.08.2006		Rs.	45,000.00	
13.01.2007		Rs.	45,000.00	
20.06.2007		Rs.	36,000.00	
13.09.2007		Rs.	45,000.00	
27.10.2007		Rs.	22,500.00	
25.01.2008 (salary arrears )		Rs.	70,000.00	
Total Amount		Rs.	<u>524,500.00</u>	
Actual Expenditure		Rs.	<u>524,500.00</u>	
Balance as at 10.11.2007			<u>Nil</u>	

Balance as at 30.11.2009

  
.....  
Mr. Mahesh Iddawela  
Senior Assistant Bursar  
Postgraduate Institute of Science

Nil  
  
.....  
Prof. N L V V Karunaratne  
Grantee

Director	Tel : 081- 2387218	Assistant Registrar	Tel : 081 - 2387542	Programme Coordinator	Tel : 081-2385669
Fax :	081- 2389026 (Local)	E-mail :	ar@pgis.lk	E-mail :	proco@pgis.lk
	+94 81 2389026 (Int.)				
E-mail :	director@pgis.lk	Senior Assistant Bursar	Tel : 081 - 2389027	PGIS Office :	Tel : 081 - 2385660
		E-mail :	sab@pgis.lk		Fax: 081 - 2389026



# POSTGRADUATE INSTITUTE OF SCIENCE (PGIS)

UNIVERSITY OF PERADENIYA  
P. O. Box 25, Peradeniya  
SRI LANKA

03.12.2009

Our ref. No. 6195

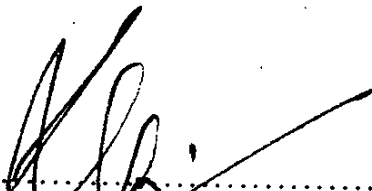
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National Science Foundation  
No. 47/5, Maitland Place  
Colombo 07.

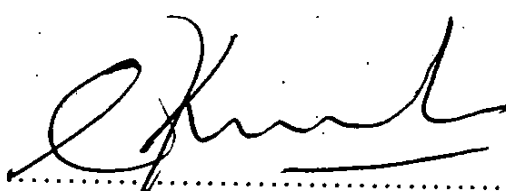
## Financial Statement for the period of 10.06.2008 to 30.11.2009

The financial position of grant no. RG/2008/EB/02 awarded to Prof. N L V V Karunaratne by National Science Foundation is as follows:

		Funds Received by Uni./ Institution	Total Expenditure Rs.	Balance available Rs.
Personnel	Research Student	300,000.00	300,000.00	--
	Technical Assistant	--	--	--
	Other	--	--	--
Equipment	Foreign	--	--	--
	Local	--	--	--
Consumables	Foreign	--	--	--
	Local	--	--	--
Travel & Subsistences		--	--	--
Miscellaneous		--	--	--
<b>Total</b>		<b>300,000.00</b>	<b>300,000.00</b>	<b>Nil</b>

Unspent Balance of the funds received	Rs.	--
Funds Received 16.06.2008	Rs.	100,000.00
24.10.2008	Rs.	100,000.00
15.01.2009	Rs.	50,000.00
19.05.2009	Rs.	50,000.00
<b>Total</b>	Rs.	<b>300,000.00</b>
Actual Expenditure	Rs.	<b>300,000.00</b>
Balance		<b>Nil.</b>
Cash Imprest/ Advance	Rs.	--
<b>Balance as at 30.11.2009</b>	Rs.	<b>Nil</b>

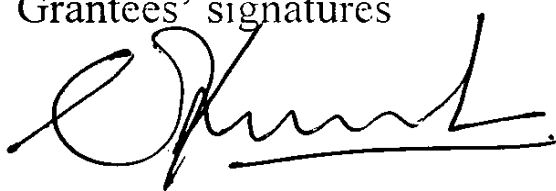
  
Mr. Mahesh Iddawela  
Senior Assistant Bursar  
Postgraduate Institute of Science  
University of Peradeniya.

  
Prof. Veranja Karunaratne  
Grantee.

<b>Director</b>	Tel : 081- 2387218	<b>Assistant Registrar</b>	Tel : 081 - 2387542	<b>Programme Coordinator</b>	Tel : 081-2385669
Fax :	081- 2389026 (Local)	E-mail :	ar@pgis.lk	E-mail :	proco@pgis.lk
	+94 81 2389026 (Int.)				
E-mail :	director@pgis.lk	<b>Senior Assistant Bursar</b>	Tel : 081 - 2389027	PGIS Office :	Tel : 081 - 2385660
		E-mail :	sab@pgis.lk		Fax: 081 - 2389026

**Section 7**

i) Grantees' signatures



ii) Comments of the Head of the Department/signature



**Recommended and Forwarded**

iii) Head of the Institution's signature

Head  
Chemistry Department  
University of Peradeniya

**Recommended and Forwarded**

*BK*  
28/2/2009  
DIRECTOR  
Postgraduate Institute of Science (PGIS)  
University of Peradeniya  
Sri Lanka.

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