การใช้ไลเคนเพื่อเป็นดัชนีในการเฝ้าระวังคุณภาพสิ่งแวดล้อมในเขตเทศบาลนครนครราชสีมาและสถานีวิจัยสิ่งแวดล้อมสะแกราช

นางสาวอมรรัตน์ พิทักษ์พงษ์

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
สาขาวิชาชีววิทยาสิ่งแวดล้อม
มหาวิทยาลัยเทคโนโลยีสุรนารี
ปีการศึกษา 2552

THE USE OF LICHEN AS AN INDICATOR FOR ENVIRONMENTAL MONITORING IN NAKHON RATCHASIMA MUNICIPALITY AND SAKAERAT ENVIRONMENTAL RESEARCH STATION

A-mornrat Pitakpong

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in Environmental Biology

Suranaree University of Technology

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THE USE OF LICHEN AS AN INDICATOR FOR ENVIRONMENTAL MONITORING IN NAKHON RATCHASIMA MUNICIPALITY AND SAKAERAT ENVIRONMENTAL RESEARCH STATION

Suranaree University of Technology has approved this thesis submitted in partial fulfillment of the requirements for a Master's Degree.

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อมรรัตน์ พิทักษ์พงษ์ : การใช้ไลเคนเพื่อเป็นดัชนีในการเฝ้าระวังคุณภาพสิ่งแวดล้อมในเขตเทศบาลนครนครราชสีมาและสถานีวิจัยสิ่งแวดล้อมสะแกราช (THE USE OF LICHEN AS AN INDICATOR FOR ENVIRONMENTAL MONITORING IN NAKHON RATCHASIMA MUNICIPALITY AND SAKAERAT ENVIRONMENTAL RESEARCH STATION) อาจารย์ที่ปรึกษา : ผู้ช่วยศาสตราจารย์ ดร.ณัฐวุฒิ ธานี, 237 หน้า.

การใช้ไลเคนเพื่อเป็นดัชนีชี้วัดมลพิษทางอากาศในจังหวัดนครราชสีมา ได้แบ่งการศึกษาออกเป็น 2 ส่วน ดังนี้ ส่วนที่ 1 ทำการเก็บตัวอย่างไลเคนและตรวจวัดคุณภาพอากาศ ในเขตเทศบาลนครนครราชสีมา จำนวน 46 ตาราง จากต้นมะม่วงทั้งหมด 276 ต้น ระหว่างเดือนมกราคม ถึง ตุลาคม พ.ศ. 2552 ศึกษาชนิดของไลเคน ความถี่ การกระจายตัวของไลเคน จัดทำแผนที่คุณภาพอากาศของเทศบาลนครนครราชสีมาโดยใช้ไลเคนเป็นตัวบ่งชี้ และการวัดปริมาณก๊าซไนโตรเจนไดออกไซด์และซัลเฟอร์ไดออกไซด์ในเขตเทศบาลนครนครราชสีมา ส่วนที่ 2 ทำการศึกษาความหลากหลายของไลเคนในป่าเต็งรังและป่าดิบแล้งในพื้นที่ของสถานีวิจัยสิ่งแวดล้อมสะแกราช ระหว่างเดือนมิถุนายน ถึง พฤศจิกายน พ.ศ. 2552

การสำรวจความหลากหลายของไลเคนบนต้นมะม่วง พื้นที่ศึกษาขนาด 1×1 ตาราง กิโลเมตร โดยใช้กรอบสำรวจความถี่ขนาด 20×50 ตารางเซนติเมตร บันทึกชนิดและความถี่ของจำนวนไลเคนแต่ละชนิด ทำการเก็บตัวอย่างอากาศเพื่อหาปริมาณก๊าซไนโตรเจนไดออกไซด์และก๊าซซัลเฟอร์ไดออกไซด์ในอากาศในฤดูฝนและฤดูหนาว โดยใช้วิธีการเก็บตัวอย่างแบบแพสซีฟ ชนิดหลอด ทำการตรวจวัดปริมาณโดยเทคนิคไอออนโครมาโตกราฟี ผลการศึกษาพบไลเคน 10 วงศ์ 17 สกุล และ 29 ชนิด ที่พบในเทศบาลนครนครราชสีมา โดยชนิดไลเคนที่พบมาก ได้แก่ *Hyperphyscia adglutinata Pyxine cocoes Physcia dimidiate Lecanora leprosa* และ*Opegrapha stirtonii* สำหรับปริมาณก๊าซไนโตรเจนไดออกไซด์ในแต่ละพื้นที่ศึกษาของฤดูฝน ในช่วงที่ตรวจวัดมีค่าเท่ากับ 0.57-4.92 ppbv และฤดูหนาว มีค่าเท่ากับ 0.46-8.93 ppbv ส่วนปริมาณก๊าซซัลเฟอร์ไดออกไซด์ในแต่ละพื้นที่ศึกษาของฤดูฝน ในช่วงที่ตรวจวัดมีค่าเท่ากับ 0.76-3.57 ppbv และฤดูหนาว มีเท่ากับ 1.23-3.74 ppbv จากการวิเคราะห์หาความสัมพันธ์ระหว่างดัชนีคุณภาพอากาศกับปริมาณก๊าซไนโตรเจนไดออกไซด์ทั้งในฤดูฝนและฤดูหนาวกับปริมาณก๊าซซัลเฟอร์ไดออกไซด์ในฤดูฝน พบว่ามีความสัมพันธ์อย่างผกผันอย่างมีนัยสำคัญที่ระดับความเชื่อมั่น 99% ส่วนปริมาณก๊าซซัลเฟอร์ไดออกไซด์ในฤดูหนาวไม่มีความสัมพันธ์กับค่าดัชนีคุณภาพอากาศ จากผลการศึกษาพบว่า เมื่อปริมาณก๊าซไนโตรเจนไดออกไซด์และปริมาณก๊าซซัลเฟอร์ไดออกไซด์มีค่าสูงขึ้น จะทำให้ค่าดัชนีคุณภาพอากาศลดลง และพบว่าในช่วงเวลาตรวจวัดปริมาณก๊าซ

ไนโตรเจนไดออกไซด์มีค่าสูงกว่าปริมาณก๊าซซัลเฟอร์ไดออกไซด์ การสำรวจความหลากหลายของไลเคนบนต้นไม้ ในป่าเต็งรังและป่าดิบแล้ง ในสถานีวิจัยสิ่งแวดล้อมสะแกราช ขนาด 20×20 ตารางเมตร จำนวน 6 แปลง โดยใช้กรอบสำรวจความถี่ขนาด 20×50 ตารางเซนติเมตร บันทึกชนิดและความถี่ของจำนวนไลเคนแต่ละชนิดและบันทึกข้อมูลทางกายภาพ พบไลเคนทั้งหมด 13 วงศ์ 19 สกุล 39 ชนิด จากการศึกษาความถี่รวมของจำนวนไลเคนแต่ละชนิดที่พบในป่าเต็งรังและป่าดิบแล้ง ซึ่งพบว่าไลเคนชนิด *Crocynia pyxinoid* มีค่าความถี่สูงสุดมีเท่ากับ 41 รองลงมาคือ *Laurera benguelensis* *Graphis* sp.1 *Clathroporina* sp. *Pyrenula wilmsiana Trypethelium tropicum Trypethelium eluterae* และอื่น ๆ ส่วนไลเคนชนิด *Parmotrema tinctorum* มีค่าความถี่ต่ำสุดมีค่าเท่ากับ 1.0 ในช่วงที่ทำการศึกษาพบว่า มีอุณหภูมิมีค่าเฉลี่ยอยู่ระหว่าง 27.5-32.7°C ความชื้นสัมพัทธ์มีค่าเฉลี่ยอยู่ระหว่าง 66-83% และแสงมีค่าเฉลี่ยอยู่ระหว่าง 262-1,002 lux จากการวิเคราะห์หาความสัมพันธ์ระหว่างดัชนีความหลากหลายของไลเคนกับปัจจัยทางกายภาพในพื้นที่ศึกษา พบว่าไม่มีความสัมพันธ์กันอย่างมีนัยสำคัญที่ระดับความเชื่อมั่น 95%

สาขาวิชาชีววิทยา ลายมือชื่อนักศึกษา_____

ปีการศึกษา 2552 ลายมือชื่ออาจารย์ที่ปรึกษา_____

ลายมือชื่ออาจารย์ที่ปรึกษาร่วม_____

A-MORNRAT PITAKPONG : THE USE OF LICHEN AS AN INDICATOR FOR ENVIRONMENTAL MONITORING IN NAKHON RATCHASIMA MUNICIPALITY AND SAKAERAT ENVIRONMENTAL RESEARCH STATION. THESIS ADVISOR : ASST. PROF. NATHAWUT THANEE, Ph.D. 237 PP.

LICHEN / FREQUENCY / PASSIVE SAMPLING / NAKHON RATCHASIMA MUNICIPALITY / SAKAERAT ENVIRONMENTAL RESEACH STATION

The study on the use of lichen as indicator for air pollution monitoring in Nakhon Ratchasima province was divided into two parts. The first part included collection of lichen samples and measurement of air quality from 276 mango trees in 46 sampling plots in Nakhon Ratchasima municipality areas during January-October 2009. The study on lichen species, frequency, distribution lichen and air quality map using lichens as indicators and to measure nitrogen dioxide and sulphur dioxide in Nakhon Ratchasima municipality areas. The second part was the study on lichen diversity in deciduous dipterocarp forest (DDF) and dry evergreen forest (DEF) in the Sakaerat Environmental Research station (SERS) areas during June-November 2009.

The survey of lichen diversity on mango trees (*Mangifera indica* L.) in a studied area of 1×1 km^2 by using frequency frame of 20×50 cm^2. The lichen species and frequency of each species were recorded. Air samples were collected in a tube by applying the passive sampling technique in the rainy and winter seasons in order to analyze amounts of nitrogen dioxide and sulfur dioxide. The ion chromatography was applied in measurement of the amounts of these two gases. A total of 10 lichen families, 17 genera, and 29 species were found in the Nakhon Ratchasima municipality. The five most widespread species were *Hyperphyscia adglutinata, Pyxine cocoes, Physcia dimidiata, Lecanora leprosa* and *Opegrapha stirtonii*. The

amounts of nitrogen dioxide (NO_2) of each sampling plot in measuring period were 0.57-4.92 ppbv in the rainy season and 0.46-8.93 ppbv in winter season. The amounts of sulphur dioxide (SO_2) of each sampling plot in measuring period were 0.76-3.57 ppbv in the rainy season and 1.23-3.74 ppbv in winter season. According to the analysis of correlation between Air Quality Index (AQI) with amounts of NO_2 in rainy and winter seasons and SO_2 in rainy season, negative significant correlation was found at 99% significant level, while there was no significant correlation between SO_2 in winter season with AQI. It was indicated that when the amount of these two gases increased, AQI decreased. However, the concentration measurement presented that there was higher NO_2 than SO_2 in both the rainy and winter seasons. The study on lichen diversity in DDF and DEF at SERS area was conducted in a study area of 20×20 m^2 which was divided into six sampling plots by using frequency frames of 20×50 cm^2. Lichen species and frequency of each species and environmental factors were recorded, 13 lichen families, 19 genera, and 39 species were found. Total lichen frequency of each species in DDF and DEF was investigated. Study results presented that the *Crocynia pyxinoid* showed the highest frequency of 41 followed by *Laurera benguelensis, Graphis* sp.1, *Clathroporina* sp., *Pyrenula wilmsiana, Trypethelium tropicum* and *Trypethelium eluterae, etc.* respectively. The lowest frequency was *Parmotrema tinctorum.* During the study period, the average temperature, relative humidity and light intensity were at 27.5-32.7°C, 66-83%, and 262-1,002 lux, respectively. The analysis of correlation between lichen diversity index and physical factors in the Sakaerat Environmental Research station was calculated. It was found that they did not significantly correlate at 95% significant level.

School of Biology

Academic Year 2009

Student's Signature_____

Advisor's Signature_____

Co-advisor's Signature_____

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A-mornrat Pitakpong

CONTENTS

Page

CONTENTS (Continued)

Page

CONTENTS (Continued)

Page

CONTENTS (Continued)

Page

CONTENTS (Continued)

Page

LIST OF TABLES

LIST OF TABLES (Continued)

Table **Page**

LIST OF FIGURES

Figure

Page

LIST OF FIGURES (Continued)

Figure **Page**

LIST OF FIGURES (Continued)

Figure **Page**

LIST OF FIGURES (Continued)

Figure **Page**

LIST OF FIGURES (Continued)

Figure **Page**

LIST OF FIGURES (Continued)

Figure

Page

LIST OF ABBREVIATIONS

°	=	Degree
°C	=	Degree celsius
AQI	=	Air Quality Index
AQC	=	Air Quality Classes
cf.	=	Confer
cm	=	Centimeter
cm^2	=	Square centimeter
$cm^{-2}\ s^{-1}$	=	Square centimeter per second
Cu	=	Copper
DDF	=	Deciduous dipterocarp forest
DEF	=	Dry evergreen forest
et al.	=	Et alii
E	=	East
Fe	=	Iron
GIS	=	Geographic information system
H_2SO_2	=	Sulfuric acid
km	=	Kilometer
km^2	=	Square kilometer
m	=	Meter
mm	=	Millimeter

LIST OF ABBREVIATIONS (Continued)

mg/m^3	=	Milligram per cubic meter
$mol/cm^2/s$	=	Mole per square centimeter per second
µg	=	Microgram
$µg/m^3$	=	Microgram per cubic meter
Mn	=	Manganese
N	=	North
Na_2CO_3	=	Sodium carbonate
$NaHCO_3$	=	Sodium bicarbonate
$NaNO_2$	=	Sodium nitrite
NE	=	Northeast
NO_2	=	Nitrogen dioxide
NW	=	Northwest
PAN	=	Peroxyacetyl nitrate
s	=	Second
sp.	=	Species
S	=	South
SD	=	Standard diviation
SE	=	Southeast
SO_2	=	Sulphur dioxide
SW	=	Southwest
TEA	=	Triethanolamine
W	=	West

CHAPTER I

INTRODUCTION

Nakhon Ratchasima province is a gateway to the northeast region of Thailand. It is also an important economic, social and transportation center of the region. At present, community, industry and transportation sectors are expanded in order to respond the need of increasing population and to provide the convenience to travelers who take this province as their passage way to other provinces in the region. The environmental effect caused by heavy transportation in the province especially air pollution from dust, soot and smoke of fuel burn has occurred. Air pollution affects livelihood of organism and population's health. With reference to statistic presented in the annual reports in 2004-2008 of the Nakhon Ratchasima provincial public health office, it is found that tendency of population's sickness caused by respiratory diseases was increased. Among them, 72% were caused by increasing air pollution. At the present time, air pollution and climate change are in the interest of both governmental and private sectors in local, national and international levels because both situations directly affect human livelihood and environment. The air pollution that is possibly caused by forest fire or volcano eruption makes groups of smoke in the atmosphere and decay of organic matters in lack of oxygen condition. Besides, air pollution can be caused by various human activities, for example fuel burn of vehicles and engines in increasing industrial factories.

Air quality measurement can be performed in various methods, such as using physical measuring instrument and using organisms. Using instruments to investigate pollutant levels, can support us to get exact figures but it cannot indicate effect of pollutants on organisms. Moreover, these instruments are expensive and need complicated working procedure. One method is using organism in the target areas as quality indicators or it could be called as “bioindicators”. Their changes in physical, biochemical and chemical structure or composition can be obserbed or variety of groups of organisms, their appearance/absence can be evaluated. By this method, we can directly investigate the effect of pollution on organisms. It is a simple way and needs lower budget without using complicated instruments. An investigation of air pollution that use organisms as quality indicators, organisms that are sensitive to air pollution, such as lichens are usually selected.

A lichen absorbs most of its mineral nutrients from air and rainfall. Pollution in the atmosphere can be especially dangerous to lichens because they retain and can accumulate to deadly amounts such as heavy metals, sulphur, radioactive elements, NO_2, and ozone. Sulphur dioxide (SO_2) is especially lethal to lichens because it lowers pH and deteriorates chlorophyll, which causes photosynthesis to cease. Anti-sulphur dioxide legislation in the last 25 years is allowing lichens to return to formerly polluted areas. Lichens have also been used to monitor the amount of pollutants in an environment by observing the condition of lichens as well as their chemical composition (Hawksworth and Rose, 1970).

Lichens are increasingly used as air quality biomonitors (Bartoli et al., 1997) because they have several advantages over electronic monitors which are expensive and their use and maintenance are not simple or cheap. In contrast,

biomonitors are available without cost and there are millions of them already functioning throughout the world (Ockenden et al., 1998). Lichens are increasingly used worldwide as air quality biomonitors because they are efficient, easy and cheap, but validation studies of the methodology are scarce (Julián et al., 2002). The component of air pollution responsible for the greatest damage to lichens is sulphur dioxide (SO_2) released by coal-burning power plants (Path, 2002).

Nowadays, the major pollutants are nitrogen compounds from road traffic and intensive farming. These compounds do not destroy all lichens because some species positively thrive on nitrogen. So different pollutants create different patterns of lichen growth and by understanding them scientists are able to chart the health of the environment. Some lichens grow very slowly so that they can indicate the history of the substrate and the environment where they are found. They have been used as indicators of ancient woodlands that have never been clear-felled. The reindeer and the caribou of the northern latitudes are well known for feeding on lichens, especially in winter when food is scarce. In fact, about 90 percentage of their winter diet consists of lichens (Brodo et al., 2001). Lichens are widely used as environmental indicators or bio-indicators. If air is very badly polluted, there may be no lichens present. Just green algae may be found. If the air is clean, shrubby, hairy and leafy, lichens become abundant. A few lichen species can tolerate quite high levels of pollution and are commonly found on pavements, walls and tree barks in urban areas (Nash, 1996).

However, one of the main problems for the general acceptance of lichen use in monitoring air pollution is the difficulty in finding a quantitative relationship between lichen data and actual pollution levels (Nimis et al., 1990). Therefore, if lichen data are to be used to monitor and formulate regulatory decisions regarding air pollution

levels, we need to know what levels are damaging to lichens and which gaseous pollutants are primary or contribute to the observed damage or distribution change of lichens (Nimis and Purvis, 2002). Thus, in this study the passive sampling technique was used to obtain the level of atmospheric air pollutants for comparison with the lichen data, since it can provide a high density of sampling points.

The objectives of this research are:

1. To study lichen species, frequency and their distribution in Nakhon Ratchasima municipality.

2. To examine air quality by using lichens as bioindicators in Nakhon Ratchasima municipality.

3. To study correlation between Air Quality Index and concentration of nitrogen dioxide and sulphur dioxide in ambient air at Nakhon Ratchasima municipality.

4. To study lichen diversity in deciduous dipterocarp and dry evergreen forests in the Sakaerat Environmental Research station of Nakhon Ratchasima province.

5. To provide basic information on lichen diversity of Nakhon Ratchasima province for future studies.

Scope and limitation of the study

This study is conducted to study lichen species, frequency, distribution, air quality using frequency lichens as bioindicators and measurement nitrogen dioxide

sulphur dioxide by passive sampling technique in Nakhon Ratchasima municipality areas.

In addition, the investigation of lichen diversity in deciduous dipterocarp and dry evergreen forest in Sakaerat Environmental Research station of Nakhon Ratchasima province.

CHAPTER II

LITERATURE REVIEW

2.1 Lichens

Millions of year ago, a single-cell organism was born and subsequently developed into a many-celled organism as it evolved and reproduced along with the physical changes of the earth. There are around 5 million species on the earth, one of which is a living thing called a “lichen” which first appeared about 400 million years ago (Figure 2.1).

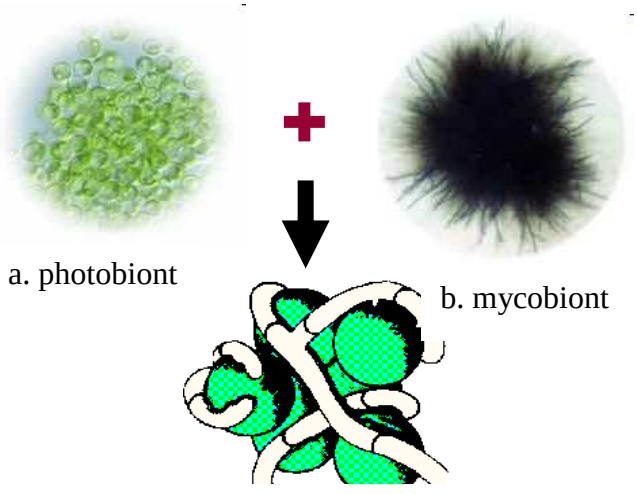


Figure 2.1 Characteristic of lichen.

Source: Lichen Research Unit and Lichen Herbarium, 1993.

Lichens are, by definition, symbiotic organisms composed of a fungal partner which is mycobiont, and one or more photosynthetic partner called photobiont. The photobiont may be either a green alga or a cyanobacterium (Brodo et al., 2001). The cyanobacteria symbiont component may specialize in fixing atmospheric nitrogen for metabolic use and occur as crusty patches or bushy growths on trees, rocks and bare ground. Over the years these two components grew up together in a harmonious association and are referred as symbiosis, or, more simply, the “together living components” and are classified in the Fungi Kingdom (Hale, 1979). Lichens are organisms that are often mistaken for plants. Most people believe they are a type of moss. In fact, they do not even belong to the Kingdom Plantae because they are not considered as a single entity but as fungi having symbiotic relationship with green algae or cyanobacteria photobionts (Brodo et al., 2001) that form the body or thallus. This classification is generally based on characteristics of the thallus and reproductive organs. In the world as a whole there are, according to Ainworth (1976) some 525 genera and 13,500 species of lichens, but Hale (1979) puts the total number of species at about 17,000. The latter figure mean that, on balance, about 20-25% of the 72,000 known fungi are lichenized (Baron, 1999). Amongst the ascomycetes, Hawksworth and Hill (1984) consider that as many as 46% of species are lichenized.

Over 95% of the fungi that form lichens or the mycobiont are members of the Ascomycota which produce their spores in a bag-shaped ascus (Figure 2.2 and 2.3). Most of the remaining fungi are found in the Basidiomycota which produce their spores on the top of cushion-shaped basidia (Figure 2.4 and 2.5) and these often grow mushroom-shaped fruiting bodies. There are also a few mycobionts from the Deuteromycota (the “fungi imperfecti” which only reproduce asexually). There are

also lichen-like relationships between other fungi such as the myxomycete (the slime moulds) and these are still being investigated. From the taxonomic point of view, it is on the characteristics, expressed in thallus form, ascus structure, spores and other features that lichen classification is based (Baron, 1999).

Figure 2.2 Examples of ascomata of Ascomycota.

Source: The National Academy of Science, 2010

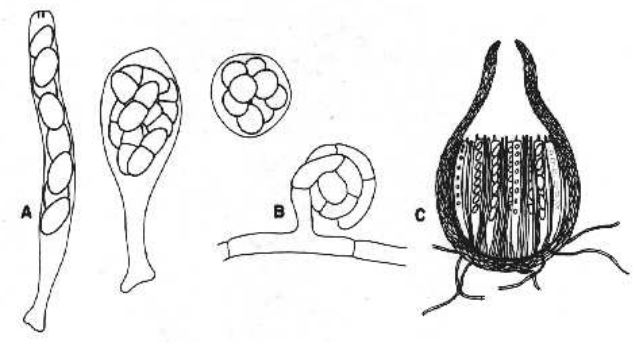


Figure 2.3 Cross section of Ascomycetes; (A) three kinds of asci: cylindrical, clavate, and spherical. (B) initial phase of sexual reproduction. (C) cross-section of a flask-shaped perithecium bearing cylindrical asci.

Source: The Mycology Web Pages, 2010.

Figure 2.4 Examples of basiomata of Basidiomycota.

Source: The Fungal Tree of Life Project, 2005.

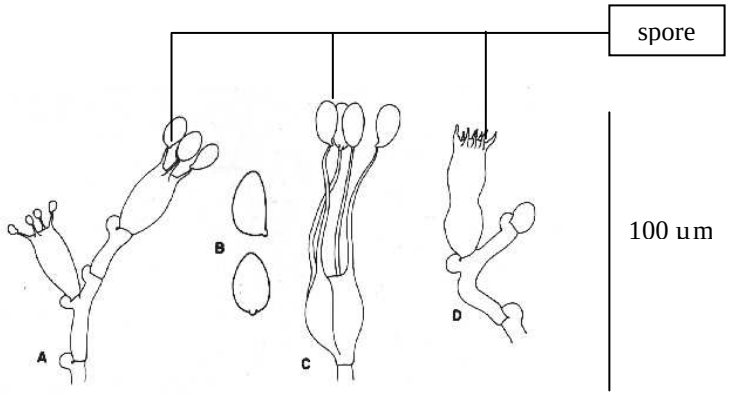


Figure 2.5 Cross section of Basidiomycetes; (A) four-spored undivided basidium (holobasidium); note the clamp connection at each cross-wall. (B) two typical basidiospores, the upper one in side view and the lower in front view. (C) a four-celled, cruciate basidium typical of many jelly fungi. (D) eight-spored holobasidium typical of species of *Sistotrema*; the spores have been discharged. The figure at right, shows the role of a clamp connection in facilitating nuclear migration.

Source: The Mycology Web Pages, 2010

The most common photobionts are the genera *Trebouxia* (Figure 2.6), *Trentepohlia* (Figure 2.7) and *Nostoc* (Figure 2.8). *Trebouxia* and *Trentepohlia* belong to the green algae and *Nostoc* to the cyanobacteria. There are approximately 100 species, 40 algal genera and cyanobacteria as photobionts (Nash, 1996) but about

85% of lichens are observed to associate only with green algae (Salix, 2004). Approximately 60% of known lichens have *Trebouxia* as their photobiont (Ahmadjian and Hale 1973) and about 10% contain cyanobacteria (Nash, 1996).

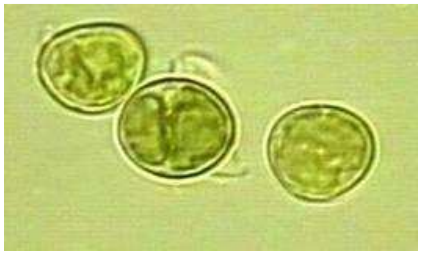


Figure 2.6 Single cells of *Trebouxia*, the most common green alga found in lichens.

Source: Fungal Biology, 2005.

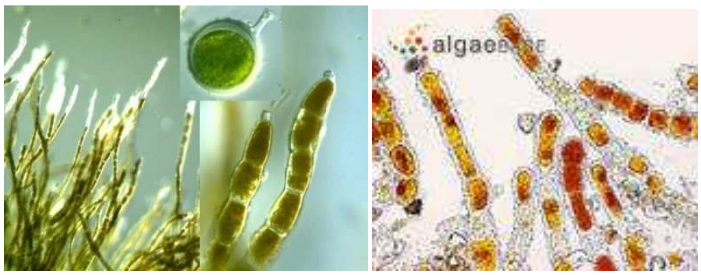


Figure 2.7 *Trentepohlia*, green algae contain an orange carotenoid pigment, which masks the green colour of chlorophyll.

Source: Protist Information Server, 2010.

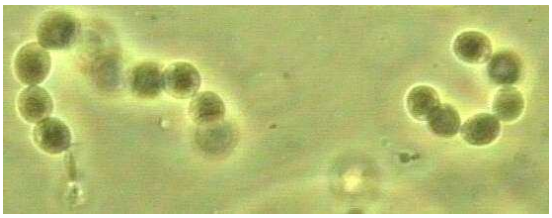


Figure 2.8 Chains of ***Nostoc*** cells released from a desert lichen.

Source: Fungal Biology, 2005.

2.1.1 Systematic character

Infrastructure that could be compared to a body of lichen is called the thallus. Thallus includes fungus and algae that allocated space as their habitat. Lichen classification, according to principle of taxonomy, is based on exterior character, interior structure and chemical composition of the thallus.

2.1.2 Exterior structure

Colour of thallus: When in a dry condition, thallus is grey or brown. When it is in wet condition or with humidity, colour of algae clearly appears and causes thallus to be green. The bright colour of lichen is caused by lichen products, e.g. orange or yellow substance is parietin pigment that could be seen in a lichen in the areas under the bright light. The substance is helpful in screening of the UV to protect algae. In lichen with the blue-green algae, colour substance or natural substance is not found (Lichen Research Unit and Lichen Herbarium, 1993).

Size of lobe: The thallus (foliose) includes lots of lobe joined together. However, lobes' ends may separate from each other. Therefore, sizes of lobe can be visibly viewed and that is one of the characters used for lichen classification. Size of lobe is measured from the separating points of lobes (Lichen Research Unit and Lichen Herbarium, 1993).

Isidia (Figure 2.9): It is similar to groups or pieces of short needle distributed on surface of thallus compound of algae and hypha covered by cortex and serves for asexual reproduction and releases to the air caused by cracking of epidermis or cortex (Lichen Research Unit and Lichen Herbarium, 1993).

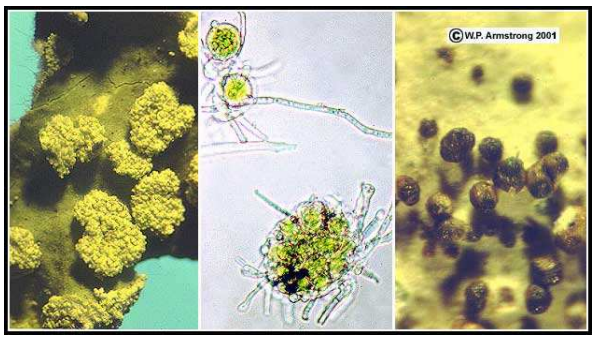


Figure 2.9 Characteristic of soredia; **Left:** *Flavoparmelia caperata*, a foliose bark lichen showing several soredia erupting from the upper surface of the thallus. **Center:** Microscopic view of soredia from the common chaparral lichen *F. caperata*. Each spherical soredium contains several green algal cells enveloped by filamentous fungal hyphae. Like dust particles, the soredia are carried by the wind to different locations where they develop into new lichens. **Right:** Close up view of the surface of the foliose rock lichen *Xanthoparmelia mexicana* showing pimplelike projections called isidia. The isidia contain algae and fungi and readily become detached and dispersed to new locations.

Source: Botany Hawaii, 2010.

Phyllidia: It is in a form of scale, similar to a small lobe that emerges from thallus. It serves for asexual reproduction (Lichen Research Unit and Lichen Herbarium, 1993).

Fibril: It looks like a short branch shot from lateral side of fruticose thallus. It is mostly found in *Usnea* genus. It serves for asexual reproduction (Lichen Research Unit and Lichen Herbarium, 1993).

Cyphellae: It is as a small hole with rim and appears at low surface of thallus. It is the permanent character of the genus *Sticta*. It serves in releasing air or exchange gas (Lichen Research Unit and Lichen Herbarium, 1993).

Pseudocyphellae: It is plane to slightly convex structure where medullary hyphae break through the thallus cortex. They are less distinctly developed than true cyphellae but like cyphellae may be surrounded by a pale, less pigmented rim as in the genus *Pseudocyphellaria* (Nash et al., 2002).

Rhizine or anchor attachments: It is a part of hypha at lower part joined up, looks similar to rootlet in different forms. It serves for attaching to substrates (Lichen Research Unit and Lichen Herbarium, 1993). These consist of bundles of hyphae which may be branched or simple. The position of the rhizines aids identification as does their shape, especially in the genus *Parmelia*. In such foliose lichens rhizines may emerge from many points on the lower cortex. They are root-like in appearance but, unlike roots, cannot actively draw in water and mineral salts although these may be taken into the thallus by capillary action. In umbilicate and most fruticose lichens the fungal hyphae at the base fuse together to form a short, stem-like “holdfast” which makes a substantial anchor. Holdfasts serve to give strong support to lichens which, because of their protruding thalli on such sites as rock and trees, are subject to wind pressure (Baron, 1999).

Tomentum: It looks like a cotton pad or Scotch-brite at the lower part of thallus. It can be in different colours, from pale-brown to black. It serves as a holder to habitat or helper to absorb humidity (Lichen Research Unit and Lichen Herbarium, 1993).

Cilia: These are white, green, black or piebald. It looks like eyelash emerged at rim of thallus. They are composed of adhering hyphal strands which cannot act as vegetative propagule, as they are without a photobiont (Baron, 1999).

Hypothallus: It is part of fast growing hypha. It can be brown or black without any algae living together. It can be found at rim of thallus (Lichen Research Unit and Lichen Herbarium, 1993).

2.1.3 Interior structure of thallus

There are two types of thallus depending on self-arrangement of fungus and algae:

2.1.3.1 Heteromerous thallus: Fungus and algae formed separately and can be divided into three levels, (Figure 2.10), including:

Upper and lower cortex includes tightly pressed hypha to protect or dam up the algae inside.

Algal layer includes phycobionts that selves-arranged in line or in groups. Meldulla is the level with loosely bound hypha.

The level has secondary metalites that cause it different colours but mostly the white, yellow or orange is found.

2.1.3.2 Homoiomerous thallus: Thallus is not obviously divided into levels. It includes cyanobacteria algae or blue-green algae such as *Nostoc* as a component. These lichens are called gelatinous lichens e.g. *Collema* and *Leptogium*. Below the algal layer is the medulla, a loosely woven layer of fungal filaments. In foliose lichens, there is a second cortex below the medulla, but in crustose and

squamulose lichens, the medulla is in direct contact with the underlying substrate, to which the lichen is attached. The cross section of lichen is shown in Figure 2.12.

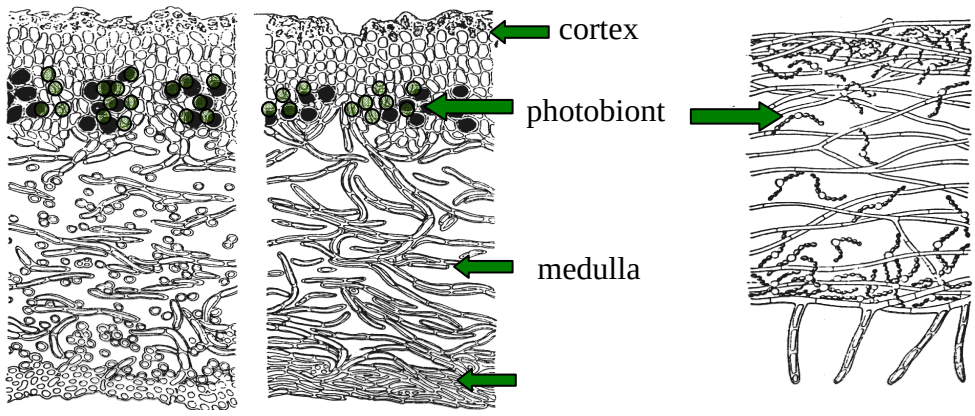


Figure 2.10 Cross section of lichen thallus; (A) Heteromerous thallus and (B) Homoiomerous thallus.

Source: University of California museum of Poleontology, 1905.

2.1.4 The structure and morphology of lichens

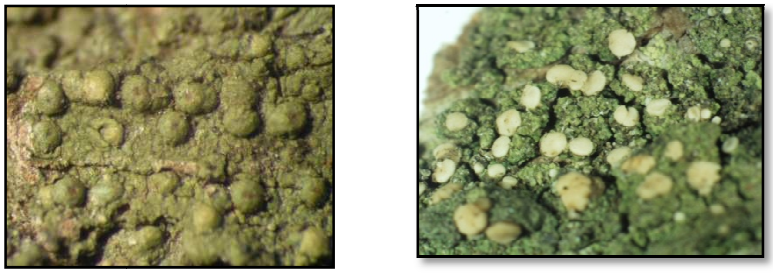
Lichens have a very wide range of forms. Some are leaf-like growths adhering closely or loosely to tree trunks, stone or brick surfaces and are occasionally found on soil and man-made materials such as rubber, glass and lead, some are long, hair-like skeins dangling from branches of trees, or tough, semi-rigid thongs anchored to rock or bark, others are thin or sometimes almost invisible crusts on substrata and may actually be living mainly within the rock or bark. Lichens are divided into three major growth forms: crustose, foliose, fruticose, more advanced books on lichens classify them into two further groups, squamulose and leprose (Brodo et al., 2001).

Morphologically, lichens are made up of a few distinct characters. The most obvious is the thallus. The form of the thallus is a result of the fungal species involved. The thallus is the body of the lichen. Most of what you see, if it is not reproductive structures, is thallus. The fungal hyphae (filaments) branch and then fuse together (anastomose) when they meet to form a mesh of hair-like threads. The top surface is normally a layer of tightly packed hyphae called a “cortex”. Below this is the algal layer where the photobiont lives. Below this is the medulla an area of loose hyphae in which nutrients are stored. Sometimes a lower cortex exists, in others the medulla rests on the surface. In crustose and squamulose lichens there is no lower cortex. In foliose lichens there is a lower cortex and in fruticose lichens the lower cortex is replaced by a central one (Ahmadjian and Hale, 1973).

2.1.4.1 Crustose

Crustose lichens are “crust-like” forms. They tightly attach to or embed in substrates, and have no lower cortex. Crustose lichens consist of about 75 percent of all lichens on earth. Crustose lichens attach so tightly to rocks, trees, sidewalks, or soils where they grow up on. They, therefore, cannot be removed without damaging the substrates (Baron, 1999).

Cracked crusts, like the species of Acarospora (or *Pleopsidium*), are separated into segments (areoles) and are called areolate. Crustose lichens that grow up immersing in rocks with only their fruiting bodies above the surface are called endolithic, and those that grow up immersing in plant tissues are called endophloidic or endophloidal. Loose, powdery lichen crusts without layered structure are called leprose (Gilbert, 2000). Crustose lichens are shown in Figure 2.11.



(A) (B)

Figure 2.11 Crustose lichens: (A) *Acarospora* or *Pleopsidium* and (B) *Basidia* sp.

Crustose lichens, as their name implies, form a crust on the surface of substrate where they are growing up. This crust can be quite thick and granular or actually can embed within the substrate. In the latter case, the fruiting bodies still rise on the surface. In many crustose lichens, surface of the thallus break up into cellulars, crazy-paving like pattern. Crustose lichens tend to grow out from their edges and have fruiting bodies in the centres. Crustose lichens are very difficult to be removed from substrates (Figure 2.12).

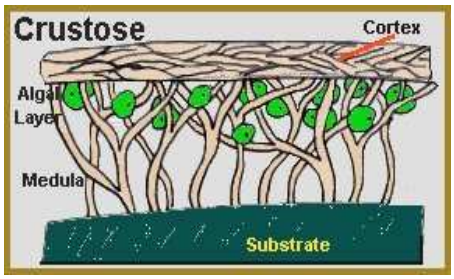


Figure 2.12 Cross section of crustose.

Source: Earth-Life Web Productions, 2008.

2.1.4.2 Foliose

Foliose lichens are “leaf-like” in both appearance and structure. They compose of lobes. They relatively loosely attach, usually by rhizines, to substrates. Their lobes

have upper and lower sides and usually grow more-or-less parallel to the substrates. *Umbilicate* lichens attach to substrates only at central points (Gilbert, 2000). Foliose lichens are shown in Figure 2.13.

(A) (B) (C)

Figure 2.13 Foliose lichens: (A) *Lobaria linita*, (B) *Melanelia* and (C) *Umbilicalia.*

Source: (A) Lichens of North America, 2005.

(B) and (C) United State Forest Service, 2008.

These have an upper and lower cortex. They are generally raised to some extent above the substrate but connected to it by rhizines (specialised root-like hyphae). They are easier to remove from their substrate when collecting because of this (Figure 2.14).

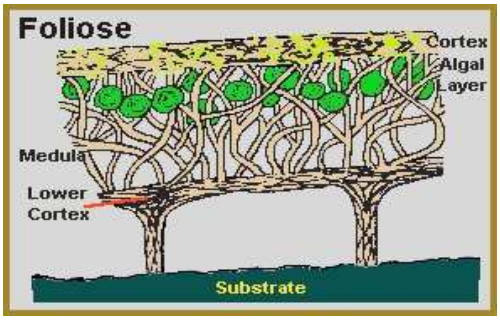


Figure 2.14 Cross section of foliose.

Source: Earth-Life Web Productions, 2008.

2.1.4.3 Fruticose

Fruticose lichens are “hair-like” and the most are three-dimensional. They are usually round in cross section (terete), and most are branched. Their thalli may be upright, shrubby, or of pendulous strands (Nash, 1996). Fruticose lichens are shown in Figure 2.15.

(A) (B) (C)

Figure 2.15 Fruticose lichens: (A) *Ramalina stenospora*, (B) *Usnea longissima* and (C) *Letralia.*

Source: (A);(B) Lichens of North America, 2005 and (C) United State Forest Service, 2008.

Fruticose lichens are shrubby lichens. They attach to substrates by a single point and rise, or more usually, dangle from these substrates (Figure 2.16).

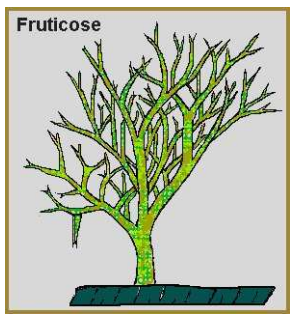


Figure 2.16 Cross section of fruticose.

Source: Earth-Life Web Productions, 2008.

2.1.4.4. Leprose

Loose, powdery lichen crusts without layered structure are called leprose. These lichens have no fruiting bodies, have a complex chemical content and are difficult to classify. Leprose lichens are shown in Figure 2.17.

Figure 2.17 Leprose lichen.

Source: The Council for Scottish Archaeology, 2007.

Leprose lichens are an odd group of lichens which have never been observed to produce fruiting bodies (Figure 2.18). These fungi not only lack an inner cortex, but also lack an outer one, i.e. no cortex, only an algal cell layer and sometimes a weakly defined medulla.

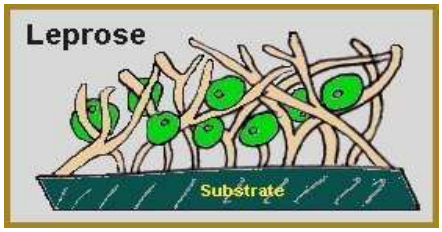


Figure 2.18 Cross section of leprose.

Source: Earth-Life Web Productions, 2008.

2.1.4.5 Squamulose

Squamulose lichens have “scale-like” lobes called squamules that are usually small, overlapping and lacking a lower cortex (Figure 2.19). These are a sub-division of the crustose lichens, peeling up at their outer edges to form “squamules” (e.g. *Cladonia* or *Toninia).*

(A) (B)

Figure 2.19 Squamulose lichens: (A) Cladonia carneola and (B) Cetraria.

Source: (A) Lichens of North America, 2005 and (B) Vegetative Morphology I, 2008**.**

Some lichens have portions of their thallus lifted off the substrate to form “squamules”. They are, otherwise, similar to crustose lichens in term of possessing upper cortexes but no lower cortex (Figure 2.20).

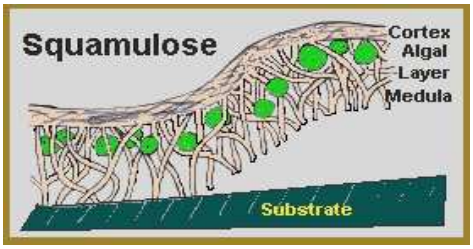


Figure 2.20 Cross section of squamulose.

Source: Earth-Life Web Productions, 2008.

2.1.5 Reproductive structure

Lichen reproduction may occur either by sexual (spore forming bodies) and asexual (vegetative reproductive bodies) reproduction.

2.1.5.1 Asexual reproduction

The fragments of thallus containing both photobiont and the mycobiont separate and form new lichens. This may happen when a piece of the thallus is accidentally broken off, but specialized structures that have evolved in lichens, namely isidia (Figure 2.21) and soredia (Figure 2.22) usually play important role in this type of reproduction (Eichorn et al., 2005).

2.1.5.2 Sexual reproduction

Two main types of ascocarps have generally been distinguished: (1) in an apothecium (pl.apothecia) the hymennium is exposed in an open disc at least at maturity, (2) in a perithecium the hymenium is not exposed during any stage of the ontogeny, but it remains enclosed in round or flask-like structure which opens with a small, darkened pore, called the ostiole (Nash et al., 2002). Character associated with them are very helpful in assigning lichens to a genus (Gilbert, 2000).

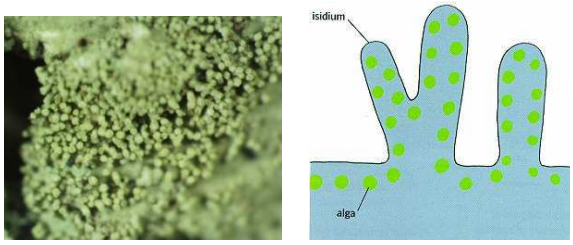
2.1.5.2.1 Perithecia

- Perithecia (Figure 2.23) open with a small tube-like ostiolum and have periphyses and sometimes paraphyses (hamathecium). They are globose to flask-shaped and are more or less immered. The exciple is carbonized in some genera, as in *Verrucaria*, and the ostiolum may be surrounded by shield-like, carbonized layer (Nash, 1996).

2.1.5.2.2 Apothecia

- Apothecia are cup or disk-shaped and two main morphological and developmental types are distinguished. Apothecia with a margin originating from the thallus are lecanorine (Figure 2.24 (A) and 2.25 (A)). In other cases where the margin develops from tissue of the fruitbody, it is called lecideine (Figure 2.24 (B) and 2.25 (B)) (Nash, 1996).

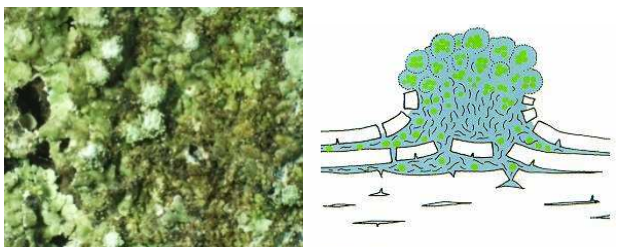
- Lirellate (Figure 2.26) fruiting bodies may be derived from apothecia. They can be simple or branched in outline. Examples of lichens with lirellate ascocarps are represented in the Sonoran Desert region such as the *Graphidaceae* and the genus *Opegrapha*. Also, some species of *Arthonia* have lirellate apothecia (Nash, 1996).



(A) (B)

Figure 2.21 Structure of isidia - darker (than thallus) finger- to knob-like propagules. (A) External structure of isidia and (B) Internal structure of isidia.

Source: Purvis, 2000.

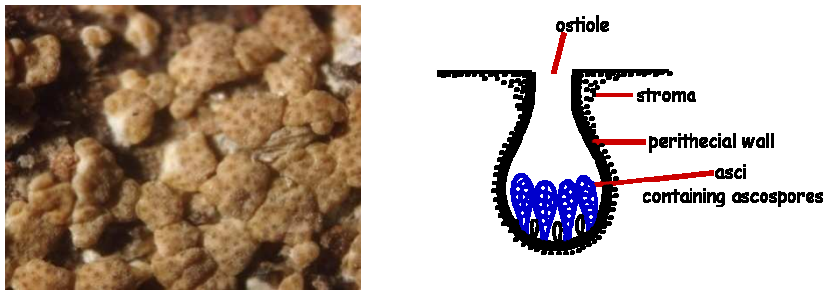


(A) (B)

(C) **(D)** **(E)** **(F)**

Figure 2.22 Structure of soredia paler (than thallus) powdery to granular propagules containing algal and fungal partners. (A) External structure of soredia (B) Internal structure of soredia. Often occurring in specialised bodies called soralia (C) on the lobe margins or ends (D) on the upper surface in cracks (E) or as dots (F).

Source: Alvin and Kershaw, 1966.



(A) (B)

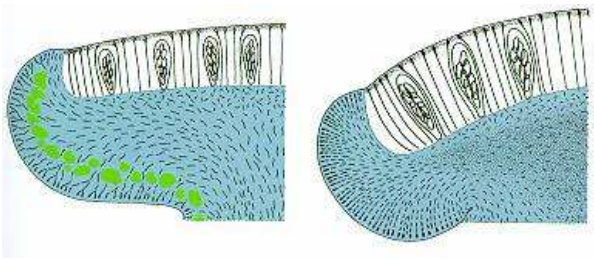
Figure 2.23 Structure and cross section of perithecia; (A) External structure of perithecia and (B) Internal structure of perithecia.

Source: (A) Tree of Life Project, 2004 and (B) British Mycological Society, 2010.

(A) (B)

Figure 2.24 Type of fruiting body: (A) Lecanorine, with a thalline margin which contains algae and is the same colour as the lichen thallus. (B) Lecideine, without a thalline margin but with a “proper” margin which is usually the same colour as the central disc.

Source: British Lichens, 2010.



(A) (B)

Figure 2.25 Cross section of fruting body: (A) lecanorine and (B) lecideine

Source: Purvis, 2000**.**

Figure 2.26 Structure of lirellate.

Source: British Lichens, 2010.

2.1.6 Factors limiting the distribution of lichens

Lichens have specific requirements for their habitats. Although they can occur on a variety of substrates, each substrate must have the individual components in the right amounts that growing lichen needs. These requirements are: water, air, nutrients, light, and substrates.

2.1.6.1 Water

Because lichens do not have a waxy cuticle like plants, they cannot conserve water during drought periods. On the other hand, lichens can absorb everything through their cortex, including water and water vapor. Many lichens are found in foggy areas like the coast, but not farther inland simply because there is not enough water in the air to support them.

When lichens are wet, they "turn on" and start photosynthesizing and growing. When lichens are dry, they "turn off", become brittle and go dormant. This process is known as “poikilohydry”, and other organisms such as mosses and liverworts operate in the same way.

The simplest way to tell if lichen is dormant or growing is by looking at its color. The darker black or brighter green lichen is, chances are that it is photosynthesizing. Of course, if it is wet and pliable, that is a good indication too.

If lichen looks pale and is dry and brittle, then it is dormant and waiting for the next rain or fog event before it starts photosynthesizing (United State Forest Service, 2008).

2.1.6.2 Air

Lichens need clean, fresh air to survive. They absorb everything through their cortex. From beneficial nutrients to harmful toxins, lichens absorb it all. They also

absorb water in the air, which is why so many are found in fog belts along oceans and big lakes.

Look around the big cities of the world. Very few lichens can survive near factories, next to highways, and other sources of pollution. The ones that do survive have a higher tolerance to the pollutants in the air, like heavy metals and acid rain (United State Forest Service, 2008).

2.1.6.3 Nutrients

Just like all living things, lichens need nutrients to survive and grow. The main nutrients include nitrogen, carbon, and oxygen.

Nitrogen is especially important since it is necessary for the production of proteins and organic acids, and not just for lichens, but for life on this planet. Lichens, like plants, have difficulty retrieving nitrogen for their use. That is why cyanobacteria are so useful. Like plants, lichens use cyanobacteria to “fix” nitrogen so it can be used. Fixing nitrogen is the process of changing unusable nitrogen into a usable form of nitrogen. Plants like legumes and rye grass use cyanobacteria to fix nitrogen from the soil. Lichens use cyanobacteria to fix nitrogen from the air (United State Forest Service, 2008).

Mineral in the air such as tiny, dust-like particles of soil are carried by the wind to the surface of lichen. There, dissolved in rainwater, they are taken up by the lichen and used for growth. Small amounts of airbone minerals, the amounts found in clean air, are beneficial to the lichens (Nash et al., 2002).

2.1.6.4 Light

Similar to plants, all lichens photosynthesize. They need light to provide energy to make their own food. More specifically, the algae in the lichen produce carbohydrates and the fungi take those carbohydrates to grow and reproduce.

Different lichens need different amounts of light. That is why you will find lichens on exposed rock and desert soils, as well as on a leafy tree or in its shadow on the mossy ground below. The color of lichen is also dependent on the amount of light it receives. For example, *Lobaria pulmonaria* is normally in a shaded environment, yet when it grows in an exposed environment, the color is different, usually darker, and browner. Different species that adapt to brighter, hotter environments are generally more pigmented. This could be a mechanism of the fungus to protect the algae from getting too much light and burning out (United State Forest Service, 2008). Most lichens achieved their maximum photosynthetic rate at light intensity 200 - 400 μmol m^{-2} s^{-1} (Nash, 1996).

2.1.6.5 Substrates

Every lichen lives on top of something else. The surface of that "something else" is called a substrate. Just about anything that holds still long enough for a lichen to attach to and grow is a suitable substrate. Trees, rocks, soil, houses, tombstones, cars, old farm equipment and more can be substrates. The most common natural substrates are trees, rocks, and soil.

Having lichens growing on your rocks, trees and ground around your property is a good thing. That means the air you breathe in is healthy and clean. Although lichens can cause some damage to buildings and man-made structures, it is a very slow process and does not endanger those substrates.

Different species of lichens prefer, or only grow on different substrates. Thus some species will be found on smooth barked trees, some on rough barked and some on only one species of tree.

Also some lichens grow on basic rocks while others only grow on acidic rocks and some have particular mineral requirements, thus *Acarospora sinopica* only grows on rocks with a high iron content. However where ever they grow lichens grow slowly so whatever it is they are growing on, the "substrate" needs to have been around for a few years. Lichens grow differently at different times in their lives. When young and very small they grow slowly, then once they are reasonably well established they grow much more quickly, obviously when they are dying, for whatever reason they grow more slowly again, or not at all.

Soil is another important substrate for lichens. It provides moisture, nutrients, space to grow, and depending on the location, shelter as well.

One unique habitat lichens can colonize is dune systems. If stable for a long enough time, shifting sands can be "held down" by soil crusts, allowing other communities to establish themselves over the top.

Soil crusts consist of cyanobacteria, mosses, and lichens. Be careful, though. Once these soil crusts are disturbed, they do not come back for many years and the process has to start over again. The shifting sands themselves pose a risk by blowing over the crust communities and covering them up, preventing light from getting to the organisms underneath and killing them (United State Forest Service, 2008).

2.1.6.6 Temperature

Lichens survive in an extremely wide range of temperatures. They have been known to survive temperatures as low as -190°C for several hours and as low as -78°C

for several days. Going to the other extreme they can also survive temperatures as high as 100°C if they are dried out, and even when moist temperatures of 40°C - 50°C do not worry them (United State Forest Service, 2008). Desert lichens can tolerate temperatures as high as 90°C (when dry, wet them and they cook!) and -195°C (in liquid nitrogen). Lichens are a dominant part of Antarctica ecosystems (Guardian and John, 2006). Natural disturbance regimes such as fire, insect outbreaks, fungal infections and wind continuously add dead wood to natural forests. These regimes are heavily controlled in managed forests, where instead dead wood is mainly created through final felling, clearing and thinning (Alexandro et al., 2008).

2.1.7 Ecology

Lichens play an important role colonising new surfaces. Among the metabolites excreted by some lichens are acids. Acids have the capacity to degrade the surfaces on which they are located, thus releasing minerals for uptake by the thallus. Acidic digestion has the effect of causing the slow disintegration of the surface, especially of limestone and other calcareous materials. "Rusting" of surfaces is probably unimportant in terms of the total uptake of minerals by lichens. Most minerals are extracted from solutes in rain or surface water flow (Baron, 1999).

Lichens grow extremely slowly. Any one thallus may be many decades old. The outer edge is probably the only active component of the thallus, unless the lichen has started to overgrow itself. The inner part is commonly inactive. Lichens have the potential to withstand a wide range of environments. Thus they adapt rapidly to local and seasonal changes in temperature and water availability, they are found in bleak artic and desert environments (Baron, 1999).

The thallus has the capacity to cope with the frequent aridity of the environment. Foliose thalli will curl as the thallus dries, and then flatten as it rehydrates. Photosynthesis follows the pattern of wetting and drying. While changes in form enable a return from dehydration, the presence of trehalose, and possibly a range of polyols, is also important. These metabolites enable the cytoplasm to desiccate, while protecting the functionality of the enzymes. Thus, primary production of lichens is highly dependent on the moisture levels of the environment, but they can survive desiccation (Nash, 1996).

The slow rate of growth and the reliance on minerals in rain or high humidity has consequences for survival of lichens in polluted environments. Lichens absorb all minerals in rain, and the presence of pollutants, including sulfur, will result in the decline of the thallus. Because of their sensitivity to pollutants, most lichens are uncommon in areas affected by acid rain and aerial pollutants (Ferry et al., 1993). However, some lichens grow on surfaces containing high concentrations of metals, and must be adapted to those metals: pollution of a single type is likely to select lichens that can tolerate the pollutant. Changing pollution will remove most. In cities, the pollution profile is variable and changing over time. Thus lichens are disappearing from cities (Nash, 1996).

Remnants of lichen communities within cities are associated with protected habitats. Church yards for instance may house a wide diversity of lichens. Lichens are not welcome inhabitants of city surfaces, however. The capacity of lichens to “rust” the surface leads to loss of the structural integrity of stone and concrete. Attempts to remove lichens, and prevent the re-colonisation of grave stones and other surfaces, are rarely successful (Baron, 1999).

2.1.8 Benefits of lichens

Lichens have been used for various purposes since the ancient age. The benefits of lichens could be classified as follows:

2.1.8.1 Food

Lichens consist of no actual carbohydrate or even cellulose. However, they have lichenin at hyphae cell walls of fungus which could be used as food. For example, in the northern hemisphere, *Cetraria islandica* or Iceland moss has been taken as food and as a medicine to better food digestion in a body. Besides, it has been pound to be mixed with flour for making "Sea biscuit" (Thailand Graduate Institute of Science and Technology, 2002).

2.1.8.2 Medicine

The ancient Egyptians used lichens as ingredients in medicines and herbs. In the 15th Century, people used lichens for treatment of *Usnea barbata, Lobaria pulmonaria, Xanthoria parietina, Peltigera canina,* etc. In Thailand, people in local areas have used lichens as herbal medicine, i.e. *Usnea* (Thailand Graduate Institute of Science and Technology, 2002).

A recent study on the *Umbilicaria esculenta* species shows that it produces substances that can inhibit the growth of HIV virus (Brodo et al., 2001).

2.1.8.3 Dyes

Lichens have been used, since the ancient Egypt age, as dyes. The one well-known is *Rocella tinctoria* and others. Lichens in this family give colors called orchill that are in purple tone. France and Holland have produced lichens in term of industry. With their property of being sensitive to the pH, they are therefore used as colors of

the litmus. In medical study and research nowadays, lichens have been used for chromosome dying (Lichen Research Unit and Lichen Herbarium, 1993).

2.1.8.4 Ingredients in perfume

In France, the *Evenia prunestri* lichen or usually called oak moss and *Lobaria pulmonaria* are ingredients in perfume. Apart from making good smell, they keep the smell stay longer (Thailand Graduate Institute of Science and Technology, 2002; Brodo et al., 2001).

2.1.8.5 Indication of stone age and antique

When any material surface is open to the air, lichen will sponge on, grow up and increase its number, the longer, the more number. Lichen usually used in this case is *Rhizocarpon geographicum.* And this method is called Lichenometry (Thailand Graduate Institute of Science and Technology, 2002).

2.1.8.6 Hair cleaning

In the 17th Century, lichen powder, *Ramalina calciaris*, was used to human hair to make it beautiful and clean, and get rid of dandruff. Besides, the *Evernia prunestri*, *Physcia ciliaris* or *Usnea* were used as well. With properties of lichens in smell absorbing and preserving, they have been produced in term of industry in Montpellier in France (Thailand Graduate Institute of Science and Technology, 2002).

2.1.8.7 Tanning and brewing

With property as being astringent of *Certraria islandica* and *Lobaria pulmonaria*, they could be used for leather tanning. Moreover, it is found that *Lobaria pulmonaria* is used instead of hop in beer brewing. In 19th Century, lichen was used in production of popular alcoholic beverage in Sweden. Lichen used in that

case was *Cladonia rangiferina*, etc (Thailand Graduate Institute of Science and Technology, 2002).

2.1.8.8 Poison

Although lichens produce various kinds of organic acids causing a bit irritation after taken, most lichens contain no poison. Two types of lichen found to have poison are *Letharia vulpine* and *Cetraria pinastri* that were used as poison to foxes by the European (Thailand Graduate Institute of Science and Technology, 2002).

2.1.8.9 Dissemblance of some kinds of animal

In virgin forest in tropical area of New Guinea, lichen occurs on backs of a kind of insect. It seems to be a dissemblance (Lichen Research Unit and Lichen Herbarium, 1993).

2.1.8.10 Index of air quality

Air pollution examination by lichens can be proceeded by 3 ways:

1) Survey lichen types in various areas as basic data on lichen types and regularly survey in the future to observe changes of lichen types

2) Examine quantity of accumulated substances in lichens

3) Transplant lichens from the places with good air to the places with pollution and observe changes in physiology

Lichens have some characters appropriate to be indicators of air quality such as no protecting cell-layer. Therefore, they can directly obtain pollutants, slowly grow up and have long life-time. In a year, crustose and foliose groups radially grow up for only 0.5-5.0 mm. As for fruticose group, they lengthwise grow up for 1-2 cm (Hawksworth and Rose, 1976; Nash, 1996). So, various substances outside are

accumulated within thallus of lichens. Moreover, it is realized that lichens are living things with most sensitivity to air pollution (Ferry et al., 1993). Factors influence lichen growth include humidity, light, temperature, receiving of nutrients from outside, season variance and annual season variety (Hale, 1979). Properties as biological indicators of lichens: a) Lichens directly obtain minerals and nutrients from atmosphere. b) Lichens do not have wax and cuticle to protect interior structure as multi-cellular plants do. Pollution from the atmosphere, thus, gets into cells and destroy their necessary process of living, for example photosynthesis and growth. c)In condition with humidity, lichens will be very sensitive to air pollution since they increase working rates of different processes in cells. d) Working rates of different processes in cells operate at low temperature. Lichens are, therefore, possibly disturbed by pollution in cold season (VDI, 1995).

Lichens have long been considered one of the most valuable air pollution biomonitors. They have been widely used to assess trace element atmospheric contaminants. The advantages of using lichens over conventional air sampling techniques are that lichens are perennial and can be found in most terrestrial habitats. They also present easy sampling, low cost and the possibility of monitoring wide areas. Besides that lichens do not have root systems and thus they are able to uptake elements and accumulate them in their tissues. The high degree of trace element accumulation enables the determination of several elements with high precision and accuracy. Consequently, several papers have been published on monitoring trace elements using lichens in different geographic areas (Loppi et al., 2002 and Garty et al., 2003). Lichens vary in their sensitivity to SO_2 pollution; in general, crustose and squamulose lichens are least sensitive, foliose lichens are more sensitive, and

fruticose lichens are most sensitive (The Georgia Conservancy, 2001).

Richardson (1992) stated that lichens can also indicate past pollution by faded or abnormal colouring and patchiness in the centre of the thallus (Table 2.1).

Table 2.1 Some lichens indicative of different levels of pollution.

Highly polluted	Moderately polluted	Slightly polluted	No pollution
Hypogymnia physodes	*Evernia prunastri*	*Parmelia caperata*	*Usnea subfloriden*
Xanthoria parietina	*Foraminella ambigua*	*Graphis scripta*	*Parmelia perlata*
Lecanora dispersa	*Lecanora chlarotera*	*Bryoria fucescens*	*Degelia plumbea*
Diploicia canescens	*Ramalina farinacea*	*Physconia distorta*	*Ramalina fraxinea*
Lepraria incana	*Lecidella elaeochroma*	*Opegrapha varia*	*Teleoschistes flavicans*

Source: Richardson (1992).

Lichens show remarkable differences with respect to their sensitivity to heavy metals. Some species are highly tolerant to high concentrations of transition metals including Cu, Fe and Mn. The Cu- and Fe-tolerant lichens include hyperaccumulors inhabiting metal-rich rock and slag . Other lichen species respond with reduced net photosynthesis or nitrogen fixation, chlorophyll degradation, and damage of thylakoids and plasmalemmas to relatively small amounts of heavy metals (Garty et al., 2003). Lichens are among the most frequently used biomonitors of atmospheric pollution. They have even been proved useful as indicators of human health (Nimis, 2002). Classic lichen-based monitoring has generated pollution maps showing areas largely devoid of epiphytic lichens, the so-called ‘‘lichen deserts’’, in and around cities, in Great Britain for example Germany the Netherlands and in many other countries (Hawksworth and Rose, 1976).

2.2 Studies on lichens in Thailand and other countries

It has been more than 200 years that scientists have studied on relationship of lichen growth and pollutions and on capabilities of lichens used as indicating biological indices in different countries worldwide. The following evidences appeared in primary age. In 1921, E. Darwin noted about incapability of lichens in growing up near the areas around metal melting machines in Anglesey North Wales Island. Later, in 1970, D. Tuner and Borrer found that lichens were sensitive and related to air quality. As for the restudy by W. Borer in 1812, it was observed that lichens were more difficultly found in areas where air was unclean (Hawksworth and Rosse, 1976).

Hawkworth and Rose (1970) performed the mapping studies. The qualitative scale of relating SO_2 concentrations ($\mu g/m^3$) for estimation of air pollution in England and Wales with epiphytic lichens was provided. Ten zones were devised, with zone 1 includes species indicating SO_2 levels more than 170 $\mu g/m^3$ whereas zone 10 representing purity atmosphere. The selected indicator species that indicate the polluted zone are *Pleurococcus viridis* s.1 and *Lecanora conizaeoides*. While the present of *Lobraria* sp., *Sticta* sp., *Pannaria* sp. and *Usnea* sp. indicate the clean air zones.

Hawkworth and Rose (1976) studied on basis of living patterns, structures and kinds of lichens on adhering substrates used as representatives of the studied areas in order to make air quality maps by using lichens. Later, used *Lecanora conizaeoides* lichen as an indicator of pollutant accumulation in industrial factory areas in Frederiksvaerk and Denmark. It was found that results of heavy metal concentrations in *L. connizaeoides* were variant according to spaces from pollution resources i.e.

more heavy metal concentrations in *L. connizaeoides* were found in the areas near industrial factories comparing to the areas far away.

Saipankaew (1994) carried out the first air quality study in Chiang Mai city using lichens as bioindicators. The air pollution map was developed based on the VDI method. The results are shown in a map indicating zones with different distributions of lichens. High lichen frequencies indicate better air quality while lower frequencies indicate worse air quality. Four air quality classes are distinguished. The air quality indices (AQI) vary from 2.3 to 31.5. The tree zones of air pollution are determined by the drawing of isolines, with characteristic of very high pollution, very high to high pollution and high pollution, respectively. The air quality of Chiang Mai city is assessed again in 2001 by Subri (2002). The same method is used and the results from the lichen mapping are compared. The author found that in 2001 the border of a high air pollution zone extends out the suburban area and is larger than in 1994. The results indicate that air pollution in Chiang Mai city has increased since 1994.

Showman (1997) used lichen to study air pollution in two forests,Fernwood and Yellow Creek at Ohio State, which served as recording data for future comparison. The reduction in lichen communities due to the impact of air pollution was observed.

Thrower (1980) used the sensitive and tolerance species to assess air pollution in Hong Kong. The results showed that lichens are absent in the worst pollution zone. This zone includes the areas where power station exists and where there is dense industrial development. The estimated concentration of SO_2 in the air is over 150 $\mu g/m^3$. The clean air zones are the areas with the present of *Parmotrema tinctorum* and *Usnea* sp.

Rossbach et al. (1999) lichens were used to follow up fine particles and found that lichens accumulated heavy metal in relation to dust quantity found in the air i.e. lichens in areas with much dust accumulated much heavy metal. Besides, little lichens were found in those areas.

Vokou et al. (1999) surveyed epiphytic lichen vegetation of 20 sites around Thessaloniki (Macedonia, Northern Greece) to monitor any changes in lichen communities and consequently, in air quality. They found impoverishment of lichen community, which was concluded to be the result of air pollution, chiefly SO_2 and NO_2.

Osathanon (2001) studied on vertical lichen distribution under the dense and clear canopies of *Cratoxylum* sp. and *Schima wallichii* in the second batch forest of the Khao Yai National Park. It was found that, areas under clear canopy, more foliose was found than crustose at every high level, except for areas under dense canopies. Both crustose and foliose were found at every high level. The lichens which were found at every light intensity were *Dirinaria* sp., *Graphis* sp., *Graphis* sp., *Parmptrema* sp. and *Pyxine* sp. and in areas under dense canopy was *Coccocarpia* sp.

van Dobben et al. (2001) demonstrated the relation between the abundance of epiphytic lichen species and pollutant concentrations in the Netherlands. They reported that nearly all species decrease with increasing concentration of atmospheric SO_2 and NO_2 which appeared to be the most important factors determining lichen diversity.

Sommerfeldt and John (2001) investigated air pollution and the occurrence of lichens in the city of Izmir, Turkey using the VDI method. The lichen air quality map showed that five air quality classes were determined and a predominant part of the

city area is heavily polluted. The best air quality values were determined in the southern and western parts of the city zone. They suggested that a range of 7.3 for the width of the air quality classes provides a method that is suitable for similar studies in Turkey.

Asta et al. (2002) The method in the guideline is largely based on the German VDI lichen mapping guideline and the Italian guideline. The main modifications concern several elements of subjectivity in the sampling process, which were present both in the VDI and in the Italian guidelines. The other modifications, which are clearly difference from the VDI method, include the positioning and the size of the sampling grid on the tree trunks. In this method, the sampling grid of 10×50 cm quadrate with 5 sampling units of 10×10 cm is attached to the tree trunk corresponding with the aspects (north, east, south and west), instead of using a 20×50 cm quadrate with 10 sampling units of 10×10 cm and attach to the one aspect of tree trunk where the lichen cover is highest, as describe in the VDI method. However, the data analysis for both VDI and standardized method is based on the sum of frequency of lichen species on a defined portion of tree bark. For this standardized method, the frequency of lichen species is used to calculate the lichen diversity values (LDVs) and the LDVs map can be constructed in the similar way of the VDI method. Moreover, the LDV results can be used to assess magnitude of alteration as the deviation from natural conditions when the natural area is available. Therefore, this procedure provides a rapid, low cost method to define zones of different environmental quality. It can be used to detect hot spots of environmental stress over a large-scale area as well as applied in the vicinity of an emission source to prove the existence of air pollution to identify its impact.

Loppi et al. (2002) used biodiversity of epiphytic lichens as lichens as indicators of air pollution in the town of Siena in central Italy. Most of the study area was in the categories semi-matural or natural, according to a calibrated scale of environmental alteration. Compared with the situation in 1995, the results showed an improvement in air quality over time.

Subsri (2002) conducted a continuum study in Chiang Mai city and outside areas. In 2001, it was found that pollution in Chiang Mai decreased. By evaluation of air quality from quantity of chlorophyll and pheophytin, it was presented that lichens in outdoor areas had more chlorophyll than the ones in indoor areas. On the other hand, the lichens in indoor areas had higher pheophytin than the ones in outdoor areas.

Thanwarat (2002) worked on distribution and frequency of lichen *Hyperphycia adglutinata* Flörke and *Lecanora* cf. *leprosa* Fée on mango trees in the city areas of Chiangmai Province. It was found that *H. adglutinata* generally distributed and had high frequency in heart of city areas with rather high pollution. As for *L.* cf. *leprosa,* it was less found and with low frequency in the heart of city areas but found with high frequency in some areas outside heart of the city. Thus, *L.*cf. *leprosa* tended to be used as good indicators of air quality and *H. adglutinata* tended to be used as minor indicators of air quality. Besides, Sudarat (2002) made a similar study as the one of Thanwarat but studied on the *Pyxine cocoes* Swartz and *Dirinaria picta* Swartz in areas of Chiangmai city. Findings showed that *P. cocoes* distributed around and had higher frequency than *D. picta. P. cocoes* tended to be used as good indicators of air pollution and *D. picta* could be used as indicators which were sensitive to air pollution.

Boonpragob et al. (2003) suggested the use of lichens as indicators of air quality. Biological variety of lichens increased according to distances from Bangkok city to the Khao Yai National Park. The survey was done on trees with lichens on them, 20 trees per surveyed area in city, outside city, rural areas and remote areas from city (Khao Yai National Park). These areas were 10, 50, 100 and 200 km. away from the heart of city. The 7, 8, 20 and 55 species of lichen were found in each area respectively. There were 7 species able to grow up in city areas i.e. *Dirinaria picta*, *Buellia punctata*, *Cryptothecia* sp., *Laurera benguelensis*, *Lacanara pallida*, *Trypethelium tropicum* and *Graphis librata*. In areas of outside city, five same species found in city areas were found and the *Eschatogonia* sp., *Laurera* and *Graphis intricate* were additionally found. In rural areas, 20 species were found and 55 species were found in areas of Khao Yai National Park. All together, there were 520 species found in total areas of Khao Yai National Park. The lichens found in every area were *D. picta, L. benguelensis* and *T. topicum.* As for the *B. punctata,* it could only be found in city areas while the *Eschatogonia* sp. was not found in city areas but found in other three surveyed areas. It, therefore, could be used as an good indicator of air quality.

Polyiam and Boonpragob (2005) studied on comparison of lichens on *Dipterocarpus costatus* with rough shell and banyan trees with smooth shell at different levels from ground layer. The study was conducted at canopy of *Dipterocarpus costatus* at 30-40 metre from ground level. The main factors of lichen distribution were light, humidity, temperature and wind. It was found also that canopy had appropriate conditions for growth of most lichens and influenced the prior mentioned factors under the canopy.

Pomphueak (2005) studied on using lichens in evaluating of air quality in city areas and areas around Lampang city in Lampang Province by identifying lichen diversity values (LDVs). It was a study of lichens on 234 mango trees. Study area was divided into 39 units with size of 1×1 square kilometre. Twenty one species were found. Then, air quality was classified into eight air levels. Passive collection of air was conducted to measure concentration of NO_2 and SO_2. The findings concluded that NO_2 influenced lichen diversity in the studied areas.

Aptroot and Herk (2006) studied on effects of global warming on lichens by considering response of lichens to weather changes in Western Europe. It was found that some kinds of lichens increased and some kinds decreased in term of quantity. In the same year, Giordani (2006) made a study on variety of lichens as indicator of the air pollution in Genova, Italy, and found that variety of lichens depended on various factors such as rainfall class and temperature. Different and various lichens could be found in rural and forest areas. In rural areas, the main effect was from SO_2. Interestingly, forest areas with deforestation and wildfire demonstrated strong effect to lichens. These areas should be mostly improved.

Frati et al. (2006) studied lichens as indicators of ammonia and nitrogen around pig farms in Italy and found that appropriate lichen to be an index indicating ammonia pollution was *Physconia grisea.* As for the *Xanthoria parietina* and *Flavopararmelia caperata,* they accumulated more nitrogen when ammonia concentration was higher.

Thanomsap (2006) studied on distribution and frequency of *Pyxine cocoes* Swartz and *Lecanora* cf. *leposa* Fee on mango trees in municipality areas of Lamphoon Province. The studied areas were 500×500 square metre, 30 squares , 6

trees in a square. All together were 180 trees. Findings presented that the *P. cocoes* distributes overall studied areas, both in and outside the city and high frequency was found in city areas. It was, therefore, concluded that the *P. cocoes* and *L.* cf. *leprosa* tended to be indicators of air quality by *L.* cf. *leprosa* indicated better quality of the air.

Larsen et al. (2007) made a study on lichens and bryophyte on oak trees in London, England, in terms of their distribution and frequency that also related to air pollution and bark's acidity. The study findings concluded that traffic pollution and the pH of barks influenced distribution of lichens and bryophyte.

2.3 Measuring air quality with passive sampling method in Nakhon Ratchasima municipality

The passive diffusion sampler was firstly applied by Palmes et al. in 1976 in order to measure quantity of NO_2 in the air in buildings. At that time, sampler tubes contained filter paper dipped into an adsorbent inside. It was found that number of adsorbent needed to be proportional to gas concentration. Gas molecules diffused to adsorbent, then diffusion rate would continuously happen (Perkauskas and Mikelinskiene, 1998).

Passive sampling is defined as any sampling technique based on free flow of analyze molecules from the sampled medium to a collecting medium, as a result of a difference in chemical potentials of the analyze between the two media (Gorecki and Namiesnik, 2002). It can be used for the analyze determination of both inorganic and organic compound in a variety of matrices, including air, water and soil.

The passive sampling has been gaining increased attention since it has the advantages of being a cheap, lightweight, robust and simple technique, which is easy to operate and handle. It does not require any power source, calibration or maintenance. It can be fixed to any objects and on persons, depending on the objective of the measurement. Passive samplers remain stable over several months after sampling and can be conveniently transported before and after exposure. Also all sampler parts are reusable (Vershney and Singh, 2003). Hence, it is ideally suited for developing a wide spatial network for atmospheric pollutant monitoring. This method can be used in a large-scale project for the measurement of atmospheric pollutants at an extremely low cost (Krochmal and Kalina, 1997). Carmichael et al., 2003 used the passive sampler to measure level of gaseous SO_2, NH_3 and O_3 at 50 stations in Asia, Africa, South America and Europe. Stevenson et al., 2001 established and NO_2 coordinated monitoring network, involving more than 1,000 monitoring sites in urban areas throughout the UK, using diffusion tube samplers.

The passive sampler is based on the principle of air diffusion. The atmospheric NO_2 diffuses into the tube where it gets absorbed on the absorber triethanolamine (TEA) coated. TEA absorbs NO_2 from the air in the form of nitrite ion. The reaction product of TEA and NO_2 has been studied and is still a subject of controversy. Glasius et al., 1999 proposed the reaction product as triethanolamine N-oxide on the basis of the following reaction;

$$2NO_2 + N(CH_2CH_2OH)_3 + 2OH^- \longrightarrow 2NO_2^- + {}^-O - N^+(CH_2CH_2OH)_3 + HO_2 \quad (2.1)$$

This reaction is in accordance with the observed 1:1 conversion of NO_2 to nitrite ions. Hydroxyl ions in the reaction probably stem from dissociation of TEA in water, and the reaction will therefore not take place in completely dry air.

The principle of diffusion in passive sampling refer to Flick's First Law as describe by Gair et al., 1991. The unidirectional flow of gas_1 through gas_2 is give as the following;

$$F = -D_{12}dc_1/dz \qquad (2.2)$$

Where

F_1 the flux of gas (mol cm^{-2} s^{-1})

D_{12} the diffusion coefficient of gas_1 in gas_2 (cm^{-2} s^{-1})

c_1 the concentration of gas_1 in gas_2 (mol cm^{-3})

z the length of diffusion (cm)

The quantity of gas transferred (Q_1 mol) on t seconds for a cylinder of radius *r* is given by the following equations;

$$Q_1 = F(\pi r^2)tmol \qquad (2.3)$$

Therefore

$$Q_1 = -D_{12}(c_1-c_0)(\pi r^2)t/Zmol \qquad (2.4)$$

Where

c_0 is the concentration experienced at the absorber surface, therefore $(c_1- c_0)/z$ is the concentration gradient along the cylinder length (z). If an efficient absorber is used to remove gas_1, then c_0 efficiently becomes zero.

Then the concentration of NO_2 and SO_2 in $\mu g\ m^{-3}$ are calculated by applying the equation (Plaisance et al., 2002);

$$C = \frac{Q \times z}{\pi r^2 \times t \times D} \quad (2.5)$$

Where

C the concentration measured by passive sampling tube ($\mu g\ m^{-3}$)

Q the quantity of absorption products present in the sampler (μg)

r the radius of diffusion tube (m)

t the sampling time (s)

z the diffusion length (m)

D the diffusion coefficient (m^2s^{-1}), $0.154\times10^{-4}\ m^2s^{-1}$ for NO_2 and $0.127\times10^{-4}\ m^2s^{-1}$ for SO_2

The corresponding quantities of NO_2 and SO_2 are calculated by the following equations;

$$QNO_2 = mNO_2^- \quad (2.6)$$

$$QSO_2 = \frac{64}{96} \times mSO_4^{2-} \quad (2.7)$$

Krochmal and Kalina (1997) developed time range of passive sample collecting to 24 hours and one month and found that the suppressed and non supressed IC provided low detection limit. One-month sample collecting provided lower detection limit (lower determination limit) of both NO_2 and SO_2 i.e. 0.5 and 0.7 $\mu g/m^3$, respectively. As for the 24 hours - sample collecting, the higher detection limit was obtained. Effects influenced by wind, rain, and light were reduced by

putting the samplers in windbreaks before having them hung. This technique had accuracy and low detection limit. Thus, it was appropriate to both measurements in urban and rural areas.

Heal and Cape (1997) measured NO_2 concentrations in urban and rural ambient air by using passive diffusion samplers with TEA as absorbent. The interferences from peroxyacetyl nitrate (PAN) and others were observed to be low for British conditions. The systematic error of within-tube chemistry was also known to be responsible for overestimation of NO_2 by the diffusion sampler, which previously was thought to be due to wind effects. They found that passive sampling is more efficient in rural ambient air compared to urban ambient air. The combined error due to the effect of wind on path length and chemical effect with cities caused up to 70% overestimation of NO_2.

Ferm and Svanberg (1998) applied the passive sampling technique in measurement of SO_2 and NO_2 quantity in urban areas in Sweden. The measurement of exterior buildings found that there were some effects by the wind. In order to reduce such effects, the longer samplers were used which later on were developed to be shorter and wider. The results of that SO_2 and NO_2 measurement were 0.1-200 $\mu g/m^3$ and 0.1-400 $\mu g/m^3$, respectively. The results, in comparison with the ones of active sampling technique, indicated that they were consistent. This technique, therefore, could be applied in measurement in both urban and controlled areas.

Perkauskas and Mikelinskiene (1998) used passive diffusion samplers for the evaluation of SO_2 and NO_2 concentration levels in the Lithuanian capital Vilnius. The results show that the SO_2 concentrations levels depend mainly on heating and exhibit average values of 7-13 $\mu g/m^3$ for warm seasons and 17-23 $\mu g/m^3$ for cold seasons.

The NO_2 average rates depend strongly on traffic (sampling place) and are highest in crossroads (52-82 µg/m^3) and lowest at the background-suburban level (9-16 µg/m^3).

Kaspwe-Giebl and Puxbaum (1999) used polyethylene diffusion tubes and TEA as an absorbent for the determination of ambient air concentrations of sulfur dioxide and nitrogen dioxide. They found the NO_2 concentrations of were 50% lower than the results given by nearly chemiluminescence monitor. The determination of SO_2 was strongly biased by the collection of particulate sulfate at the entrance part of the tube and along the tube wall.

Cruz et al. (2004) constructed a passive sampler, which was designed to minimize particle interference and turbulent diffusion. They tested the SO_2 diffusive passive sampler using Na_2CO_3 filter impregnation under ambient conditions, during periods of exposure ranging from 1-4 weeks. Its precision varied between 2.4% and 10% for a SO_2 concentration rang of 1.9-13 mg/m^3, when applied to two different types of tropical environments. The field measurement results showed good agreement between passive and active methods during the same exposure period. The authors concluded that, considering the growing demands for environmental monitoring, passive samplers represent a cost-effective tool for SO_2 monitoring.

Shakya (2004) applied the passive sampling method to measure NO_2 and SO_2 concentration in the air in Chiangmai province by using the whatman 40 filter papers dipped into triethanolamine and put them in Polystyrene and Polyethylene tubes to entrap the two mentioned gases. The samplers were contained in the Polyethylene box to be protected from disturbance by climate factors. The SO_2 quantity was calculated by the ion chromatrography in the form of sulfate ion. Results of this passive sampling method indicated that applying of the stated samplers provided good

measurement results both for NO_2 and SO_2. Accuracy of this passive sampling method was about 18% and 16% for NO_2 and SO_2, respectively.

CHAPTER III

MATERIALS AND METHODS

3.1 Materials

3.1.1 Apparatus

3.1.1.1 Grid frames size of 20×50 cm^2

3.1.1.2 Lichen identification keys

3.1.1.3 Recording form

3.1.1.4 Pencil, Waterproof pen

3.1.1.5 Pocketknife

3.1.1.6 Compass

3.1.1.7 Hand lenses

3.1.1.8 Surveying quadrat

3.1.1.9 Measuring tape

3.1.1.10 Parafilm

3.1.1.11 Polyethylene diffusion tube

3.1.1.12 Whatman no.40 filter paper

3.1.1.13 Protective shields, Wires

3.1.1.14 Micropipettes, Pipettes, Forceps

3.1.1.15 Test tubes, Volumetric flasks

3.1.1.16 Cellulose acetate membrane filter 0.45 µm

3.1.1.17 Paper bag, Plastic zip lock bag

3.1.1.18 Map of Nakhon Ratchasima municipality

3.1.1.19 Map of the Sakaerat Environmental Research Station

3.1.2 Chemicals

3.1.2.1 Triethanolamine (TEA)

3.1.2.2 Sodium nitrite ($NaNO_2$)

3.1.2.3 Sulfuric acid (H_2SO_2)

3.1.2.4 Sodium carbonate (Na_2CO_3)

3.1.2.5 Sodium bicarbonate ($NaHCO_3$)

3.1.2.6 Sulfate stock standard (1000 µg/ml)

3.1.2.7 Deionised water, Milli-Q water

3.1.3 Instruments

3.1.3.1 Compound microscope

3.1.3.2 Stereo microscope

3.1.3.3 Ion chromatography

3.1.3.4 pH meter

3.1.3.5 Ultrasonic cleaner

3.1.3.6 Analytical balance

3.1.3.7 Oven

3.1.3.8 Camera

3.2 Description of study area

3.2.1 Research sites

In this study, research sites are divided into 2 parts, i.e. Nakhon Ratchasima municipality area, deciduous dipterocarp forest and dry evergreen forest in Sakaerat Environmental Research station of Nakhon Ratchasima province.

3.2.1.2 In municipality area of Nakhon Ratchasima

A. Conditions and geography

According to the National Economic and Social Development Plan, Nakhon Ratchasima municipality is a central city of business progress in the northeast region of Thailand. It situates between latitude 14-16°North and longtitude 101-103°East at around 150-300 metres above sea level. It is about 259 km east of Bangkok by car and about 264 km by train. It takes about 30 minutes by plane from Bangkok. City area mainly slopes to the east. The northern part of city is low land and the southwest part of town is high land.

B. Size of area

The study area, which located in Nakhon Ratchasima municipality (Figure 3.1) covered about 37.50 km^2 or comparable to 2,343 rais and 2 ngarn in Thai measure scale or 4.96% of total area of muang district (which covers around 755.596 km^2) or around 0.18% of total area of Nakhon Ratchasima province (which covers around 20,493.9 km^2). The land use within the study area is shown in Figure 3.2.

C. Nakhon Ratchasima municipality borders are described as follow

North is adjacent to Nongjabok, Muenwai, Bankhor sub-districts, Muang Nakhon Ratchasima district

South is adjacent to Nongpailom sub-district, Muang Nakhon Ratchasima district

East is adjacent to Huathalae sub-district, Muang Nakhon Ratchasima district

West is adjacent to Banmai sub-district, Muang Nakhon Ratchasima district

D. Population

There are 145,793 people who inhabit the Nakhon Ratchasima municipality, 77,240 are females and 68,553 are male. In the area, there are 60,105 family

households, according to the house registrations, and there are 33,720 families. An average density is 4,431 persons per square kilometer.

E. Transportation

Since Nakhon Ratchasima municipality is a community situated in a province which is a gate way to the northeast region, it is convenient and fast for traveling and transportation to many provinces in the north, central and east regions (the area of the Eastern Sea Board Project- ESB) including other provinces in the northeast region. Roads in Nakhon Ratchasima municipality are classified into main roads and local roads. The main roads are also classified into arterial roads and spreading roads. Format of road network is divided into 2 parts:

Part 1 is road network, neatly designed in table format, covers the ancient city area surrounded by moats. Most of the roads are in good conditions.

Part 2 is the road network the covers the ancient city area. Roads were constructed for city enlargement to the west of the city which lacked good planning. These roads, therefore, were not well-arranged. This road network connects to the Mittapab highway, Suranarai road, Mittapab-Chokchai highway, including other roads, alleys from town e.g. Mukkamontri, Atsadang, Ratchanikul, Kamhaeng songkram, Sappasit, Changpheuk, Ratchadamnern, Benjarong, Prajak and Kudanroads,etc.

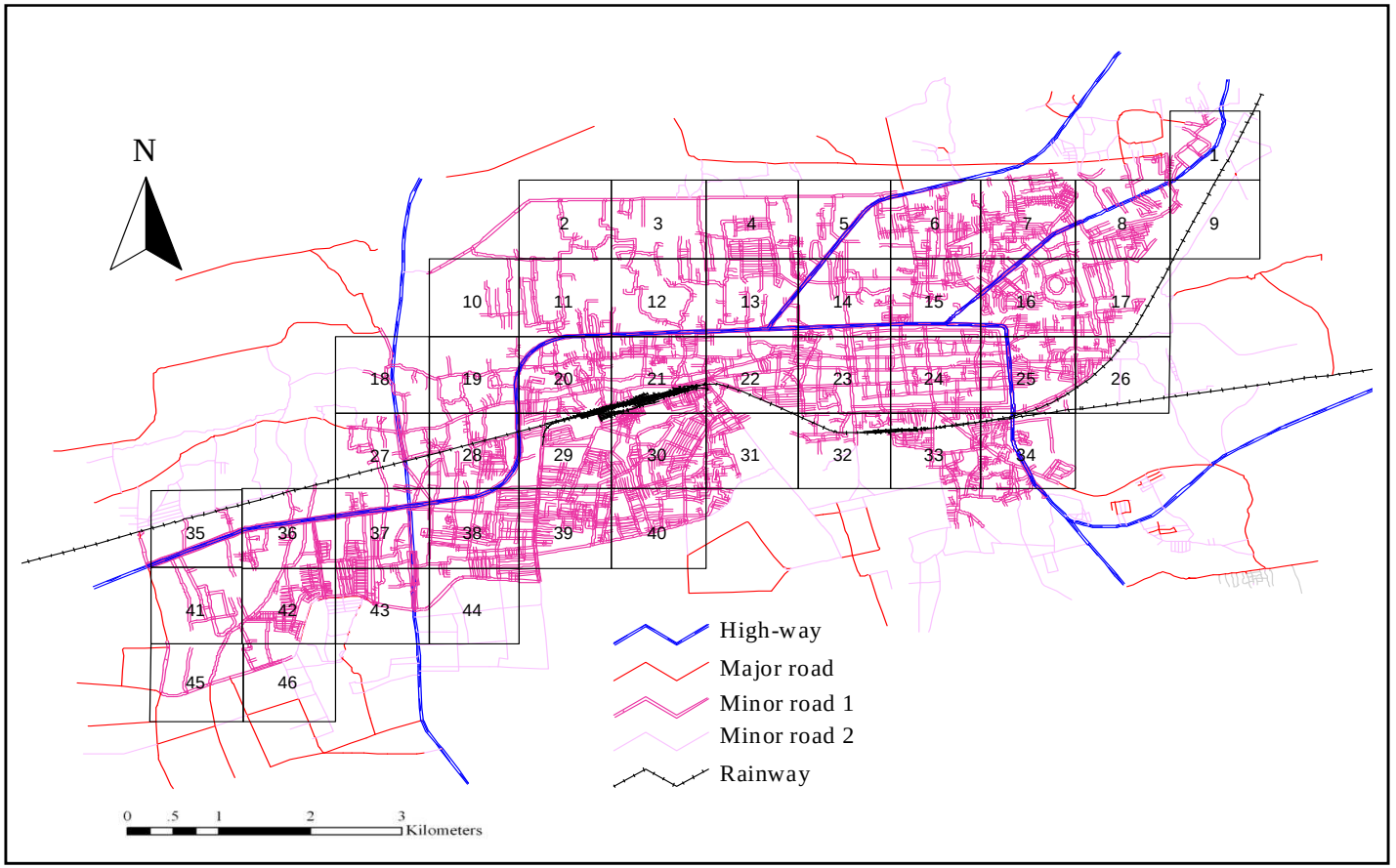


Figure 3.1 Area of the Nakhon Ratchasima municipality in 2009.

Source: Royal Thai Survey Department, 2009.

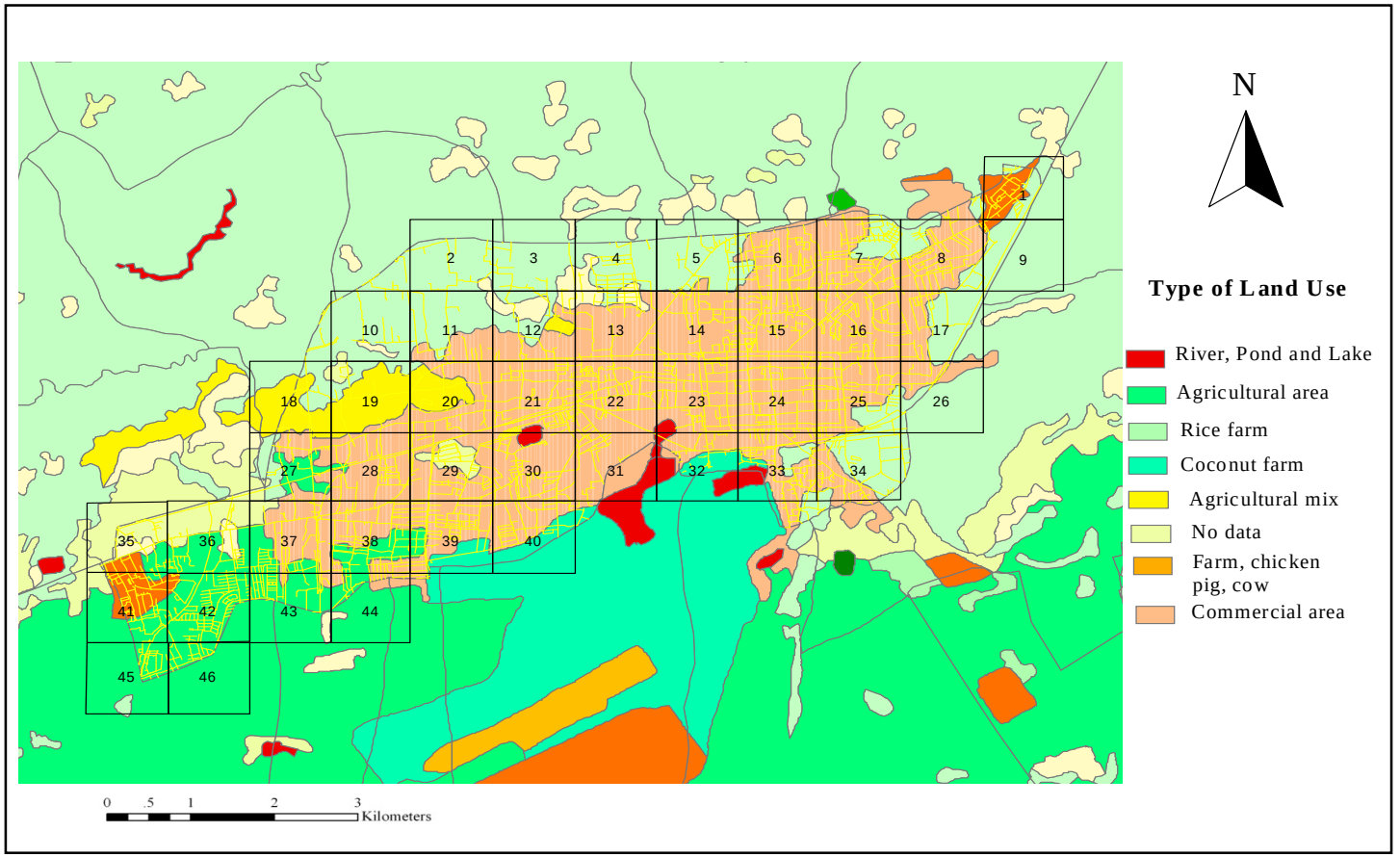


Figure 3.2 Land use type within Nakhon Ratchasima municipality area in 2009

Source: Royal Thai Survey Department, 2009.

The annual temperature, rainfall and wind speed average of Nakhon Ratchasima municipality from in 2009 are shown in Figure 3.3, Figure 3.4 and Figure 3.5 respectively. The annual prevailing wind speed average direction in year 2009 is shown in Figure 3.6.

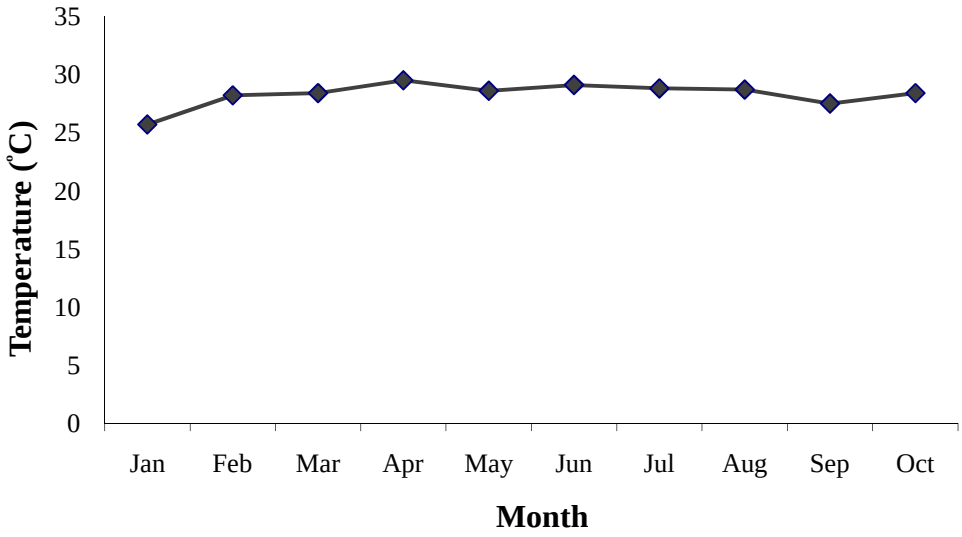


Figure 3.3 The annual temperature of Nakhon Ratchasima municipality in 2009.

Source: Nakhon Ratchasima municipality station, 2009.

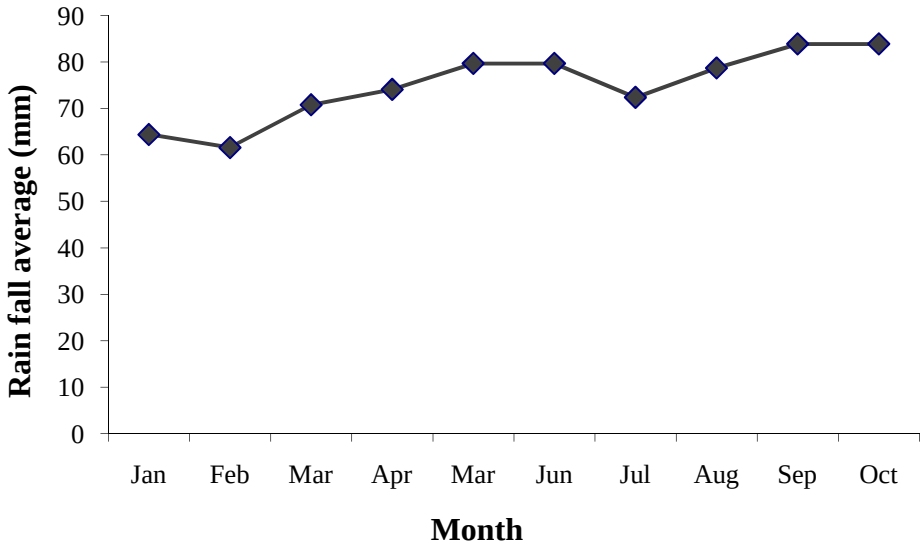


Figure 3.4 The annual rainfall average of Nakhon Ratchasima municipality.

Source: Nakhon Ratchasima municipality station, 2009.

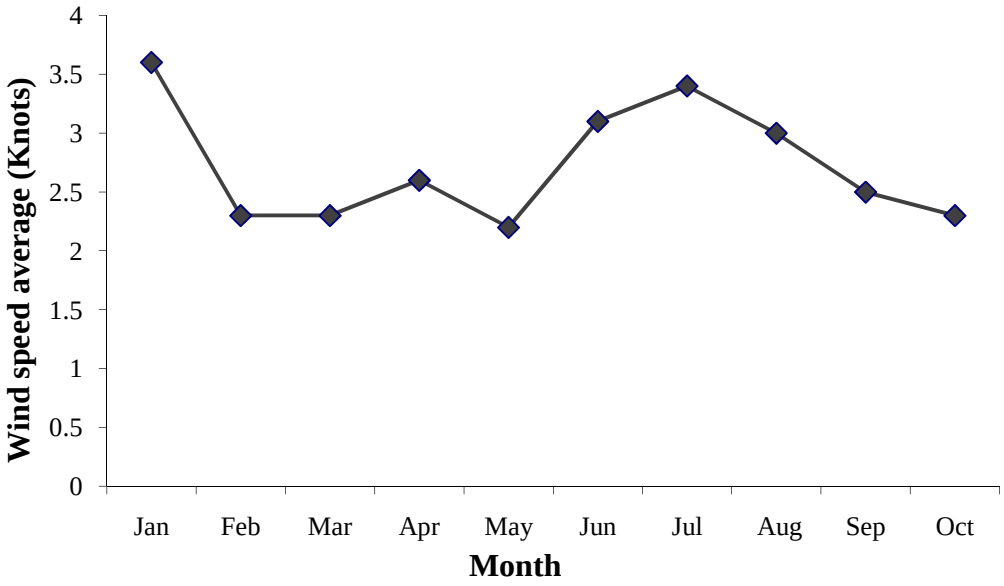


Figure 3.5 The annual wind speed average of Nakhon Ratchasima municipality.

Source: Nakhon Ratchasima municipality station, 2009.

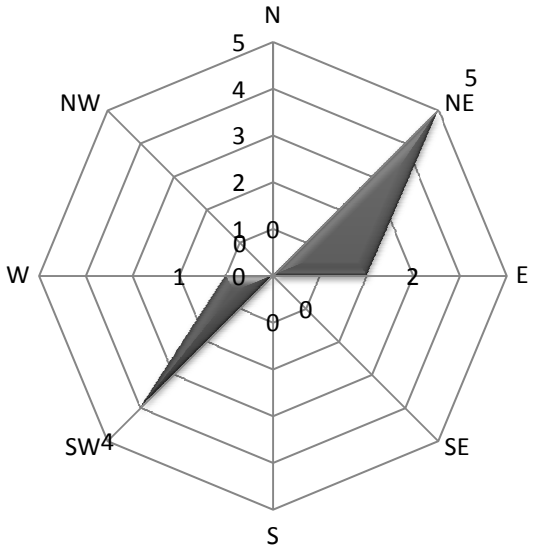


Figure 3.6 Annual prevailing wind distributions in study area.

Source: Nakhon Ratchasima municipality station, 2009.

3.2.1.3 Sakaerat Environmental Research Station

A. Size of area and geography

The Sakaerat Environmental Research station (SERS) covers the area about 48,750 rais or 80 km^2 which is the south border of the Korat plateau, at longitude 101°51 East and latitude 14°30 North**.** The station grounds rise from 250 m above sea-level to 762 metres at the top of its highest mountain, Khao Phiat. Mountains dominate the south-west region, with the slopes easing to smaller hills in the north-east. There are high mountains in the south of the Station area i.e. Kliad (762 metres) Khiew (729 metres), and Soong (725 metres) mountains. Bedrock is exposed only along streams and at the escarpments bounding SERS on the south-east, elsewhere there is heavy soil and vegetation cover. The entire area appears to be underlain with sandstone. No mineral deposits of economic importance have been found within the station boundaries, except for laterite soils which have been used for road construction.

In the newly specified areas of the Sakaerat Biosphere Reserve that covers 771 km^2, there are mountains in the north, including the area of the Sakaerat Environmental Research station. The mountains lie along from the northwest to the southeast. The highest mountain is the So Mountain, about 807 metres from the mean sea level, which is in the west of the Lam praplerng Dam. As for in the southwest of the Sakaerat Biosphere Reserve, it is a plain area between mountains or the Wangnamkhiew Shallow Lake and is 300 metres, in average, high from mean sea level.

B. Location and border

Sakaerat Environmental Research Station located in Phooluang Sub-district, Pakthongchai District, and in Wangnamkhiew and Udomsap Sub-districts, Wangnamkhiew District, Nakhon Ratchasima Province. It is about 60 km from Nakhon Ratchasima downtown in the southwest on the highway no.304 (Chacherngsao-Nakhon Ratchasima). It is about 300 km. from Bangkok.

Sakaerat Environmental Research station covers the area of 78.06 km^2 or about 48,800 rais. The boundary line in the east border along the highway no. 304 is 10 km long (Figure 3.7).

In 1976, the UNESCO, under the project of Man and Biosphere-MAB guaranteed Sakaerat Environmental Research station as one of the world biosphere reserves which covers 48,800 rais. However, in 2000, the UNESCO/MAB announced a policy of increased of biosphere reserves and enlargement of the existing biosphere reserves areas. Thus, the area of the Sakerat Biosphere Reserve was enlarged from 48,800 rais to 481,969 rais or comparable to 771 km^2.

Table 3.1 The enlarged area has covered areas of 11 sub-districts of Wangnamkhiew and Pakthongchai districts of Nakhon Ratchasima province as follows:

Wangnamkhiew district	**Pakthongchai district**
1. Udomsap sub-district	1. Phooluang sub-district
2. Wangnamkhiew sub-district	2. Takhob sub-district
3. Wangmee sub-district	3. Toom sub-district
4. Thaisamakhee sub-district	4. Sukkasem sub-district
5. Rarerng sub-district	5. Lamnangkaew sub-district
	6. Ngiew sub-district

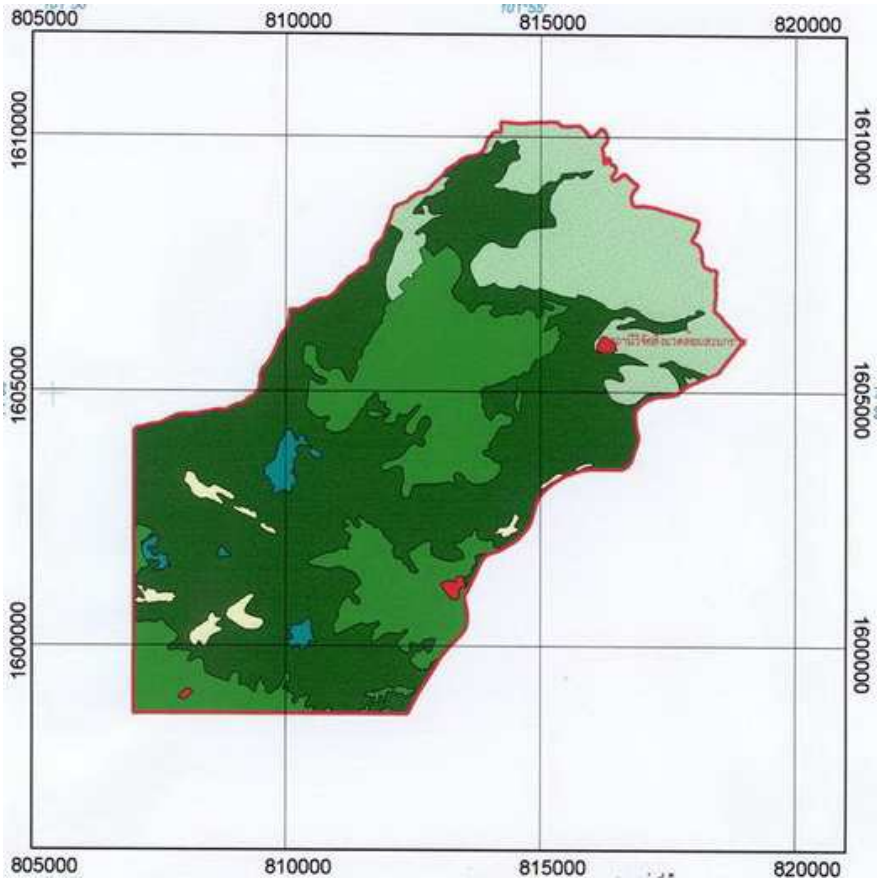


Figure 3.7 Area of the Sakaerat Environmental Research Station.

Source: Sakaerat Environmental Research station, 2009.

C. Land use

In the Sakaerat Environmental Research station is divided into 5 types :

1. dry evergreen forest	46.82	km^2	or	29,260	rais
2. deciduous dipterocarp forest	14.51	km^2	or	9,066	rais
3. grown forest	14.46	km^2	or	9,038	rais
4. grass land	0.93	km^2	or	582	rais
5. bamboo forest	1.12	km^2	or	697	rais
6. buildings	0.25	km^2	or	157	rais
Total	78.06	km^2	or	48,800	rais

As for the area of the Sakaerat Biosphere Reserve which covers 771 km^2 outside the Sakaerat Environmental Research Station, land use is different. The area includes forest, both natural and grown forests. Most forests are on mountains in the northwest and the southeast of the Sakaerat Environmental Research station. However in the southern part in the Wangnamkhiew Shallow Lake, it is agricultural area used for corn and cassava,etc. Moreover, economic plants such as grape, longan and lychee, etc. are also grown in the area.

D. General climatic condition

The climate at SERS is tropical with no occurrence of frost. The winters are cool and dry, while the summers are hot and humid. Average maximum temperature is 35°C, and the average low is 16°C. The wet-season occurs from May to mid-October, with rainfall peaks in May and September. The average annual rainfall is 1,200 mm.

3.3 Research methodology

The research was divided into 4 main parts:

1. Study on lichen species, frequency and distribution of lichen species in Nakhon Ratchasima municipality.
2. Air quality mapping in area of Nakhon Ratchasima municipality.
3. Measuring air quality with passive sampling method in Nakhon Ratchasima municipality.
4. Studying lichen diversity in the Sakaerat Environmental Research Station, Nakhon Ratchasima province.

3.3.1 Study on lichen species, frequency and distribution of lichen species in Nakhon Ratchasima municipality

3.3.1.1 Studying lichen species and frequency

The research area in the Nakhon Ratchasima municipality was divided into 46 grid squares, each of 1,000×1,000 m^2 (Figure 3.8). Selected mango trees (*Mangifera indica* Linn.) were used to survey for lichens. Barks of mango trees has appropriate pH for lichen growth and could be easily found in most town areas (Saipankaew, 1994). Six mango trees were selected for each grid square. The total number of 276 mango trees were investigated in this research. Survey for lichens by randomly selecting mango trees with trunk circumference of 50 cm or more when measured at 150 cm above ground-level (Saipankaen, 1994). Trunk of each tree must be straight or in the case of crooked trunk not more than 5 degrees-crooked. Straight and crooked trunks cause different nutrient storage, and moistness which result in different light quantities different lichen growths. Moreover, trunks must not be damaged since this can affect lichen growth (VDI, 1995). Lichen samples were collected by using a grid frame size of 20×50 cm^2 with 10 small grids size of 10×10 cm^2. A grid frame on was placed a truck of mango tree where most of lichens were found. The lower part of the grid frame was about 1 m above the ground (Figure 3.9). Environmental data was record around that mango tree and grid frame direction. If a repetition of the inventory was planned, it was advisable to mark the location of the area examined on the truck accurately and durably for which the approval by the owner of the tree was necessary. All lichen species present within the grid were recorded (lichens with a diameter of smaller than 3 m were registered to avoid errors). The frequency of occurrence of each species in the 10 divisions of the grid was taken down. Species not

occurring in any of the 10 units but just outside the grid are also chronicled (1 is taken down for frequency of occurrence of such species). This study recorded the environment around the trees on which lichens grew or expected to result in lichen growth. The data recorded were consist of area characteristics, areas around the studied trees, conditions effected by traffic, characteristics of barks, directions of tree trunks where lichens were found, space from each studied tree to road and circumferences.

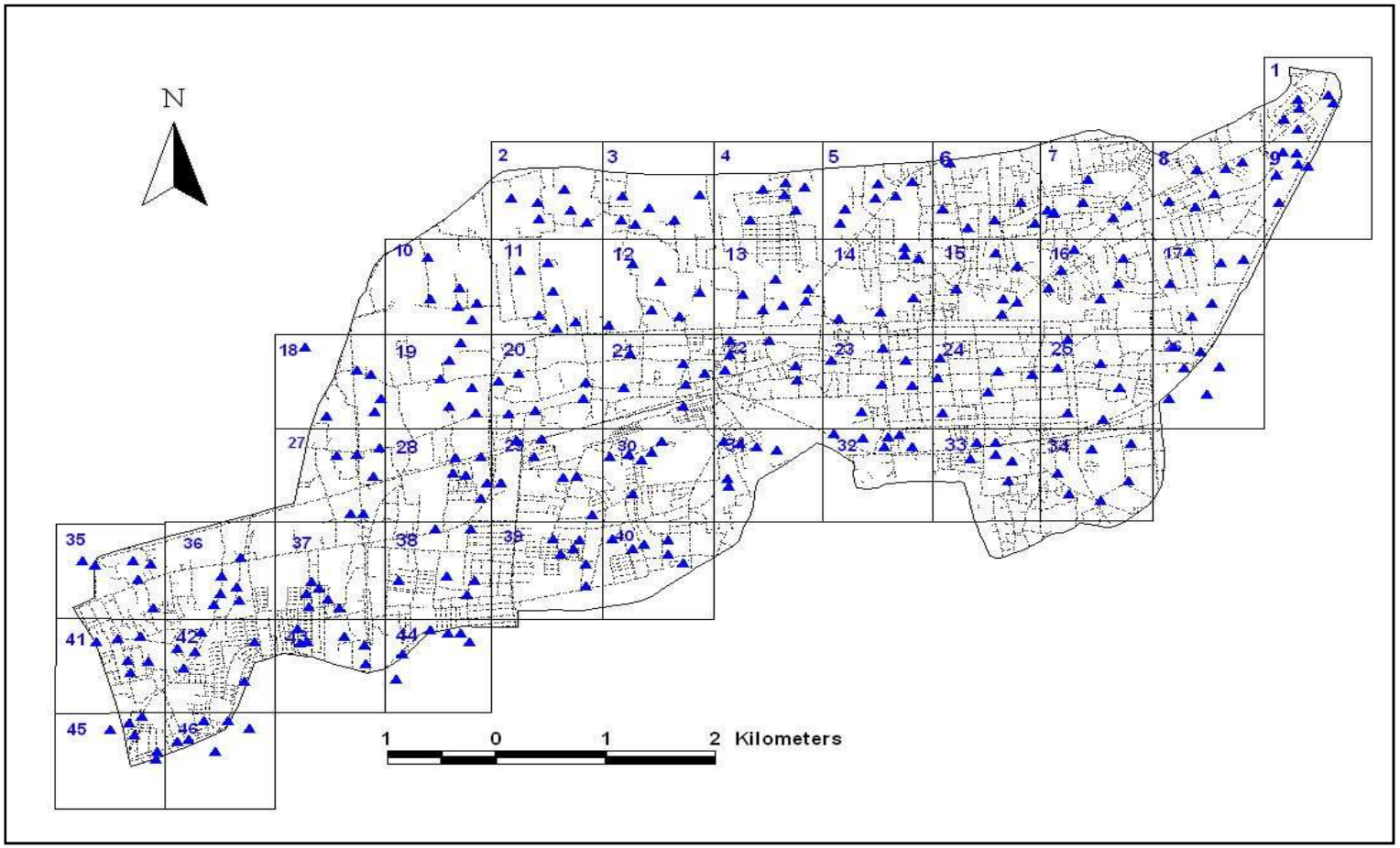


Figure 3.8 Sampling plots and the location of the investigated mango tree area.

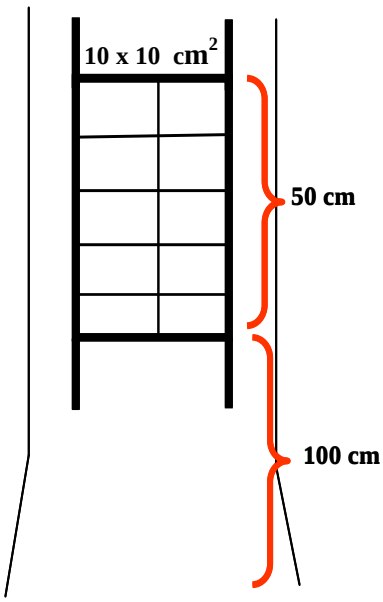


Figure 3.9 Location of grid frame.

Source: VDI, 1995.

The collected lichen samples were classified by external structures such as thallus, rhizine, cilia, reproduction structure, etc. and internal structures such as spore, ascus, including chemical substances used in testing such as K substance, C substance, Lugol's iodine substance, etc. In order to classified the lichens into groups, lichen classification manuals were used such as Key to the Lichen Genera of Bogor, Cibodas and Singapore (Sipman, 2003) and A Key to Microlichens of India, Napal and Sri Lanka (Awasthi, 1991). Some samples were delivered to lichen for further classification.

3.3.1.2 Colour test of lichen

A colour test was made simply by applying a drop of reagent on the thallus surface or exposed medulla. If the test was positive, there would be a rapid colour change, usually red or yellow; if negative, nothing happens. Ideally the tests should be done under a low-power stereoscopic scope, leaving both hands free to apply the

reagent, but a hand lens would be satisfactory with practice. The reagent; calcium hypochlorite or clorox was replaced in everyday use by bleaches (abbreviated C). Potassium hydroxide (KOH or abbreviated K) was purchased from drug stores or chemical supply houses; it was caustic and must be handled with care. It could be used directly from the container (Hale, 1979).

Color test should be done with a hand lens. Part of the upper cortex was carefully scraped away with a razor blade to expose an area of medulla about 2-3 mm square (Figure 3.10). Reagent was applied with a thin pipette or fine medicine dropper and noted any colour change as the reagent was being applied (Hale, 1979).

Figure 3.10 Colour test of lichen or spot test.
Source: Purvis, 2000.

3.3.1.3 Analysis of bark pH

Pieces of bark 2-3 mm thick without lichens were removed around respective trees trunk at 1.50 m above the ground using a pocketknife. Chips of bark were collected in plastic bags and stored in a freezer until the time of analysis. The bark samples were dried at 80°C for 24 hours and then grounded. Samples of 2 g of bark were soaked with 10 ml distilled water. After 24 hours, pH was determined directly in the solution by pH meter (Staxäng, 1969).

3.3.1.4 The study on frequency of number and distribution of lichen species in Nakhon Ratchasima municipality

Some lichen species were selected to produce a distribution map. In this study, the Geographic Information System (GIS) program were used in mapping distribution of lichen.

Six types of lichen were chosen. Among them, three types were foliose i.e. *Dirinaria pica*, *Hyperphyscia adglutinata* and *Pyxine cocoes*. The other two types were crustose i.e. *Lecanora leprosa* and *Opegrapha stirtonii*. Another last type will be leprose i.e. *Chrysothix xanthina*. These types of selected lichen were easily found in the city. Moreover, these lichen species that they could be used as air quality indices (Subsri, 2002; Thanawarat, 2002; Saipunkaew et al., 2005 and 2007). In this study, the Arcview GIS 3.3 was used in mapping distribution of lichens.

The ranges of frequency of lichen were divided into 7 ranges (applied from Subsri, 2002):

1) 0 = lichen not found

2) 1 to less than 10 = very little lichens found

3) 10 to less than 20 = little lichens found

4) 20 to less than 30 = fairly lichens found

5) 30 to less than 40 = lichens often found

6) 40 to less than 50 = lichens very often found

7) 50 to less than 60 = lichens most often found

3.3.1.5 Data analysis of the study on frequency and distribution in Nakhon Ratchasima municipality

Data on number of lichen species and frequency of each studied area. The study area grouping was conducted by the Clutter program. Data on lichen frequency of each area were studied for lichen distribution in an area by the Arcview GIS 3.3 and correlation analysis of lichen frequency and context surrounding the study trees and bark pH in each study area were study by using the Pearson Correlation Coefficient / Pearson Correlation: r. Correlation analysis was done by the Statistical Package for Social Science (SPSS) for window version 17.0.

3.3.2 Air quality mapping in area of Nakhon Ratchasima municipality

Air quality mapping was a study on pollution conditions in the area of Nakhon Ratchasima municipality by observing lichen found by using research method applied from the VDI method (VDI, 1995). The method was slightly adjusted in order to be suitable for environmental studies in Thailand.

3.3.2.1 Determination of the Air Quality Index (AQI)

The air quality index (AQI) of the individual examination units was computed. The AQI was the average of the total sum of the frequencies of occurrence on the examined trees within one grid square, It represented a statistical estimate of the true conditions in this unit. The accuracy of the estimate depended on the standard deviation of the results and was best described by the confidence limits. These indicate how far the true value deviates from the AQI with what statistical certainty (in this case the 95% certainly level is recommended). The following equation was used for calculating the AQI.

Air Quality Index (AQI) in Table (j)

$$AQI = \frac{F_{ij}}{n_j} \tag{3.1}$$

Standard deviation of squares (S)

$$S_j = \sqrt{\frac{\sum (F_{ij} - AQI_j)^2}{n_j - 1}} \tag{3.2}$$

Lower class boundary (L1j) and upper class boundary (L2j)

$$L_{1j}, L_{2j} = AQI_j \pm t_j \frac{S_j}{\sqrt{n_j}} \tag{3.3}$$

Where

i	refers to each mango tree of the survey in Table j.
j	refers to number of square of the survey.
F_{ij}	refers to sum total of lichen frequencies on mango trees of the survey.
n_j	refers to number of mango trees of the survey in each square.
S_j	refers to standard deviation of squares of the survey.
L_{1j}, L_{2j}	refers to lower class boundary and upper class boundary of Air Quality Index, considering from values between L_2-L_1.
t_j	refers to values from Table t by studying distribution of independent variables from n_i -1.

Table 3.2 Critical value t of student distribution.

n-1	t	n-1	t
3	3.182	9	2.262
4	2.776	10	2.228
5	2.571	11	2.201
6	2.447	12	2.179
7	2.365	13	2.160
8	2.306	14	2.145

3.3.2.2 Determination of the Air Quality Class (AQC)

The air quality indices were assigned to classes of air quality which represented the different ranges of air quality. The standard deviation of the results of the study determined the class width which corresponded to half the confidence interval. If the standard deviation was large, the air quality classes were broad and no fine differentiation between various degrees of air pollution was possible; if the standard deviation was small, a more differentiated distinction between the various degrees of pollution was feasible. Thus the air quality classes and mapped zoned of air quality were characterized by following properties:

- The quality (standard deviation, number of trees examined per square, ecological homogeneity of the area investigated) of the results plotted in a map determined how many different air quality classes, or how many zones of different air quality can be distinguished at a given exposure range.
- Non-adjoining air quality classes have statistically significant differences (e.g. the examined grid squares with class 1 air quality differ significantly from those with class 3 air quality).

The width of each of the air quality classes was determined with the help of the mean standard deviation of all grid squares examined during the study:

Mean standard deviations of the investigation (S_p)

$$S_p = \sqrt{\frac{\sum_j \sum \left(F_{ij} - AQI_j\right)^2}{m\left(n_p - 1\right)}} \qquad (3.4)$$

Width of each of the air quality classes

$$AQC = t_p . \frac{S_p}{\sqrt{n_p}} \qquad (3.5)$$

Where

S_p refers to mean of standard deviations of all grid squares in studied area.

n_p refers to mean of number of trees in each grid square of all squares in studied area.

m refers to number of total surveyed squares in studied area.

t_p refers to value(s) from Table t by studying distribution of independent variables from $n_p - 1$

Table 3.3 The air quality index of the examined grid squares j are assigned to air quality classes according to following scheme:

0	<AQI≤	Width of the 1st Class
Width of the 1st Class	<AQI≤	Width of the 2nd Class
	Continuous	

For better understanding, the air quality classes are numbered beginning with the class with the highest pollution.

3.3.2.3 Evaluation and presentation of the air quality classes

An exposure scale were used for evaluation whose thresholds were the values of atmospheric pollution of 0-12.5, 12.5-25.0, 25.0-37.5 and 37.5-50.0 (VDI, 1995). Verbal expressions and colour codes were assigned to these numerical values (Figure 3.11), which were used for plotting the results in a map. The thresholds of the exposure scale were derived from several extensive surveys. The air quality classes were assigned to the exposure scale so that they match the best suitable verbal expressions and colour codes. Sometimes the air quality classes fell into two exposure categories. This was indicated by combining the verbal expressions of both categories, for example “moderate to low exposure”, and by using hatched colour codes (e.g. green hatching on yellow background). Those values have been studied in European countries for more than 25 years, in order to get the most appropriate ranges of value (VDI, 1995). However, the calculated values were wide ranging and studied from countries in humid climates not been studied in countries in tropical zone. Thus, Thailand could use the impact scale as the basic values only. Therefore, the scale should be applied for calculation of the appropriate values in the future.

The received widths represented different levels of air pollution, replaced with different places in the studied map. In classification of air quality, values of quality classes possibly caused collaborative quality result for two classes. For example if the air quality class was 0-14.5, that was between standard value of the high pollution red class (12.5) and the rather high pollution orange class (25.0), it could be interpreted that the studied air quality had high to rather high pollution, etc. Assigning colours to each square was to represent characteristics of air quality class in each

square or enable are to build isoline. An air quality map were constructed by using Arcview GIS 3.3.

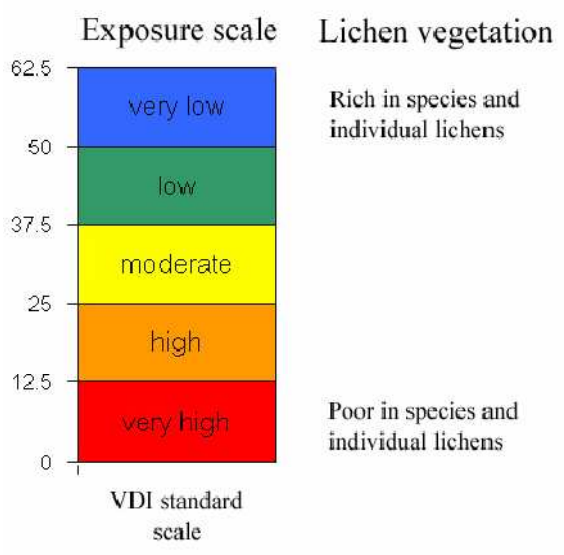


Figure 3.11 Impact scale standard.

Source: VDI, 1995.

3.3.3 Measuring air pollution in Nakhon Ratchasima municipality

3.3.3.1 Preparation of diffusion tube

Polyethylene tubes with a length of 5.4 cm and an internal diameter of 1.3 cm were cleaned and sonicated for one hour, then rinsed with milli-Q water. Filter paper, Whatman no.40, was cut in a circle with the diameter being equal to the inner diameter of the tube. The filter paper was sonicated for 1 hour and then soaked overnight with milli-Q water. After being air-dried at 103°C for 1 hour, filter paper was placed inside the bottom of the tubes (Shakya, 2004 and Pomphueak, 2005).

3.3.3.2 Exposure of diffusion tube

On the exposure day, absorbent 50 µl of 20% TEA in mili-Q water was added directly onto the filter paper (Pomphueak, 2005). The diffusion tubes were vertically fixed, with the open end facing upward, inside the shields to protect them from wind,

sunlight and rain. The protective shield containing tree replications of tube was hung at 1.50 m above the ground level.

After 2 weeks of exposure, the tubes were collected and closed with caps immediately, then sealed with parafilm. The tubes were placed in plastic zip lock bags and stored in a refrigerator until the time of analysis. The times of installation and collection were noted to calculate the exposure time.

For the laboratory blank, the diffusion tubes were prepared with the same procedure. Three replication tubes were fixed under the protective shield in the laboratory at room temperature without opening the caps.

3.3.3.3 Extraction of sample

Before extraction, the outer body of the tube was cleaned with deionised water and 4 ml of milli-Q water was added directly in the tube. The tube was capped and sonicated for 15 min to extract nitrite and sulfate ions that were absorbed by TEA, in the form of solution. The sample solution was then filtered through cellulose acetate membrane 0.45 µm by the help of syringe (Pomphueak, 2005).

3.3.3.4 Analysis of nitrate ion (NO_2^-) and sulfate ion (SO_4^{2-}) by ion chromatography

a) Preparation of eluent

Stock standard of 180 mM Na_2CO_3 / 170 mM $NaHCO_3$ was prepared by dissolving 1.9078 g of Na_2CO_3 and 1.4282 g of $NaHCO_3$ in milli-Q water and diluting to 100 ml. The eluent of 1.8 mM Na_2CO_3 / 1.7 mM $NaHCO_3$ was then prepared by pipetting 10 ml of standard stock solution and diluting to 1 liter with milli-Q water. The eluent was filtered through a 0.45 µm cellulose acetate membrane to remove

micro-particle, then degassed in an ultrasonic bath for 15 min to remove dissolved gasses (Shakya, 2004 and Pomphueak, 2005).

b) Preparation of standards

The working standards with combined NO_2^- and SO_4^{2-} was then prepared in the following concentration; 0.2, 0.4, 0.6, 0.8 and 1.0 ppm. Therefore, in 10 ml volumetric flasks, a volume of 20 µl, 40 µl, 60 µl,80 µl ad 100 µl for each nitrate and sulfate primary standard was pipetted and diluted up to the mark with milli-Q water (Shakya, 2004 and Pomphueak, 2005).

c) Analysis nitrate ion (NO_2^-) and sulfate ion (SO_4^{2-})

NO_2^- and SO_4^{2-} were determined as nitrate and sulfate ions with analysis of extract by ion chromatography. Analytical conditions for this system were as follows;

- flow rate 1.0 ml/min
- eluent 1.8 mM Na_2CO_3 / 1.7 mM $NaHCO_3$
- sample volume 20 µl

After setting the analytical condition, the base line was run until it remained constant. The working standards were injected to determine the calibration curve. Then the sample was injected. The concentrations of NO_2 and SO_2 in $\mu g/m^{-3}$ are calculated by applying the equation 2.5, 2.7 and 2.9 (Pomphueak, 2005).

3.3.3.5 Data analysis of measuring air pollution in Nakhon Ratchasima municipality

Correlation analysis of nitrogen dioxide and sulphur dioxide with AQI of each study area, Correlation analysis of nitrogen dioxide and sulphur dioxide with pH of each study area were done by using the Pearson Correlation coefficient / Pearson

Correlation: r. Correlation analysis was done by the Statistical Package for Social Science (SPSS) for window version 17.0.

3.3.4 The study on lichens diversity in the Sakaerat Environmental Research station, Nakhon Ratchasima province

The deciduous dipterocarp forest (DDF) and dry evergreen forest (DEF) in the Sakaerat Environmental Research station, Nakhon Ratchasima province. With the basic study by species area curve method, the following quadrate will be specified:

3 plots of DDF, area size of 20×20 m^2 per plot

3 plots of DEF, area size of 20×20 m^2 per plot

Survey every perennial with 50 cm and more circumference. At 150 cm above ground level, lichen species and their frequency were recorded by using grid frame size of 20×50 cm^2 with 10 small grids size of 10×10 cm^2. A grid frame was placed on a truck of tree where most lichens were found. Trunk of each tree must be straight or in the case of crooked trunk, not more than 5 degrees-crooked. Straight and crooked trunks cause different nutrient storage, light and moistness. There different factor can cause different lichen growths. Moreover, trunks must not be damaged since this can affect lichen growth (VDI, 1995). Environmental factor around that tree and grid frame direction were recorded such as temperature, light intensity and relative humidity etc.

3.3.4.1 Data analysis of the study in the Sakaerat Environmental Research station

Data on lichen species and frequency of each studied area were calculated for Shannon - Wiener's diversity index (H'), evenness (E), and species richness. Similarity of lichens found in deciduous dipterocarp forest and dry evergreen forest was calculated by Sørensen similarity index. Correlation analysis of lichen diversity index and physical factors of each studied area were done by using the Pearson Correlation coefficient / Pearson Correlation: r. Correlation analysis was done by the SPSS (Statistical Package for Social Science) for window version 17.0.

CHAPTER IV

RESULTS

The study was divided into two parts. The first part included collection of lichen samples and measurement of air quality from 276 mango trees in 46 sampling plots in Nakhon Ratchasima municipality areas in January - October 2009. Lichen samples were analyzed for frequency and distribution in order to make a Nakhon Ratchasima municipality air quality map using lichens as indicators and to measure nitrogen dioxide and sulphur dioxide in Nakhon Ratchasima municipality areas. The second part included study on lichen diversity in deciduous dipterocarp forest and dry evergreen forest in the Sakaerat Environmental Research station areas in June - November 2009. The results were as follows:

4.1 Study on lichen species, frequency and distribution of lichen species in Nakhon Ratchasima municipality.

4.1.1 Lichen species

A total of 10 families, 17 genera, and 29 lichen species were found in the Nakhon Ratchasima municipality areas. The most widespread species were *Hyperphyscia adglutinata*, *Pyxine cocoes*, *Physcia dimidiata*, *Opegrapha stirtonii*, *Lecanora leprosa* and *Chrysothrix xanthina* (Table 4.1) and the pictures of lichen species were presented in Appendix B.

Table 4.1 Lists of total lichen species found in Nakhon Ratchasima municipality

Thallus type	Family	Genus	Species
Crustose	Arthoniaceae	*Arthonia*	*Arthonia tumidula*
			Arthonia sp.
		Cryptothecia	*Cryptothecia* sp.
	Bacidiaceae	*Bacidia*	*Bacidia* sp.
	Caloplacaceae	*Caloplaca*	*Caloplaca diplacia*
			Caloplaca diplacioides
	Chrysothricaceae	*Chrysothrix*	*Chrysothrix xanthina*
	Graphidaceae	*Graphina*	*Graphydaeae* sp.
			Graphina symplocorum
	Lecanoraceae	*Lecanora*	*Lecanora achroa*
			Lecanora leprosa
			Lecanora tropica
	Physciaceae	*Buellia*	*Buellia* sp.
		Rinodina	*Rinodina* sp.
	Roccellaceae	*Lecanographa*	*Lecanographa* sp.
			Opegrapha stirtonii
	Trypetheliaceae	*Laurera*	cf. *Laurera* sp.
		Trypethelium	*Trypethelium eluteriae*
			Trypethelium tropicum
			Sterile crust sp.1 (pycnedia)
			Sterile crust sp.2
			Sterile crust sp.3

Table 4.1 (Continued) Lists of total lichen species found in Nakhon Ratchasima municipality.

Thallus type	Family	Genus	Species
Foliose	Physciaceae	*Dirinaria*	*Dirinaria picta*
		Dirinaria	*Dirinaria applanata*
	Physciaceae	*Hyperphyscia*	*Hyperphyscia adglutinata*
	Physciaceae	*Pyxine*	*Pyxine cocoes*
	Physciaceae	*Physcia*	*Physcia poncinsii*
			Physcia atrostriata
		Hyperphyscia	*Hyperphyscia* sp.

4.1.2 Lichen frequency

The frequency illustrated of each lichen species found in the Nakhon Ratchasima municipality was in Table 4.2. The highest frequency with a total frequency of 175 was found in the sampling plot no.31. The highest frequencies were in sampling plot no.9 (153), sampling plot no.10 (142), and sampling plot no.2 (138). The lowest frequency was found in sanpling plot no.21 (28).

The lichen found in the municipality areas indicated that *Hyperphycia adglutinata* was found the most with a total frequency of 436 or 11%. The second most was the *Physcia atrostriata* with a total frequency of 421 or 10%. The third most was *Pyxine cocoes* with a total frequency of 362 or 9%. The fourth most was *Opegrapha stirtonii* with a total frequency of 344 or 8.10%. The fifth most was *Chrysothix xanthina* with a total frequency of 314 or 7.61%. and the last, that *Lecanora tropica* was found the lowest with a total frequency of 3 or 0.07% of all found lichens (Figure 4.1).

Table 4.2 The frequency of lichen number in each sampling plot of Nakhon Ratchasima municipality.

Species	Sampling plots							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Arthonia tumidula	0	0	6	10	12	8	0	11
Arthonia sp.1	0	0	2	0	5	0	0	3
Bacidia sp.	0	6	6	0	8	5	9	0
Buellia sp.	0	7	3	0	8	0	8	10
Caloplaca diplacia	8	0	8	0	0	6	0	0
Caloplaca diplacioides	0	0	6	0	6	5	0	12
cf. *Laurera* sp.	4	0	0	0	0	0	0	0
Chrysothrix xanthina	13	6	18	6	10	8	15	6
Cryptothecia sp.	0	0	0	0	0	5	0	0
Dirinaria picta	16	8	0	6	0	3	0	10
Dirinaria applanata	0	4	0	0	0	7	0	0
Graphina sp.	0	3	0	10	9	0	0	0
Graphina symplocorum	0	5	10	12	8	8	6	4
Hyperpesia sp.	0	3	0	0	0	0	0	0
Hyperphyscia adglutinata	15	19	7	8	0	8	19	25
Lecanora achroa	0	0	8	5	0	0	5	0
Lecanora leprosa	5	11	6	10	2	6	17	6
Lecanora tropica	4	7	0	4	0	0	0	0
Lecanographa sp.	0	2	0	0	0	0	10	0
Opegrapha stirtonii	3	5	10	8	5	11	0	0
Physcia atrostriata	11	6	0	0	0	5	10	8
Physcia poncinsii	18	6	5	10	0	0	0	0
Pyxine cocoes	21	15	8	12	3	5	11	12
Rinodina sp.	0	7	3	5	0	8	7	10
Sterile crust sp.1 (pycnedia)	0	2	0	4	0	0	0	5
Sterile crust sp.2	0	3	0	0	3	0	0	0
Sterile crust sp.3	0	0	0	0	6	4	0	0
Trypethelium eluteriae	0	5	0	0	0	0	0	8
Trypethelium tropicum	5	8	6	5	0	0	0	0
Total	123	138	112	115	85	102	117	130

Table 4.2 (Continued) The frequency of lichen number in each sampling plot of Nakhon Ratchasima municipality.

Species	Sampling plots							
	9	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Arthonia tumidula	6	5	8	8	0	5	3	0
Arthonia sp.1	0	4	0	0	0	0	0	0
Bacidia sp.	0	7	10	5	0	5	5	0
Buellia sp.	0	0	5	8	0	0	0	6
Caloplaca diplacia	6	6	3	8	0	0	0	0
Caloplaca diplacioides	5	9	8	0	0	6	0	0
cf. *Laurera* sp.	0	0	0	5	0	0	0	0
Chrysothrix xanthina	14	10	12	0	0	10	8	0
Cryptothecia sp.	0	0	0	0	0	0	0	0
Dirinaria picta	10	6	5	0	0	0	0	0
Dirinaria applanata	10	0	0	0	0	0	0	0
Graphina sp.	0	0	0	0	0	0	8	0
Graphina symplocorum	0	12	11	0	0	5	5	0
Hyperpesia sp.	0	0	0	0	0	0	0	0
Hyperphyscia adglutinata	20	18	18	5	0	0	0	6
Lecanora achroa	0	0	8	10	0	0	0	0
Lecanora leprosa	15	6	6	0	10	0	0	6
Lecanora tropica	12	0	2	5	5	0	0	0
Lecanographa sp.	0	0	0	6	5	0	3	0
Opegrapha stirtonii	4	12	7	10	20	7	5	8
Physcia atrostriata	12	15	6	0	0	2	0	3
Physcia poncinsii	10	0	0	0	0	0	0	3
Pyxine cocoes	13	15	12	8	0	5	2	5
Rinodina sp.	0	7	10	0	3	0	3	5
Sterile crust sp.1 (pycnedia)	0	0	0	0	7	0	0	5
Sterile crust sp.2	0	0	0	0	0	0	0	10
Sterile crust sp.3	10	0	0	0	0	0	0	0
Trypethelium eluteriae	6	10	0	0	0	0	0	0
Trypethelium tropicum	0	0	0	0	0	0	0	0
Total	153	142	131	78	50	45	42	57

Table 4.2 (Continued) The frequency of lichen number in each sampling plot of Nakhon Ratchasima municipality.

Species	Sampling plots							
	17	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Arthonia tumidula	3	0	0	0	0	0	0	6
Arthonia sp.1	0	0	5	0	8	4	0	12
Bacidia sp.	0	0	5	0	0	3	0	0
Buellia sp.	0	0	5	8	0	0	0	0
Caloplaca diplacia	7	5	0	0	0	0	5	0
Caloplaca diplacioides	0	5	4	0	0	0	0	0
cf. *Laurera* sp.	0	0	0	8	0	0	0	0
Chrysothrix xanthina	5	6	8	0	0	0	6	0
Cryptothecia sp.	0	0	0	0	0	0	0	0
Dirinaria picta	5	4	8	4	0	0	3	0
Dirinaria applanata	3	4	0	5	0	0	2	0
Graphina sp.	0	0	0	0	0	0	0	0
Graphina symplocorum	0	3	0	7	0	8	5	7
Hyperpesia sp.	0	0	0	0	0	0	0	0
Hyperphyscia adglutinata	12	15	7	6	0	0	10	0
Lecanora achroa	0	5	0	0	0	0	0	0
Lecanora leprosa	0	8	7	6	0	0	3	0
Lecanora tropica	2	0	0	0	0	0	0	0
Lecanographa sp.	0	0	0	0	0	5	0	0
Opegrapha stirtonii	7	5	0	0	15	7	0	13
Physcia atrostriata	10	5	15	4	0	0	5	0
Physcia poncinsii	0	0	0	0	0	0	0	0
Pyxine cocoes	11	18	12	3	0	0	6	0
Rinodina sp.	0	6	5	0	0	0	6	0
Sterile crust sp.1 (pycnedia)	0	0	0	0	0	8	0	0
Sterile crust sp.2	0	0	0	0	0	0	0	0
Sterile crust sp.3	0	0	0	13	5	0	0	0
Trypethelium eluteriae	0	4	0	0	0	0	0	0
Trypethelium tropicum	0	0	0	0	0	0	0	0
Total	65	93	81	64	28	35	51	38

Table 4.2 (Continued) The frequency of lichen number in each sampling plot of Nakhon Ratchasima municipality.

Species	Sampling plots							
	25	**26**	**27**	**28**	**29**	**30**	**31**	**32**
Arthonia tumidula	0	0	2	0	0	8	0	10
Arthonia sp.1	0	0	0	7	0	0	12	5
Bacidia sp.	7	0	2	0	0	0	3	0
Buellia sp.	0	0	0	0	8	0	0	4
Caloplaca diplacia	4	3	0	4	0	0	6	0
Caloplaca diplacioides	0	5	3	3	0	0	5	11
cf. *Laurera* sp.	0	0	0	0	8	0	0	0
Chrysothrix xanthina	8	10	6	0	0	7	25	10
Cryptothecia sp.	0	0	0	0	0	0	0	0
Dirinaria picta	6	7	8	10	4	0	11	9
Dirinaria applanata	4	4	0	0	5	0	8	7
Graphina sp.	0	0	0	0	0	0	0	0
Graphina symplocorum	3	0	0	4	7	0	18	5
Hyperpesia sp.	0	0	0	0	0	0	0	0
Hyperphyscia adglutinata	8	16	14	13	6	0	18	7
Lecanora achroa	5	0	0	0	0	0	0	8
Lecanora leprosa	4	5	11	9	6	0	15	7
Lecanora tropica	0	0	0	3	0	0	7	3
Lecanographa sp.	0	0	0	0	0	0	0	0
Opegrapha stirtonii	5	4	0	8	0	15	17	8
Physcia atrostriata	4	9	18	8	4	0	13	14
Physcia poncinsii	0	0	0	0	0	0	0	0
Pyxine cocoes	5	18	11	10	3	0	14	10
Rinodina sp.	0	4	0	3	0	0	3	7
Sterile crust sp.1 (pycnedia)	0	0	0	5	0	0	0	0
Sterile crust sp.2	0	5	0	0	0	13	0	0
Sterile crust sp.3	0	0	0	0	13	0	0	0
Trypethelium eluteriae	0	0	0	0	0	0	0	5
Trypethelium tropicum	0	0	0	0	0	0	0	0
Total	63	90	75	87	64	43	175	130

Table 4.2 (Continued) The frequency of lichen number in each sampling plot of Nakhon Ratchasima municipality.

Species	Sampling plots							
	33	**34**	**35**	**36**	**37**	**38**	**39**	**40**
Arthonia tumidula	0	0	6	5	0	0	3	0
Arthonia sp.1	0	3	0	4	0	0	11	0
Bacidia sp.	7	5	0	6	0	5	0	0
Buellia sp.	5	6	0	2	7	3	0	8
Caloplaca diplacia	8	0	7	3	0	0	8	5
Caloplaca diplacioides	4	0	0	5	0	6	3	5
cf. *Laurera* sp.	0	0	0	0	0	0	8	0
Chrysothrix xanthina	5	13	5	7	11	0	0	9
Cryptothecia sp.	0	0	0	0	0	0	0	0
Dirinaria picta	8	3	4	6	2	4	8	5
Dirinaria applanata	0	0	0	2	3	0	0	0
Graphina sp.	0	0	0	0	0	0	0	0
Graphina symplocorum	0	0	4	0	5	0	0	12
Hyperpesia sp.	0	0	0	0	0	0	0	0
Hyperphyscia adglutinata	12	8	9	14	13	6	7	10
Lecanora achroa	6	0	0	0	0	0	0	0
Lecanora leprosa	8	5	9	5	8	4	5	7
Lecanora tropica	0	2	4	2	0	0	0	3
Lecanographa sp.	0	0	0	0	0	0	0	0
Opegrapha stirtonii	12	10	6	8	15	0	0	14
Physcia atrostriata	23	9	12	13	10	8	8	15
Physcia poncinsii	0	0	0	0	0	0	0	0
Pyxine cocoes	11	13	8	11	10	4	7	16
Rinodina sp.	0	5	0	0	6	0	2	3
Sterile crust sp.1 (pycnedia)	0	7	0	0	0	0	5	0
Sterile crust sp.2	7	0	0	0	6	0	0	11
Sterile crust sp.3	8	0	0	0	0	0	0	0
Trypethelium eluteriae	0	0	0	0	0	0	0	0
Trypethelium tropicum	0	0	0	0	0	0	0	0
Total	124	89	74	93	96	40	75	123

Table 4.2 (Continued) The frequency of lichen number in each sampling plot of Nakhon Ratchasima municipality.

Species	Sampling plots					
	41	**42**	**43**	**44**	**45**	**46**
Arthonia tumidula	0	0	5	0	0	6
Arthonia sp.1	8	0	5	0	0	0
Bacidia sp.	0	0	8	0	0	7
Buellia sp.	0	0	4	5	8	0
Caloplaca diplacia	0	0	0	7	6	0
Caloplaca diplacioides	0	0	6	4	8	9
cf. *Laurera* sp.	0	0	0	0	0	0
Chrysothrix xanthina	8	0	4	5	7	13
Cryptothecia sp.	0	0	0	0	0	0
Dirinaria picta	6	0	4	3	5	6
Dirinaria applanata	3	5	3	3	2	0
Graphina sp.	0	0	0	0	0	0
Graphina symplocorum	7	10	0	5	7	11
Hyperpesia sp.	0	0	0	0	0	0
Hyperphyscia adglutinata	7	14	13	6	8	9
Lecanora achroa	0	0	0	0	0	6
Lecanora leprosa	8	0	6	8	12	7
Lecanora tropica	8	5	0	3	4	0
Lecanographa sp.	0	7	0	0	0	0
Opegrapha stirtonii	11	12	11	6	5	5
Physcia atrostriata	17	14	11	10	18	7
Physcia poncinsii	0	0	0	0	0	0
Pyxine cocoes	8	13	12	15	11	14
Rinodina sp.	8	0	4	0	6	0
Sterile crust sp.1 (pycnedia)	6	4	0	7	0	0
Sterile crust sp.2	0	3	0	5	8	0
Sterile crust sp.3	0	0	0	0	0	0
Trypethelium eluteriae	7	0	0	0	3	0
Trypethelium tropicum	0	0	0	0	0	0
Total	112	87	96	92	118	100

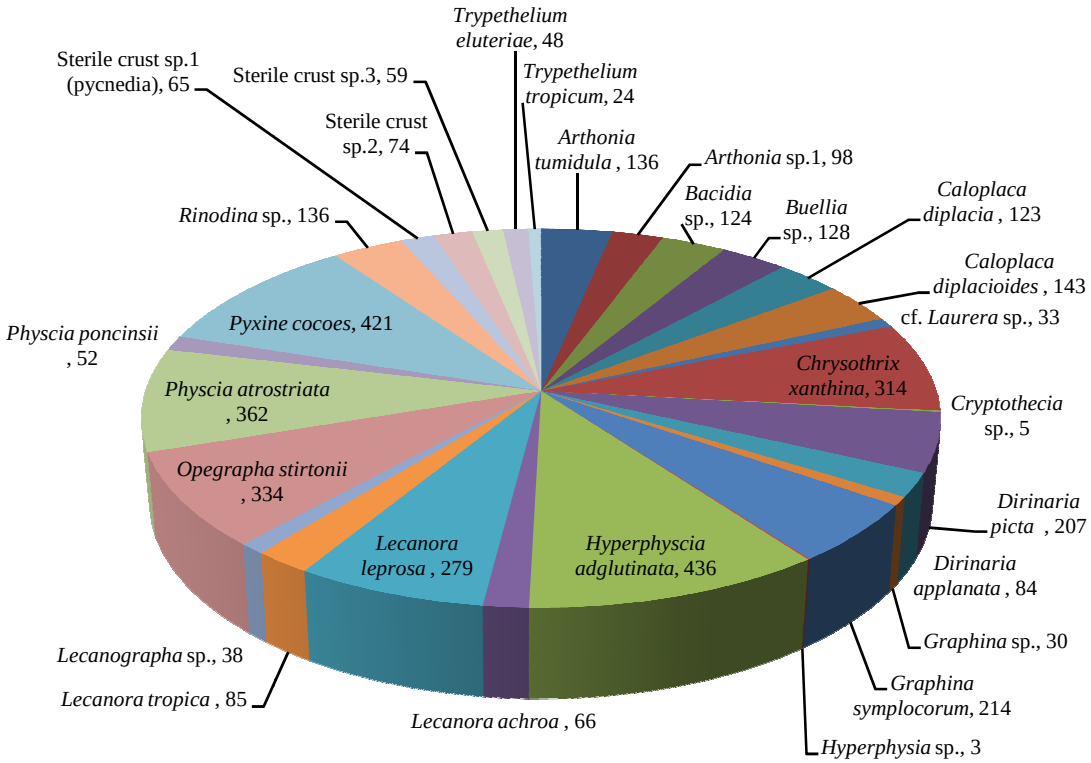


Figure 4.1 The frequency of number lichens found in Nakhon Ratchasima municipality.

Comparing between number of lichen species in crustose and in foliose found in sampling plots, it was found that in all sampling plots, there were more number of species in crustose than number of species in foliose. The sampling plots no.2, 11, 17, 23 and 39 represented high-density residential areas. Most lichen species or 18 species were found in areas around moats. The second most lichen species was 17 species found in sampling plots no.8, 25, 37 and 44 which represented areas of Mittapab highway and high-density residential areas. The sampling plots no.30 represented areas along the railways where the least species of lichen, only six, were found (Table 4.3 and Figure 4.2).

Table 4.3 Number of lichen species in crustose and foliose in each sampling plot of Nakhon Ratchasima municipality.

Sampling plots	Thallus type		Sampling plots	Thallus type	
	Crustose	Foliose		Crustose	Foliose
1	6	5	24	4	0
2	14	7	25	7	5
3	12	3	26	7	5
4	10	4	27	5	4
5	12	1	28	9	4
6	11	5	29	5	5
7	8	3	30	4	0
8	10	4	31	10	5
9	10	6	32	12	5
10	11	4	33	10	4
11	12	4	34	9	4
12	9	2	35	7	4
13	6	0	36	10	5
14	6	2	37	7	5
15	8	1	38	4	4
16	6	4	39	8	4
17	5	5	40	10	4
18	9	5	41	9	5
19	7	4	42	6	4
20	5	5	43	9	5
21	3	0	44	10	5
22	6	0	45	11	5
23	5	5	46	8	4

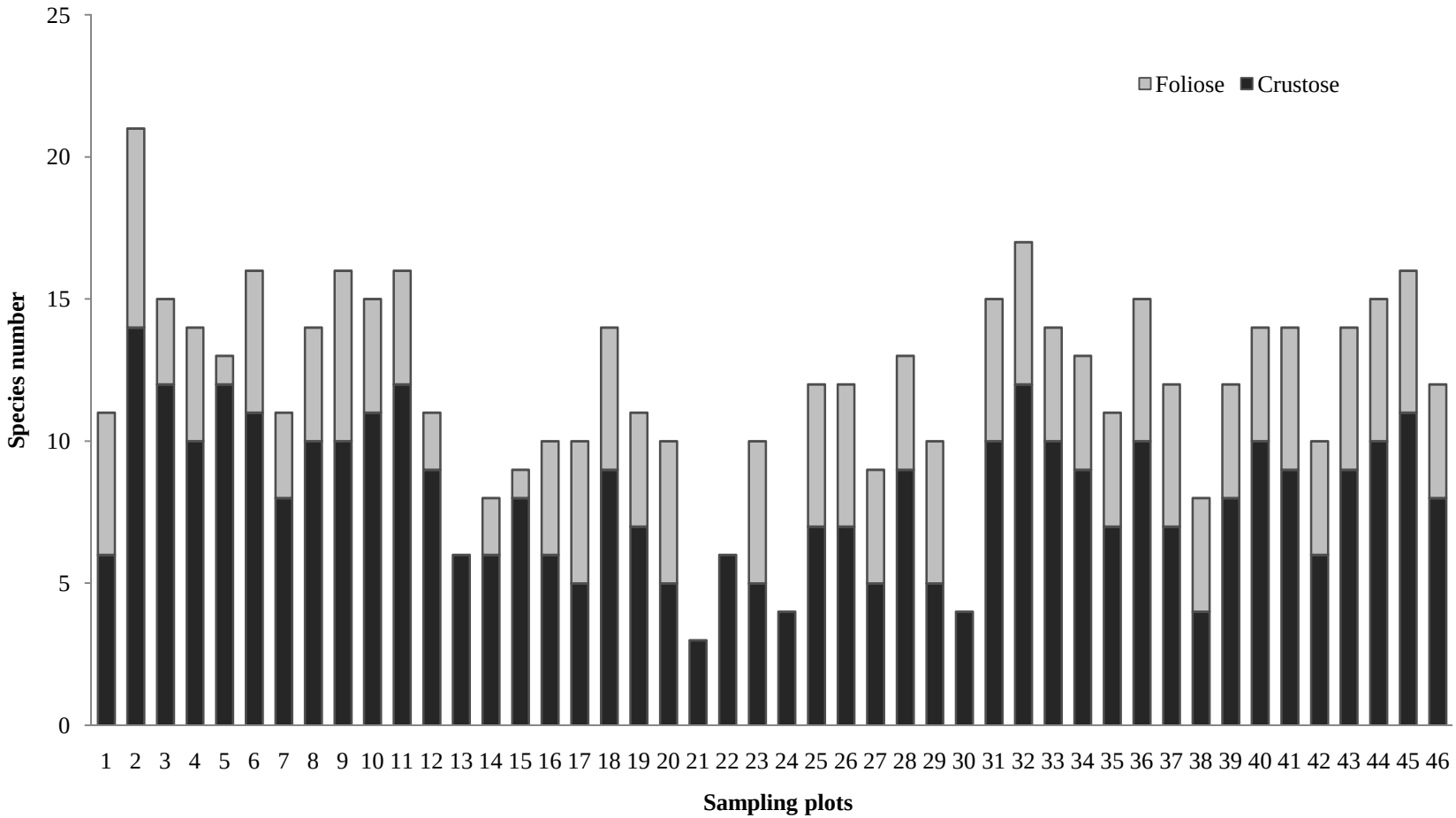


Figure 4.2 Number of lichen species in crustose and foliose found in Nakhon Ratchasima municipality.

The similarity of ecological behaviour and floristic composition among lichen flora in the study area were then observed based on lichen frequencies and type of land use. The hierachical cluster analysis was performed by SPSS using cosine as the resemblance measure method and average linkate (between groups) as a clustering algorithm. The dendrogram is presented in Figure 4.3.

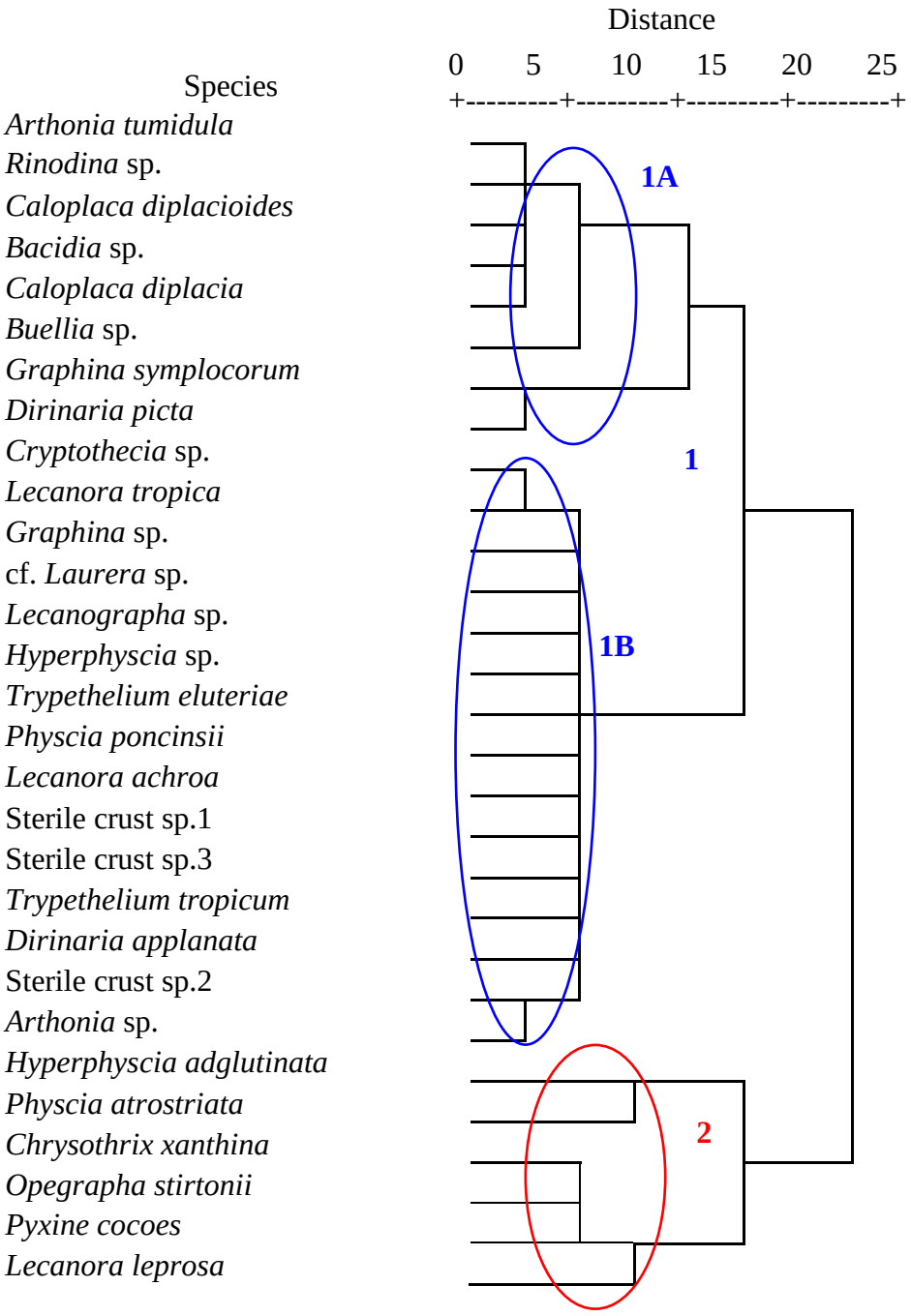


Figure 4.3 Dendrogram of lichen species found in Nakhon Ratchasima municipality.

The lichen analysis data were submitted for lichen species classification by cluster analysis. The resulting dendrogram from this treatment revealed two main groups of lichen species (Figure 4.3). The first, group 1, were formed by lichen species considered clean regions of *Arthonia tumidula, Rinodina* sp., *Buellia* sp., *Caloplaca diplacia, Bacidia* sp., *Caloplaca diplacioides, Rinodina* sp., *Opegrapha stirtonii* and *Dirinaria picta* (Subgroup1A) and *Cryptothecia* sp., *Lecanora tropica, Graphina* sp., cf. *Laurera* sp., *Arthonia* sp., *Dirinaria applanata, Trypethelium tropicum,* Sterile crust sp., *Lecanora achroa, Physcia poncinsii, Trypethelium eluteriae, Physcia* sp., *Lecanographa* sp. (Subgroup 1B). Subgroup 1B lichen species are located in less polluted urban areas. The second group 2, were formed by the lichen species near urban area and had a high volume of traffic and include the following species; *Lecanora leprosa, Pyxine cocoes, Chrysothrix xanthina, Physcia atrostriata, Hyperphyscia adglutinata*. The cluster analysis substantially confirmed coherent groups of pollution levels.

4.1.3 Frequency and distribution of the found lichens in Nakhon Ratchasima municipality

During lichen in Nakhon Ratchasima municipality areas, the auther noticed that the sampling plots no. 5, 12, 13, 14, 15, 16, 20, 21, 22, 23, 24, 28, 29, 35, 36, 37 and 38 were located in the areas around moats of the municipality and Mittapab high-way where were high-density residential areas. The other sampling plots were located in less high-density residential areas. There were six lichen species with high frequency and distribution found. Among them, three species were foliose i.e. *Dirinaria pica*, *Hyperphyscia adglutinata* and *Pyxine cocoes*. The other two species

were crustose i.e. *Lecanora leprosa* and *Opegrapha stirtonii*. The last one was leprose i.e. *Chrysothix xanthina*. More details were as stated below.

4.1.3.1 Frequency and distribution of *Dirinaria pica*

The study on *Dirinaria pica* lichen in the municipality areas found that this species grown on 133 mango trees. After calculation of lichen frequency of each sampling plot, it was found that this species distributed all over the studied areas in the municipality. The highest frequency was 16 and was classified into three ranges as follows:

The ranges of frequency of lichen was divided into 3 ranges:

1) 0 = lichen not found

2) 1 - less than 10 = very little lichens found

3) 10 - less than 20 = little lichens found

Dirinaria pica lichen was distributed over all study areas and its frequency found in high-density residential areas was lower than the one in less-density residential areas (Figure 4.4). It was not found in sampling plots no. 3, 5, 7, 12, 13, 14, 15, 16, 21, 22, 24, 30 and 42 which located in area of a Mittapab highway and roads in the municipality.

The areas where very little numbers of lichen (range: 1 - less than 10) found were sampling plots no. 2, 4, 6, 10, 11, 17, 18, 19, 20, 23, 25, 26, 27, 29, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 43, 44, 45 and 46. These areas were agricultural areas, such as integrated agricultural areas, neglected farming fields, or rural areas with light traffic. Most of these areas had shades and rather high humidity.

The areas where little numbers of lichen (range: 10 - less than 20) found were sampling plots no. 1, 8, 9, 28 and 31. These areas were most were high-density

residential areas with light traffic, shades and average number of trees. There were some activities caused air pollution to these areas, such as waste incineration, etc.

4.1.3.2 Frequency and distribution of *Hyperphyscia adglutinata*

The study on *Hyperphyscia adglutinata* lichen in the municipality areas found that this species grown on 178 mango trees and distributed all over the study areas. The highest frequency was 43 and was classified into six ranges as follows:

The ranges of frequency of lichen was divided into 6 ranges:

1) 0 = lichen not found

2) 1 - less than 10 = very little lichens found

3) 10 - less than 20 = little lichens found

4) 20 - less than 30 = fairly lichens found

5) 30 - less than 40 = lichens often found

6) 40 - less than 50 = lichens very often found

Hyperphyscia adglutinata lichen was frequently found with frequency in a range of 40 to less than 50. This lichen species distributed over all study areas and mostly found in high-density residential areas than the one in less-density residential areas (Figure 4.5). *Hyperphyscia adglutinata* is distributed all over the study areas, except in sampling plots no. 5, 14, 21, 22 and 30. The observation found that these sampling plots are located in the areas where not many buildings constructed.

The areas where very little numbers of lichen (range: 0 - less than 10) found were sampling plots no. 6, 12, 13, 16, 29, 37, 41 and 46. These areas where were in both high-density residential and not high-density residential areas with heavy traffic in some periods of time, such as at the end of daily school time and working time, etc.

The areas where little numbers of lichen (range: 10 - less than 20) found were sampling plots no. 1, 3, 4, 7, 11, 15, 18, 20, 23, 25, 27, 28, 31, 32, 33, 35, 40, 42, 43, 44 and 45 where most areas were communities close to downtown with small number of shades.

The areas where fairly numbers of lichen (range: 20 - less than 30) found were sampling plots no. 2, 9, 10, 17, 19, 26 and 38 where were rather dry with strong sunlight and much of dust caused by heavy traffic.

The areas where lichen often found (range: 30 - less than 40) were sampling plots no. 36 and 39. The sampling plot no. 36 located on the Friendship Road was a location of two educational institutes with heavy traffic in the morning and late afternoon when daily school time was ended. As for at sampling plot no.39, it covered the areas of the Wing I and a golf course where were rather damp.

The areas where lichen was found very often (range: 40 - less than 50) were sampling plots no.8 and 34. The sampling plot no.8 covered the areas where two hospitals and a stadium located. So, traffic was heavy. During the survey period, the sampling plot no.34 was close to a road-construction area.

4.1.3.3 Frequency and distribution of *Pyxine cocoes*

Pyxine cocoes lichen was found growing on 187 mango trees in the municipality areas. This species distributed all over the study areas in the municipality. The highest frequency was 31 and was classified into five ranges as follows.

The ranges of frequency of lichen was divided into 5 ranges:

1) 0 = lichen not found

2) 1 - less than 10 = very little lichens found

3) 10 - less than 20 = little lichens found

4) 20 - less than 30 = fairly lichens found

5) 30 - less than 40 = lichens often found

Pyxine cocoes lichen was frequently found with frequency in a range of 30 to less than 40. This lichen species distributed over all studied areas and its frequency found in high-density residential areas, especially in less-density residential areas (Figure 4.6). *Pyxine cocoes* was distributed all over study areas, except in the sampling plot no.13 where this species was not found. The areas where very little numbers of this lichen (range: 0 - less than 10) found were sampling plots no. 5, 6, 12, 14, 15, 16, 20, 21, 22, 29, 32, 35, 38, 39 and 41where most were areas for agriculture with light traffic. Some areas had heavy traffic. There were some burning trails appeared in some agricultural areas and there were some road constructions.

The areas where little numbers of lichen (range: 10 - less than 20) found were sampling plots no. 2, 4, 7, 8, 9, 10 11, 17, 18, 19, 23, 24, 26, 27, 28, 30, 31, 33, 36, 37, 42, 43, 44, 45 and 46 where were both high-density and not high-density residential areas. In some areas, there were heavy traffic and small number of shade.

The areas where fairly numbers of lichen (range: 20 - less than 30) found were sampling plots no.1, 3, and 25 where were areas with high-density residence, especially for sampling plots no.1 which was a location of the Makro supermarket, and Suranaree market.

The area where lichen was often found (range: 30 - less than 40) was the sampling plots 40 where traffic was heavy since it was a location of governmental offices such as the Fort Suranaree hospital. It was also an entrance to the Wing I.

4.1.3.4 Frequency and distribution of *Lecanora leprosa*

Lecanora leprosa lichen was found growing on 163 mango trees. After calculation of lichen frequency of each sampling plot, it was found that this species distributed all over the study areas in the municipality. The highest frequency was 39 and was classified into five ranges as follows.

The ranges of frequency of lichen was divided into 5 ranges:

1) 0 = lichen not found

2) 1 - less than 10 = very little lichens found

3) 10 - less than 20 = little lichens found

4) 20 - less than 30 = fairly lichens found

5) 30 - less than 40 = lichens often found

Lecanora leprosa lichen was frequently found with frequency in a range of 30 to less than 40. This lichen species distributed over all study areas and its frequency found in high-density residential areas than the one in not high-density residential area (Figure 4.7). It was not found in sampling plots no. 13, 14 and 16. The areas where very little numbers of lichen (range: 0 – less than 10) found were sampling plots no. 1, 3, 5, 6, 8, 10, 11, 15, 17, 18, 19, 23, 24, 26, 29, 30, 32, 33, 35, 36, 42, 43, 44 and 46. The areas were composed of rice fields, schools, hospital, supermarket and residences, etc. with high-density communities, rather heavy traffic and abundant residences. Large buildings and residences provided shades to most areas. Small mango trees without any lichen growth were found in some areas.

The areas where little numbers of lichen (range: 10 - less than 20) found were sampling plots no. 2, 4, 7, 9, 12, 20, 21, 27, 28, 31, 38, 39 and 41, where mostly were communities in downtown with heavy traffic and small number of shade.

The areas where fairly numbers of lichen (range: 20 - less than 30) found were sampling plots no. 22, 25, 34 and 45 where most areas were high-density residence.

The area where lichen was often found (range: 30 - less than 40) was sampling plots no.37 which covered areas around the Mittapab highway and factories.

4.1.3.5 Frequency and distribution of *Opegrapha stirtonii*

Opegrapha stirtonii lichen was found growing on 191 mango trees. After calculation of lichen frequency of each sampling plot, it was found that this species distributed all over the study areas in the municipality. The highest frequency was 15 and was classified into three ranges as follows.

The ranges of frequency of lichen was divided into 3 ranges:

1) 0 = lichen not found

2) 1 - less than 10 = very little lichens found

3) 10 - less than 20 = little lichens found

Opegrapha stirtonii lichen was frequently found with frequency in a range of 10 to less than 20. This lichen species distributed over all study areas and its frequency found in high-density residential areas than the one in not high-density residential areas (Figure 4.8). The areas where this species was not found were sampling plots no. 1, 5, 9, 12, 19, 20, 21, 22, 26, 21, 33, 35, 36, 38, 42, 44 and 46 where were agricultural areas such as plantation, rice fields, schools, residences, etc.

The areas where very little numbers of lichen (range: 0 - less than 10) found were sampling plots no. 2, 3, 4, 6, 7, 10, 13, 14, 16, 17, 18, 23, 24, 25, 27, 29, 30, 34, 37, 39, 40, 41, 43 and 45 where were high-density residential areas with heavy traffic. Most areas obtained shades from buildings and residences. There was no burning trail of agricultural area.

The areas where little numbers of lichen (range: 10 - less than 20) found were sampling plots no. 8, 11, 15, 28 and 32 where were areas in downtown with heavy traffic and only some shades because there were only some trees.

4.1.3.6 Frequency and distribution of *Chrysothix xanthina*

The study on *Chrysothix xanthina* lichen in the municipality areas found that this species grown on 179 mango trees and distributed all over the studied areas in the municipality. The highest frequency was 34 and was classified into five ranges as follows.

The ranges of frequency of lichen was divided into 5 ranges:

1) 0 = lichen not found

2) 1 - less than 10 = very little lichens found

3) 10 - less than 20 = little lichens found

4) 20 - less than 30 = fairly lichens found

5) 30 - less than 40 = lichens often found

Chrysothix xanthina lichen was frequently found with frequency in a range of 30 to less than 40. This lichen species distributed over all study areas and its frequency found in high-density residential areas than the one in not high-density residential areas (Figure 4.9).

The areas where very little numbers of lichen (range: 0 - less than 10) found were sampling plots no. 2, 4, 6, 8, 13, 15, 17, 18, 19, 23, 24, 25, 27, 30, 33, 35, 36, 39, 40, 41, 43, 44 and 45 where most were areas of high-density residence. Some areas were less-density residence. There was no burning trail of agricultural area found.

The areas where little numbers of lichen (range: 10 - less than 20) found were sampling plots no.1, 3, 5, 7, 9, 10, 11, 14, 21, 22, 26, 29, 32, 34, 37 and 46 where

most areas were high-density residences.

The area where fairly number of lichen (range: 20 - less than 30) found was sampling plots no.31 where was not high-density residential area. It was a Bung Talua park area.

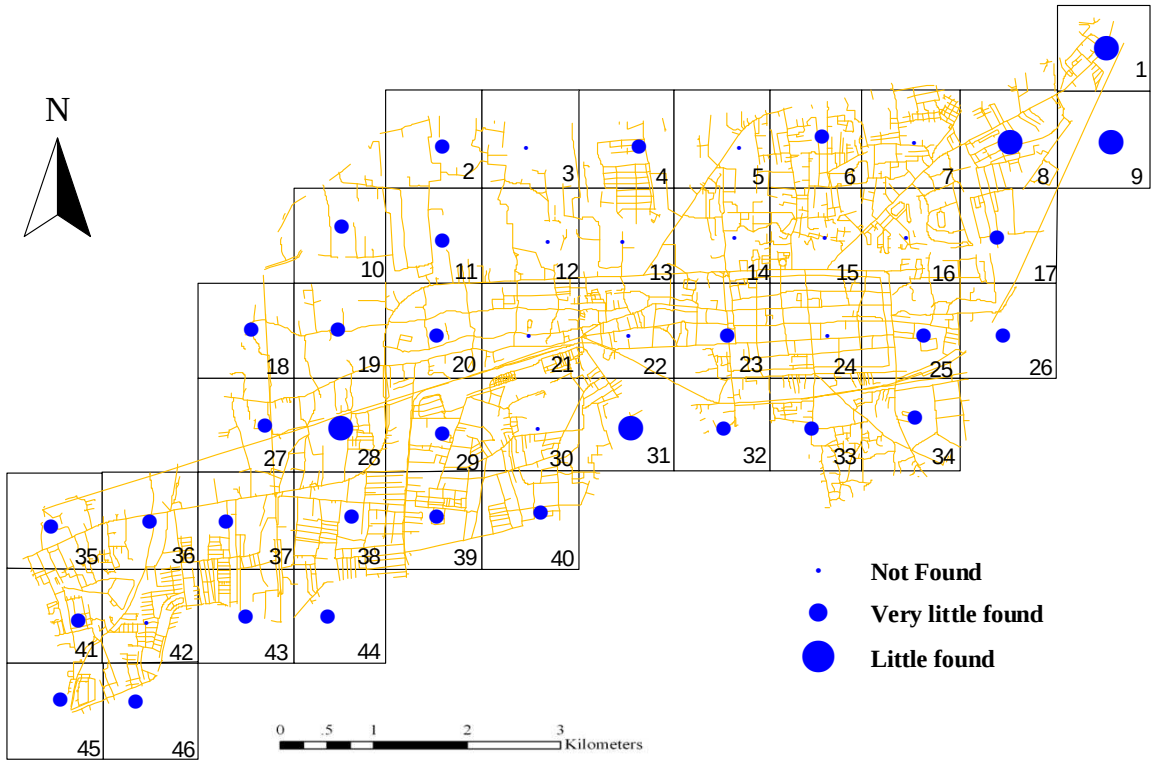


Figure 4.4 Frequency and distribution map of the *Dirinaria pica* in Nakhon Ratchasima municipality.

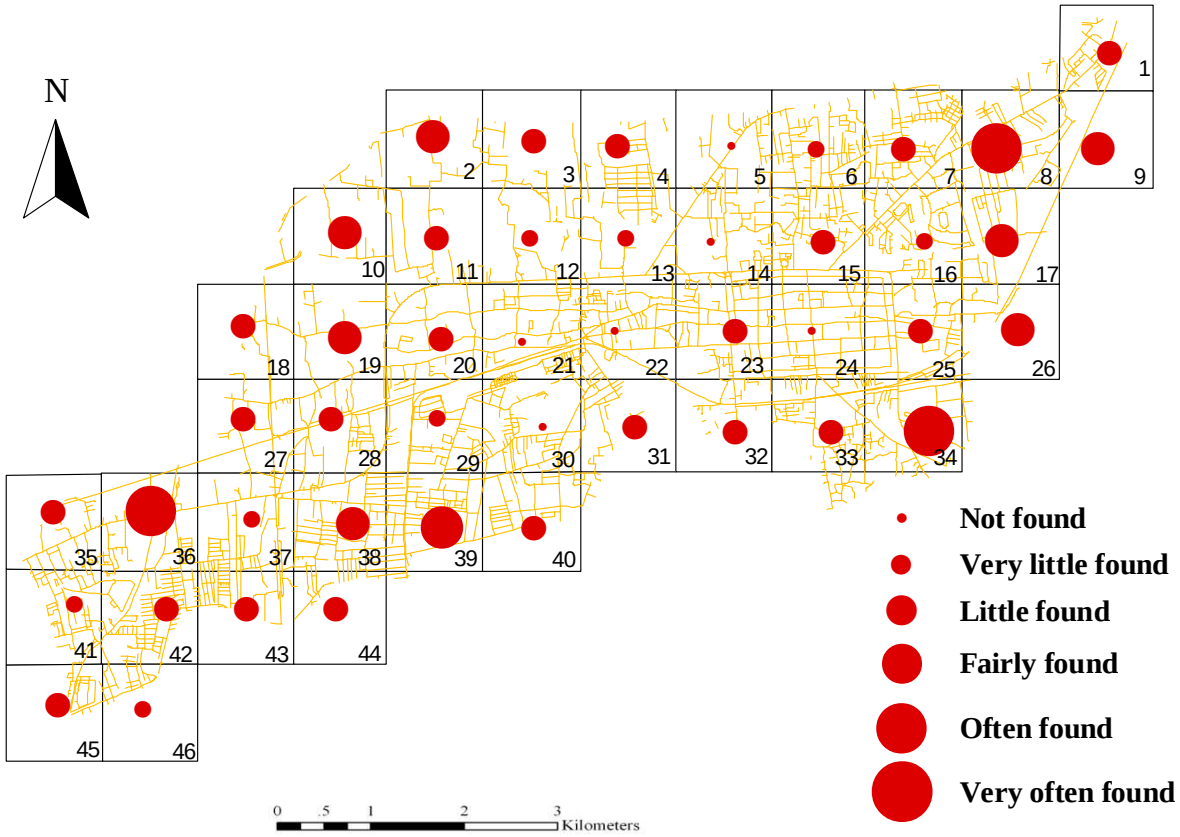


Figure 4.5 Frequency and distribution map of the *Hyperphyscia adglutinata* in Nakhon Ratchasima municipality.

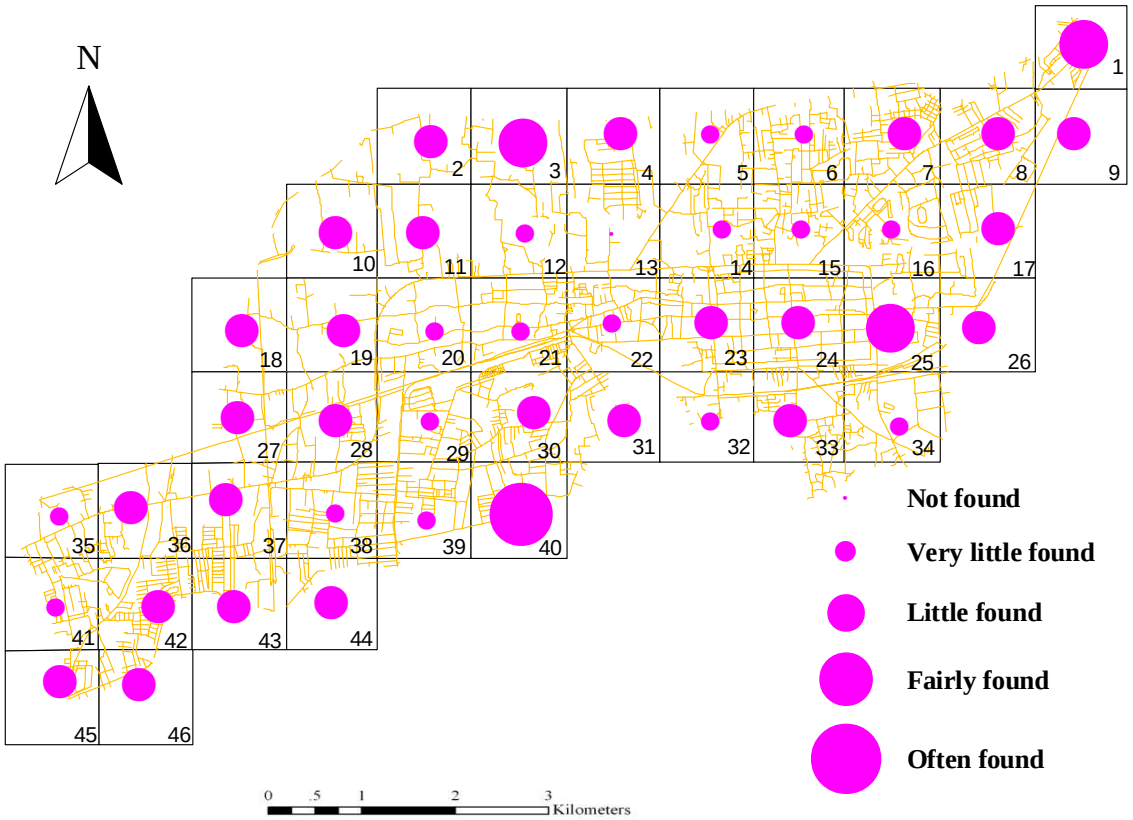


Figure 4.6 Frequency and distribution map of the *Pyxine cocoes* in Nakhon Ratchasima municipality.

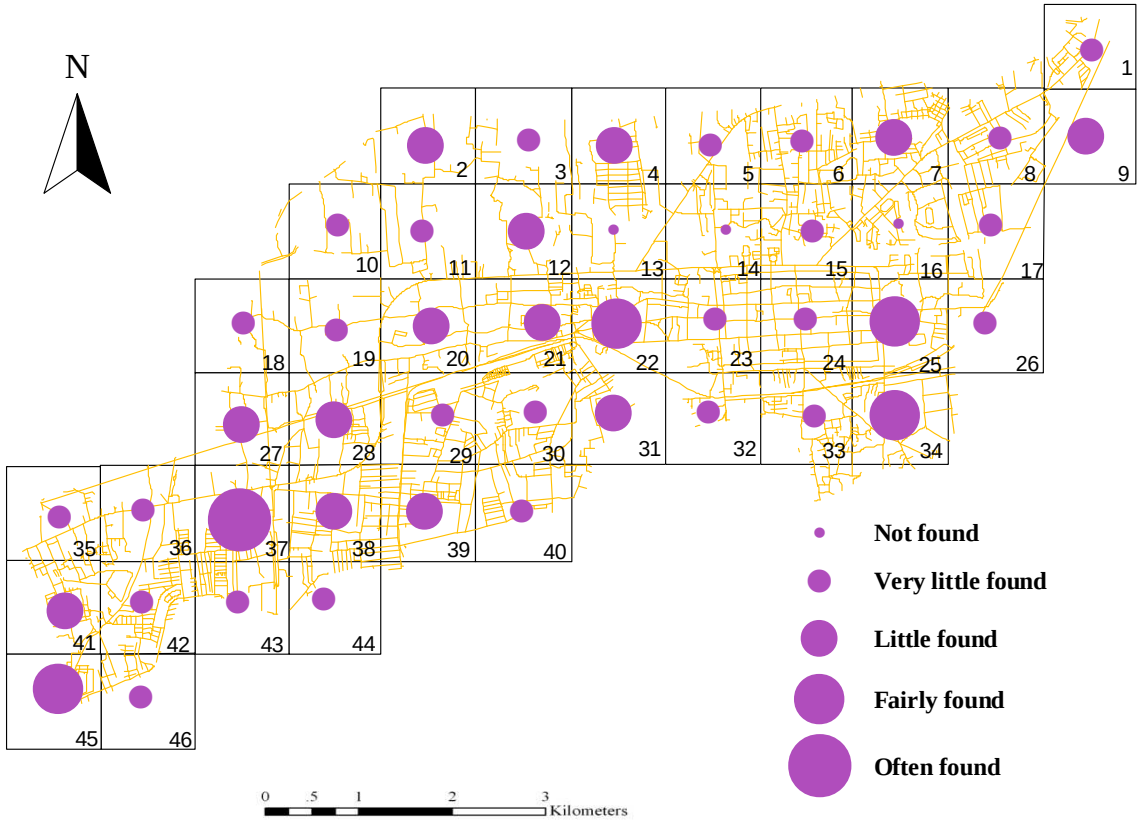


Figure 4.7 Frequency and distribution map of the *Lecanora leprosa* in Nakhon Ratchasima municipality.

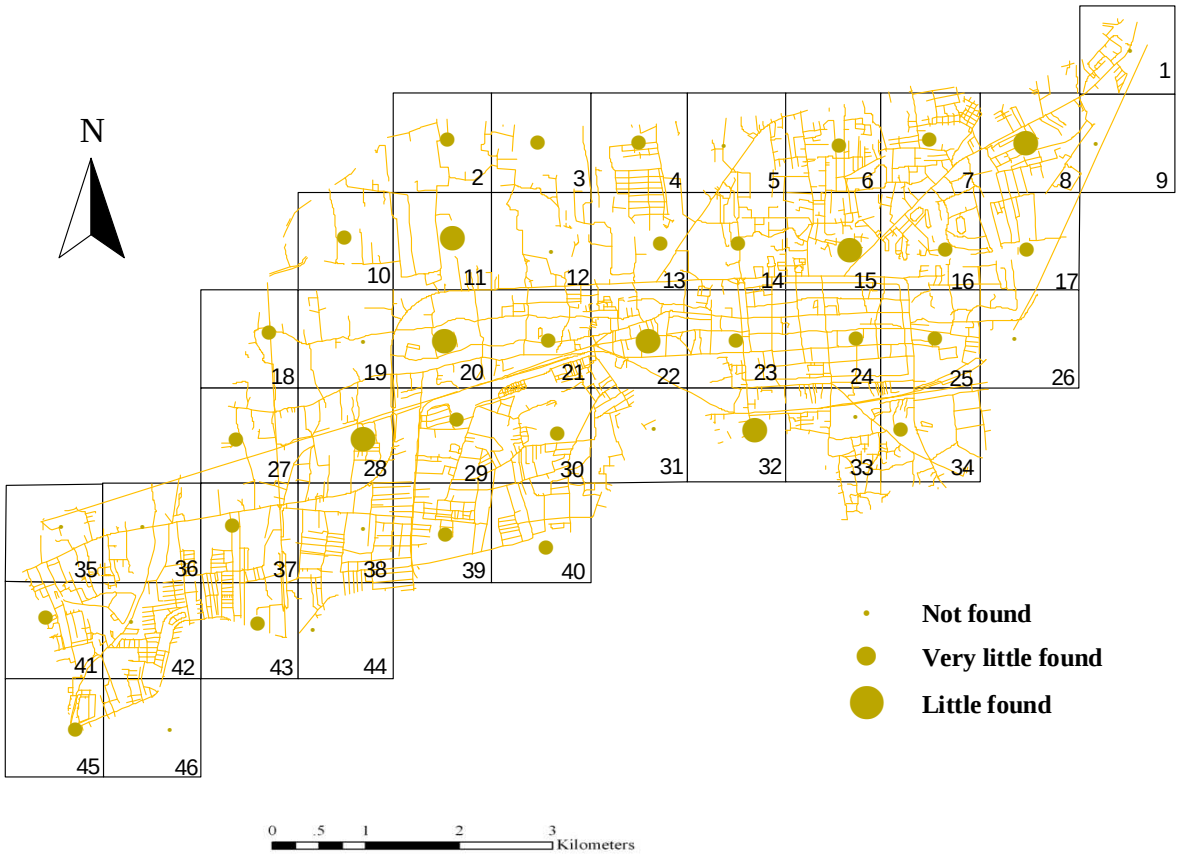


Figure 4.8 Frequency and distribution map of the *Opegrapha stirtonii* in Nakhon Ratchasima municipality.

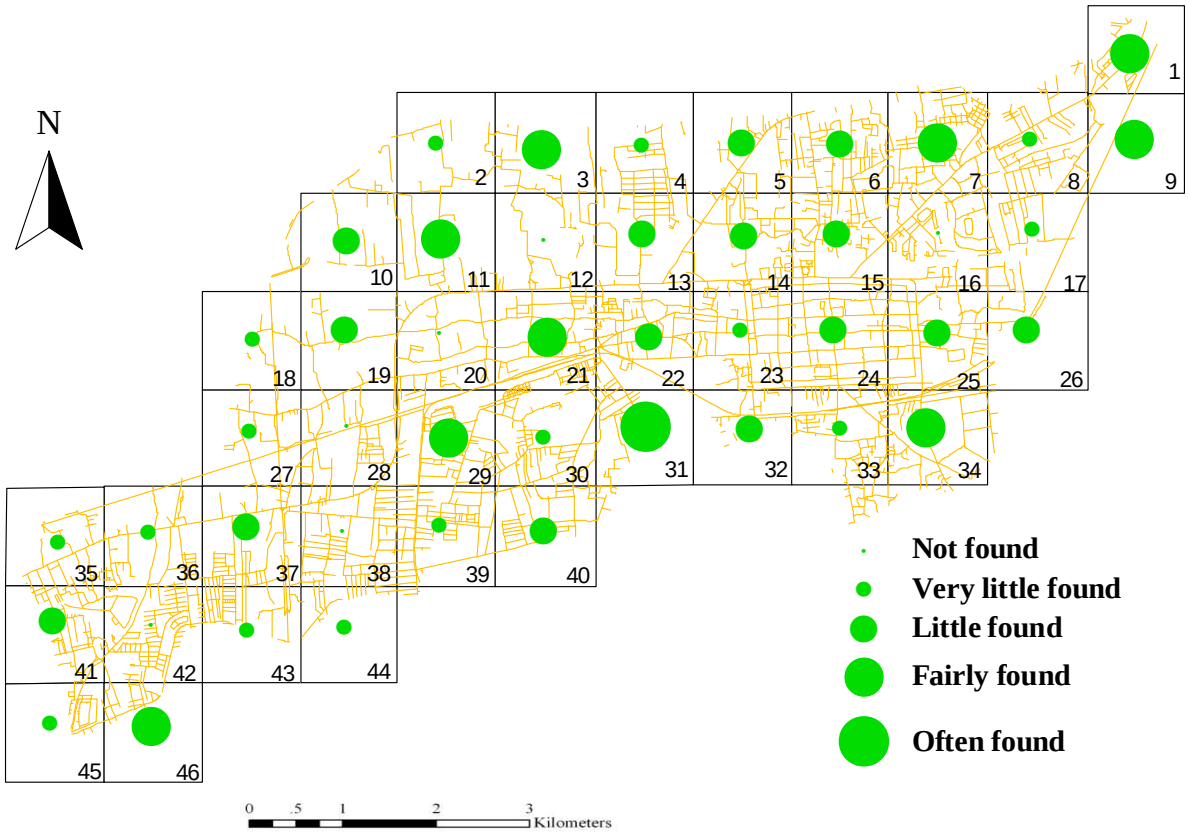


Figure 4.9 Frequency and distribution map of the *Chrysothix xanthina* in Nakhon Ratchasima municipality.

4.1.4 Environmental factor around mango trees in Nakhon Ratchasima municipality.

Environmental factor around the studied mango trees were expected as a factor influencing lichen growth. The studied context consisted of area condition, areas surrounding the study trees, traffic effects, tree bark characteristics, directions of lichens found on the trees, distance from study trees to roads, tree circumferences, and bark pH. Further details were as follows.

4.1.4.1 Area condition referred to buildings density around the studied trees (Figure 4.10). Area condition was divided into 3 groups:

1. High-density residential area: an area where was abundantly with buildings such as commercial buildings, connected buildings, etc. According to the survey, high density residential areas were comparable to 9% of the surveyed areas in the municipality.

2. Not high-density residential area: an area with medium-density buildings such as houses, temples with spaces, etc. According to the survey, not high-density residential areas were comparable to 61% of the surveyed areas in the municipality.

3. Open area: an area without buildings such as small parks, areas closed-to pools, etc. According to the survey, open areas were comparable to 30% of the surveyed areas in the municipality.

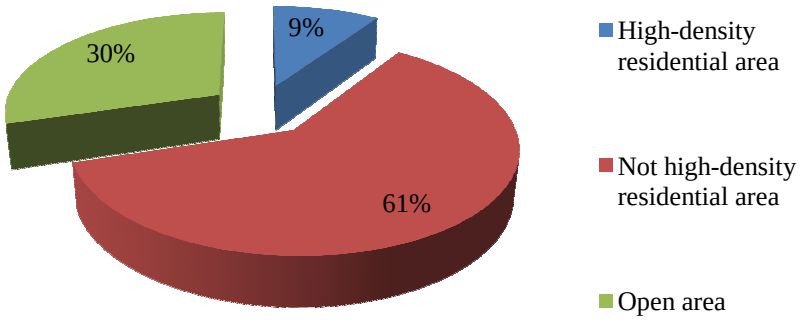


Figure 4.10 Percentage of each study area condition in Nakhon Ratchasima municipality.

It appeared that most of studied trees in the municipality areas were not high-density residential area. After an analysis of correlation between area condition and lichen frequency in each sampling plot by the Pearson's correlation coefficient was done, it was found that buildings density around was negative significant correlate with lichen frequency of each study area at 95% significant level (r = -0.100).

4.1.4.2 Areas surrounding the study trees (Figure 4.11) were divided into 3 main groups:

1. Lawn area: The study trees were surrounded by lawn area. According to the survey, lawn areas were comparable to 13% of the surveyed areas in the municipality.

2. Cement area: The study trees were surrounded by cement area. According to the survey, lawn areas were comparable to 10% of the surveyed areas in the municipality.

3. Ground area: The study trees were surrounded by ground area. According to the survey, lawn areas were comparable to 77% of the surveyed areas in the municipality.

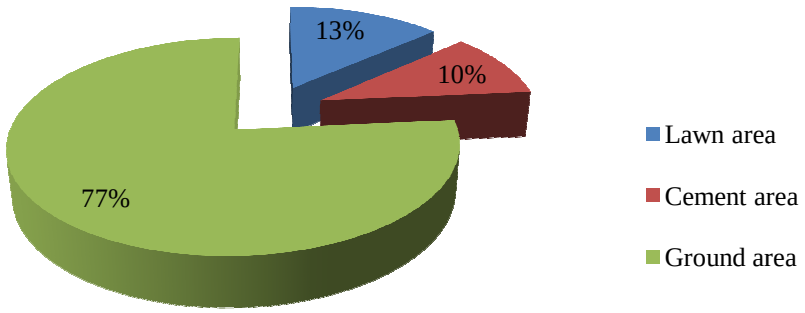


Figure 4.11 Percentage of each areas study surrounding the trees in Nakhon Ratchasima municipality.

It was presented that most of the study ground area, the rest of lawn area and cement area respectively. After an analysis of correlation between areas surrounding the studied trees and lichen frequency in each sampling plot by the Pearson's correlation coefficient was done, it was found that areas surrounding the studied trees negative significant correlate with lichen frequency of each study area at 95% significant level (r = -0.092).

4.1.4.3 Traffic effects

The study trees had different adjacent traffic conditions (Figure 4.12). These traffic conditions were classified into 6 aspects:

1. Public highway or super highway: It was a main road with 8-10 lanes and high-density traffic. According to the survey, this traffic aspect was comparable to 14% of the surveyed areas in the municipality.

2. Main road with high number of vehicles: It was a main road with 4-6 lanes and high-density traffic. According to the survey, this traffic aspect was comparable to 37% of the surveyed areas in the municipality.

3. Main road with low number of vehicles: It was a main road with 4-6 lanes and not high-density traffic. According to the survey, this traffic aspect was comparable to 13% of the surveyed areas in the municipality

4. Secondary road with high number of vehicles: It was a main road with 2 lanes with high-density traffic. According to the survey, this traffic aspect was comparable to 25% of the surveyed areas in the municipality.

5. Secondary road with low number of vehicles: It was a main road with 2 lanes and not high-density traffic. According to the survey, this traffic aspect was comparable to 11% of the surveyed areas in the municipality.

6. Lateritic-soil road: It was a road made of lateritic soils with no asphalt or cement on top and not high-density traffic. According to the survey, this traffic aspect was not found in the surveyed areas.

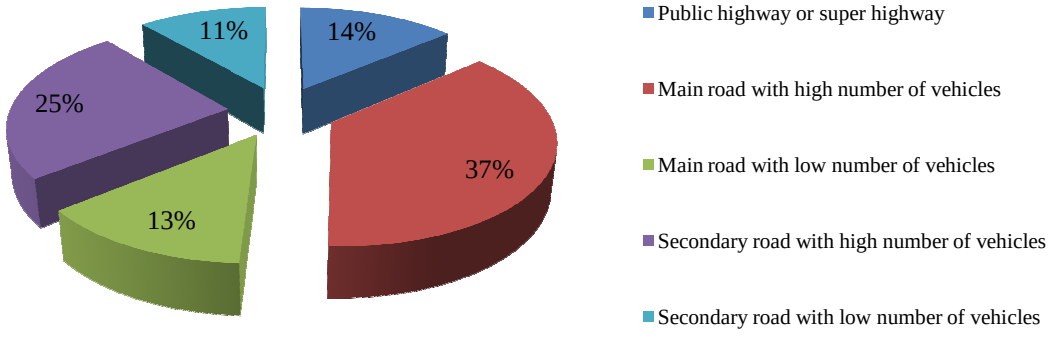


Figure 4.12 Percentage of road and traffic density of each studied traffic condition in Nakhon Ratchasima municipality.

It was presented that most of the studied trees near with main road with high number of vehicles the rest of trees near with secondary road with high number of vehicles, public highway or super highway, main road with low number of vehicles and secondary road with low number of vehicles, respectively. After an analysis of

correlation between traffic effects and lichen frequency in each sampling plot by the Pearson's correlation coefficient was done, it was found that traffic effects did not significant correlate with lichen frequency of each study area at 95% significant level (r = 0.126).

4.1.4.4 Tree bark characteristics

According to a survey form, tree bark characteristics (Figure 4.13) could be classified into 3 groups:

1. Smooth bark: A bark was smooth and thin with not many cracks. According to the tree survey in the municipality areas, 29% of smooth barks were found in the surveyed areas.

2. Average smooth bark: A bark was a little thicker than the smooth bark and not smooth with fairly cracks. According to the tree survey in the municipality areas, 52% of average smooth barks were found in the surveyed areas.

3. Deep-wrinkle bark: A bark was rough and the thickest among these three characteristics with large and deep cracks. According to the tree survey in the municipality areas, 19% of deep-wrinkle barks were found in the surveyed areas.

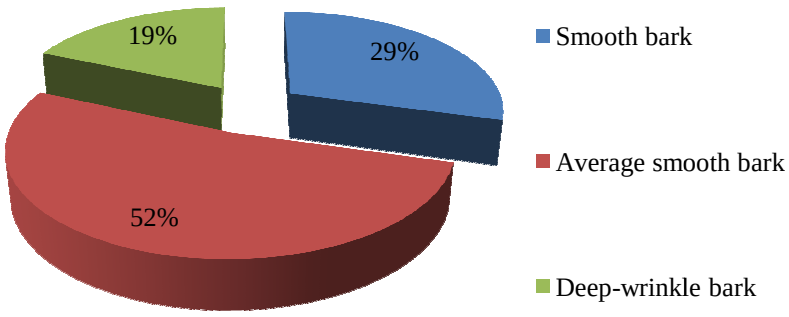


Figure 4.13 Percentage of each study bark characteristic in Nakhon Ratchasima municipality.

It was presented that most of the study average smooth bark the rest of trees had smooth bark and deep-wrinkle bark, respectively. After an analysis of correlation between bark characteristic and lichen frequency in each sampling plot by the Pearson's correlation coefficient was done, it was found that bark characteristic negative significant correlate with lichen frequency of each study area at 95% significant level (r = -0.011).

4.1.4.5 Directions of lichens found on the trees

Due to the record about directions of survey frame setting on the tree trunks at the sides where the most lichens or most diversity were found, it appeared that most lichens were found in the northeast and the north of the trunks, respectively (Figure 4.14).

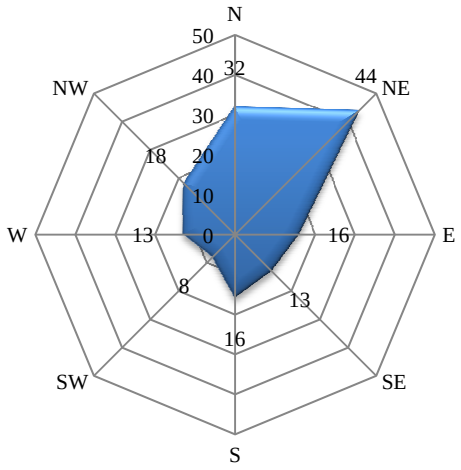


Figure 4.14 Directions of lichens found on the study trees in Nakhon Ratchasima municipality.

It was presented northeast that most lichen of the study the rest of presented lichen had north, south, northwest, east, southeast and west, respectively. After an analysis of correlation between directions of lichens found on the study trees and

lichen frequency in each sampling plot by the Pearson's correlation coefficient was done, it was found that directions of lichens found on the study trees negative significant correlate with lichen frequency of each study area at 95% significant level (r = -0.143).

4.1.4.6 Distance from study trees to roads

From the study on distance from study trees to roads of areas in the municipality, distance could be divided into ranges i.e. 1-5 m, 5-10 m, 10-15 m, 15-20 m and longer that 20 m (Figure 4.15). In the municipality areas, it was found that each distance range was calculated into 80%, 14%, 3%, 1% and 2% of all surveyed trees of these areas, respectively.

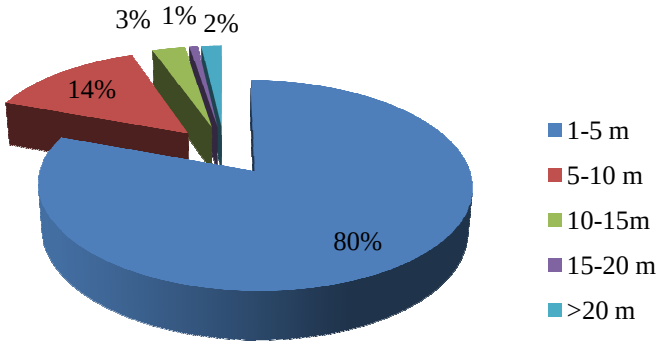


Figure 4.15 Percentage of distance from study trees to roads in Nakhon Ratchasima municipality.

It appeared that most of studied trees in the municipality areas were 1-5 m far from roads the rest of trees were 5-10 m, 10-15 m, 15-20 m and above 20 m far from roads, respectively. After an analysis of correlation between distance from studied trees to roads and lichen frequency in each sampling plot by the Pearson's correlation

coefficient was done, it was found that distance from road to tree significantly correlate with lichen frequency of each study area at 95% significant level (r = 0.016).

4.1.4.7 Tree circumferences at the level of 1 meter height from the ground

Circumferences of the studied trees were different. It was found that most big trees in areas of the municipality had average circumferences at 93.5 cm (Figure 4.16).

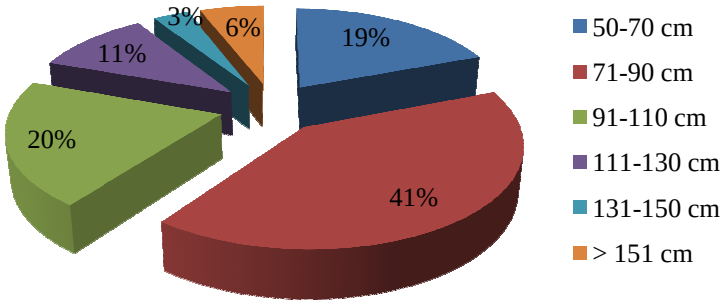


Figure 4.16 Circumferences of the study trees in Nakhon Ratchasima municipality.

It was presented that most of the studied trees had 71-90 cm. of circumference the rest of trees had circumferences of 91-110 cm., 50-70 cm., above 150 cm., and 131-150 cm., respectively. After an analysis of correlation between tree trunk circumference and lichen frequency in each sampling plot by the Pearson's correlation coefficient was done, it was found that trunk circumference significant correlate with lichen frequency of each study area at 95% significant level (r = -0.003).

4.1.4.8 Bark pH

According to the pH test of the barks of 276 studied mango trees in 46 sampling plots, it was found that the average pH was at 5.09-5.62 indicating that bark pH of all studied areas represented acid condition. The pH ranges of barks in Nakhon Ratchasima municipality areas could be divided into three ranges i.e. 5.09-5.27, 5.28-5.46 and 5.47-5.65. The mostly found range was 5.47-5.65 or calculated as 54% of all studied trees in the municipality areas. The next one was the range of 5.28-5.46 or calculated as 28%, while the range of 5.09-5.27 found in only 18% of all study trees in the mentioned areas (Figure 4.17).

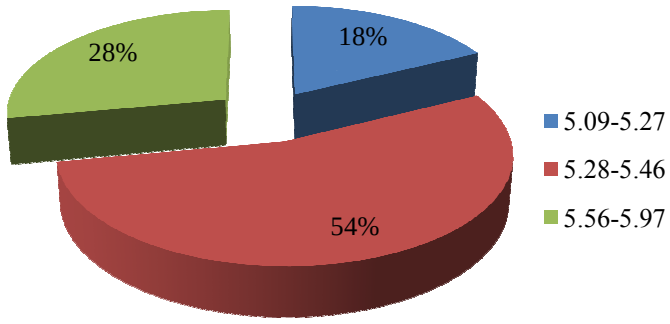


Figure 4.17 The pH of study barks in Nakhon Ratchasima municipality.

The study area where barks had the lowest average pH was the sampling plot no. 38 (5.09) and the area with the highest average pH was the sampling plot no.16 (5.62) as presented in Table 4.17. According to the analysis of bark pH of each studied area for average pH differences by one-way ANOVA, it was found that bark pH of sampling plot were not significantly different as demonstrated in Table 4.4.

After an analysis of correlation between bark pH and lichen frequency in each sampling plot by the Pearson's correlation coefficient was done, it was found that

bark pH significant correlate with lichen frequency of each study area at 95% significant level ($r = 0.020$).

Regarding an analysis of correlation between bark pH and lichen diversity index of each studied area using Pearson's correlation coefficient, the results indicated that the bark pH was not correlate to the AQI of each sampling plot (Figure 4.18).

Table 4.4 Average bark pH of mango tree barks in each study area.

Sampling plots	Bark pH ± SD	AQI	Sampling plots	Bark pH ± SD	AQI
1	5.49±0.28^{abc}	20.5	24	5.56±0.34^{bc}	6.3
2	5.52±0.29^{bc}	23.0	25	5.31±0.08^{abc}	10.5
3	5.54±0.24^{bc}	18.7	26	5.32±0.32^{abc}	15.0
4	5.32±0.18^{abc}	19.2	27	5.45±0.41^{abc}	12.5
5	5.39±0.33^{abc}	14.2	28	5.50±0.33^{abc}	14.5
6	5.44±0.10^{abc}	17.0	29	5.54±0.44^{bc}	6.3
7	5.37±0.24^{abc}	19.5	30	5.17±0.22^{ab}	7.2
8	5.47±0.37^{abc}	21.7	31	5.26±0.27^{abc}	29.2
9	5.30±0.22^{abc}	25.5	32	5.42±0.41^{abc}	21.7
10	5.27±0.18^{abc}	23.7	33	5.21±0.22^{abc}	20.7
11	5.47±0.26^{abc}	21.8	34	5.25±0.26^{abc}	14.8
12	5.50±0.30^{a}	13.0	35	5.38±0.22^{abc}	12.3
13	5.56±0.38^{bc}	8.3	36	5.42±0.35^{abc}	15.5
14	5.36±0.21^{abc}	7.5	37	5.39±0.41^{abc}	16.0
15	5.57±0.32^{bc}	7.0	38	5.09±0.23^{a}	6.7
16	5.62±0.25^{c}	9.5	39	5.18±0.22^{ab}	12.5
17	5.33±0.26^{abc}	10.8	40	5.44±0.31^{abc}	20.5
18	5.33±0.31^{abc}	15.5	41	5.35±0.23^{abc}	18.7
19	5.41±0.37^{abc}	13.5	42	5.23±0.34^{abc}	14.5
20	5.31±0.22^{abc}	10.7	43	5.39±0.27^{abc}	16.0
21	5.16±0.20^{ab}	4.7	44	5.41±0.19^{abc}	15.3
22	5.25±0.16^{abc}	5.8	45	5.29±0.18^{abc}	19.7
23	5.44±0.49^{abc}	8.5	46	5.26±0.10^{abc}	16.7

Remark: a, b, and c significantly presented average bark pH. The sets of data with same alphabet did not show statistic difference (one-way ANOVA, $p < 0.05$).

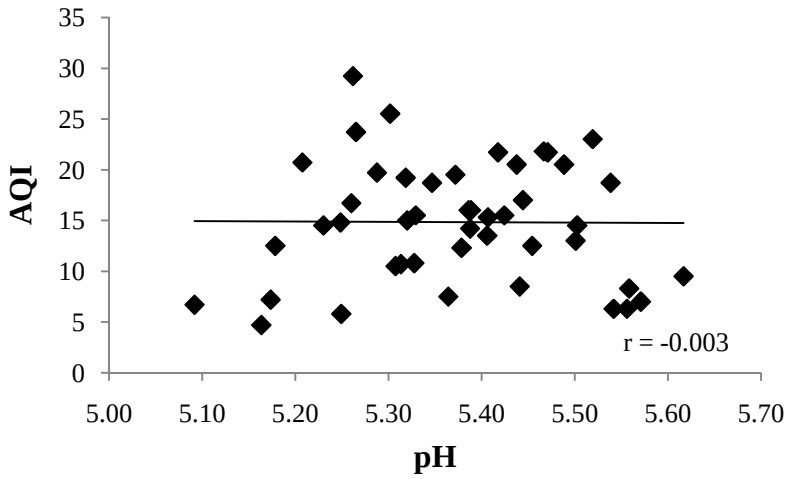


Figure 4.18 Correlation between bark pH and AQI in Nakhon Ratchasima municipality.

4.2 Making Nakhon Ratchasima municipality air quality map by lichen frequency.

The calculation of total lichen frequency appearing in grid frames on 276 mango trees in 46 sampling plots was conducted. After the total frequency of lichen in the study areas was obtained, it was used for analysis of an Air Quality Index (AQI), standard deviation, lower limit and upper limit (Table 4.5).

Table 4.5 Total frequency of lichen appearing on the study trees, Air Quality Index (AQI), standard deviation (S), lower limit (L_1) and upper limit (L_2).

Sampling plot	Frequencies of lichen						F_{ij}	AQI	S	L1	L2
	1	2	3	4	5	6					
1	12	20	25	23	12	31	123	20.5	45.8	-27.6	68.6
2	16	28	23	32	19	20	138	23.0	51.4	-31.0	77.0
3	18	15	28	12	16	23	112	18.7	41.7	-25.1	62.5
4	16	24	20	16	18	21	115	19.2	42.9	-25.8	64.1
5	24	12	5	0	21	23	85	14.2	31.7	-19.1	47.4
6	20	13	25	12	10	22	102	17.0	38.0	-22.9	56.9
7	26	24	18	8	16	25	117	19.5	43.6	-26.3	65.3
8	26	20	24	19	23	18	130	21.7	48.4	-29.2	72.5
9	24	33	18	25	31	22	153	25.5	57.0	-34.3	85.3
10	30	22	26	21	19	24	142	23.7	52.9	-31.9	79.2
11	24	25	28	11	20	23	131	21.8	48.8	-29.4	73.1
12	15	22	10	23	8	0	78	13.0	29.1	-17.5	43.5
13	3	0	20	17	10	0	50	8.3	18.6	-11.2	27.9
14	17	10	13	0	0	5	45	7.5	16.8	-10.1	25.1
15	0	15	0	19	8	0	42	7.0	15.7	-9.4	23.4
16	7	0	21	24	0	5	57	9.5	21.2	-12.8	31.8
17	11	10	12	8	16	8	65	10.8	24.2	-14.6	36.3
18	12	15	6	18	26	16	93	15.5	34.7	-20.9	51.9
19	13	12	0	17	18	21	81	13.5	30.2	-18.2	45.2
20	0	22	16	12	0	14	64	10.7	23.9	-14.4	35.7
21	16	0	4	8	0	0	28	4.7	10.4	-6.3	15.6
22	10	9	10	0	6	0	35	5.8	13.0	-7.9	19.5
23	11	0	14	14	0	12	51	8.5	19.0	-11.4	28.4

Table 4.5 (Continued) Total frequency of lichen appearing on the study trees, Air Quality Index (AQI), standard deviation (S), lower limit (L_1) and upper limit (L_2).

Sampling plot no.	Frequencies of lichen						F_{ij}	AQI	S	L1	L2
	1	2	3	4	5	6					
24	12	0	0	16	10	0	38	6.3	14.2	-8.5	21.2
25	0	18	15	0	12	18	63	10.5	23.5	-14.1	35.1
26	9	20	10	10	25	16	90	15.0	33.5	-20.2	50.2
27	18	20	8	5	21	3	75	12.5	28.0	-16.8	41.8
28	15	22	0	10	14	26	87	14.5	32.4	-19.5	48.5
29	6	8	0	10	14	0	38	6.3	14.2	-8.5	21.2
30	0	15	0	10	18	0	43	7.2	16.0	-9.6	24.0
31	30	31	26	27	28	33	175	29.2	65.2	-39.3	97.6
32	28	26	17	14	20	25	130	21.7	48.4	-29.2	72.5
33	24	16	23	21	25	15	124	20.7	46.2	-27.8	69.2
34	18	24	10	0	12	25	89	14.8	33.2	-20.0	49.6
35	8	10	22	10	21	3	74	12.3	27.6	-16.6	41.3
36	4	8	25	16	18	22	93	15.5	34.7	-20.9	51.9
37	26	21	8	16	9	16	96	16.0	35.8	-21.5	53.5
38	8	0	13	15	4	0	40	6.7	14.9	-9.0	22.3
39	16	20	0	2	17	20	75	12.5	28.0	-16.8	41.8
40	18	27	15	23	13	27	123	20.5	45.8	-27.6	68.6
41	26	9	21	12	25	19	112	18.7	41.7	-25.1	62.5
42	15	13	20	5	18	16	87	14.5	32.4	-19.5	48.5
43	18	12	10	22	15	19	96	16.0	35.8	-21.5	53.5
44	25	10	12	18	10	17	92	15.3	34.3	-20.6	51.3
45	19	18	14	18	23	26	118	19.7	44.0	-26.5	65.8
46	16	23	10	21	20	10	100	16.7	37.3	-22.4	55.8

From Table 4.5, after a calculation for air quality index, it was found that the air quality index of the sampling plot no.21 was 4.7 which was the least value. This sampling plot covered areas of the Khon Kaen intersection, a road in front of the Big C supermarket, and the Nakhon Ratchasima transportation station. The highest air quality index was found at the sampling plot no.31 which was 29.2. This sampling plot covered the areas of the Hermitage hotel, farming fields, and the Nakhon Ratchasima waste water treatment pond where were undisturbed areas covered with many weeds. In Table 4.6, the calculated results shown were calculated for width of air quality ranks using equations 3.4 and 3.5.

Table 4.6 The range of air quality classes, sum of all squared deviations, mean number of trees per examined unit and mean squared deviation of the survey.

	Value
Sum of all squared deviations	12200.7
Mean number of trees per examined unit (n_p)	6
Mean squared deviation of the survey (S_p)	7.3
Range of air quality classes	7.6

In a survey of the study areas, areas with different air qualities could be divided by drawing three isolines which represented air quality indices of 7.6, 15.2 and 25.5. Air quality class arrangement of the study areas was classified into four classes. When comparing to the VDI standard scale (Figure 4.19) and being replaced by obviously different colors in order to clearly see air quality differences (Table 4.7 and 4.8), it appeared that the areas with an extent of the isoline at 7.6 were areas

where there were very high air pollution, represented by the red and contained eight sampling plots i.e. 14, 15, 21, 22, 24, 29 and 38. At the same time, areas with an extent of the isoline 7.6-15.2 were areas where there were high-very high air pollution, represented by the orange-red and contained 16 sampling plots i.e. 5, 12, 13, 16,17, 19, 20, 23, 25, 26, 27, 28, 34, 35 and 42. The areas with an extent of the isoline 15.2-22.5 were the areas where expected to have high air pollution, represented by the orange and contained 17 sampling plots i.e. 1, 3, 4, 7, 8, 11, 18, 32, 33, 36, 37, 40, 41, 43, 44, 45 and 46. Lastly, areas within an extent of isoline of 22.5 and more where had fair-high air pollution contained four sampling plots i.e. 2, 9, 10 and 31. These sampling plots covered areas of public parks, agricultural fields and undisturbed forest. The colour codes of air quality classes 2 and 4 in this study were indicated by the combined colour codes of the two classes because their ranges overlapped low air quality classes according to the VDI standard scale.

Table 4.7 The air quality classes in the study area by the VDI standard scale (VDI, 1995).

AQC	AQI	Air pollution	Colour in map
1	$0.0<AQI\leq7.6$	very high	red
2	$7.6<AQI\leq15.2$	very high to high	orange to red
3	$15.2<AQI\leq22.8$	high	orange
4	$22.8<AQI\leq30.4$	high to moderate	yellow to orange

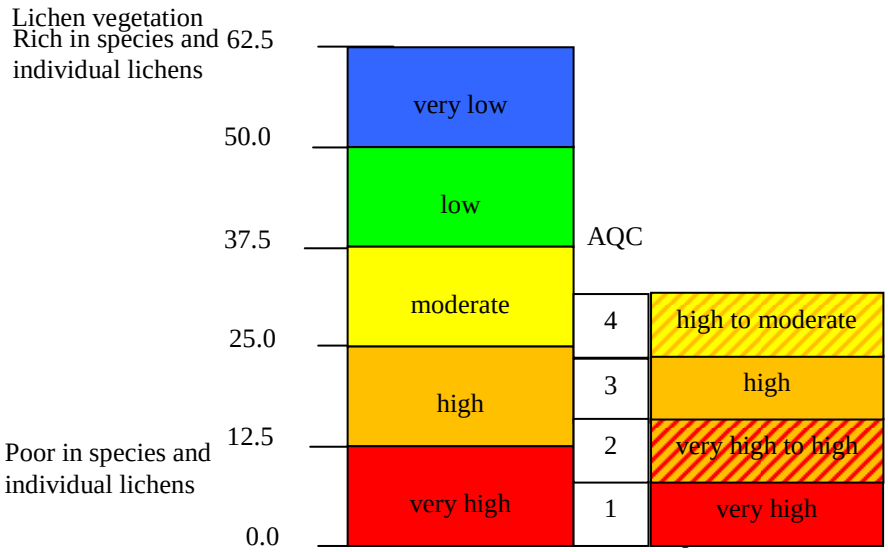


Figure 4.19 Comparison between VDI standard scale and exposure scale.

Table 4.8 Air quality classes (AQC) and their levels of air pollution.

Sampling plot	AQI	Impact scale	Impact	Limit of AQC	Level of air pollution	AQC
21	4.7					
22	5.8					
24	6.3					
29	6.3	0.0 < AQI ≤ 12.5		0.0 < AQI ≤7.6	Very high	1
38	6.7					
15	7.0					
30	7.2					
14	7.5		Very high			
13	8.3					
23	8.5					
16	9.5				High	
25	10.5			7.6 < AQI ≤ 15.2	to	2
20	10.7				Very high	
17	10.8					
35	12.3					
27	12.5					
39	12.5					

Table 4.8 (Continued) Air quality classes (AQC) and their levels of air pollution.

Sampling plot	AQI	Impact scale	Impact	Limit of AQC	Level of air pollution	AQC
12	13.0					
19	13.5					
5	14.2				High	
28	14.5			7.6 < AQI ≤ 15.2	to	2
42	14.5				Very high	
34	14.8					
26	15.0					
44	15.3					
18	15.5					
36	15.5					
37	16.0					
43	16.0					
46	16.7					
6	17.0	12.5 < AQI ≤ 25.0	High	15.2 < AQI ≤ 22.9	High	3
3	18.7					
41	18.7					
4	19.2					
7	19.5					
45	19.7					
1	20.5					
40	20.5					
33	20.7					
8	21.7					
32	21.7					
11	21.8					
2	23.0					
10	23.7			22.9 < AQI ≤30.5	Moderate	4
9	25.5	25.5 < AQI ≤ 37.5	Moderate		to	
31	29.2				High	

From Table 4.8, the air quality results in Nakhon Ratchasima municipality using lichen mapping are demonstrated in two figures. The first air quality map, (Figure 4.20) presents each sampling plots coloured according to the air quality class. Another lichen map (Figure 4.21) presents the isoline indicating the air quality zone.

The percentages of total areas in each air quality class (Figure 4.22).

Air quality index (AQI) of class 1 varied from $0.0<AQI\leq7.6$, which represented very high air pollution. This classification covered 17% of the study area. This class was located in the central area, which had the highest volume of traffic and the highest density of human population.

Air quality class 2 varied from $7.6<AQI\leq15.2$, which represented very high to high air pollution. This classification covered 35% of the study area. This class consisted of suburban areas, highway and main roads but the human population density was lower than the central area.

Air quality class 3 varied from $15.2<AQI\leq22.8$, which represented high air pollution. This classification covered 39% of study area and occupied village areas with the low human population density.

Air quality class 4, varied from $22.8<AQI\leq30.4$, which represented high to moderate air pollution. This classification covered 9% of study area of agricultural areas and some villages.

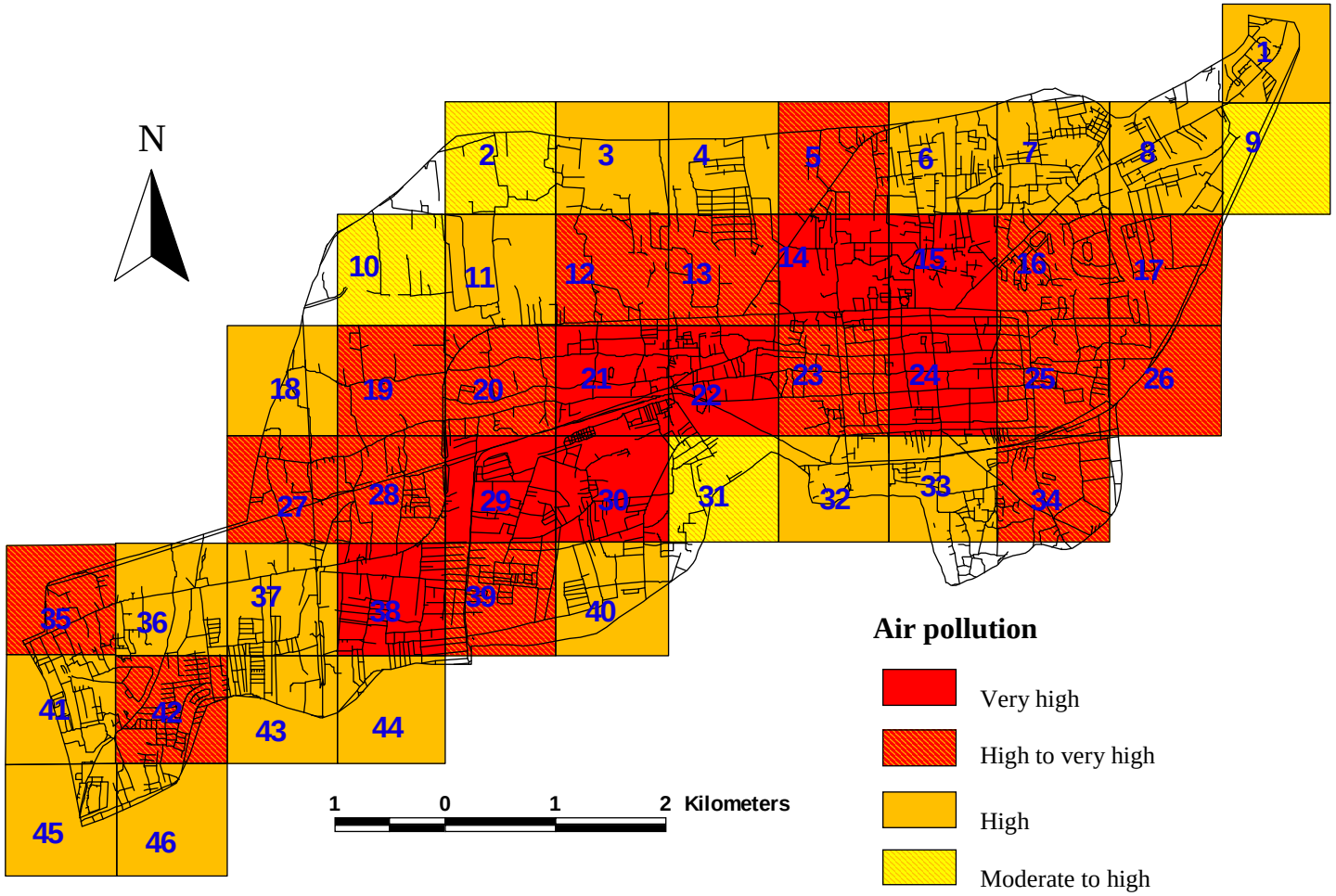


Figure 4.20 Map of lichens indicating air quality in Nakhon Ratchasima municipality.

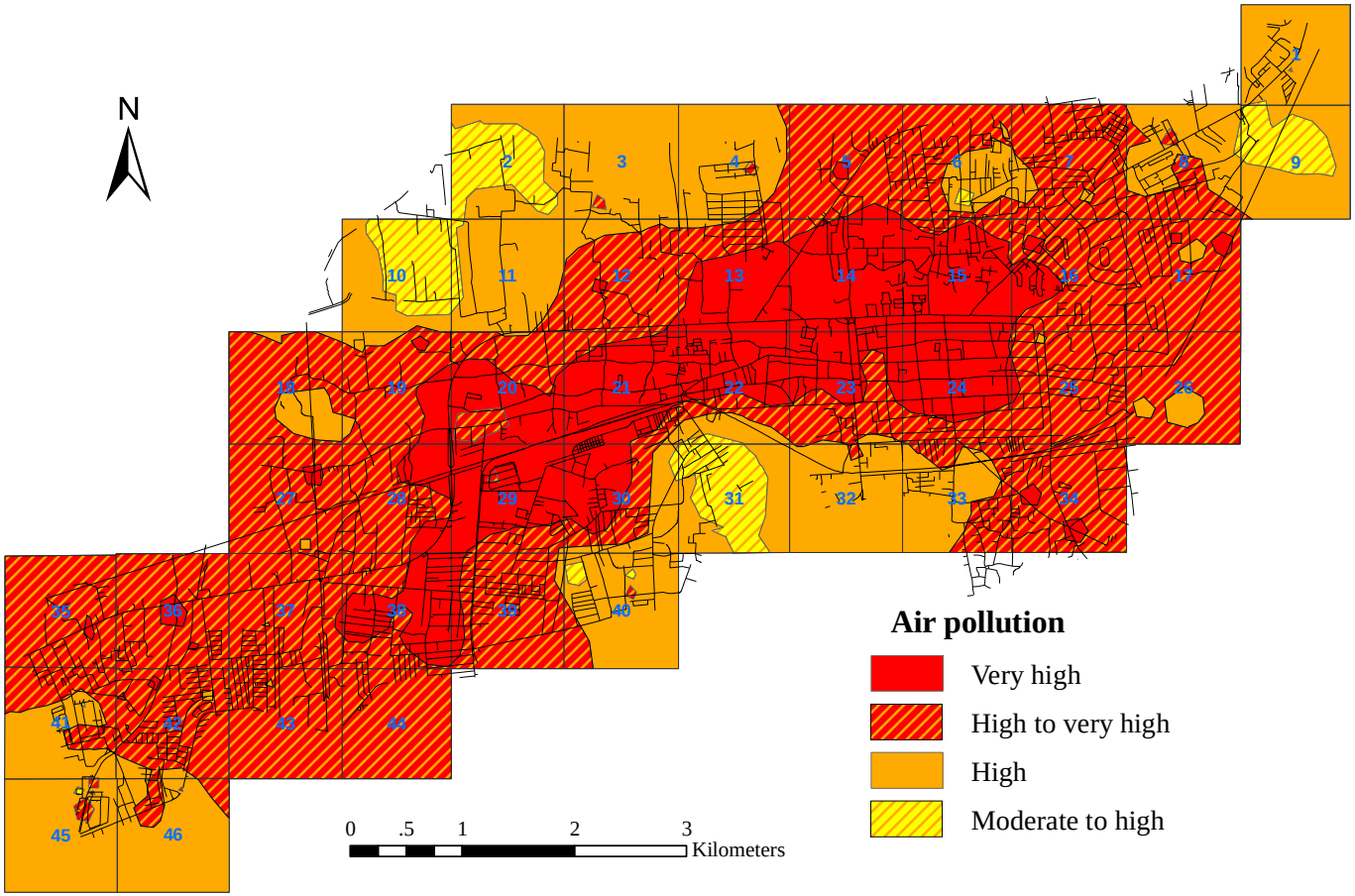


Figure 4.21 Map of the linear interpolation of the air quality values of neighbouring in Nakhon Ratchasima municipality.

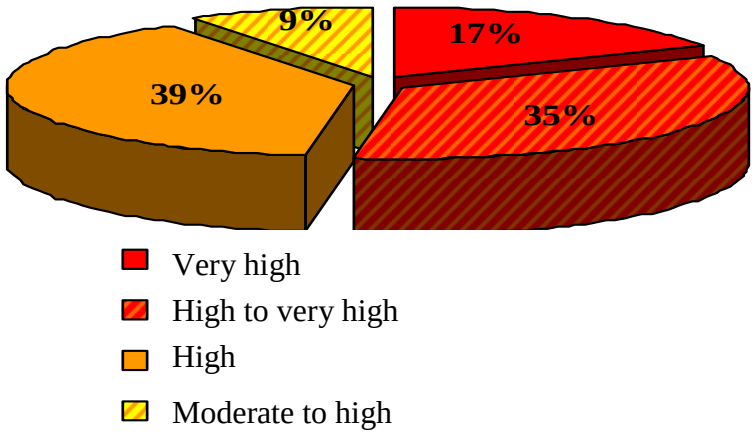


Figure 4.22 Percentage of landscape in each air pollution.

4.3 Measurement of nitrogen dioxide and sulphur dioxide

Measurement of nitrogen dioxide and sulphur dioxide in the air was conducted by using the passive sampling in all 46 sampling plots. Air samples in the rainy season were collected on 3-17 August 2009 and in the winter season was on 3-17 October 2009. The samples were collected through four air sample tubes contained in a preventing box, 4 tubes/studied area. The sample tubes were hung in the sites for 15 days. The locations of sampling sites were presented in Figure 4.23.

After 15 days, sample tubes with air inside were carried back and sample air was analyzed for nitrogen dioxide and sulphur dioxide in the form of nitrate ion (NO_2^-) and sulfate ion (SO_4^{2-}) using ion chromatography technique. Concentration of NO_2^- and SO_4^{2-} in ppm from ion chromatography machine could be calculated by using a standard graph in the rainy season and in the winter season.

Nitrogen dioxide concentration in the air in each sampling plot was calculated using equation 2.5 in $\mu g/m^3$ unit, then, calculated by an equation 2.6 and finally, nitrogen dioxide in a unit of ppbv was obtained.

Sulphur dioxide concentration in the air in each sampling plot was calculated using equation 2.5 in $\mu g/m^3$ unit, then, calculated by an equation 2.7 and finally, sulfur dioxide in a unit of ppbv was obtained.

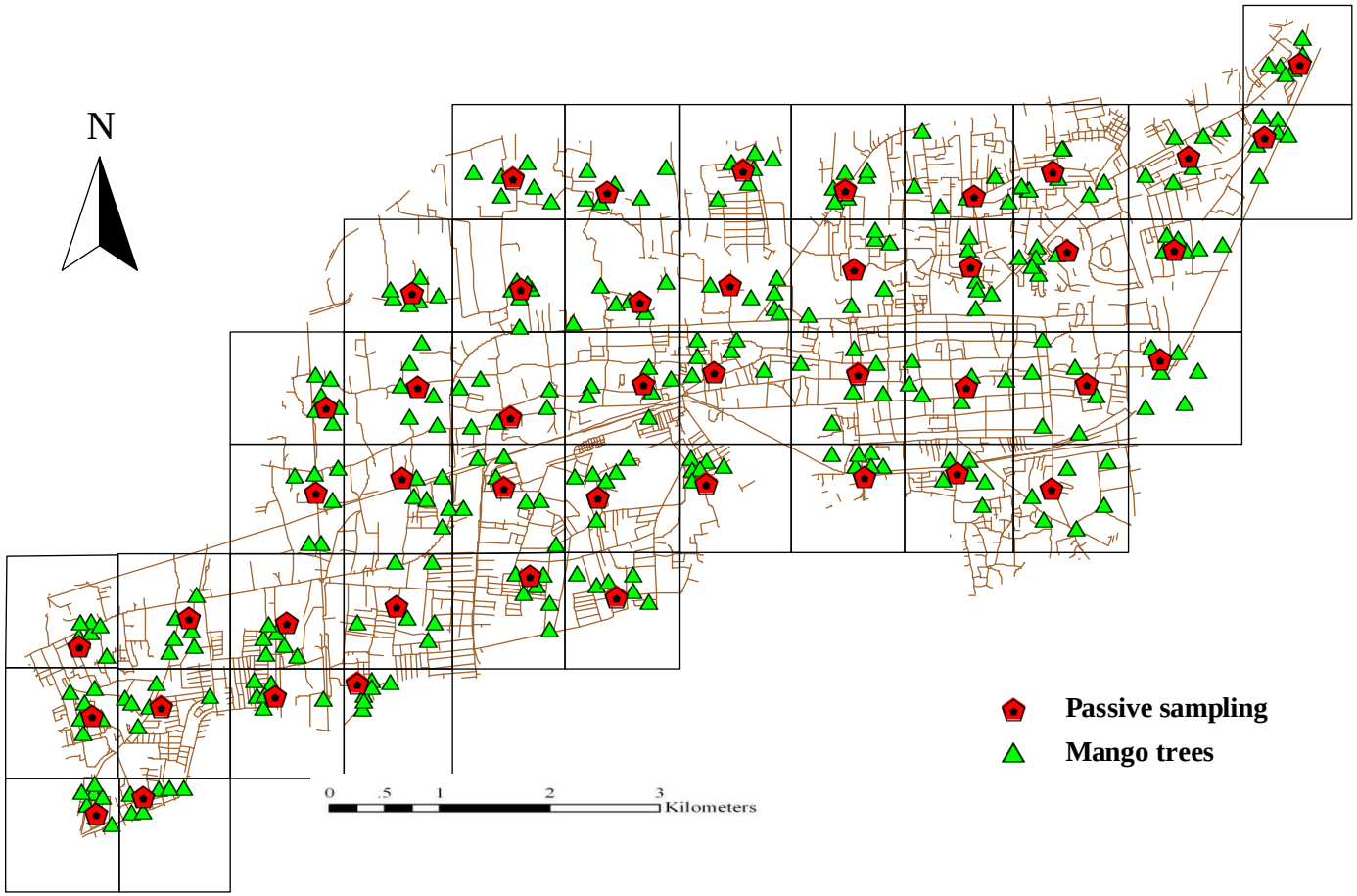


Figure 4.23 Location of the hung air-sample tubes in Nakhon Ratchasima municipality.

4.3.1 Climatic condition during the exposure period

The daily light intensity, temperature and relative humidity during the exposure period, rainy season (3-17 August 2009) and winter season (3-17 October 2009) are shown in Figure 4.24, 4.25 and 4.26.

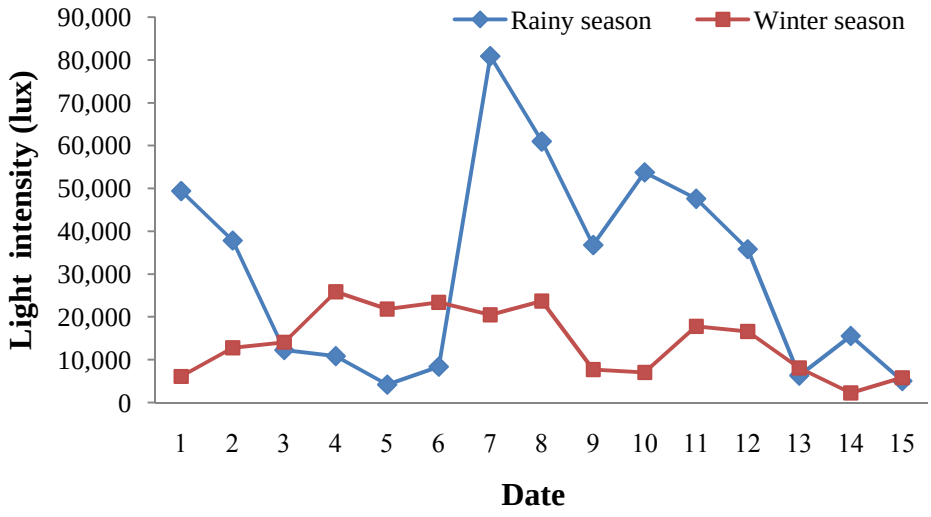


Figure 4.24 Daily light intensity during the exposure period.

Light intensity was at range of 4,238-80,913 lux in rainy season while and which one in the winter season was at range of 2,262-25,884 lux. It could be seen that higher light intensity was found in the rainy season, comparing to the one found in the winter season. This was due to measurement in the rainy season was done when the sky was clear.

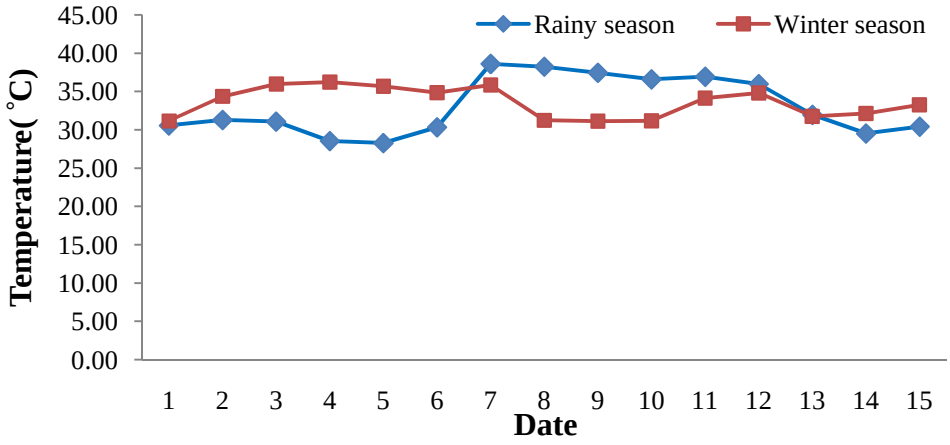


Figure 4.25 Daily temperature during the exposure period.

Considering the figure of the rainy season, temperature was 28.27- 38.60 ˚C and 36.21- 31.11˚C in the winter season. Moreover, daily temperatures in the winter season were similar.

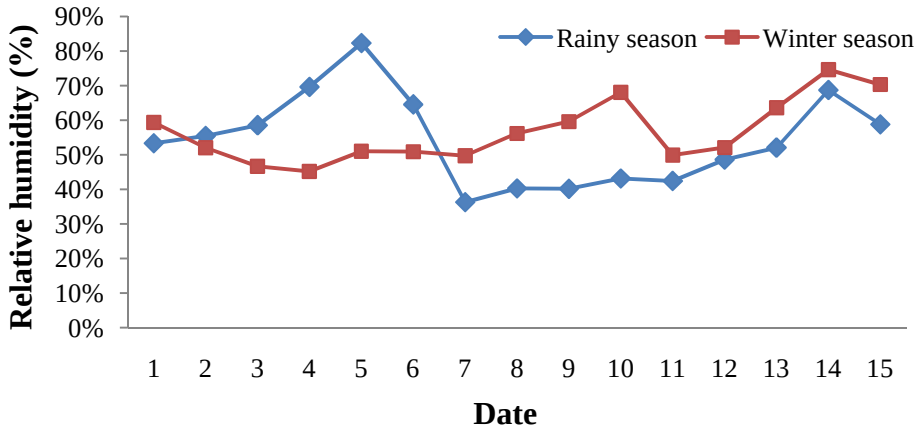


Figure 4.26 Daily relative humidity during the exposure period.

In the rainy season, relative humidity was 36-82 % and 45-75% in the winter season. According to humidity measurement using a meter, it was found that humidity in the rainy season was higher than the one in the winter season. The reason was the relative humidity in the air was high.

4.3.2 Measurement of nitrogen dioxide in rainy and winter seasons

The measurement of average nitrogen dioxide concentration in each studied area in the rainy season was conducted. The average nitrogen dioxide concentration found was 0.57-4.92 ppbv. The lowest average was found at sampling no.32 which covered areas of Bung Talua park and golf course. The highest average was found at sampling plot no.21 which covered areas of Thao Suranaree Monument and Mae Gim Heng market. The average concentration of nitrogen dioxide quantity measured in the winter season was 0.46-8.93 ppbv. The lowest average was found at sampling no. 46 which covered areas of a route to Suranaree University of Technology where located communities were not dense. The areas were neglected forest. The highest average was found at sampling plot no.27 which covered areas of railway station. The average nitrogen dioxide concentration measured in the winter season was higher than the average measured in the rainy season and nitrogen dioxide concentration in the urban areas more than suburban areas (Figure 4.27, 4.28 and 4.29).

According to comparison of average concentration of nitrogen dioxide of each studied areas by one-way ANOVA (Table 4.9), it was found that the average concentration of nitrogen dioxide of each studied area in the rainy season did not show significant difference at significant level 95%. As for the average concentration of nitrogen dioxide in of each studied area in the winter season, there was significant difference at 95% significant level ($F = 2.588^*$, $p<0.05$). When a comparison of results of average concentrations of nitrogen dioxide both in the rainy and the winter seasons was conducted by the t-test, it was found that the average concentrations measured in the two seasons were significantly different at 95% significant level ($t = -8.276^*$, $p<0.05$).

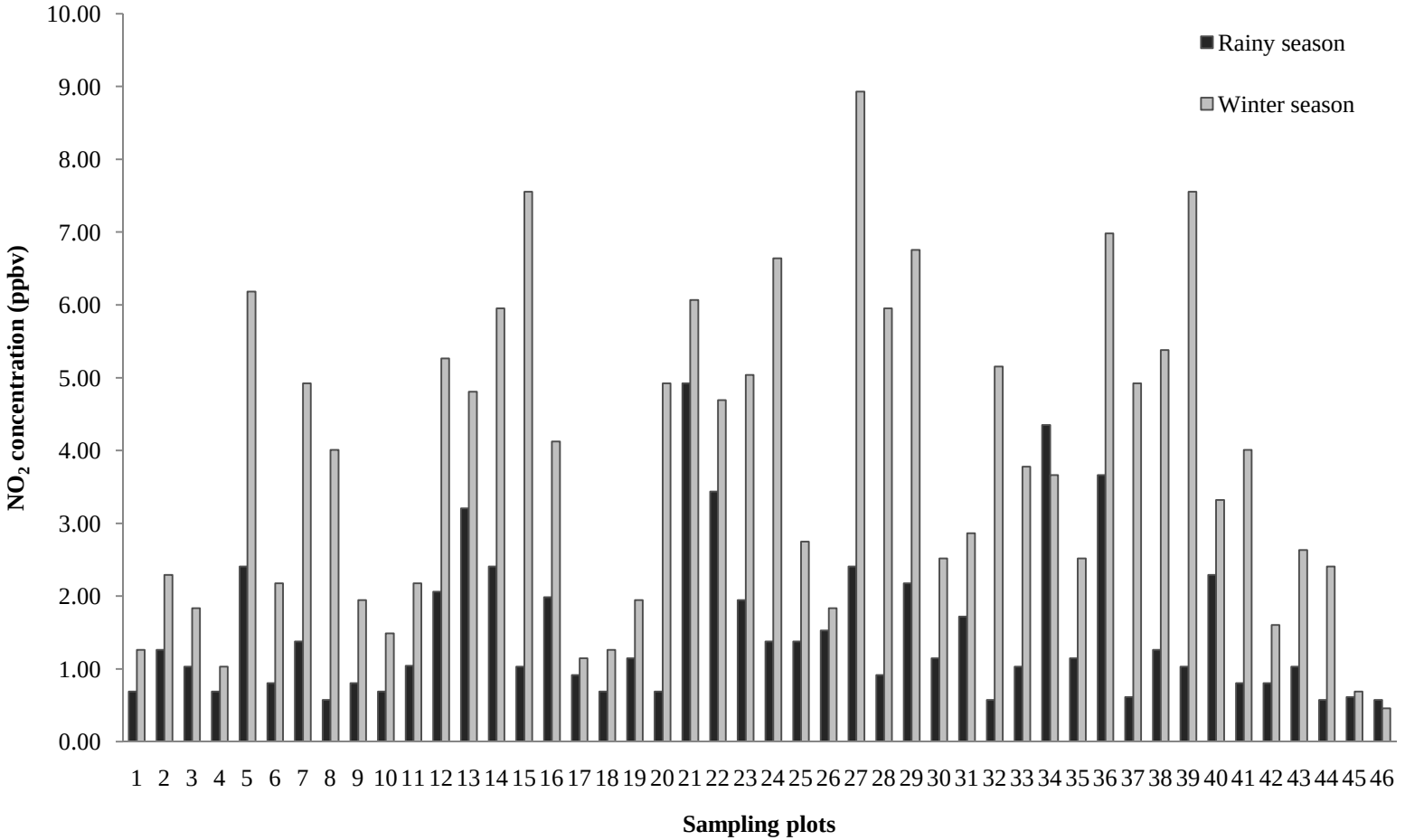


Figure 4.27 Average concentration of nitrogen dioxide in the study areas in rainy and winter seasons.

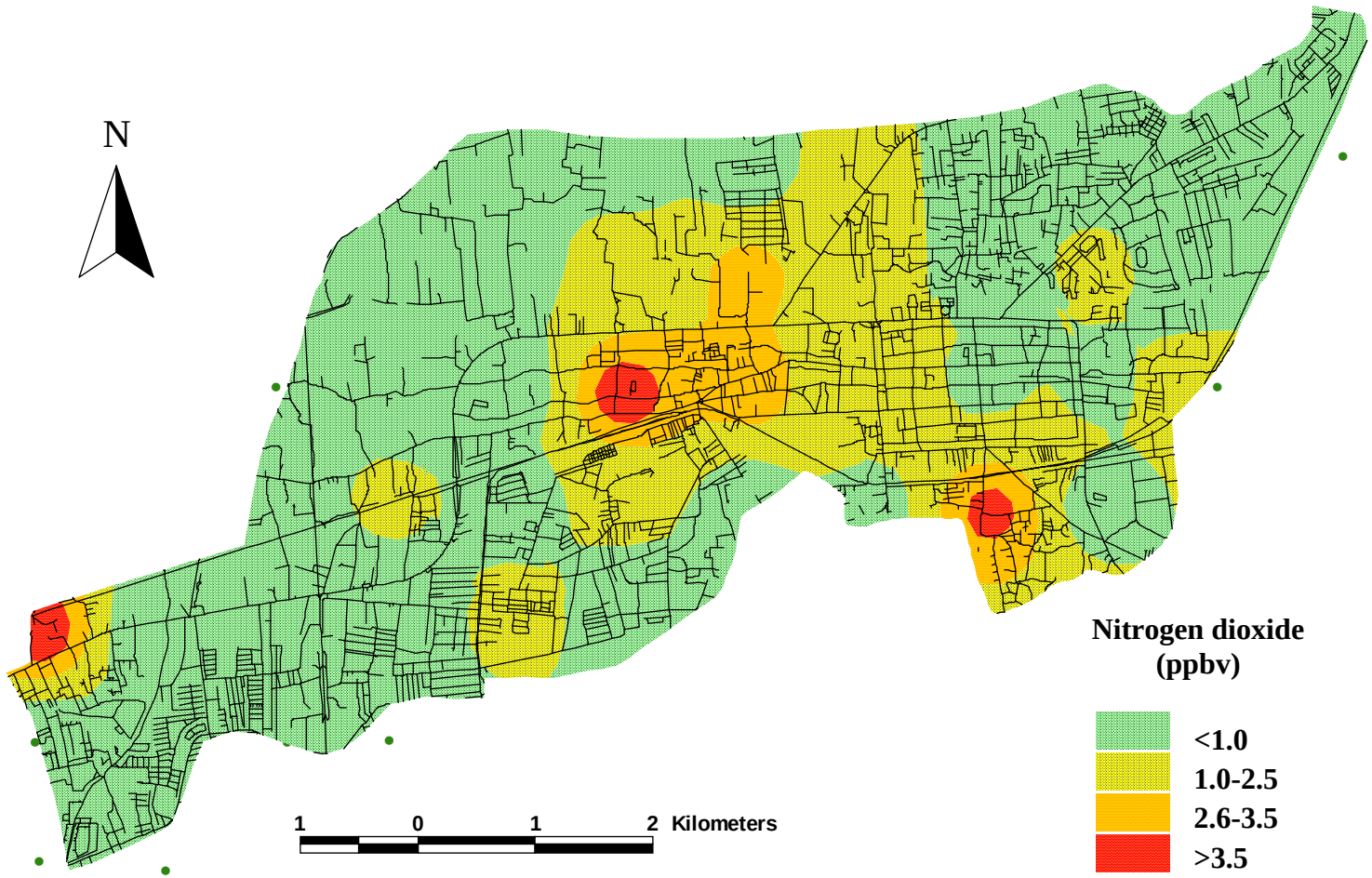


Figure 4.28 Map of nitrogen dioxide concentration in the study areas in rainy season.

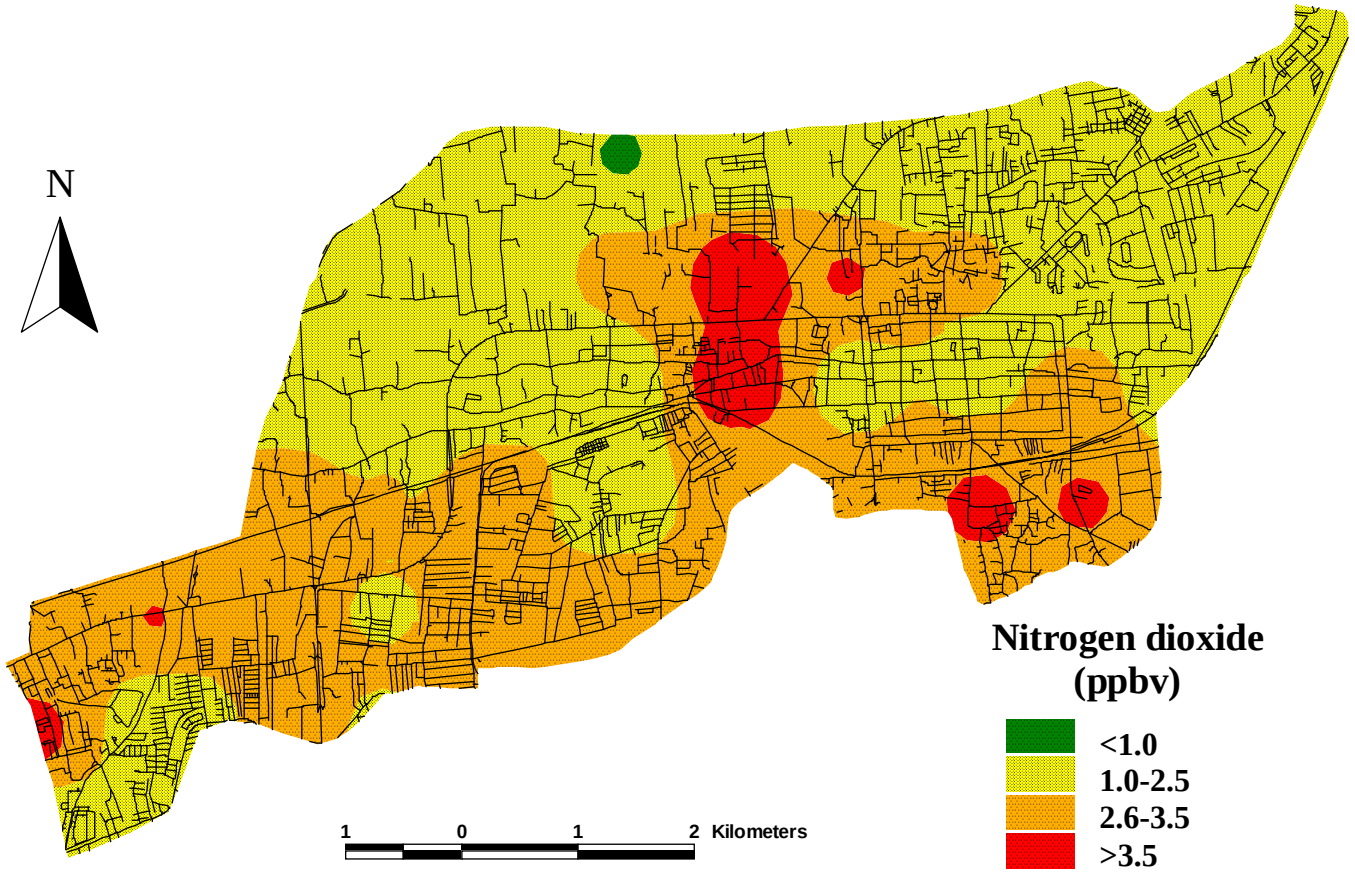


Figure 4.29 Map of nitrogen dioxide concentration in the study areas in winter season.

Table 4.9 Average NO_2 measured in Nakhon Ratchasima municipality.

Sampling plots	Concentration average NO_2 (ppbv) ±SD		AQI
	Rainy season[A]	Winter season[B]	
1	0.69±0.26[a]	1.26±0.44[abc]	20.5
2	1.26±0.44[ab]	2.29±2.15 [abcdef]	23.0
3	1.03±0.23[ab]	1.83±0.83 [abcd]	18.7
4	0.69±0.46[a]	1.03±0.44[ab]	19.2
5	2.40±1.77[abc]	6.18±5.29 [defghi]	14.2
6	0.80±0.23[a]	2.18±1.92 [abcdef]	17.0
7	1.37±0.37[ab]	4.92±2.09 [abcdefghi]	19.5
8	0.57±0.23[a]	4.01±1.37 [abcdefgh]	21.7
9	0.80±0.23[a]	1.95±0.94 [abcde]	25.5
10	0.69±0.46[a]	1.49±0.94[abcd]	23.7
11	1.04±0.42[ab]	2.18±1.08 [abcdef]	21.8
12	2.06±2.60[abc]	5.27±0.95 [bcdefghi]	13.0
13	3.12±2.12[abc]	4.81±1.42 [abcdefghi]	8.3
14	2.40±2.16[abc]	5.95±2.15 [cdefghi]	7.5
15	1.03±0.44[ab]	7.56±1.21[hi]	7.0
16	1.98±1.14[ab]	4.12±5.51 [abcdefgh]	9.5
17	0.92±0.37[a]	1.14±0.26[ab]	10.8
18	0.69±0.46[a]	1.26±0.58[abc]	15.5
19	1.14±0.26[ab]	1.95±1.02 [abcde]	13.5
20	0.69±0.26[a]	4.92±3.78 [abcdefghi]	10.7
21	4.92±3.80[c]	6.07±3.55[defghi]	4.7
22	3.43±1.89[abc]	4.69±0.94 [abcdefghi]	5.8
23	1.95±1.47[abc]	5.04±3.83 [abcdefghi]	8.5

Remark: a, b, c, d, e, f, g, h and i represented significant difference of the average concentration of NO_2. The sets of data with same alphabet did not show statistic difference (one-way ANOVA, $p<0.05$).

Table 4.9 (Continued) Average NO_2 measured in Nakhon Ratchasima municipality.

Sampling plots	Concentration average NO_2 (ppbv) ±SD		AQI
	Rainy season[A]	Winter season[B]	
24	1.37±0.92^{ab}	6.64±1.09^{efghi}	6.3
25	1.37±1.54^{ab}	2.75±1.30 ^{abcdefg}	10.5
26	1.53±0.79^{ab}	1.83±0.37 ^{abcd}	15.0
27	2.40±2.32^{abc}	8.93±6.71^{i}	12.5
28	0.92±0.37^{a}	5.95±5.11 ^{cdefghi}	14.5
29	2.18±1.56^{abc}	6.75±5.12^{fghi}	6.3
30	1.14±0.26^{ab}	2.52±2.32 ^{abcdefg}	7.2
31	1.72±1.06^{ab}	2.86±1.32 ^{abcdefg}	29.2
32	0.57±0.23^{a}	5.15±1.65 ^{abcdefghi}	21.7
33	1.03±0.23^{ab}	3.78±1.37 ^{abcdefgh}	20.7
34	4.35±3.57^{bc}	3.66±1.87 ^{abcdefgh}	14.8
35	1.14±0.46^{ab}	2.52±0.88 ^{abcdefg}	12.3
36	3.66±2.00^{abc}	6.98±3.76^{ghi}	15.5
37	0.61±0.37^{a}	4.92±2.43 ^{abcdefghi}	16.0
38	1.26±0.23^{ab}	5.38±1.99 ^{bcdefghi}	6.7
39	1.03±0.23^{ab}	7.56±4.56^{hi}	12.5
40	2.29±2.77^{abc}	3.32±0.78 ^{abcdefgh}	20.5
41	0.80±0.23^{a}	4.01±1.96 ^{abcdefgh}	18.7
42	0.80±0.44^{a}	1.60±0.88 ^{abcd}	14.5
43	1.03±0.23^{ab}	2.63±1.02 ^{abcdefg}	16.0
44	0.57±0.23^{a}	2.40±0.89 ^{abcdefg}	15.3
45	0.61±0.37^{a}	0.69±0.26^{ab}	19.7
46	0.57±0.23^{a}	0.46±0.00^{a}	16.7

Remark: a, b, c, d, e, f, g, h and i represented significant difference of the average concentration of NO_2. The sets of data with same alphabet did not show statistic difference (one-way ANOVA, $p<0.05$).

When average concentration of nitrogen dioxide were analyzed for correlation with AQI of each studied area using Pearson's correlation coefficient, it was found that the average concentration of nitrogen dioxide in the rainy season negative significantly correlated with the AQI at 99% significant level (Figure 4.30). Besides, the average concentration of nitrogen dioxide in the winter season negative significantly correlated with AQI at 99% significant level (Figure 4.31).

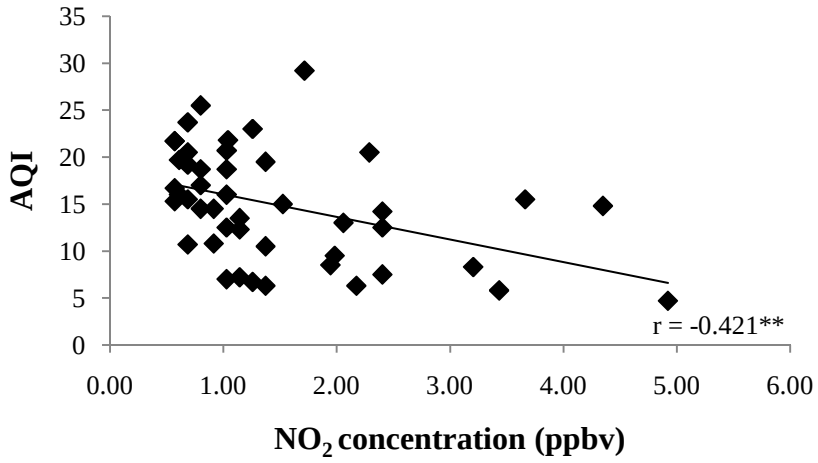


Figure 4.30 Correlation between NO_2 in the rainy season and AQI.

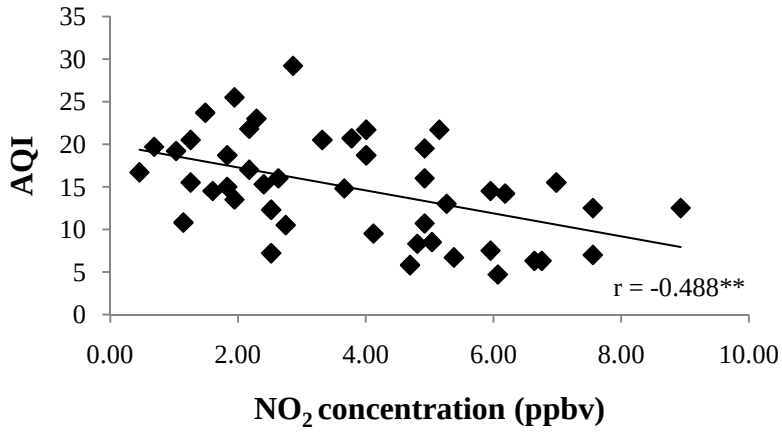


Figure 4.31 Correlation between NO_2 in the winter season and AQI.

Referring to Figure 4.30, it was indicated that the average concentration of nitrogen dioxide and the AQI in the rainy season conversely correlated. It tended that if nitrogen dioxide concentration in the area is higher, the AQI in the area will tend to be lower ($r = -0.421$, $p<0.01$).

Moreover, with reference to Figure 4.31, it was indicated that the average concentration of nitrogen dioxide and the AQI in the winter season conversely correlated. It tended that if nitrogen dioxide concentration in the area is higher, the AQI in the area will tend to be lower ($r = -0.488$, $p<0.01$).

4.3.3 Measurement of sulphur dioxide in the rainy and winter seasons

The measurement of average concentration of sulphur dioxide at each studied area in the rainy season, the average concentration during the measurement period was 0.76-3.57 ppbv. The lowest concentration was found at sampling no. 31 which covered the area of the Bung Talua park. The highest concentration was found at sampling no.14 which covered the areas of the IT center department store, Prapa market and Thai hotel. The average concentration of sulphur dioxide measured in the winter season was 1.23-3.74 ppbv. The lowest concentration was found at sampling plot no.46 which covered the areas of a route to Suranaree Univeristy of Technology where communities were not dense with neglected forest. The highest concentration was found at sampling plot no.11 which covered the areas of The Mall department store and Ya Mo market. It was also found that the average concentration of sulphur dioxide measured in the winter season was higher than the one measured in the rainy season and sulphur dioxide concentration in the urban areas more than suburban areas (Figure 4.32, 4.33 and 4.34).

According to a comparison of average concentration of sulphur dioxide of each study area by one-way ANOVA (Table 4.10), it was found that the average concentration of sulphur dioxide of each study area in the rainy season had significant difference at 95% significant level ($F = 1.470^*$, $p<0.05$). As for the average concentration of sulphur dioxide in of each study area in the winter season, there was no significant difference at 95% significant level. When a comparison of results of average concentration of sulphur dioxide the both in rainy and winter seasons was conducted by the t-test, it was found that the average concentrations measured in the two seasons were significant difference at 95% significant level ($t = -8.276^*$, $p<0.05$).

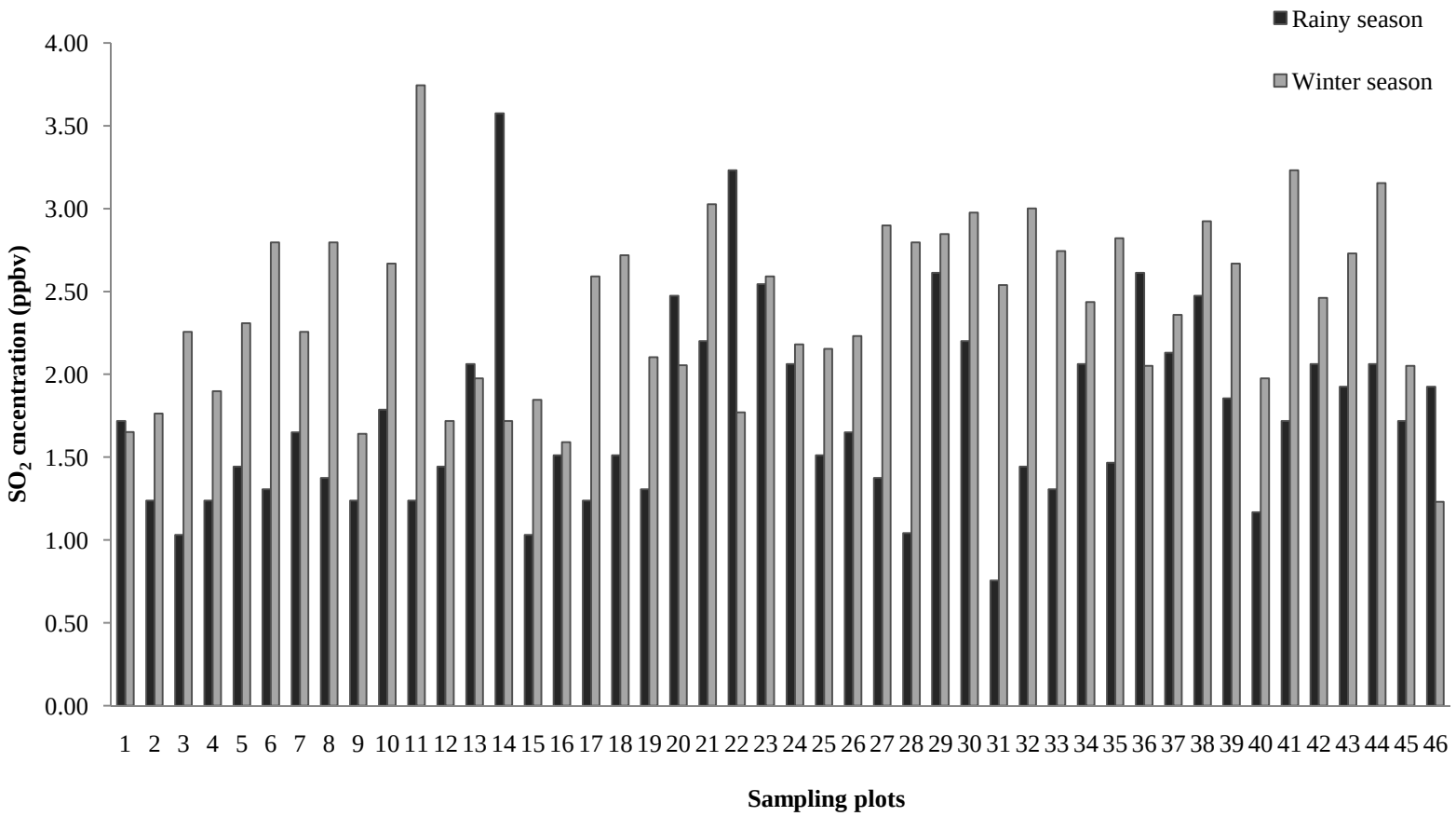


Figure 4.32 Average concentration of sulphur dioxide in the study areas in rainy and winter seasons.

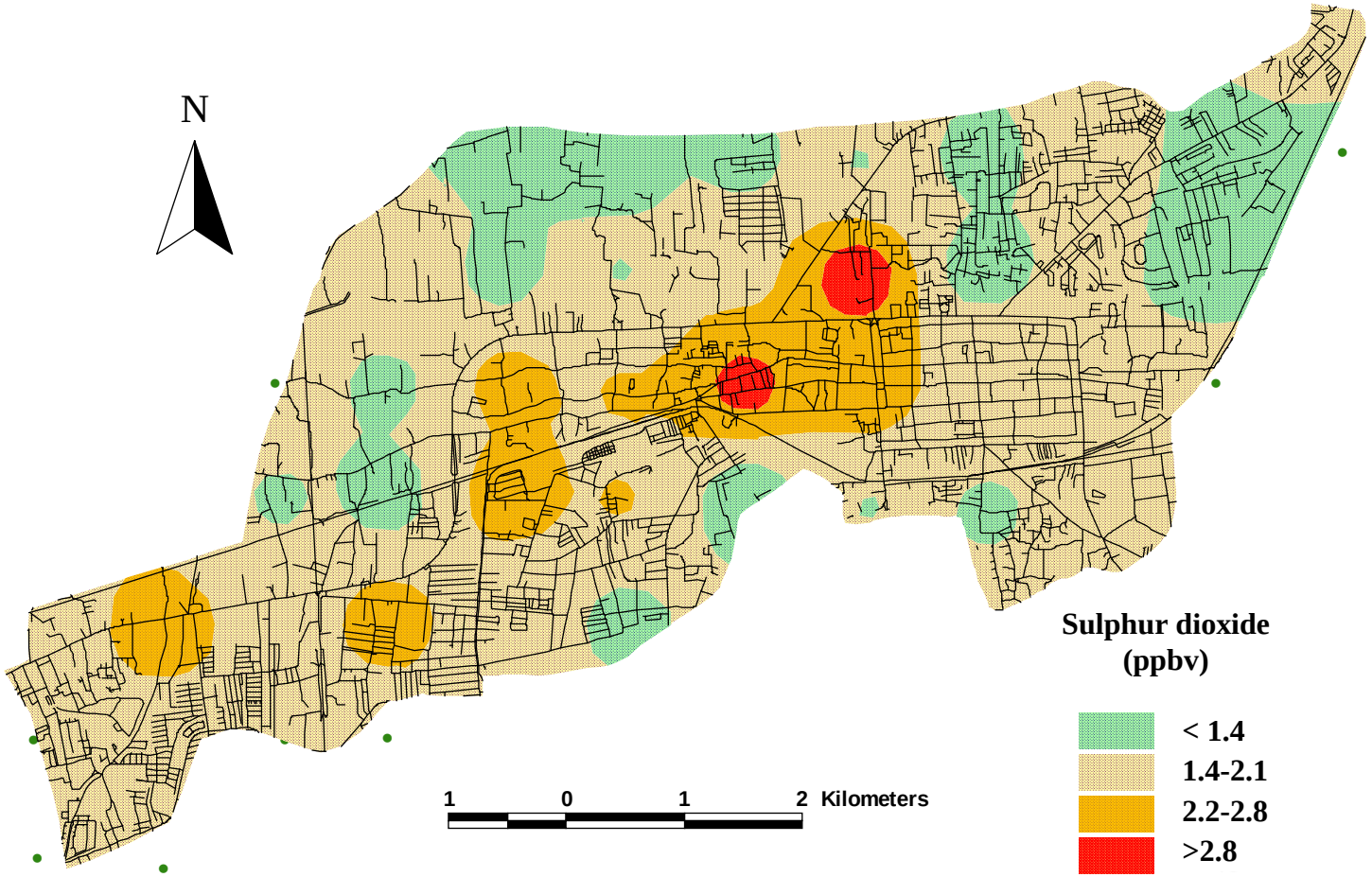


Figure 4.33 Map of sulphur dioxide concentration in the study areas in rainy season.

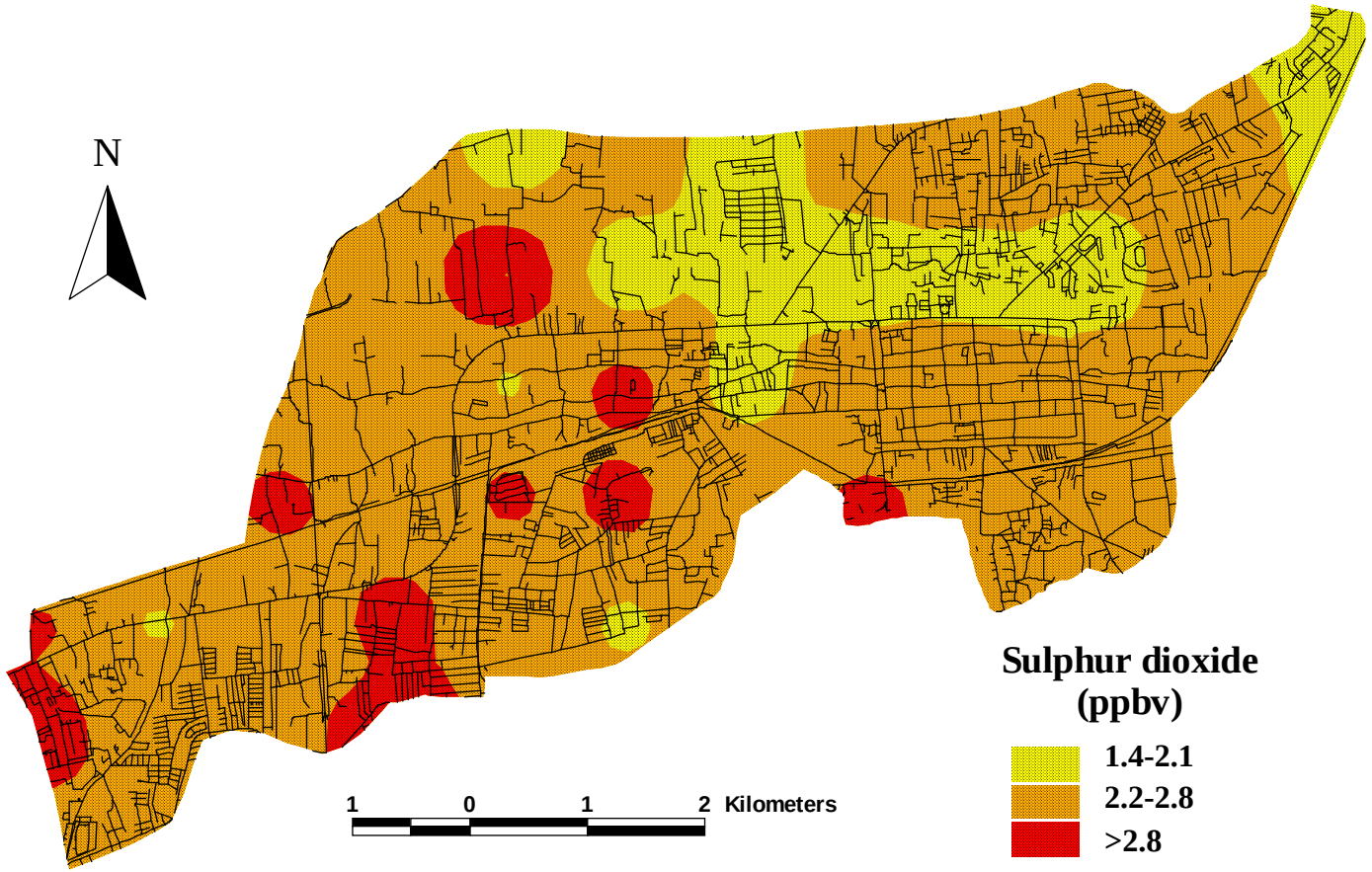


Figure 4.34 Map of sulphur dioxide concentration in the study areas in winter season.

Table 4.10 Average SO_2 measured in Nakhon Ratchasima municipality.

Sampling plots	Concentration average SO_2 (ppbv) ±SD		AQI
	Rainy season[A]	Winter season[B]	
1	1.72±1.44 [abc]	1.65±0.48 [ab]	20.5
2	1.24±0.65 [ab]	1.76±0.50 [ab]	23.0
3	1.03±0.47 [ab]	2.26±0.83 [abc]	18.7
4	1.24±0.65 [ab]	1.90±0.39 [ab]	19.2
5	1.44±0.88 [ab]	2.31±0.81 [abc]	14.2
6	1.31±0.61 [ab]	2.80±1.45 [abc]	17.0
7	1.65±0.74 [abc]	2.26±0.89 [abc]	19.5
8	1.37±0.39 [ab]	2.80±1.21 [abc]	21.7
9	1.24±0.48 [ab]	1.64±0.49 [ab]	25.5
10	1.79±1.20 [abc]	2.67±0.98 [abc]	23.7
11	1.24±0.35 [ab]	3.74±2.66 [c]	21.8
12	1.44±0.14 [ab]	1.72±0.61 [ab]	13.0
13	2.06±0.35 [abcd]	1.98±0.48 [ab]	8.3
14	3.57±2.28[d]	1.72±0.61 [ab]	7.5
15	1.03±0.26[ab]	1.85±0.36 [ab]	7.0
16	1.51±0.82 [ab]	1.59±0.42 [ab]	9.5
17	1.24±0.48 [ab]	2.59±1.62 [abc]	10.8
18	1.51±1.56 [ab]	2.72±1.31 [abc]	15.5
19	1.31±0.14 [ab]	2.10±1.26 [abc]	13.5
20	2.47±0.81[bcd]	2.05±0.34 [abc]	10.7
21	2.20±0.45 [abcd]	3.03±0.99 [bc]	4.7
22	3.23±2.45[cd]	1.77±0.83 [ab]	5.8
23	2.54±1.24 [bcd]	2.59±0.96 [abc]	8.5

Remark: a, b, c and d represented significant difference of the average concentration of SO_2. The sets of data with same alphabet did not show statistic difference (one-way ANOVA, $p<0.05$).

Table 4.10 (Continued) Average SO_2 measured in Nakhon Ratchasima municipality.

Sampling plots	Concentration average SO_2 (ppbv) ±SD		AQI
	Rainy season[A]	Winter season[B]	
24	2.06±0.65 [abcd]	2.18±0.70 [abc]	6.3
25	1.51±0.85 [ab]	2.15±0.67 [abc]	10.5
26	1.65±0.78 [abc]	2.23±0.80 [abc]	15.0
27	1.37±0.39 [ab]	2.90±1.67 [abc]	12.5
28	1.04±0.27 [ab]	2.80±0.63 [abc]	14.5
29	2.61±1.16 [bcd]	2.85±0.92 [abc]	6.3
30	2.20±0.81[abc]	2.98±1.23 [abc]	7.2
31	0.76±0.35[a]	2.54±0.45 [abc]	29.2
32	1.44±0.61[ab]	3.00±0.88 [bc]	21.7
33	1.31±0.47 [ab]	2.74±0.70 [abc]	20.7
34	2.06±1.58 [abcd]	2.44±1.18 [abc]	14.8
35	1.47±0.52 [abc]	2.82±1.39 [abc]	12.3
36	2.61±0.94 [bcd]	2.05±012 [abc]	15.5
37	2.13±0.47 [abcd]	2.36±0.79 [abc]	16.0
38	2.47±0.95[bcd]	2.92±0.59 [abc]	6.7
39	1.86±0.52[abc]	2.67±1.03 [abc]	12.5
40	11.7±0.35 [ab]	1.98±0.24 [ab]	20.5
41	1.72±0.26 [abc]	3.23±0.84 [bc]	18.7
42	2.06±0.35 [abcd]	2.46±0.72 [abc]	14.5
43	1.92±0.50 [abc]	2.73±069 [abc]	16.0
44	2.06±1.32 [abcd]	3.15±1.04 [bc]	15.3
45	1.72±0.14 [abc]	2.05±1.65 [abc]	19.7
46	1.92±0.39 [abc]	1.23±0.35[a]	16.7

Remark: a, b, c and d represented significant difference of the average concentration of SO_2. The sets of data with same alphabet did not show statistic difference (one-way ANOVA, $p<0.05$).

When average concentration of sulphur dioxide were analyzed for correlation with AQI of each studied area using Pearson's correlation coefficient, it was found that the average concentration of sulphur dioxide in the rainy season negative significantly correlated with the AQI at 99% significant level (Figure 4.35). Besides, the average concentration of sulphur dioxide in the winter season was not correlate with AQI at 95% significant level (Figure 4.36).

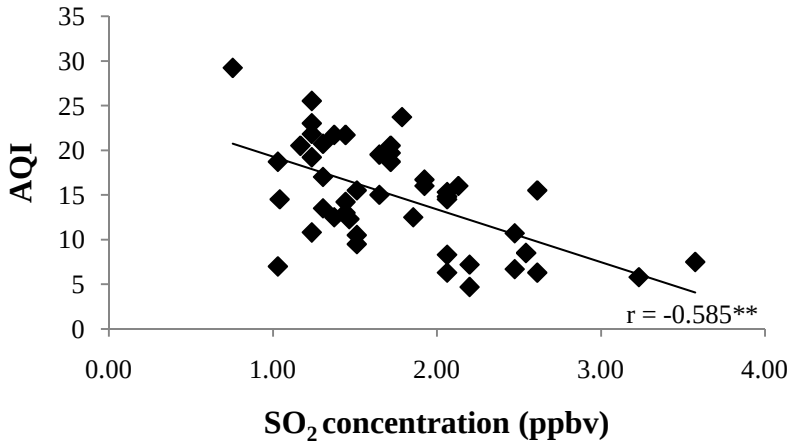


Figure 4.35 Correlation between SO_2 in the rainy season and AQI.

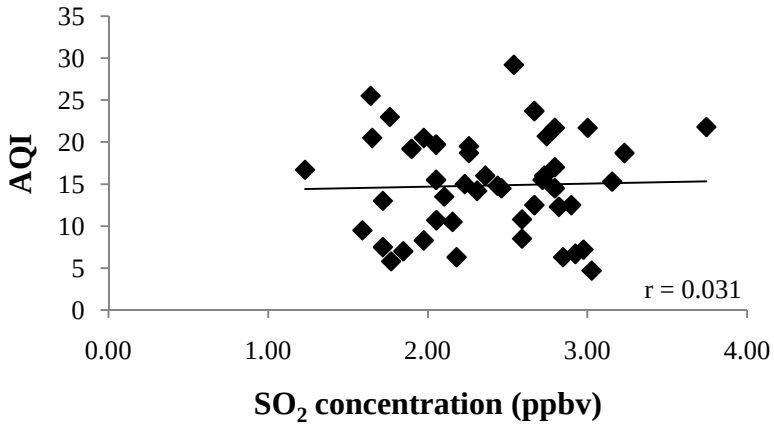


Figure 4.36 Correlation between SO_2 in the winter season and AQI.

Referring to Figure 4.35, it was indicated that the average concentration of sulphur dioxide and the AQI in the rainy season conversely correlated. It tended that if sulphur dioxide concentration in the area is higher, the AQI in the area will tend to be lower ($r = -0.585$, $p<0.01$).

Moreover, with reference to Figure 4.36, it was indicated that the average concentration of sulphur dioxide and the AQI in the winter season were not correlate ($r = 0.031$, $p<0.05$).

4.3.4 Analysis of correlation between average concentrations of nitrogen dioxide and sulphur dioxide with the average pH of barks

According to an analysis of correlation between the amount of nitrogen dioxide in each area and the average pH of barks in each studied area using Pearson's Correlation Coefficient, it was indicated that pH of barks not significant correlate with amount of nitrogen dioxide in each studied area at 95% significant level in both seasons (Figure 4.37 and 4.38).

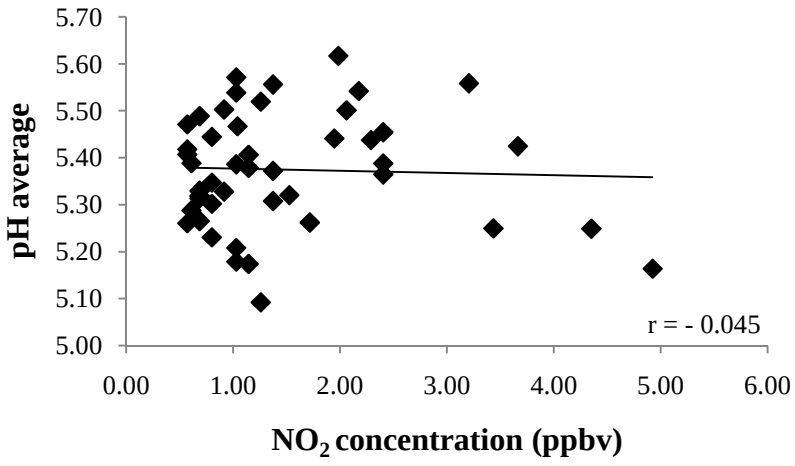


Figure 4.37 Correlation between NO_2 in the rainy season and average pH of barks.

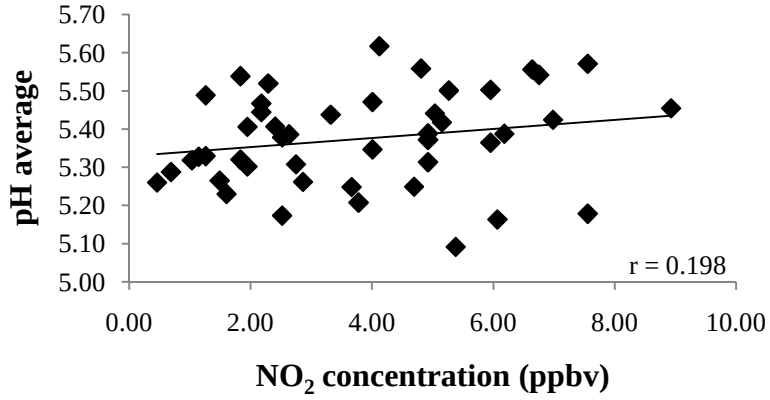


Figure 4.38 Correlation between NO_2 in the winter season and average pH of barks.

The Figures 4.37 and 4.38 indicated that the average concentration of nitrogen dioxide and the average pH in the rainy season (r = -0.045) and the winter season (r = 0.198) were not correlate.

The results of analysis of correlation between amount of sulphur dioxide in each area and the average pH of barks in each studied area using Pearson's correlation coefficient indicated that pH of barks were not significantly correlated with amount of sulfur dioxide of each study area at 95% significant level in both seasons (Figure 4.39 and Figure 4.40).

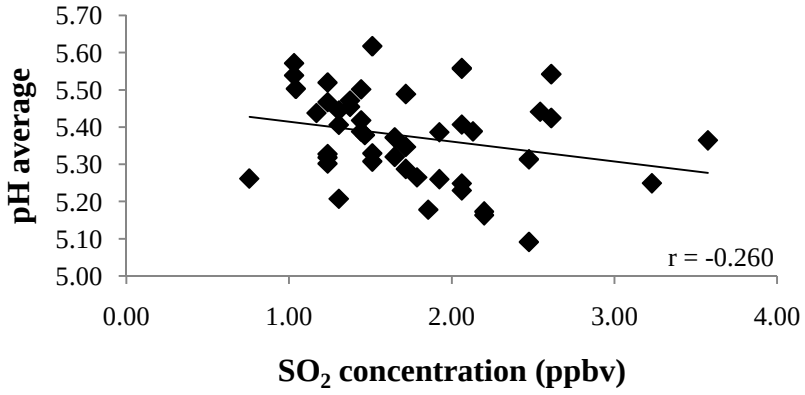


Figure 4.39 Correlation between SO_2 in the rainy season and average pH of barks.

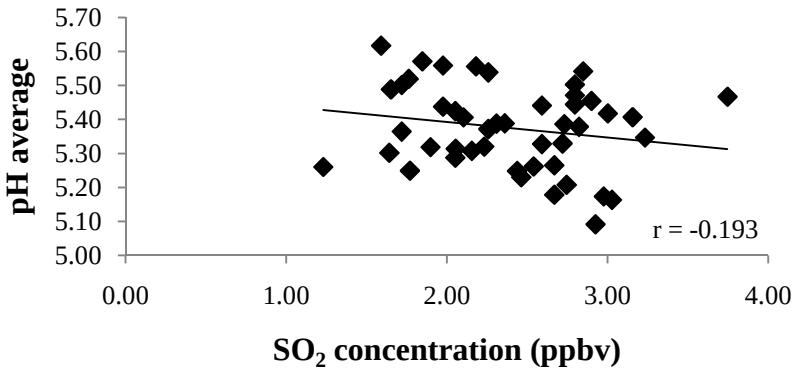


Figure 4.40 Correlation between SO_2 in the winter season and average pH of barks.

The Figures 4.39 and 4.40 indicated that the average concentration of sulphur dioxide and the average pH in the rainy season (r = -0.260) and the winter season (r= -0.193) were not correlate.

4.4 The study on lichen diversity in area of Sakaerat Environmental Research station, Nakhon Ratchasima province.

4.4.1 Study on species and lichen frequency found in deciduous dipterocarp forest and dry evergreen forest

From observation of lichen species in all 6 sampling plots, 38 species were found. In the three plots of deciduous dipterocarp forest, 40 trees were observed. Ninety percent of trees were *Shorea obtusa* Wall. *ex* Blume and *Shorea siamensis* Miq. respectively. In this area, 22 lichen species were found, i.e. three foliose lichens, 19 crustose lichens. Most lichens found were in Graphideceae, Thelotremataceae, Physciaceae and Porinaceae families (Table 4.11 and Appendix C). In the three plots of dry evergreen forest, 40 trees were observed. Ninety percent of trees in the area were *Hopea ferrea* Heim. and *Hydnocarpus ilicifolia* King respectively. In this area,

26 species were found, i.e. two squamulose lichens and 24 crustose lichens. Most lichens found were in Thelotremataceae, Graphidaceae, Porinaceae and Pyrenulaceae families (Table 4.12 and Appendix C). Most lichens found in the both areas were crustose lichens, for example lichens in Graphideceae, Physciaceae, Porinaceae, Pyrenulaceae and Thelotremataceae families, etc (Appendix C).

From the study on lichen frequency of each species found in deciduous dipterocarp forest and dry evergreen forest, it was found that the *Crocynia pyxinoid* had the highest frequency which was 41. The next highest were *Laurera benguelensis, Graphis* sp.1, *Clathroporina* sp., *Pyrenula wilmsiana*, *Trypethelium tropicum* and *Trypethelium eluterae*, respectively. *Parmotrema tinctorum* had the lowest frequency which was 1 (Table 4.13). When compared numbers of crustose lichens with foliose lichens found in the two forest areas, there were more crustose than foliose in all study areas as shown in Figure 4.42.

Table 4.11 List of lichen group and species found in the surveyed deciduous dipterocarp forest.

Thallus type	Family	Genus	Species
Foliose	Parmeliaceae	*Parmotrema*	*Parmotrema tinctorum*
	Physciaceae	*Dirinaria*	*Dirinaria picta*
		Pyxine	*Pyxine cocoes*
Crustose	Chrysotricaceae	*Chrysothrix*	*Chrysothrix xanthina*
	Graphidaceae	*Graphis*	*Graphis* sp.3
			Graphis sp.5
			Graphis sp.6
			Graphis sp.7
			Graphis sp.8
			Graphis sp.9
			Graphis dumastoides
			Graphina incrustans
	Physciaceae	*Buellia*	*Buellia* sp.
		Rinodina	*Rinodina* sp.
	Porinaceae	*Clathroporina*	*Clathroporina* sp.
	Pyrenulaceae	*Pyrenula*	*Pyrenula wilmsiana*
	Roccellaceae	*Opegrapha*	*Opegrapha stirtonii*
	Thelotremataceae	*Trypethelium*	*Thelotrema pycnophragmium*
		Trypethelium	*Trypethelium eluterae*
		Trypethelium	*Trypethelium tropicum*
		Ocellularia	*Ocellularia* sp1.
	Trypetheliaceae	*Laurera*	*Laurera benguelensis*

Table 4.12 List of lichen group and species found in the surveyed dry evergreen forest**.**

Thallus type	Family	Genus	Species
Squamulose	Cladoniaceae	*Cladonia*	*Cladonia* sp.1
	Crocyniaceae	*Crocynia*	*Crocynia pyxinoid*
Crustose	Chrysotricaceae	*Chrysothrix*	*Chrysothrix xanthina*
	Graphidaceae	*Graphis*	*Graphis* sp.1
			Graphis sp.2
			Graphis sp.3
			Graphis sp.4
			Graphis sp.5
	Monoblastiaceae	*Anisomeridium*	cf. *Anisomeridium*
	Porinaceae	*Clathroporina*	*Clathroporina sp.*
		Porina	*Porina eminentior*
			Porina internigrans
			Porina subinterstes
	Pyrenulaceae	*Pyrenula*	*Pyrenula* sp.1
			Pyrenula wilmsiana
	Ramalinaceae	*Phyllopsora*	*Phyllopsora* sp.1
	Roccellaceae	*Opegrapha*	*Opegrapha stirtonii*
	Thelotremataceae	*Myriotrema*	*Myriotrema* sp.1
			Myriotrema sp.2
		Ocellularia	*Ocellularia* sp1.
		Thelotrema	*Thelotrema pycnophragmium*
		Trypethelium	*Trypethelium eluterae*
		Trypethelium	*Trypethelium tropicum*
	Unknown	Unknown	Sterile crust sp.1(pycnedia)
			Sterile crust sp.2
			Sterile crust sp.3

Table 4.13 Total frequency of each lichen species in deciduous dipterocarp and dry evergreen forests.

Lichen species	DDF1	DDF2	DDF3	Total DDF	DEF1	DEF2	DEF3	Total DEF
Cladonia sp.1				0			10	10
Crocynia pyxinoid				0		8	33	41
Dirinaria picta	1		4	5				0
Parmotrema tinctorum			1	1				0
Pyxine cocoes		3	4	7				0
cf. *Anisomeridium*				0			8	8
Buellia sp.	5			5				0
Clathroporina sp.	3			3	7	10		17
Chrysothrix xanthina	4	3	5	12	2			2
Graphis sp.1				0		11	18	29
Graphis sp.2				0	6		4	10
Graphis sp.3	5			5	2			2
Graphis sp.4				0		6		6
Graphis sp.5	4		5	9		4		4
Graphis sp.6	3			3				0
Graphis sp.7	4		3	7				0
Graphis sp.8	2	5	6	13				0
Graphis sp.9		4	5	9				0
Graphis dumastoides		2		2				0
Graphina incrustans	3	2	2	7				0
Laurera benguelensis	18	6	15	39				0
Myriotrema sp.1				0			14	14
Myriotrema sp.2				0			9	9
Ocellularia sp1.		2		2	2	6		8
Opegrapha stirtonii	3			3		4	8	12
Rinodina sp.		4	2	6				0
Phyllopsora sp.1				0			10	10
Porina eminentior				0		5		5
Porina internigrans				0	3	3		6
Porina subinterstes				0	4			4
Pyrenula sp.1				0	12			12
Pyrenula wilmsiana	5	3		8	8		4	12
Steril crust sp.1 (picnedia)				0			8	8
Steril crust sp.2			5	5	4			4
Steril crust sp.3			7	7				0
Thelotrema pycnophragmium			6	6		5		5
Trypethelium eluterae	4	5	3	12	3	2	2	7
Trypethelium tropicum	7	3		10		5	5	10

Among the 38 surveyed lichen species found in the Sakaerat Environmental Research station, it was found that 19 species distributed in both kinds of forest (Figure 4.41). The calculation for similarity of lichen in two kinds of forest was conducted using Sørensen similarity index. The calculation result was 0.79 which indicated that lichens found in both forests were very similar.

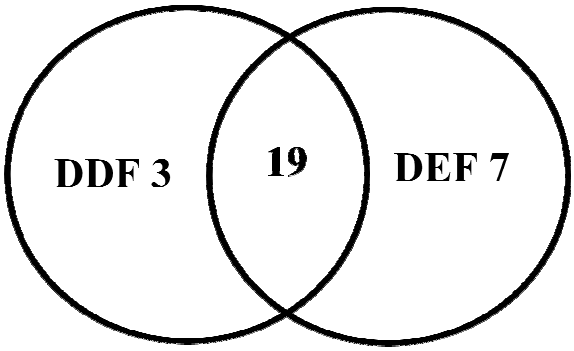


Figure 4.41 Number of lichen species found in deciduous dipterocarp forest, dry evergreen forest and both forest.

When a comparison of number of crustose and foliose lichens was made, it was found that in all study areas, there were more crustose than foliose lichens. The 1st plot of dry evergreen forest had the highest number of lichen species of 14. The second most was the 2nd plot of deciduous dipterocarp forest where 10 species were found. The lowest species of lichen, which was 8 species, were found in the 3rd plot of dry evergreen forest and the 1st plot of deciduous dipterocarp forest. There was no foliose lichen found in the 1st plot of dry evergreen forest (Figure 4.42).

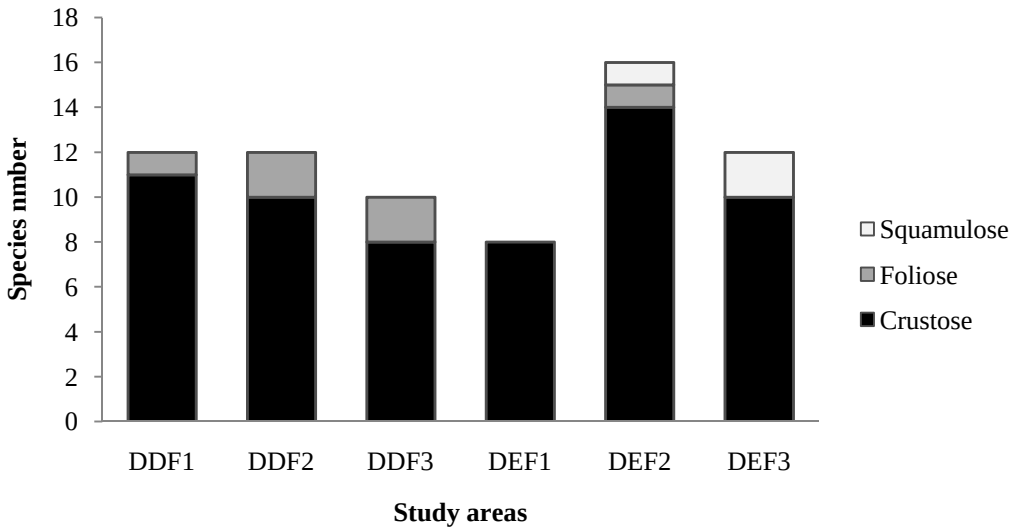


Figure 4.42 Number of lichen species in crustose, foliose and squamulose found in the study areas.

4.4.2 Study on lichen diversity

Data on lichen species and frequency found in six study plots were calculated for Shannon - Wiener's diversity index (H'), evenness (E), and species richness. Results indicated that the 1st plot of deciduous dipterocarp forest contained the highest diversity index (2.48) and the highest species richness (15 species). The next highest were the 2nd plot of dry evergreen forest, the 2nd plot of deciduous dipterocarp forest and the 3rd plot of deciduous dipterocarp forest, respectively. The 1st and the 3rd plots of dry evergreen forest had the lowest diversity index (2.33). The plots that had the lowest species richness were the 2nd plot of deciduous dipterocarp forest and the 1st plot of dry evergreen forest where only 12 species were found. Lichen evenness of each study area, it was at the range of 0.91-0.97. The 1st plot of deciduous dipterocarp forest had the highest lichen evenness (Table 4.14).

Table 4.14 Diversity index, evenness and species richness of lichen in Sakaerat Environmental Research station.

Study area	Total frequencies	Diversity index	Evenness	Species richness
DDF1	71	2.48	0.92	15
DDF2	42	2.42	0.97	12
DDF3	61	2.36	0.92	13
DEF1	61	2.33	0.94	12
DEF2	73	2.47	0.96	13
DEF3	133	2.33	0.91	13

4.4.3 Study on physical factors in the Sakaerat Environmental Research station.

The physical factors measurement was conducted by measuring temperature, humidity and light in deciduous dipterocarp forest and dry evergreen forest in June-November 2009. Results of measurement were demonstrated in Table 4.15.

Table 4.15 Physical factors in deciduous dipterocarp forest and dry evergreen forest.

Study area	Diversity index	Temperature (^{o}C)	Relative humidity (%)	Light intensity (lux)
DDF1	2.48	32.1	68	1002
DDF2	2.42	32.7	69	963
DDF3	2.36	31	66	822
DEF1	2.33	29.4	83	280
DEF2	2.47	27.8	82	262
DEF3	2.33	27.5	83	385

It was found that the average temperature was between 27.5-32.7°C. The lowest average temperature (27.5°C) was found at the plot no.3 in dry evergreen forest while the highest average temperature (32.7°C) was found at plot no.2 in deciduous dipterocarp forest. Please see Table 4.17. A correlation analysis of an average temperature in each studied area and lichen diversity index of each area by the Pearson's correlation coefficient was conducted. The results indicated that an average temperature was not significantly correlated with lichen diversity index at 95% significant level (r = 0.330).

The average humidity was between 66-83%. The lowest average humidity (66%) was found at the plot no.3 of deciduous dipterocarp forest and the highest average humidity (83%) was found at plots no.1 and 3 of dry evergreen forest as shown in Table 4.17. According to a correlation analysis of average humidity and lichen diversity index of each study area by the Pearson's correlation coefficient, the results indicated that the average humidity was not significantly correlated with lichen diversity index of each study area at 95% significant level (r = -0.337).

Average light intensity was between 262-1,002 lux. The lowest average light (262 lux) was found at the plot no.2 on dry evergreen forest and the highest average light (1,002 lux) was found at the plot no.1 in deciduous dipterocarp forest as shown in Table 4.17. According to a correlation analysis of average light and lichen diversity index of each studied area, it was found that the average light intensity was not significantly correlated with lichen diversity index at 95% significant level (r = 0.377).

CHAPTER V
DISCUSSION

5.1 Study on lichen species, frequency and distribution of lichen species in Nakhon Ratchasima municipality

According to the study on 10 families, 17 genera, and 29 species of lichen, it was found that the most lichens found in the Nakhon Ratchasima municipality areas were *Hyperphyscia adglutinata, Pyxine cocoes, Physcia atrostriata, Opegrapha stirtonii* and *Lecanora leprosa*, etc. The findings were similar to the results studied by Saipankaew et al. (2005 and 2007) which demonstrated that the *Dirinaria picta* and *Pyxine cocoes* largely spread in the areas where were 250-400 m above sea level in the upper north region of Thailand. Moreover, the study of Pruksakorn (2007) found that *Lecanora leprosa*, *Pyxine cocoes* and *Hyperphyscia adglutinata* were mostly distributed in the areas of Lumphun municipality. Besides, in the Northern Industrial zone, *Lecanora leprosa* was found the most or comparable to 70% of all lichens found in the area.

The results of the present study indicated that in all study areas, more number of lichen species in crustose were found, comparing to number of lichen species in foliose. The study areas were around 150-300 m above sea level which was similar to the study of Saipankaew et al. (2005) that stated that elevation influenced on number and species of crustose and foliose lichens. The study also mentioned that in areas where were 250-400 m above sea level, the crustose lichens were the prominent group

found, and in the areas of 600 m above sea level, more foliose lichens were found. The mentioned study results conformed to study results of Pomphueak (2005) which lichens both in urban and rural areas of Lampang province were investigated. The study found that crustose lichens than were found more foliose lichens in all study areas. The study of Buaruang et al. (2005) investigated lichens on the Kram Island and the Samaesarn Island and indicated that there were more crustose lichen species than the foliose species found in the study. The reason was the thallus of crustose was not complicate, flat, sticked to substrate, and grew up well.

The lichen analysis data were submitted for lichen species classification by cluster analysis. The resulting dendrogram from this treatment revealed two main groups of lichen species, as can be seen in Figure 4.3. The first, group 1, were formed by lichen species considered clean regions of *Arthonia tumidula, Rinodina* sp., *Buellia* sp. and *Dirinaria picta* (Subgroup1A) and *Dirinaria applanata, Physcia poncinsii, Trypethelium eluteriae, Hyperphyscia* sp. and *Lecanographa* sp. (Subgroup 1B). Subgroup 1B lichen species are located in less polluted urban areas. The second, group 2, were formed by the lichen species near urban area and had a high volume of traffic and include the following species; *Lecanora leprosa*, *Pyxine cocoes*, *Chrysothrix xanthina*, *Physcia atrostriat* and *Hyperphyscia adglutinata*. The cluster analysis substantially confirmed coherent groups of pollution levels.

According to the grouping of study areas by data on lichen species and frequency, studied areas were classified into two groups as presented in Figure 4.3. In the first group, the *Chrysothrix xanthina*, and *Pyxine cocoes* were found in high frequency and was a tolerant group (Saipankaew et al., 2005 and 2007). *Chrysothrix xanthina* was found in all study areas, except in sampling plots no.12, 16, 20, 38 and

42. The mentioned results conformed to the study of Saipankaew et al. (2005) which found the prior stated lichens both in urban and suburban areas of Chiangmai city. *Chrysothrix xanthina* was found spreading on both high-land and plain areas. In the high-land areas, *Chrysothrix xanthina* was found in the forest where wildfire often happened. It was a tolerant species. According to this study, this species was found both on mango trunks and on wooden house-fences. Moreover, from this study, frequency of *Hyperphyscia adglutinata* was found in all sampling plots, except in the sampling plots no.5, 14, 21, 22, 24 and 30 which were consistent with the study of Saipankaew et al. (2005). The stated study investigated lichens that tolerated to air pollution, *Hyperphyscia adglutinata*, widely spread in plain areas of the upper north of Thailand. It also spread highly in urban and industrial areas. Besides, Saipankaew et al. (2007) found the *Hyperphyscia adglutinata* highly spread in urban areas with high population. This was conformed to the study of Frati et al. (2006), which indicated that *Hyperphyscia adglutinata* was found spreading up to 85% in Italy. In the second group, *Arthonia tumidula*, *Lecanora leprosa* and *Trypethelium eluteriae* were found with higher frequency, comparing to the first group. The found species were lichens usually found in areas where less affected by human being (Saipankaew et al., 2005 and 2007).

According to the study on frequency and distribution of *Dirinaria pica*, it indicated that it distributed all over the study areas but not regularly. High frequency was found in less-density community where traffic was light and residence was not tight. This lichen species was scarcely or not found in dry areas. This indicated that this lichen species was not tolerate to pollution which was consistent with the study results of Pimwong (2002) and Pruksakorn (2007) who investigated lichen

distribution and frequency in urban areas of Chiangmai and Lamphun provinces, respectively. The results presented that this lichen mostly spread in suburban areas. Saipankaew et al. (2005) found that this species could be found both in agricultural and urban areas indicating that the species could partly tolerate to pollution in urban areas. Subsri (2002) suggested that this species was very sensitive to polluted air. It was, therefore, possibly used as a good air quality indicator. *Hyperphyscia adglutinata* usually grew up on tree trunks near roads or in outdoor where were full of nutrients, especially in areas where were full of dust, or on walls and rocks with calcium (Puvis et al., 1992). The present study found that *Hyperphyscia adglutinata* distributed in all study areas. Its high frequency was found in high-density residential areas. As for in not-high density residential areas or in the areas where there were plenty of trees, and light traffic, this kind of lichen was scarcely or not found. This information was consistent with the study results of Subsri (2002), Thanwarat (2005), Saipankaew et al. (2005; 2007) and Pruksakorn (2007) which study areas around cities of Chiangmai and Lamphun. The results found high frequencies of this lichen species in areas of downtowns with rather high air pollution. *Pyxine cocoes* was found that lichens mostly distributed regularly all over the study areas. High lichen frequency was found both in high-density and less-density residential areas. The stated findings conformed to study results of Pimwong (2002) and Pruksakorn (2007). These two studies investigated lichen distribution and frequency in urban areas of Chiangmai and Lamphun provinces. The results indicated that this lichen species distributed all over the urban and suburban areas with not much different frequencies. Moreover, Saipankaew et al. (2005; 2007) indicated that this species well tolerated to the environment of Chiangmai province. *Lecanora leprosa* was found that most

lichens distributed. Frequency was high in the high-density residential areas where traffic was heavy and residences were in high density. The high frequencies were found at areas around the Mittapab highway. It indicated that this species tended to tolerate well to pollution. This was consistent with the study of Pruksakorn (2007) which studied lichen distribution and frequency in urban areas in Lamphun province. *Opegrapha stirtonii* were found in high-density residential areas with heavy traffic and high-density residences. It demonstrated that this species well tolerated to pollution. *Chrysothix xanthina* was found both in high-density and less-density residential areas. According to a study of Saipankaew et al. (2005), results demonstrated that this species was usually found on mango trees in the plain areas with human disturbance, such as areas where were damaged by fire. There were various factors that influenced lichen frequency. Area condition, traffic effect, distance from pollution source to study lichens, bark pH, and wind direction were also important factors. This information conformed to the study results obtained by van Dobben and ter Braak (1999) indicating that the spatial micro distribution of lichens was associated with atmospheric pollutants in a complex way because pollutant impact depended on substrate texture, shape and inclination, wind, light, relative humidity, organism activity and other factors. The study of Policnik et al. (2008) demonstrated that the epiphytic lichen distribution depended on both substrate- and environmental-related factors. Therefore, the differences in species richness between forest sites and open areas were expected. When space from road was enlarged, pollution concentration was reduced (Riga-Karandios and Karandios, 1998). The most lichens were found at the middle barks of mango trees in the studied areas. The second most lichens were found at the plain and rough- skin barks. These results

were similar to the study results of Subsri (2002) mentioning that different mango tree characteristics depended on tree ages. The study found that the old aged trees had more cracks on barks. From observation, young lichens found at deep-cleft barks, comparing to rather smooth barks where numerous lichens were found. Regular wind swept through and greatly affected Thailand were two types of seasonal wind, i.e. the southwest monsoon or summer monsoon and the northeast monsoon or winter monsoon (The Meteorological Department, 2009). According to the study in January-October, most lichens were found in the northeast. Thus, lichens on studied trees in the southwest were possibly and mostly affected when wind blew with air pollutants from roads. The study presented that most lichens found on trunks of studied trees in the municipality areas were in the northeast. The next most were in the north, south, northwest, east, southeast and west, respectively. The stated findings conformed to the study of Subsri (2002) which found most lichens grew up in the northeast of studied trees. The findings also conformed to the study of Saipankaew et al. (2007) which demonstrated that many lichens were found on tree trunks in the east and north but small numbers were found in the west and south. It was supposed that trees in the west and south received much light in the afternoon which caused low humidity of substrates. Again, the mentioned findings were consistent to the study of Cristofolini et al. (2008) indicating a negative synergistic effect due to the high correlations between SO_2 and NO_2. We observed that his effect was particularly evident in the northern part of the Italian Prealps, probably due to are lapse effect caused by the geomorphologic feature of the valley and the prevalent wind direction (S-N). This interaction was reported worldwide for a large suite of environments. Due to the study of Branquinho (1999), the impact was more wide spread towards

east, and was correlated with the frequency of the winds and thus with the dispersion of particles. No relationship with the wind speed was found due to the lack of variation in this factor between the different directions. Lichens were slow-growing organisms, hence, they may be used as long-term integrators of environmental conditions. The lichen biodiversity data allowed easy identification of the zones of influence of the mine reflecting the long-term emissions. This biodiversity study suggested that pollutant emission from the centre of the mine might be important in terms of the lichen survival at short distances around the mine site. Besides, pollutants in the air could be blown by wind to lichens in surrounding studied areas (Garty et al., 2003) and caused the spacing areas in the wind direction differently affected by air pollution.

Referring to the study on bark pH measurement in the study areas, the average pH was at 5.09-5.62. Nitrogen dioxide, sulfur dioxide and ammonia influenced bark pH. Sulfur dioxide showed more influence bark pH than ammonia (van Dobben and ter Braak, 1998). Low pH of barks resulted by high concentration of ammonia gas (van Herk, 2001; Wolseley and James, 2002, Frati et al., 2006). The statistical analysis found that the study bark pH did not correlate with lichen diversity index and amount of nitrogen dioxide and sulfur dioxide in the study areas. According to studies of Subsri and Saipankaew (2002) which examined mango bark pH in urban and suburban areas in Chiangmai, the results found that bark pH was 5.0-5.3. Bark pH in urban areas was higher than the one of suburban areas. The stated results were consistent with the results examined by Subsri (2002) on pH of mango-tree barks in urban and suburban of Chiangmai and found that barks in urban areas had higher acid numbers than barks in suburban areas. However, the more pollution sources were close to roads, the more acid numbers of mango-tree barks.

Moreover, according to the study of Pomphueak (2005) investigated pH of mango-tree barks in areas of Muang district, Lampang province and found that bark pH was 5.22-5.74. The lowest pH was found in area with the least pollution and the highest 166 found in area with the highest pollution. Larsen et al. (2007) reported that high bark pH in central London might be due to calcareous dusts from buildings and demolitions contributing to the alkaline dust effect.

5.2 Making Nakhon Ratchasima municipality air quality map by lichen frequency

The total lichen frequency on studied tree trunks was calculated by the VDI for air quality index. The analysis results indicated that the lowest air quality index at sampling plot no.21 was 4.7 or expected that there was high quantity of air pollution in the area which covered areas of Khon Kaen intersection, area in front of the Big C supermarket and Nakhon Ratchasima transportation Station2 in the central of the Nakhon Ratchasima municipality area. The highest air quality index at sampling plot no.31 was 29.5 or expected that there was moderate-high quantity of air pollution in the area which covered areas of the Bung Talua park, rice field, and agricultural area located in suburban of the municipality where overgrown, and covered by weeds. Pruksakorn (2007), after a study, drew a map indicating air quality of areas in Lamphun municipality by using lichen frequency. It was found that expected areas with such very high air pollution consisted of areas where road along railway was constructed. The area with high air pollution covered overgrown longan orchards. Communities located in this area were distributed with light traffic load. This area, therefore, had better air quality, comparing to the other areas in municipality. These findings

conformed to study results of Pomphueak (2005) indicating that air quality in the city center of Amphoe Mueang Lampang was evaluated based on lichen diversity value, which was calculated from the frequency counts of all lichen species within a particular sampling quadrate positioned on the tree trunks. The lichen diversity index can be used as evaluation values for assessing air pollution, as well as indicators for the abundance of lichen and lichen species in the sampling unit. The lowest lichen diversity index was found in the center of city, indicating that the abundance of lichen and lichen s 167 was low. In the outer zone of the city, lichen diversity index increased, which indicate that the abundance of lichen was higher than in the city center. Moreover, the findings were also consistent with the study of Na Ma (2004) presenting that the air quality zones indicated by lichens were found to correspond with the land use type and the population density in the study area. In the center part of Lampang city the highest level of air pollution was indicated. This zone was a very densely developed area with the highest population density. Furthermore, in the present study, this area was the central commercial area of Nakhon Ratchasima municipality, including government institutes, schools, colleges, markets, hotels, hospitals and densely populated residential areas. Therefore, the heavily polluted air occurring was caused by the heavy traffic load particularly during the rush hours, since there were many schools and colleges located. Moreover, in the urban area where development was very dense, the air pollutants were more likely to be trapped inside the area because the wind speed was reduced due to the frictional drag of buildings on the air moving around them (Saipankaew, 1994).

5.3 Measurement of nitrogen dioxide and sulphur dioxide

The average nitrogen dioxide concentration measured in the winter season was higher than the average measured in the rainy season. The nitrogen dioxide measurement applied in the present study was done by the passive sampling technique which proceeded for 14 days. However, the measured value was lower than the standard value specified by the Pollution Control Department i.e. the average nitrogen dioxide concentration/hour was not above 320 ppm (Pollution Control Department, 2009). According to a study on correlation between average concentration of nitrogen dioxide both in the rainy and winter seasons and AQI was analyzed conversely correlated.

The measurement of average concentration of sulphur dioxide at each studied area in the rainy and winter seasons. It was also found that the average concentration of sulfur dioxide measured in the winter season was higher than the one measured in the rainy season. This finding conformed to study results conducted by Saipankaew et al. (2007) which indicated that amount of sulphur dioxide measured in December, the winter season, was higher than the one measured in July, the rainy season, since pollutants in atmosphere were washed away by rain. Although the sulphur dioxide measurement was proceeded by the passive sampling for 7 days, the measured value was lower than the standard value specified by the Pollution Control Department, i.e. the average sulfur dioxide concentration/hour was not over 300 ppbv (Pollution Control Department, 2009). It was indicated that the average concentration of sulphur dioxide and the AQI in the rainy season conversely correlated. Moreover, it was indicated that the average concentration of sulphur dioxide and the AQI in the winter season were not correlate.

The above mentioned results conformed to the study of Kasper-Giebl and Puxbaum (1999) that used polyethylene diffusion tubes and TEA as an absorbent for the determination of ambient air concentrations of sulphur dioxide (SO_2) and nitrogen dioxide (NO_2). They found the concentrations of nitrogen dioxide were 50%, lower than the results given by nearly chemiluminescence monitors. The underestimation could be corrected by placing two grids into the diffusion tube. The determination of sulfur dioxide was strongly biased by the collection of particulate sulfate at the entrance part of the tube and along the tube walls. According to the study of Pomphueak (2005), the passive sampling technique was used to measure primary air pollutants, NO_2 and SO_2 in each sampling unit of Amphoe Mueang Lampang. Polyethylene diffusion tubes and adsorb with 20% TEA were used to collect nitrogen dioxide (NO_2) and sulphur dioxide (SO_2) for 2 weeks period of exposure. NO_2 and SO_2 were determined as nitrite and sulfate ions by ion chromatography. The concentration of nitrogen dioxide of studied area measurement period was 7.00-36.5 ppbv. and concentration of sulfur dioxide of studied area measurement period was 3-20 ppbv. The high air pollution was found in the city center area where the development was dense, and the population density was high. The air quality was slightly better in the outer zone of city where there was more open area and low population density. From the result, the correlation test between concentration of NO_2 and SO_2 in each sampling plot measured by the passive sampling technique and AQI, Pearson's correlation showed negative significantly correlation between the both in rainy and winter seasons of NO_2 and in rainy season of SO_2 with AQI, while there was no significant correlation between SO_2 in winter season with AQI. However, the concentration measurement presented that there was higher nitrogen dioxide than sulphur dioxide in both the rainy and winter

seasons. Since there was no pollution source at the measured area, the measured sulphur dioxide concentration was low. The measured nitrogen dioxide concentration was high because of there were main pollution sources located, incomplete fuel burning such as from vehicles with waste-energy engines, etc. Loppi and Stergios (2003) found that NO_x derived from domestic heating emissions was considered responsible for changes in diversity at Pistoia, Italy. This was consistent with the study of van Dobben and ter Braak (1999) indicating that the epiphytic lichens respond to atmospheric pollution, a negative relationship of most species was observed only for SO_2, or the combination of SO_2 and NO_x which generally were strongly correlated, and thus biodiversity counts could only be used as a monitor for SO_2. Due to the study by van Dobben et al., 2001 about the importance of the factors determining epiphytic vegetation on way side trees in the Netherlands, the most important were the toxic atmospheric pollutants SO_2 and NO_2. Nearly all species decreased with increasing concentrations of these compounds which therefore strongly negatively affect species diversity. This phenomenon was the basis of a large number of bioindicator studies using lichens. The epiphytic lichen diversity could still be successfully used as a biomonitoring method. Furthermore, our results confirmed some observations reporting that high NO_x concentrations from road traffic negatively affected lichen presence (Giordani, 2007), and might presently be the main limiting factor for lichen colonization in urban areas (van Dobben et al., 2001). Roorda-Knape et al. (1998) studied in the Netherlands where NO_2 concentration was found to be positively correlated with traffic density and negatively correlated with distance from the nearest highway. A negative correlation between distance from high way and NO_2 levels, according to a logarithmic function, was also found at Los Angeles (Rodes and

Holland, 1981), Montreal (Gilbert et al., 2003) and in Scotland (Cape et al., 2004). Moreover, a study conducted by Loppi et al. (2002) presented that concentrations of SO_2 measured in Siena from 1996 to 1999 (4-5 g/m3) were probably too low to kill or damage lichens. However, in urban environments, in addition to SO_2, the simultaneous occurrence of the phytotoxic gaseous pollutants NO_x was typical, and combined effects could therefore be expected. Using lichens as biological indicators for monitoring and inspecting of air quality by air quality mapping by lichen frequency and pollution measurement could indicate areas affected by air pollution. According to the study, nitrogen dioxide and sulphur dioxide should be measured in each season. Re-measurement should be done in order to get inclusive data to assure experimental results.

5.4 The study on lichen diversity in area of Sakaerat Environmental Research station

There were 38 lichen species were found in the deciduous dipterocarp forest and dry evergreen forest where were 320-510 m above sea level. Some species distributed in almost every sampling plot such as *Trypethelium tropicum, Trypethelium eluterae, Opegrapha stirtonii, Chrysothrix xanthina, Rinodina* sp. and *Laurera benguelensis*. Due to the study results, the *Parmotrema tinctorum* was found at the area where was 320-380 meters high from the sea level. This was consistent with the study results of Kanjerm (2009) which found *Parmotrema tinctorum* at the studied area where was 300-400 m above sea level. This result was also consistent with the study of Saipankaew et al. (2005) indicating that this lichen species was not found on tree trunks in plain area, but was found in high land.

The lichen species found in the two forests were calculated for similarity by Sørensen similarity index. Calculated result indicated similarity of 0.79 or 79% indicating that lichens in the two forests were very similar. It might be because elevation of both forests were not much different. Moreover, temperature, humidity and light intensity of each sampling plot were not much different. When calculation for Shannon - Wiener's diversity index (H'), evenness (E) and species richness was calculated, results showed that the highest lichen diversity index (2.48) and the highest species richness (15 species) were found in the 1st sampling plot of deciduous dipterocarp forest. The next highest were found in the 2nd sampling plot of dry evergreen forest, 2nd sampling plot of deciduous dipterocarp forest, the 3rd deciduous dipterocarp forest, respectively. The evenness of each sampling plot was similar (0.91-0.97).

Average temperature, humidity, and light intensity measured in deciduous dipterocarp forest and dry evergreen forest in June-November 2552 were 27.5-32.7°C, 66-83% and 262-1,002 lux, respectively. Based on analysis of correlation between temperature, humidity and light intensity of each studied areas and lichen diversity index by using the Pearson's correlation coefficient, it was indicated that temperature, humidity and light intensity did not significantly correlate with lichen diversity index at 95% significant level. With reference to the study of Armstrong (1977) and Ahmadjian (1993), it showed that water availability was the environmental factor of foremost importance in determining rates of primary production, other than light intensity, temperature and nutrients. Loppi et al. (2002) mentioned that in the study area, under the same level of air pollution, confirming the need for regional scales for interpreting patterns of LDV (Lichen Diversity Value) values in different bioclimatic regions. Due

to the study by Lawery (1984), light intensity was the most important factor influencing lichen growth and distribution in the temperature region following by temperature, relative humidity and nutrients. This was consistent with the study of Osathanon (2001) which investigated climate in specific areas and growth of some lichen species in the Khao Yai National Park in June 1999-January 2001 and indicated that in the hot season, the average temperature, relative humidity, and light intensity were 28-35°C, 40-70%, and 200-700 µmol/m^2s, respectively. In the rainy season, the av

temperature, relative humidity, and light intensity were 30-35°C, 50-80%, and 200-600 µmol/m^2s, respectively. As for in the winter season, the average temperature, relative humidity, and light intensity were 29-30°C, 70-80%, and 200-1,000 µmol/m^2s, respectively. It was found that those factors were essential factors for lichen growth. From this present study, temperature, relative humidity and light intensity did not correlate with lichen diversity index in each studied area since study period might be too short or did not cover enough. The study of lichen diversity in deciduous dipterocarp forest and dry evergreen forest did not cover all areas. The further study is recommended to study in areas of deciduous dipterocarp forest, eco-tone forest, and dry evergreen forest in order to cover all areas. Moreover, more subplots are recommended to obtain more types of data leading to more accurate and obvious conclusions.

CHAPTER VI

CONCLUSIONS

6.1 The study on lichen frequency, nitrogen dioxide and sulphur dioxide measurement in Nakhon Ratchasima municipality

According the investigation of lichens on 276 mango trees, 10 families, 17 genera and 29 species were found in study areas. Most lichens found consisted of *Hyperphyscia adglutinata, Pyxine cocoes, Physcia dimidiata, Lecanora leprosa* and *Opegrapha stirtonii*. From the mentioned investigation, the crustose lichens were found more than the foliose lichens at every study area.

Hyperphyscia adglutinata was found most was found the least in study areas. The highest lichen frequency was found at the sampling plot no.31 which covered the areas of the Bung Talua park. The lowest frequency was found at sampling plot no.21 which covered areas of the Hua Rodfai intersection, the municipality office, and Nakhon Ratchasima regional electricity office. Air quality mapping using lichen frequency as an air quality indicator in areas of Nakhon Ratchasima Municipality could classify air quality into four levels as follows:

The first level: Air quality index was at a width range of more than 0.0 to less than or at 7.6 indicating very high polluted air quality. Air quality index of sampling plots classified into this level was 4.7-7.6.

The second level: Air quality index was at a width range of more than 7.6 to less than or at 15.2 indicating high to very high polluted air quality. Air quality index of sampling plots classified into this level was 8.3-15.0.

The third level: Air quality index was at a width range of more than 15.2 to less than or at 22.8 indicating high polluted air quality. Air quality index of sampling plots classified into this level was 15.3-21.8.

The fourth level: Air quality index was at a width range of more than 22.8 to less than or at 30.4 indicating moderate to high polluted air quality. Air quality index of sampling plots classified into this level was 23.0-29.2.

A study for differences of air quality characteristics by constructing three isolines indicating air quality indices of 7.6, 15.2 and 25.5 was done. These three isolines divided areas into three zones, i.e. Zone 1 predicting very high air pollution, Zone 2 predicting high-very high air pollution, and Zone 3 predicting high air pollution. This was a primary study that might predict the pollution presently occurred in the studied municipality areas or predict to choose appropriate areas with good air quality for construction of residences or commercial buildings, etc.

Regarding the monitoring and inspecting the amounts of nitrogen dioxide and sulphur dioxide in atmosphere, the results showed that during 14 days of measurement. The measurement of NO_2 and SO_2 in rainy and winter seasons, concentration of NO_2 and SO_2 in winter season was higher than the in the rainy season, concentration of NO_2 and SO_2 in urban area higher than suburban area, NO_2 concentration (0.46-8.93 ppbv) more than SO_2 concentration (0.76-0.74 ppbv) because of pollutant from road traffic in Nakhon Ratchasima municipality. After the analysis of correlation between the both in rainy and winter seasons of nitrogen dioxide and sulphur dioxide in rainy season with AQI by the Pearson's correlation coefficient, it was found that they negative significantly correlate at 99% significant level. According to the study results, it could be concluded that the amounts of NO_2 and SO_2 measured in the inspection period were

low and did not effect lichen frequency. However, when considered tendency of NO_2 and SO_2 amounts and AQI, it was indicated that when the amount of these two pollutants increased, AQI decreased.

When amounts of NO_2 and SO_2 were studied about correlation with bark pH by the Pearson's correlation coefficient, it was found that there was no significant correlation at 95% significant level. According to the study results, it could be concluded that both NO_2 and SO_2 did not affect bark pH in Nakhon Ratchasima municipality area, but low barks pH were found in urban areas with high concentrations of NO_2 and SO_2.

6.2 The study on lichen diversity in the Sakaerat Environmental Research station

The study on lichen diversity in deciduous dipterocarp forest and dry evergreen forest was conducted in the six plots on 40 trees. The 13 families, 19 genera and 38 species were found. Most found lichens were in the families of Graphideceae, Physciaceae, Porinaceae, Pyrenulaceae and Thelotremataceae. The lowest number of lichen found were in the families of Cladoniaceae, Crocyniaceae, Roccellaceae and Ramalinaceae. Three lichen samples could not be classified into family. In all studied areas, there were more crustose lichens found than the foliose and squamulose lichens. The diversity index and species richness found in the deciduous dipterocarp forest were higher than the ones in dry evergreen forest. However, when the evenness was investigated, the results showed that evenness found in both types of forest were similar. Besides, according to calculation for similarity of lichens found in the two forests, it was found that lichens from the two forests were similar at 79%.

The correlation between lichen diversity and physical factors, i.e. temperature, humidity, and light intensity, was studied by the Pearson's correlation coefficient. The results indicated that the physical factors did not significantly correlate with lichen diversity index at 95% significant level.

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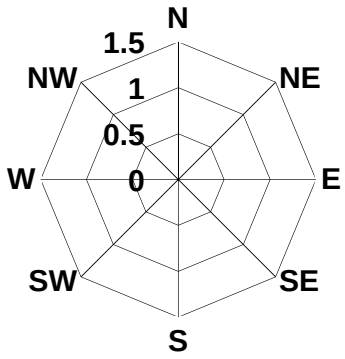
APPENDICES

APPENDIX A

SURVEY FORM

Direction



Examiner……...

Date……..……..

Sampling plot No.…….....

Tree No……..……..

Circumference 1.5 m…….……..(cm.)

Temperature …….……ºC Relative humidity ……%

Intensity light……lux Height from sea level……m

Latitude…N……..……Longitude…E……

Distance from road

1	2	3	4	5
0-5 m	6-10 m	11-15 m	16-20 m	> 20 m

Area conditions

1	2	3
High-density residential area	Not high-density residential area	Open area

Area around the mango's tree

1	2	3
Lawn area	Cement area	Ground area

Influence by traffic

1	2	3	4	5	6
Highway	Main road car>	Main road car<	Small road car>	Small road car<	Country road

Bark

1	2	3
Smooth	Quite smooth to medium deep	**Deep-wrinkle**

No.	**Species**		**Frequency**
	Foliose	**Crustose**	

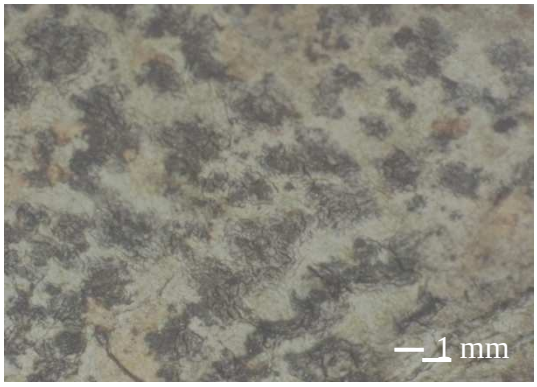
Sum:			

Remark :

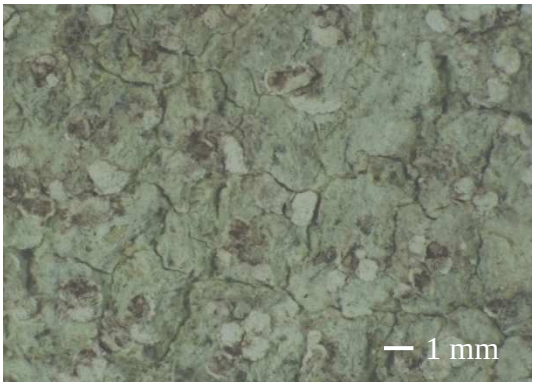
……
……
……
……
……

APPENDIX B

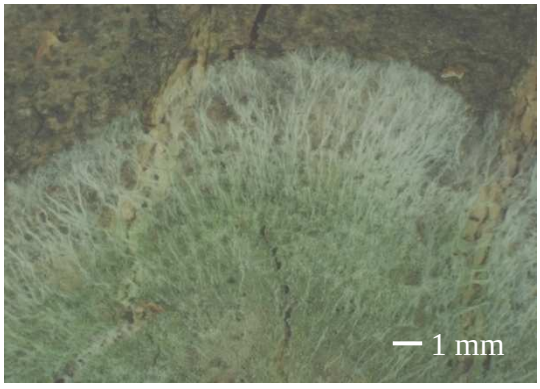
BLICHENS SPECIES FOUND IN THE NAKHON RATCHASIMA MUNICIPALITY AREAS



Arthonia tumidula

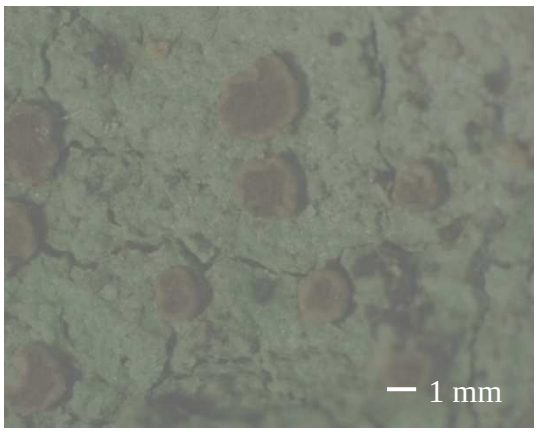


Arthonia sp.

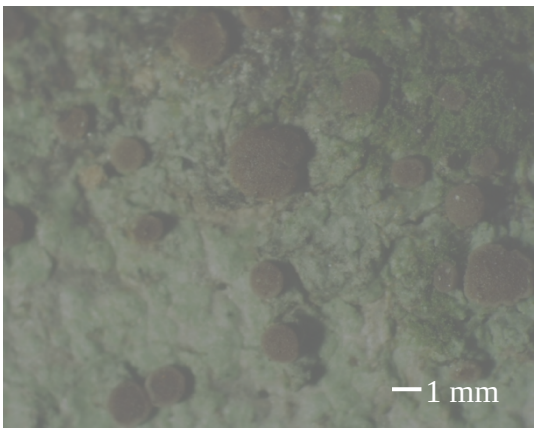


Cryptothecia sp.

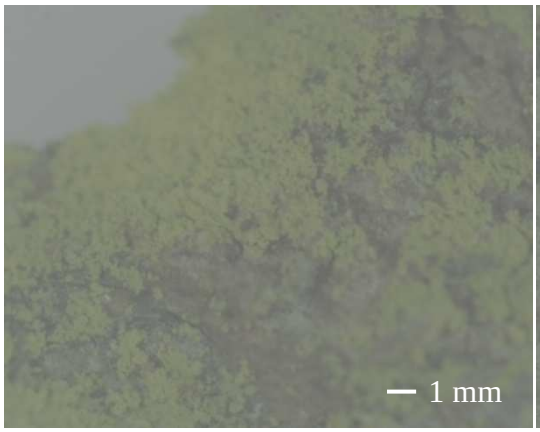
Bacidia sp.



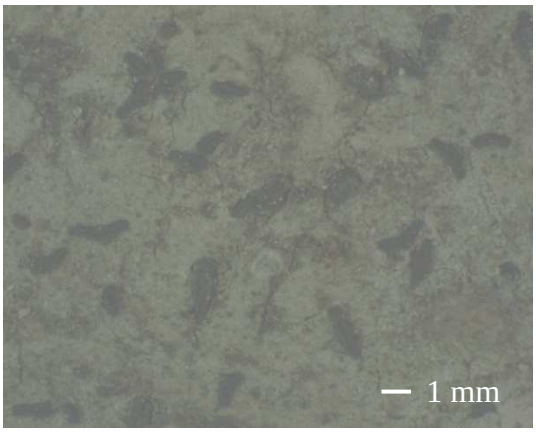
Caloplaca diplacia



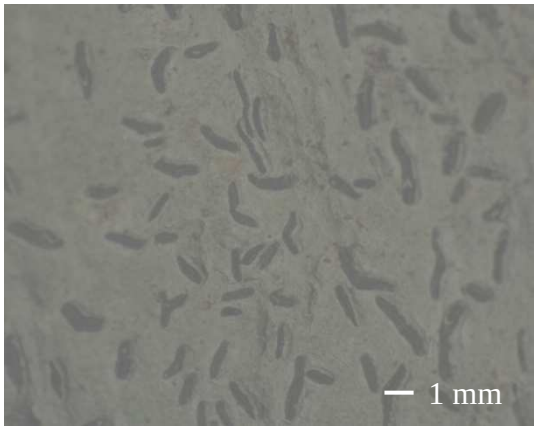
Caloplaca diplacioides



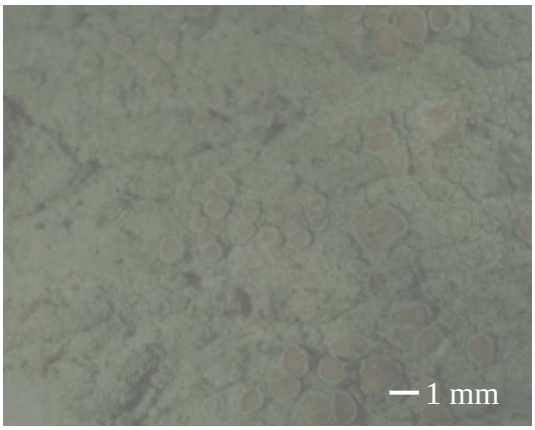
Chrysothrix xanthina



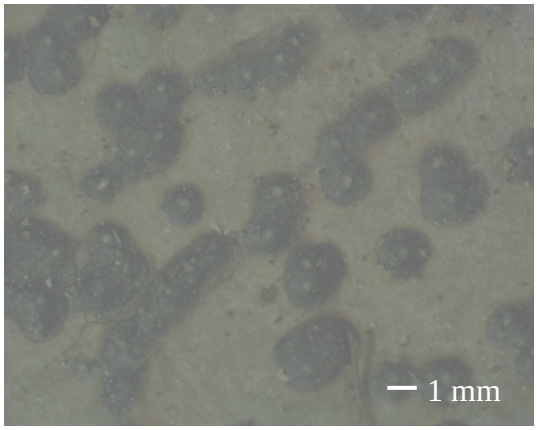
Graphis sp.



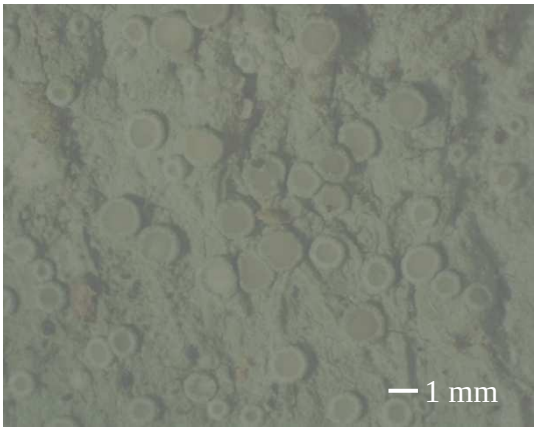
Graphina symplocorum



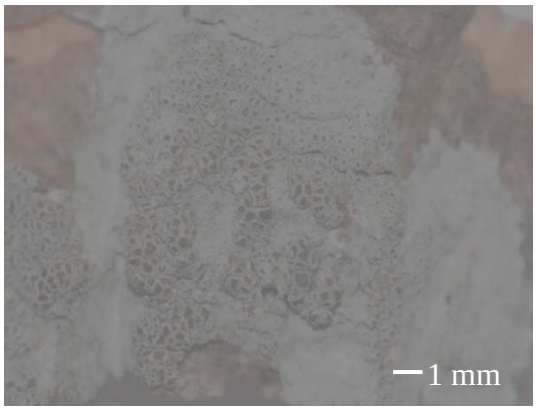
Lecanora achroa



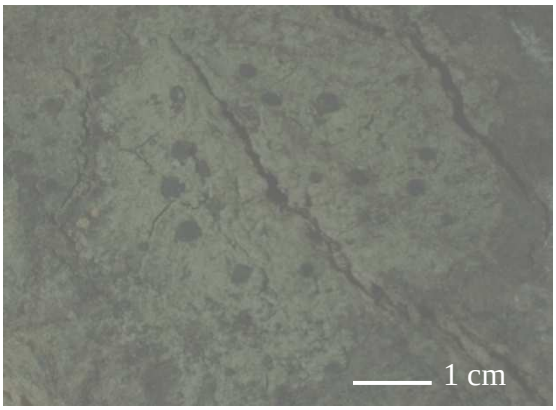
Trypethelium tropicum



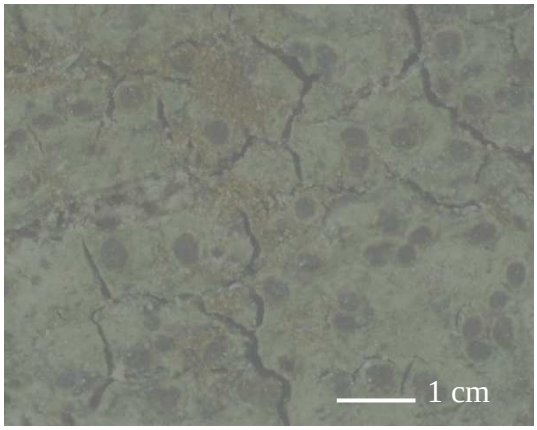
Lecanora leprosa



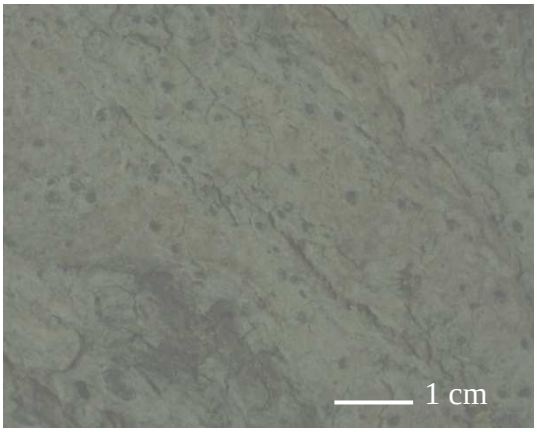
Lecanora tropica



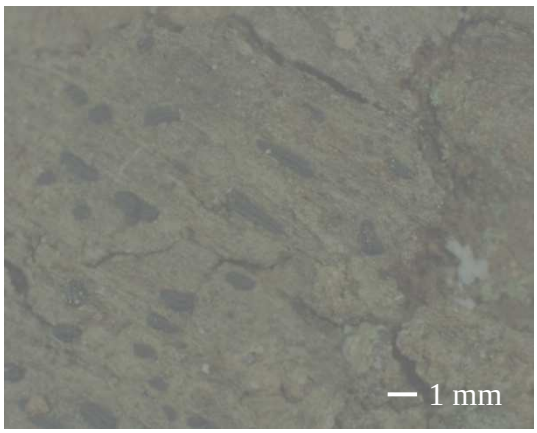
Buellia sp.



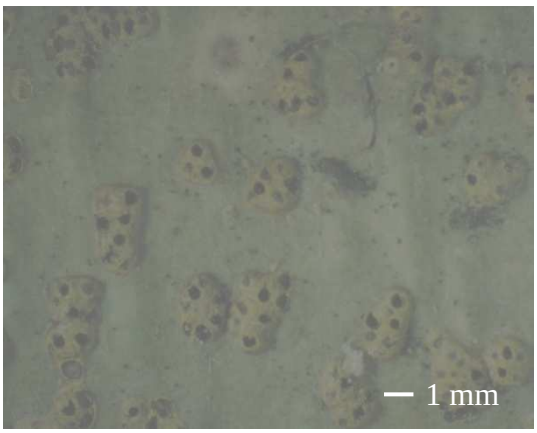
Rinodina sp.



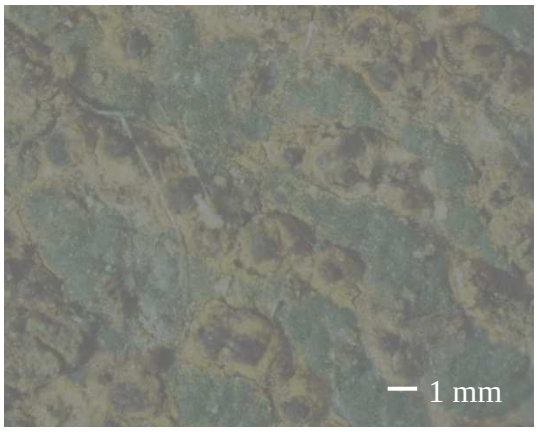
Lecanographa sp.



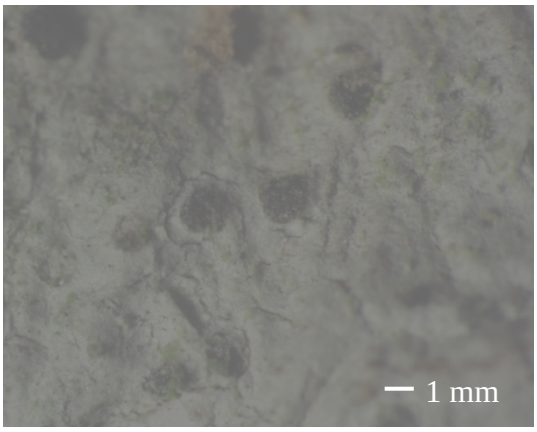
Opegrapha stirtonii



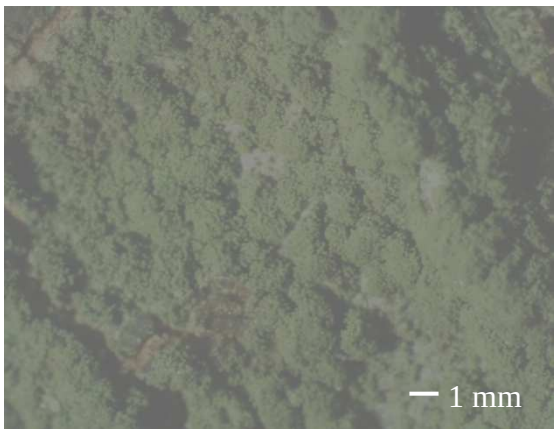
Trypethelium eluteriae



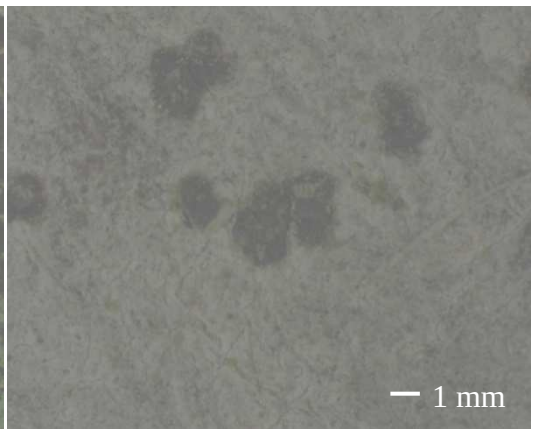
cf. *Laurera* sp.



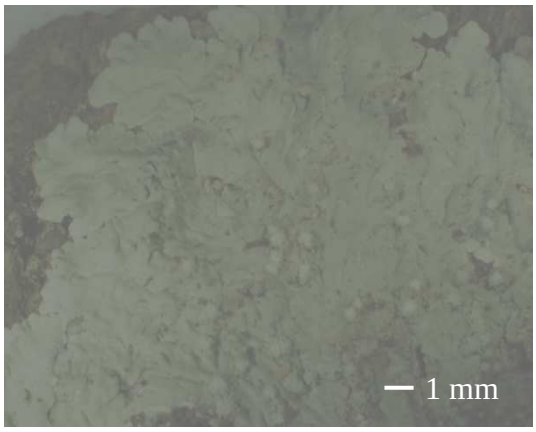
Sterile crust sp.1 (pycnedia)



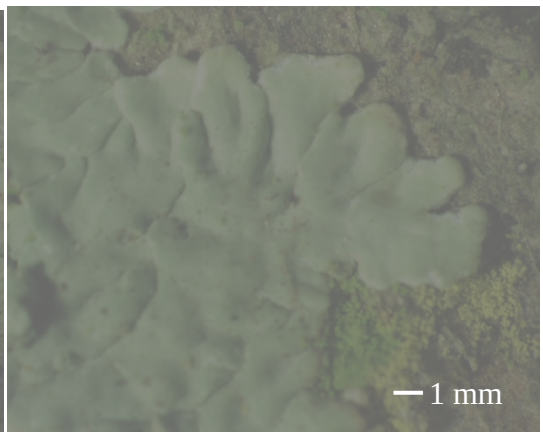
Sterile crust sp.2



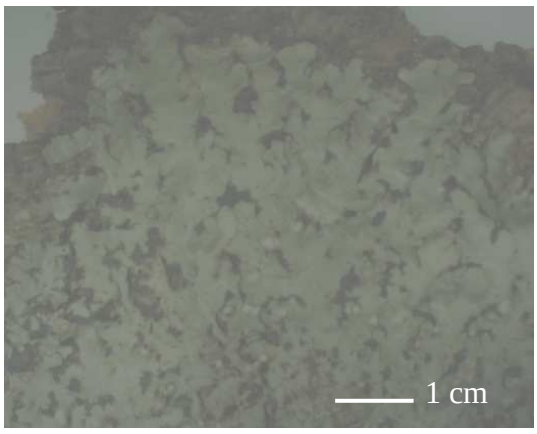
Sterile crust sp.3



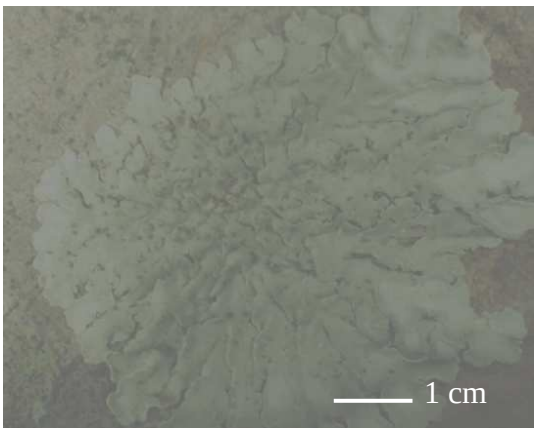
Dirinaria picta



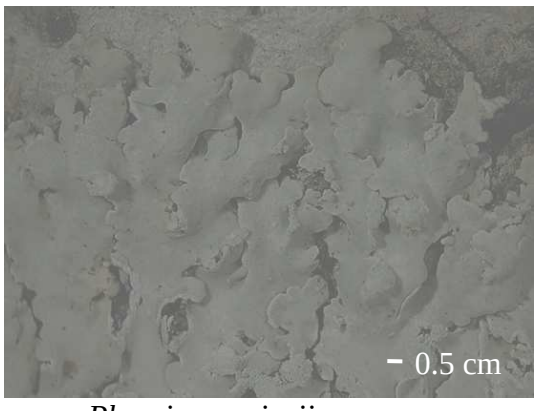
Dirinaria applanata



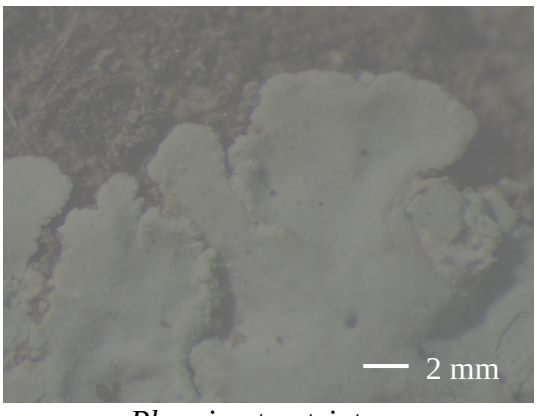
Hyperphyscia adglutinata



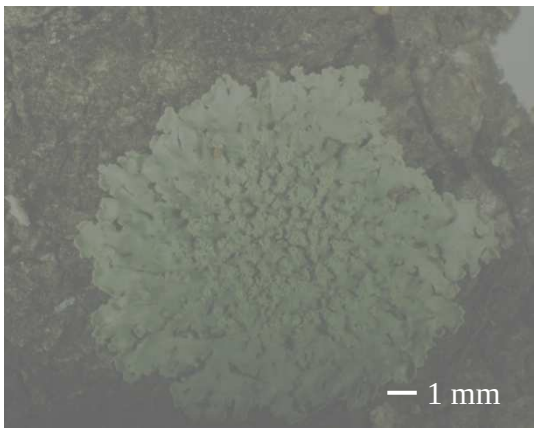
Pyxine cocoes



Physcia poncinsii



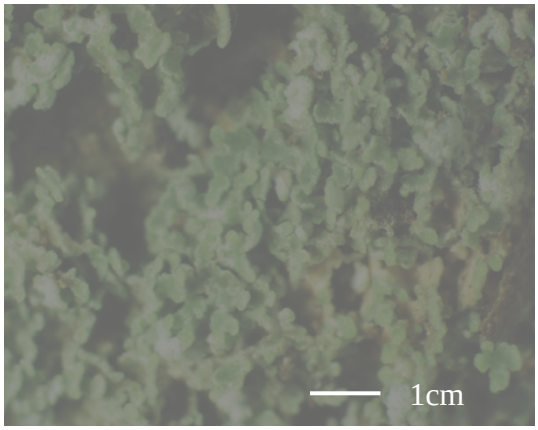
Physcia atrostriata



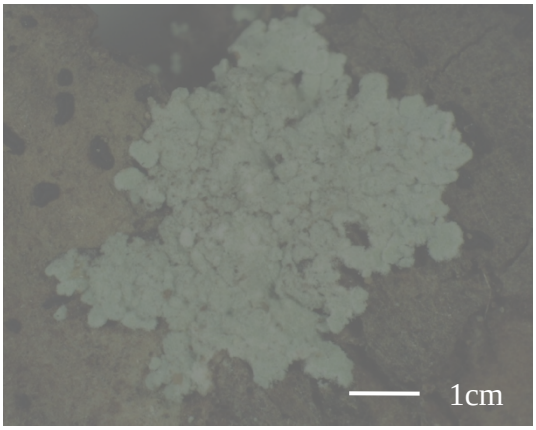
Hyperphyscia sp.

APPENDIX C

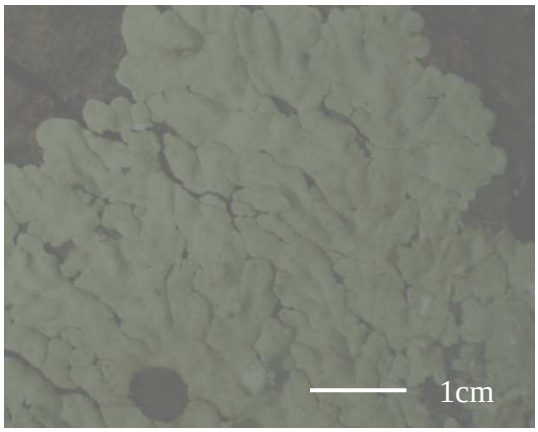
LICHENS SPECIES FOUND IN THE SAKAERAT ENVIRONMENTAL RESEARCH STATION AREAS



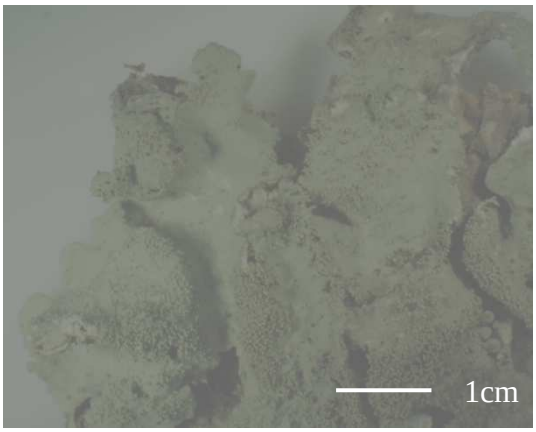
Cladonia sp.1



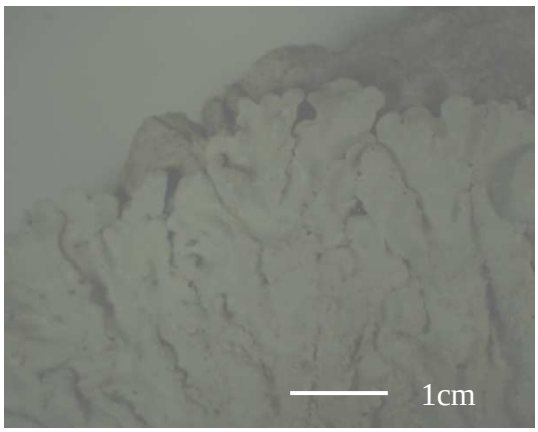
Crocynia pyxinoid



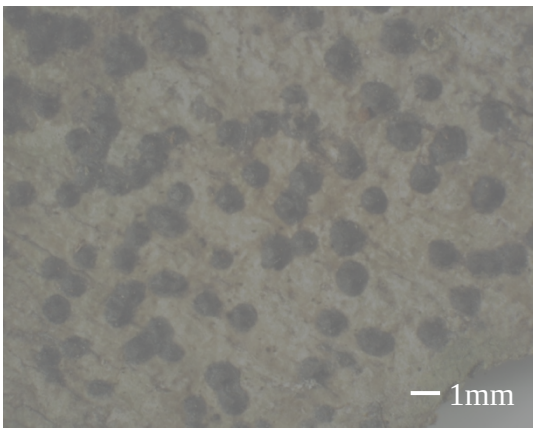
Dirinaria picta



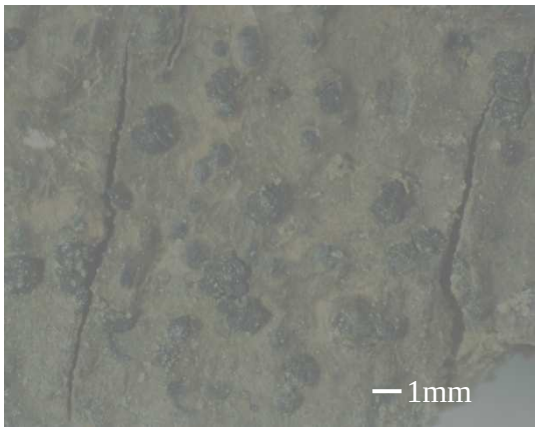
Parmotrema tinctorum



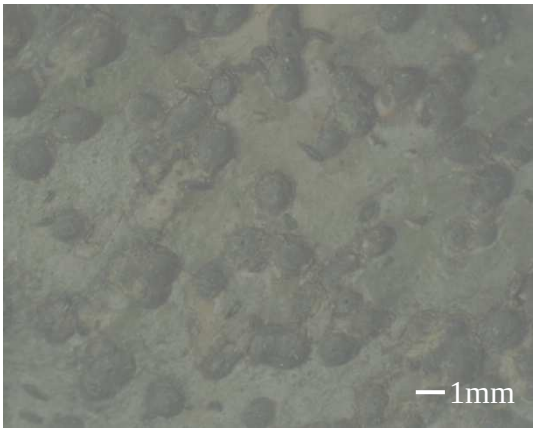
Pyxine cocoes



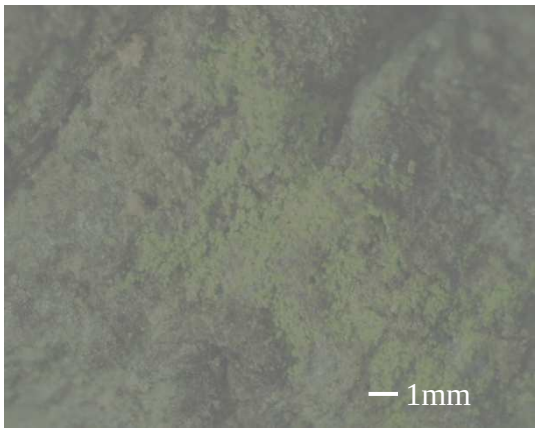
cf. *Anisomeridium*



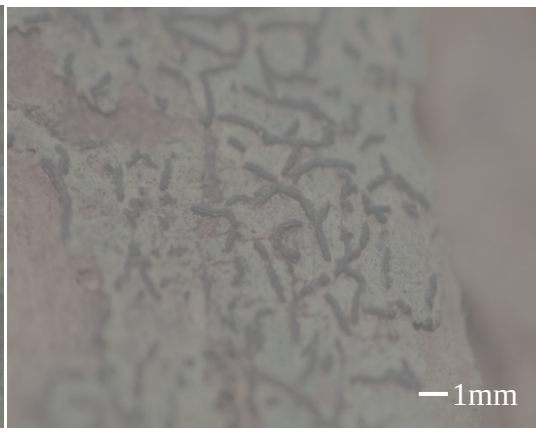
Buellia sp.



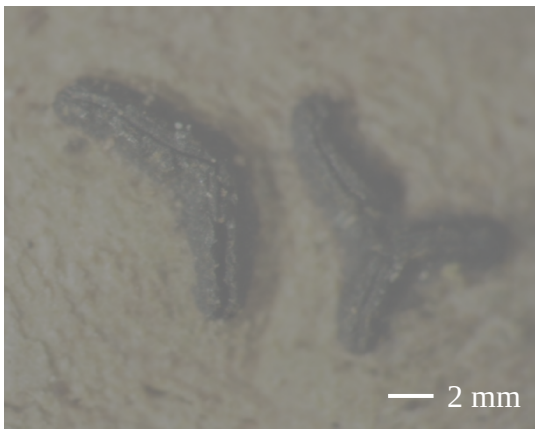
Clathroporina sp.



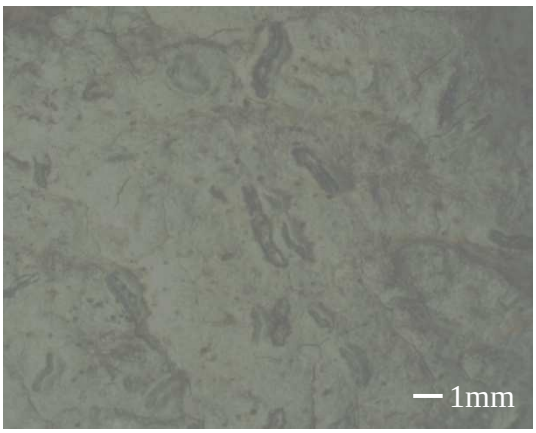
Chrysothrix xanthina



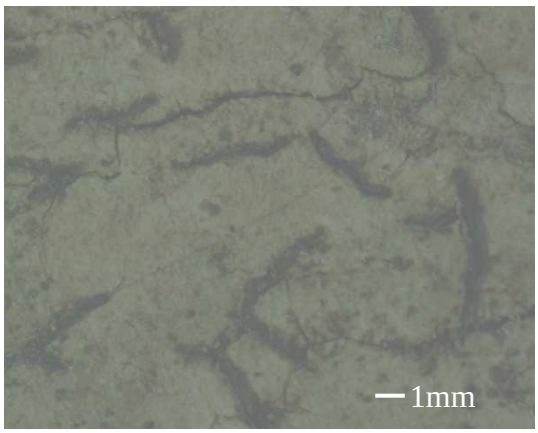
Graphis sp.1



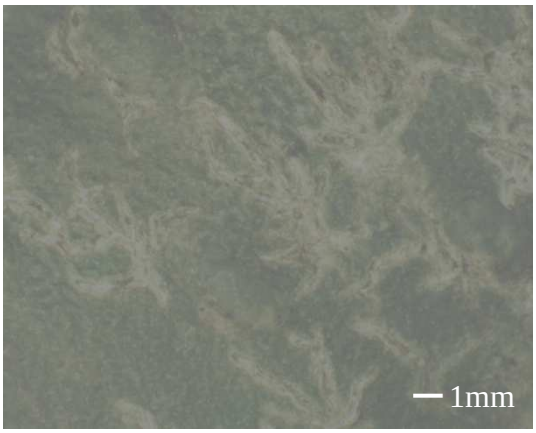
Graphis sp.2



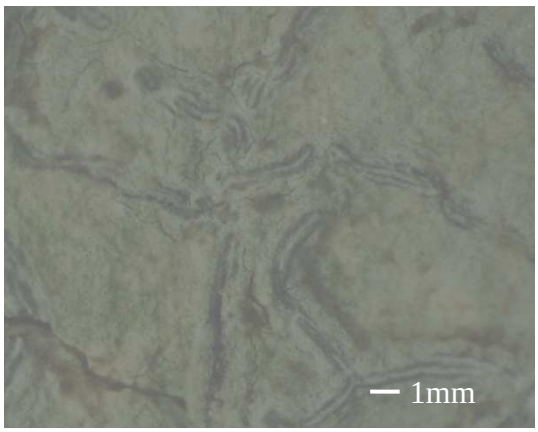
Graphis sp.3



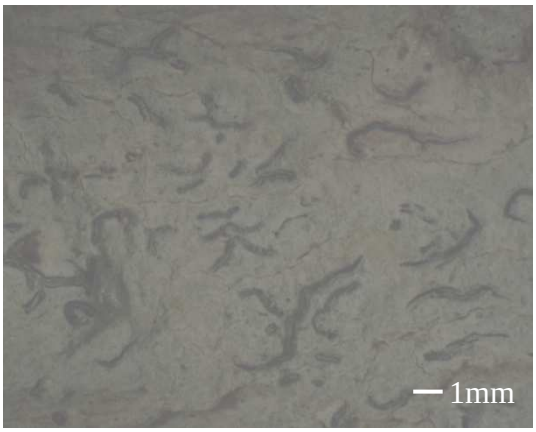
Graphis sp.4



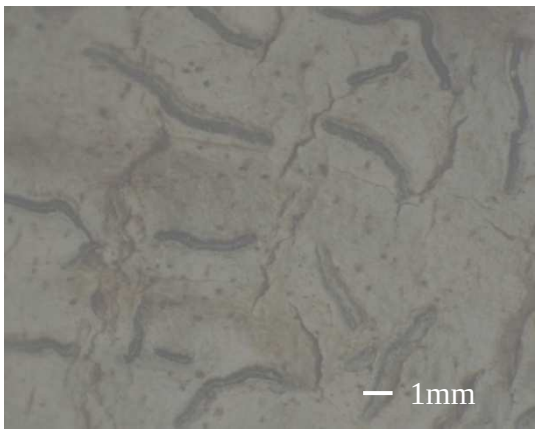
Graphis sp.5



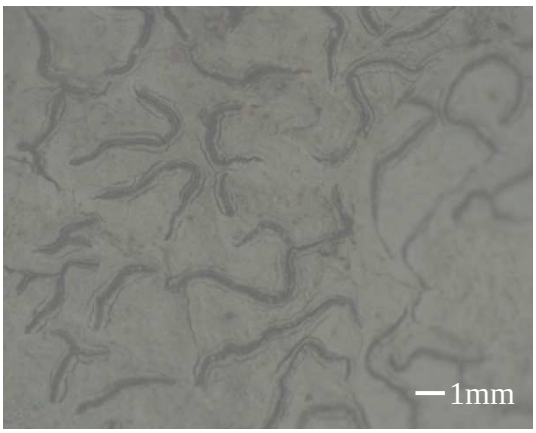
Graphis sp.6



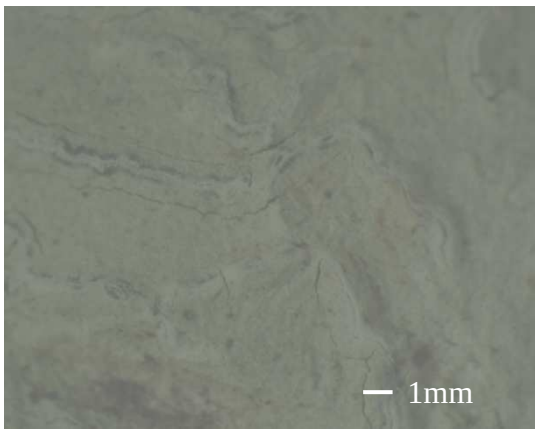
Graphis sp.7



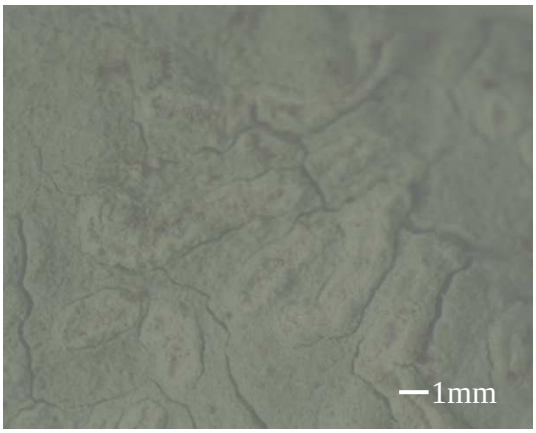
Graphis sp.8



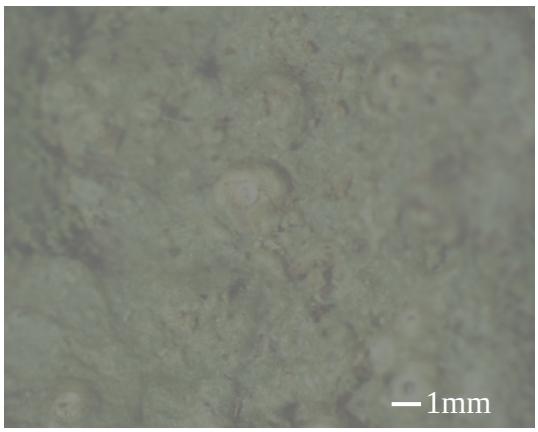
Graphis sp.9



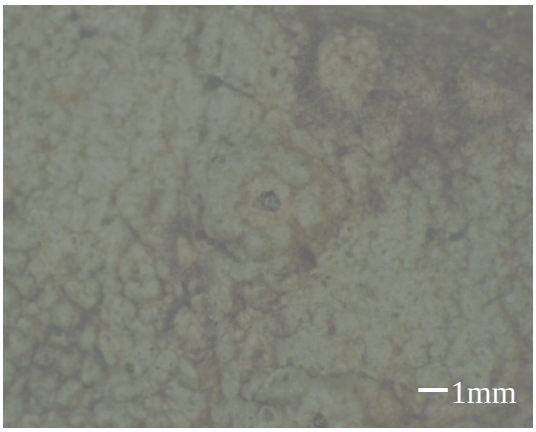
Graphis dumastoides



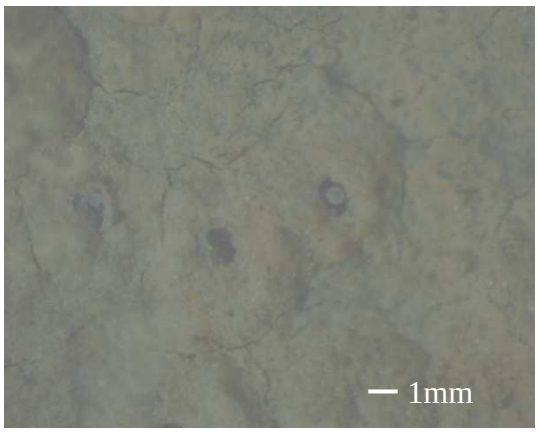
Graphina incrustans



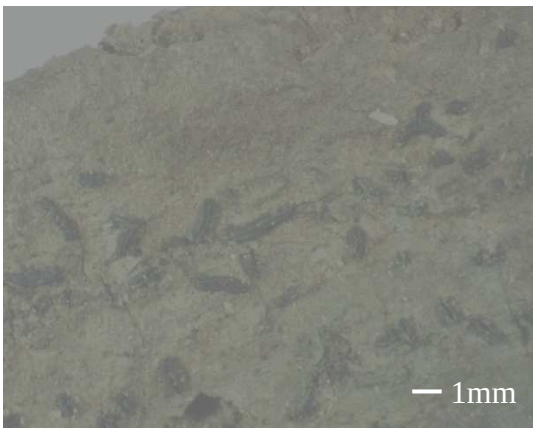
Myriotrema sp.1



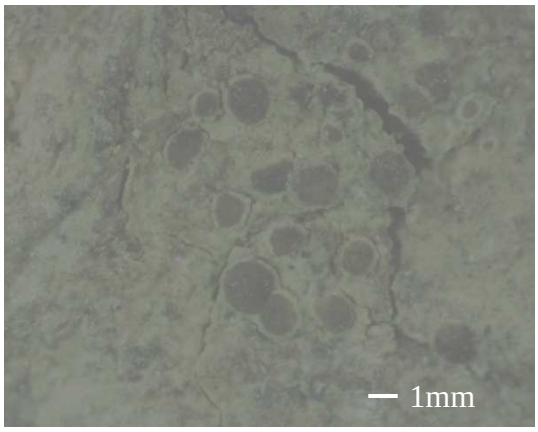
Myriotrema sp.2



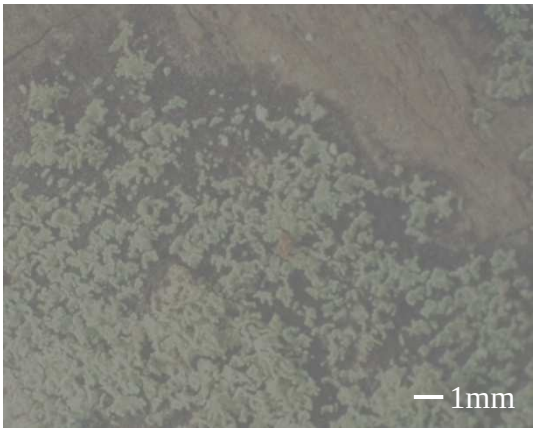
Ocellularia sp1.



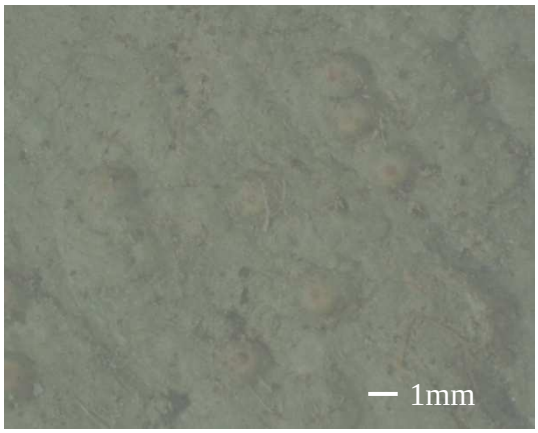
Opegrapha stirtonii



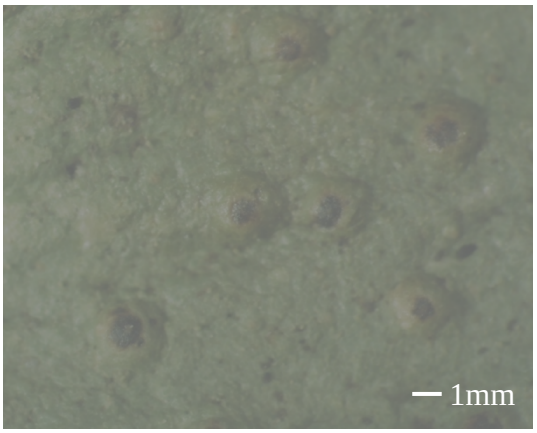
Rinodina sp.



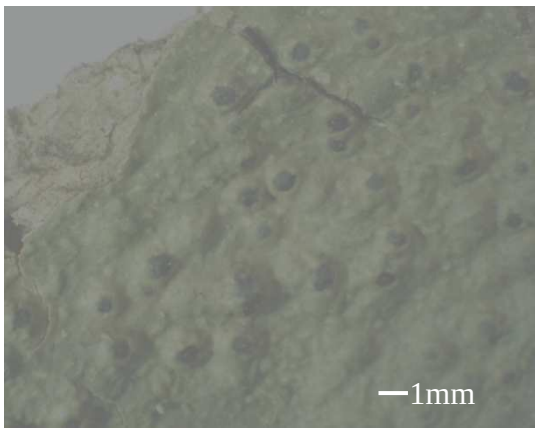
Phyllopsora sp.1



Porina eminentior

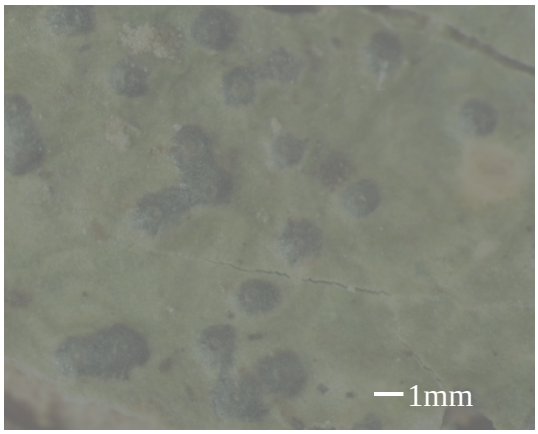


Porina internigrans

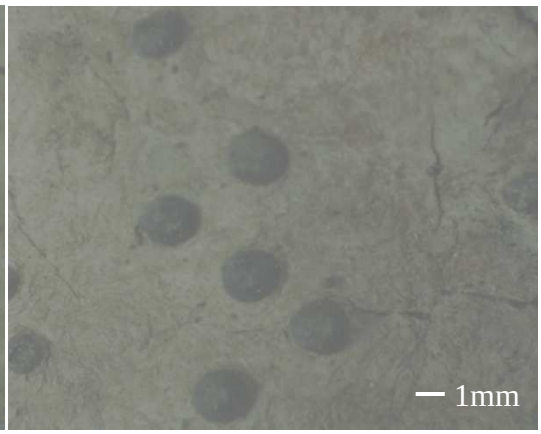


Porina subinterstes

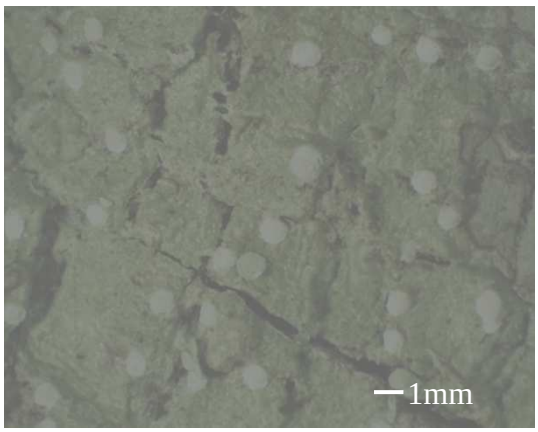
Pyrenula sp.1



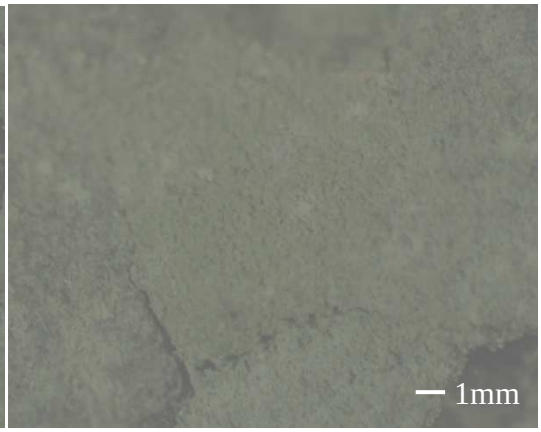
Pyrenula wilmsiana



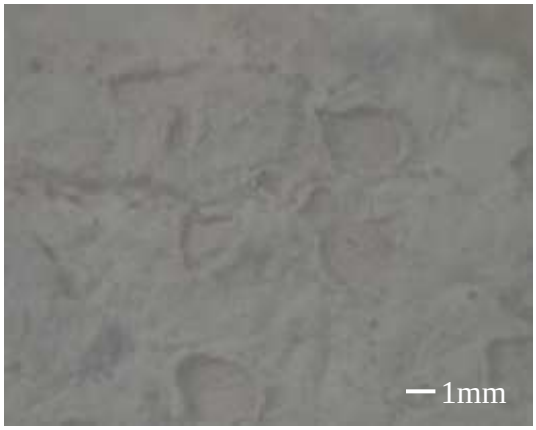
Steril crust sp.1 (pycnedia)



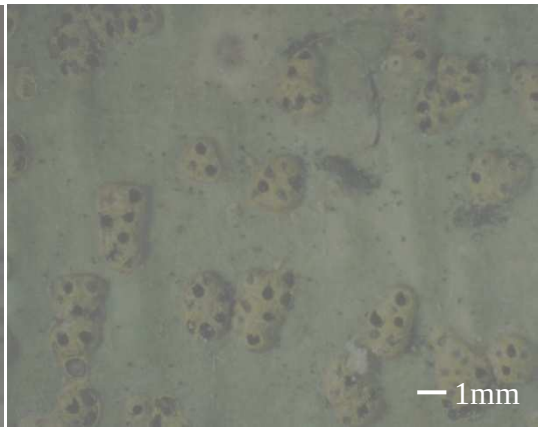
Steril crust sp.2



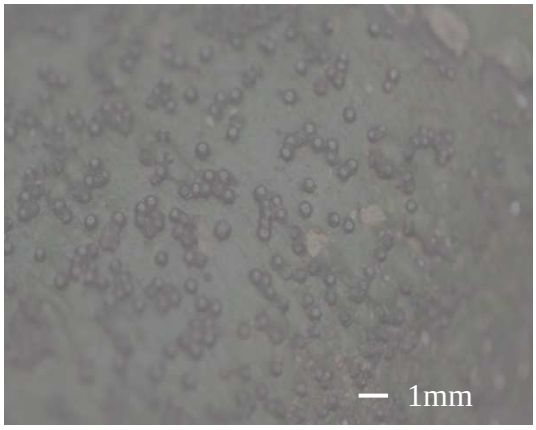
Steril crust sp.3



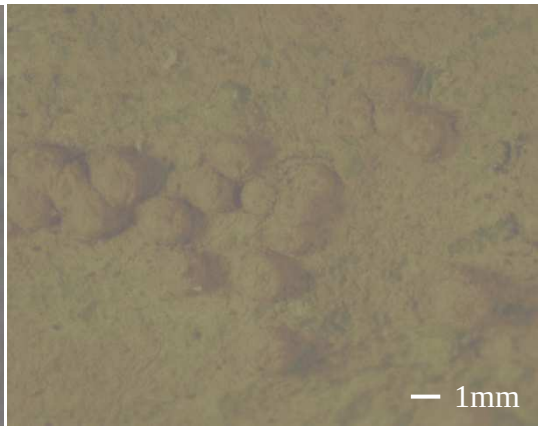
Thelotrema pycnophragmium



Trypethelium eluteriae



Trypethelium tropicum



Laurera benguelensis

APPENDIX D

CONTEXT INFORMATION AROUND MANGO TREES IN NAKHON RATCHASIMA MUNICIPALITY

Tree no.	C(cm)	D	Direction	Bc	Ac	As	Te
S1/1	62	1	NE	2	3	C	5
S1/2	112	1	N	2	2	A	5
S1/3	230	1	N	2	2	A	5
S1/4	75	1	-	1	3	C	2
S1/5	88	1	NE	2	2	C	2
S1/6	64	1	E	2	2	C	2
S2/1	80	4	NE	2	2	B	5
S2/2	54	1	-	2	3	C	3
S2/3	69	2	SE	2	2	B	4
S2/4	77	4	W		2	B	5
S2/5	112	1	-	2	2	C	4
S2/6	98	1	S	2	2	C	4
S3/1	168	1	W	2	2	B	3
S3/2	58	2	NE	1	2	B	3
S3/3	69	1	E	1	2	C	4
S3/4	106	1	NE	1	2	B	4
S3/5	95	1	SE	2	3	C	4
S3/6	83	1	N	2	3	C	4
S4/1	76	1	NE	1	2	C	5
S4/2	80	1	-	1	2	C	4
S4/3	55	1	N	1	3	C	5
S4/4	60	1	W	1	3	C	4
S4/5	85	2	NE	2	2	A	5
S4/6	96	2	S	2	2	A	5

(Continued)

Tree no.	C (cm)	D	Direction	Bc	Ac	As	Te
S5/1	58	1	-	1	2	C	1
S5/2	83	1	-	3	3	C	1
S5/3	170	1	E	3	3	B	1
S5/4	79	1	-	1	2	C	2
S5/5	90	1	-	2	1	C	2
S5/6	76	1	-	2	1	C	2
S6/1	181	1	-	1	2	B	2
S6/2	121	1	NE	2	2	A	2
S6/3	152	1	-	1	1	C	2
S6/4	186	2	W	3	3	C	2
S6/5	86	1	E	2	1	C	2
S6/6	77	1	-	1	1	C	2
S7/1	98	2	NE	3	3	C	2
S7/2	61	1	NE	3	2	C	2
S7/3	207	1	-	3	2	C	2
S7/4	89	2	N	1	3	C	2
S7/5	106	1	-	1	3	C	1
S7/6	90	1	W	1	2	C	1
S8/1	65	2	-	1	1	C	1
S8/2	131	2	N	1	3	C	1
S8/3	87	2	-	2	3	C	1
S8/4	70	1	-	2	3	C	2
S8/5	98	1	S	1	2	C	2
S8/6	53	1	NE	1	2	C	2

(Continued)

Tree no.	C (cm)	D	Direction	Bc	Ac	As	Te
S9/1	83	1	N	3	2	C	4
S9/2	176	1	E	3	2	C	4
S9/3	94	1	NE	2	2	C	4
S9/4	125	1	NW	2	2	C	4
S9/5	97	1	N	1	1	C	3
S9/6	104	1	-	1	1	C	3
S10/1	100	1	S	3	2	C	4
S10/2	75	1	-	2	2	C	4
S10/3	70	1	NE	2	2	C	2
S10/4	53	1	NE	2	2	C	2
S10/5	95	1	SE	1	3	C	3
S10/6	91	1	-	1	2	C	3
S11/1	150	1	N	2	2	B	2
S11/2	85	1	NE	2	3	C	2
S11/3	128	1	-	1	3	C	3
S11/4	98	1	N	2	3	C	3
S11/5	79	1	-	3	2	C	4
S11/6	57	1	-	1	2	C	3
S12/1	103	1	NE	2	3	C	1
S12/2	69	1	NW	2	3	C	1
S12/3	78	1	W	1	3	C	2
S12/4	84	1	S	1	3	C	2
S12/5	135	1	S	1	2	C	3
S12/6	73	1	-	2	2	C	3

(Continued)

Tree no.	C (cm)	D	Direction	Bc	Ac	As	Te
S13/1	68	1	-	3	1	C	3
S13/2	76	1	-	1	1	C	3
S13/3	65	1	NE	2	2	C	2
S13/4	71	1	N	1	2	C	2
S13/5	113	1	NE	2	2	C	3
S13/6	175	1	-	1	1	C	3
S14/1	83	3	NW	2	3	A	1
S14/2	68	1	SW	2	3	A	2
S14/3	69	1	SE	2	3	A	2
S14/4	86	1	-	2	3	A	2
S14/5	142	1	-	3	1	C	2
S14/6	155	1	-	3	1	C	2
S15/1	79	2	-	3	2	A	1
S15/2	143	2	NE	2	3	A	1
S15/3	87	1	-	2	3	A	2
S15/4	86	1	N	2	3	A	2
S15/5	160	1	-	1	1	C	2
S15/6	95	1	-	1	1	C	2
S16/1	89	1	-	2	3	A	2
S16/2	83	1	-	2	3	A	2
S16/3	76	1	N	1	2	C	3
S16/4	81	1	SE	1	2	C	3
S16/5	101	1	-	1	1	C	1
S16/6	84	1	-	1	2	C	1

(Continued)

Tree no.	C (cm)	D	Direction	Bc	Ac	As	Te
S17/1	89	1	N	3	2	C	2
S17/2	85	1	NE	1	2	C	3
S17/3	93	1	E	1	2	C	2
S17/4	105	1	W	2	2	B	4
S17/5	74	1	-	1	2	C	4
S17/6	193	1	-	3	1	C	4
S18/1	98	1	NW	2	3	B	2
S18/2	87	1	-	1	3	C	2
S18/3	70	1	E	1	2	C	3
S18/4	81	1	NE	1	2	C	2
S18/5	187	1	-	3	2	C	4
S18/6	130	1	SW	3	2	C	4
S19/1	76	1	N	1	2	C	2
S19/2	65	1	N	3	2	A	2
S19/3	84	1	-	3	2	C	2
S19/4	75	1	-	3	2	C	4
S19/5	99	2	SE	2	3	A	4
S19/6	86	1	NE	2	3	C	4
S20/1	87	1	-	2	2	C	1
S20/2	64	1	W	2	2	A	1
S20/3	76	1	SE	2	3	C	2
S20/4	70	1	S	3	3	C	2
S20/5	149	1	-	1	2	B	3
S20/6	68	1	-	1	2	C	3

(Continued)

Tree no.	C (cm)	D	Direction	Bc	Ac	As	Te
S21/1	87	1	NE	2	3	C	2
S21/2	81	1	-	2	1	C	2
S21/3	108	1	-	2	3	C	2
S21/4	92	1	-	2	3	C	4
S21/5	75	1	-	1	1	A	4
S21/6	69	1	-	1	1	A	4
S22/1	86	1	NE	2	1	C	2
S22/2	79	1	NW	2	3	B	2
S22/3	73	1	-	2	1	C	2
S22/4	80	2	-	2	3	A	2
S22/5	81	1	-	3	1	C	2
S22/6	186	3	-	1	1	C	2
S23/1	68	1	S	3	3	C	2
S23/2	74	3	-	3	2	C	2
S23/3	87	1	N	2	2	B	2
S23/4	83	1	-	2	2	C	2
S23/5	65	1	-	1	1	A	4
S23/6	107	1	-	1	2	C	4
S24/1	98	1	NE	2	2	C	4
S24/2	68	1	-	2	2	C	4
S24/3	64	1	-	2	2	C	4
S24/4	88	1	-	2	2	C	2
S24/5	107	1	N	1	1	A	2
S24/6	77	3	-	1	1	B	2

(Continued)

Tree no.	C (cm)	D	Direction	Bc	Ac	As	Te
S25/1	101	1	-	2	2	C	2
S25/2	73	1	NW	2	3	C	2
S25/3	88	1	NE	2	3	C	4
S25/4	59	1	-	2	3	C	4
S25/5	90	2	N	1	2	C	3
S25/6	82	1	NW	3	2	C	3
S26/1	96	1	SE	2	3	C	2
S26/2	92	2	SW	2	3	C	2
S26/3	89	1	N	2	3	C	4
S26/4	86	1	NE	2	2	C	4
S26/5	142	1	-	1	2	C	5
S26/6	66	1	S	1	2	C	5
S27/1	74	1	NE	2	2	C	1
S27/2	123	1	E	2	3	C	1
S27/3	65	1	NW	1	3	C	1
S27/4	107	1	S	1	3	C	2
S27/5	76	1	-	3	2	C	2
S27/6	84	1	SE	3	2	C	2
S28/1	115	1	N	3	2	C	1
S28/2	82	1	-	1	1	C	1
S28/3	90	1	-	2	1	C	1
S28/4	121	1	NE	3	2	C	1
S28/5	95	1	W	3	2	C	2
S28/6	92	1	-	2	2	C	2

(Continued)

Tree no.	C (cm)	D	Direction	Bc	Ac	As	Te
S29/1	90	1	NE	3	2	B	1
S29/2	128	1	N	3	2	B	1
S29/3	80	1	-	1	3	C	2
S29/4	88	2	NE	2	3	A	2
S29/5	91	1	S	2	2	C	4
S29/6	96	1	-	2	2	C	4
S30/1	72	1	-	2	3	C	4
S30/2	81	1	N	2	2	C	4
S30/3	86	1	-	1	2	C	2
S30/4	78	1	NE	1	2	C	2
S30/5	85	1	S	1	2	C	4
S30/6	162	1	-	2	2	C	4
S31/1	63	1	-	1	2	C	4
S31/2	75	1	SE	3	3	C	4
S31/3	82	2	SW	2	3	C	3
S31/4	160	2	NE	3	2	A	3
S31/5	94	1	-	2	1	C	5
S31/6	138	1	W	2	1	C	5
S32/1	73	1	-	1	2	C	4
S32/2	121	1	N	1	2	A	4
S32/3	60	1	-	1	2	B	4
S32/4	69	1	E	1	2	B	5
S32/5	96	1	W	2	2	C	5
S32/6	83	1	NE	2	2	C	5

(Continued)

Tree no.	C (cm)	D	Direction	Bc	Ac	As	Te
S33/1	180	1	-	3	2	B	2
S33/2	67	1	NW	1	2	B	2
S33/3	78	1	-	1	2	C	4
S33/4	84	1	N	1	2	C	3
S33/5	75	2	-	2	2	C	4
S33/6	94	2	E	2	2	C	4
S34/1	97	1	-	1	2	C	2
S34/2	176	1	-	2	2	C	2
S34/3	73	1	NE	2	2	A	4
S34/4	92	1	-	2	2	A	4
S34/5	114	1	NW	2	3	C	3
S34/6	82	1	S	2	3	C	3
S35/1	86	3	E	2	3	A	2
S35/2	98	3	SE	2	2	C	2
S35/3	86	1	-	2	3	C	1
S35/4	76	1	NE	2	3	B	1
S35/5	154	1	-	2	2	C	1
S35/6	95	1	-	2	2	C	1
S36/1	64	5	SW	2	2	C	1
S36/2	90	5	E	2	2	C	1
S36/3	142	1	-	2	2	B	1
S36/4	95	1	NE	3	3	C	2
S36/5	87	2	N	2	2	C	2
S36/6	75	1	-	2	2	C	2

(Continued)

Tree no.	C (cm)	D	Direction	Bc	Ac	As	Te
S37/1	80	1	-	2	2	B	1
S37/2	98	1	-	2	2	C	1
S37/3	128	1	N	2	2	C	1
S37/4	92	1	-	2	2	B	1
S37/5	68	1	NE	3	2	C	2
S37/6	94	2	NW	3	2	C	2
S38/1	76	1	S	2	3	C	1
S38/2	94	1	-	2	3	C	2
S38/3	90	3	NE	2	3	C	2
S38/4	122	1	-	2	3	C	2
S38/5	74	1	-	2	2	A	3
S38/6	97	1	-	2	2	A	3
S39/1	122	2	E	2	2	C	2
S39/2	67	2	SE	2	3	B	2
S39/3	219	1	-	2	3	C	2
S39/4	188	1	-	2	3	C	4
S39/5	66	1	W	3	2	A	4
S39/6	74	1	NE	3	2	C	5
S40/1	169	2	NW	2	3	C	2
S40/2	53	3	W	2	2	C	2
S40/3	66	1	NE	2	2	B	4
S40/4	80	1	-	2	2	B	4
S40/5	83	2	N	3	2	C	3
S40/6	94	1	NE	2	2	C	3

(Continued)

Tree no.	C (cm)	D	Direction	Bc	Ac	As	Te
S41/1	112	1	-	2	2	B	2
S41/2	95	1	NW	2	2	C	2
S41/3	83	2	NE	2	2	C	2
S41/4	77	1	NW	2	3	C	4
S41/5	96	1	-	3	2	C	4
S41/6	87	2	NW	3	2	C	4
S42/1	69	2	-	2	3	A	2
S42/2	57	2	N	2	3	A	2
S42/3	55	1	SW	2	2	C	4
S42/4	88	1	SW	2	2	C	4
S42/5	153	1	-	1	3	C	3
S42/6	116	1	NE	1	2	C	3
S43/1	98	1	SW	2	2	C	4
S43/2	78	1	S	2	2	C	4
S43/3	86	1	E	2	3	B	3
S43/4	54	2	-	1	3	B	3
S43/5	95	2	W	1	2	C	2
S43/6	53	2	N	1	2	C	2
S44/1	103	1	-	0	2	C	2
S44/2	112	1	-	0	2	C	2
S44/3	57	1	N	2	2	A	4
S44/4	63	1	SE	2	3	A	4
S44/5	77	2	N	3	3	B	5
S44/6	92	2	NE	3	2	C	5

(Continued)

Tree no.	C (cm)	D	Direction	Bc	Ac	As	Te
S45/1	85	2	NW	2	2	A	2
S45/2	74	2	NE	2	3	C	2
S45/3	86	1	E	2	3	A	4
S45/4	93	1	S	3	3	C	3
S45/5	67	1	-	1	2	C	5
S45/6	83	1	-	1	2	C	5
S46/1	68	2	NW	2	2	C	2
S46/2	66	1	NW	2	2	C	4
S46/3	90	1	NE	3	2	B	2
S46/4	87	1	E	1	3	C	4
S46/5	172	1	NE	3	3	C	2
S46/6	130	1	NE	3	3	C	2

Note Ac = Area conditions (1=High-density residential area, 2=Not high-density residential area and 3=Open area)

As = Area surrounding (A=Lawn area, B=Cement area and C= Ground area)

Bc = Bark characteristic (1=Smooth, 2=Average smooth and 3=Deep-wrinkle)

C = Circumferences (cm)

D = Distance trees to road (1=0-5 m, 2=6-10 m, 3=11-15 m, 4=16-20 m and 5=> 20 m)

Te = Traffic effects (1=Highway, 2=Main road car>, 3=Main road car<, 4=Small road car>, 5=Small road car< and 6=Country road)

APPENDIX E

THE CALCULATION OF NO_2 AND SO_2

CONCENTRATION

1. Calculation of Nitrogen dioxide (NO_2) concentration in air, calculate as follows;

No.	$[NO_4^{2-}]$ X (ppm)	Q (µg)	$[NO_2]$ C (µg/m3)	$[NO_2]$ ppbv	$[NO_2]$ average (ppbv)
S1/1	0.01	0.04	0.86	0.46	0.69
S1/2	0.01	0.04	0.86	0.46	
S1/3	0.02	0.08	1.73	0.92	
S1/4	0.02	0.08	1.73	0.92	

Concentration NO_2^- (ppm)

X = 0.01 ppm

Q (µg) = concentration SO_4^{2-} (ppm) x 4 ml

= 0.01 x 4

= 0.04

Concentration NO_2 (µg/m^3)

$$C\ (\mu g/m^3) = \frac{[Q \times z]}{[(\pi r^2) \times t \times D]}$$

$$C\ (\mu g/m^3) = \frac{0.04 \times 0.054}{0.000154 \times 1209600 \times 0.000133}$$

$$C = 0.86\ \mu g/m^3$$

Where $Q = 0.04$

$z = 0.054$ m

$\pi r^2 = 0.000154\ m^2$

$t = 1209600$ s (15 day)

$D = 1.54 \times 10^{-5}\ m^2/s$ หรือ $0.0000154 m^2/s$

The change unit of gas NO_2 from $\mu g/m^3$ to ppb or ppbv equation follow.

$$ppbv = \frac{\mu g/m^3 \times \text{molecular volume (litres)}}{\text{molecular weight}}$$

when molecular volume $= \frac{22.41 \times (273 + 25)}{273} \times \frac{101.3}{101.3}$

ๆ molecular volume $= 24.46$

when P = atmospheric pressure 1 atm = 101.3 kPa

$$\text{concentration } NO_2 \text{ (ppbv)} = \frac{0.86 \times 24.46}{46}$$

ๆ concentration $NO_2 = 0.46$ ppbv

2. Calculation of sulfur dioxide (SO_2) concentration in air, calculate as follows;

No.	$[SO_4^{2-}]$ X (ppm)	Q (µg)	$[SO_2]$ C (µg/m3)	$[SO_2]$ ppbv	$[SO_2]$ Average (ppbv)
S1/1	0.14	0.38	10.13	3.85	
S1/2	0.05	0.13	3.62	1.37	1.72
S1/3	0.03	0.08	2.17	0.82	
S1/4	0.03	0.08	2.17	0.82	

Concentration SO_4^{2-} (ppm)

X = 0.14 ppm

Q (µg) = concentration SO_4^{2-} (ppm) x 4 ml x 64/96

= 0.14 x 4 x 64/96

= 0.38

Concentration SO_2 (µg/m^3)

$$C\ (\mu g/m^3) = \frac{[Q \times z]}{[(\pi r^2) \times t \times D]}$$

$$C\ (\mu g/m^3) = \frac{0.38 \times 0.054}{0.000154 \times 1209600 \times 0.0000127}$$

C = 10.13 µg/m^3

Where Q = 0.38

z = 0.054 m

πr^2 = 0.000154 m^2

t = 1209600 s (15 day)

D = 1.27 x 10^{-5} m^2/s หรือ 0.00001270 m^2/s

The change unit of gas SO_2 from $\mu g/m^3$ to ppb or ppbv equation follow.

$$ppbv = \frac{\mu g/m^3 \times \text{molecular volume (litres)}}{\text{molecular weight}}$$

when molecular volume = $\frac{22.41 \times (273 + 25)}{273} \times \frac{101.3}{101.3}$

o o molecular volume = 24.46

when P = atmospheric pressure 1 atm = 101.3 kPa

concentration SO_2 (ppbv) = $\frac{10.13 \times 24.46}{64}$

o o concentration SO_2 = 3.85 ppbv

APPENDIX F

CONCENTRATION NO_2 IN RAINY SEASON

(3-17 AUGUST 2009)

(when z = 0.054, πr^2 = 0.0001540, t = 1209600 s, D = 0.0000154, MV = 24.46, Mw = 46)

Sampling plot no.	Sample	X (ppm)	Q (µg)	C (µg/m3)	ppbv	average	SD
	S1/1	0.01	0.04	0.86	0.46		
	S1/2	0.01	0.04	0.86	0.46		
	S1/3	0.02	0.08	1.73	0.92		
1	S1/4	0.02	0.08	1.73	0.92	0.69	0.26
	S2/1	0.04	0.16	3.46	1.83		
	S2/2	0.02	0.08	1.73	0.92		
	S2/3	0.02	0.08	1.73	0.92		
2	S2/4	0.03	0.12	2.59	1.37	1.26	0.44
	S3/1	0.02	0.08	1.73	0.92		
	S3/2	0.03	0.12	2.59	1.37		
	S3/3	0.02	0.08	1.73	0.92		
3	S3/4	0.02	0.08	1.73	0.92	1.03	0.23
	S4/1	0.01	0.04	0.86	0.46		
	S4/2	0.01	0.04	0.86	0.46		
	S4/3	0.01	0.04	0.86	0.46		
4	S4/4	0.03	0.12	2.59	1.37	0.69	0.46
	S5/1	0.03	0.12	2.59	1.37		
	S5/2	0.04	0.16	3.46	1.83		
	S5/3	0.11	0.44	9.5	5.04		
5	S5/4	0.03	0.12	2.59	1.37	2.4	1.77

(Continued)

Sampling plot no.	Sample	X (ppm)	Q (µg)	C (µg/m3)	ppbv	average	SD
	S6/1	0.01	0.04	0.86	0.46		
	S6/2	0.02	0.08	1.73	0.92		
	S6/3	0.02	0.08	1.73	0.92		
6	S6/4	0.02	0.08	1.73	0.92	0.8	0.23
	S7/1	0.03	0.12	2.59	1.37		
	S7/2	0.03	0.12	2.59	1.37		
	S7/3	0.02	0.08	1.73	0.92		
7	S7/4	0.04	0.16	3.46	1.83	1.37	0.37
	S8/1	0.01	0.04	0.86	0.46		
	S8/2	0.01	0.04	0.86	0.46		
	S8/3	0.02	0.08	1.73	0.92		
8	S8/4	0.01	0.04	0.86	0.46	0.57	0.23
	S9/1	0.02	0.08	1.73	0.92		
	S9/2	0.02	0.08	1.73	0.92		
	S9/3	0.01	0.04	0.86	0.46		
9	S9/4	0.02	0.08	1.73	0.92	0.8	0.23
	S10/1	0.01	0.04	0.86	0.46		
	S10/2	0.03	0.12	2.59	1.37		
	S10/3	0.01	0.04	0.86	0.46		
10	S10/4	0.01	0.04	0.86	0.46	0.69	0.46

(Continued)

Sampling plot no.	Sample	X (ppm)	Q (µg)	C (µg/m3)	ppbv	average	SD
	S11/1	0.03	0.12	2.59	1.37		
	S11/2	0.01	0.04	0.95	0.5		
	S11/3	0.03	0.12	2.59	1.37		
11	S11/4	0.02	0.08	1.73	0.92	1.04	0.42
	S12/1	0.13	0.52	11.23	5.95		
	S12/2	0.02	0.08	1.73	0.92		
	S12/3	0.02	0.08	1.73	0.92		
12	S12/4	0.01	0.04	0.86	0.46	2.06	2.6
	S13/1	0.03	0.12	2.59	1.37		
	S13/2	0.03	0.12	2.59	1.37		
	S13/3	0.11	0.44	9.5	5.04		
13	S13/4	0.11	0.44	9.5	5.04	3.21	2.12
	S14/1	0.02	0.08	1.73	0.92		
	S14/2	0.12	0.48	10.37	5.5		
	S14/3	0.02	0.08	1.73	0.92		
14	S14/4	0.05	0.2	4.32	2.29	2.4	2.16
	S15/1	0.02	0.08	1.73	0.92		
	S15/2	0.03	0.12	2.59	1.37		
	S15/3	0.03	0.12	2.59	1.37		
15	S15/4	0.01	0.04	0.86	0.46	1.03	0.44

(Continued)

Sampling plot no.	Sample	X (ppm)	Q (µg)	C (µg/m3)	ppbv	average	SD
	S16/1	0.07	0.28	6.05	3.21		
	S16/2	0.02	0.08	1.73	0.92		
	S16/3	0.02	0.08	1.73	0.92		
16	S16/4	0.02	0.08	1.73	0.92	1.98	1.14
	S17/1	0.03	0.12	2.59	1.37		
	S17/2	0.01	0.04	0.86	0.46		
	S17/3	0.02	0.08	1.73	0.92		
17	S17/4	0.02	0.08	1.73	0.92	0.92	0.37
	S18/1	0.03	0.12	2.59	1.37		
	S18/2	0.01	0.04	0.86	0.46		
	S18/3	0.01	0.04	0.86	0.46		
18	S18/4	0.01	0.04	0.86	0.46	0.69	0.46
	S19/1	0.03	0.12	2.59	1.37		
	S19/2	0.03	0.12	2.59	1.37		
	S19/3	0.02	0.08	1.73	0.92		
19	S19/4	0.02	0.08	1.73	0.92	1.14	0.26
	S20/1	0.02	0.08	1.73	0.92		
	S20/2	0.01	0.04	0.86	0.46		
	S20/3	0.01	0.04	0.86	0.46		
20	S20/4	0.02	0.08	1.73	0.92	0.69	0.26

(Continued)

Sampling plot no.	Sample	X (ppm)	Q (µg)	C (µg/m3)	ppbv	average	SD
	S21/1	0.03	0.12	2.59	1.37		
	S21/2	0.33	1.32	28.51	15.11		
	S21/3	0.03	0.12	2.59	1.37		
21	S21/4	0.04	0.16	3.46	1.83	4.92	6.8
	S22/1	0.04	0.16	3.46	1.83		
	S22/2	0.04	0.16	3.46	1.83		
	S22/3	0.12	0.48	10.37	5.5		
22	S22/4	0.1	0.4	8.64	4.58	3.43	1.89
	S23/1	0.03	0.12	2.59	1.37		
	S23/2	0.03	0.12	2.59	1.37		
	S23/3	0.09	0.36	7.78	4.12		
23	S23/4	0.02	0.08	1.73	0.92	1.95	1.47
	S24/1	0.06	0.24	5.18	2.75		
	S24/2	0.02	0.08	1.73	0.92		
	S24/3	0.02	0.08	1.73	0.92		
24	S24/4	0.02	0.08	1.73	0.92	1.37	0.92
	S25/1	0.08	0.32	6.91	3.66		
	S25/2	0.01	0.04	0.86	0.46		
	S25/3	0.01	0.04	0.86	0.46		
25	S25/4	0.02	0.08	1.73	0.92	1.37	1.54

(Continued)

Sampling plot no.	Sample	X (ppm)	Q (µg)	C (µg/m3)	ppbv	average	SD
	S26/1	0.02	0.08	1.73	0.92		
	S26/2	0.05	0.2	4.32	2.29		
	S26/3	0.02	0.08	1.73	0.92		
26	S26/4	0.01	0.04	0.86	0.46	1.53	0.79
	S27/1	0.01	0.04	0.86	0.46		
	S27/2	0.11	0.44	9.5	5.04		
	S27/3	0.08	0.32	6.91	3.66		
27	S27/4	0.01	0.04	0.86	0.46	2.4	2.32
	S28/1	0.02	0.08	1.73	0.92		
	S28/2	0.01	0.04	0.86	0.46		
	S28/3	0.02	0.08	1.73	0.92		
28	S28/4	0.03	0.12	2.59	1.37	0.92	0.37
	S29/1	0.02	0.08	1.73	0.92		
	S29/2	0.02	0.08	1.73	0.92		
	S29/3	0.06	0.24	5.18	2.75		
29	S29/4	0.09	0.36	7.78	4.12	2.18	1.56
	S30/1	0.02	0.08	1.73	0.92		
	S30/2	0.02	0.08	1.73	0.92		
	S30/3	0.03	0.12	2.59	1.37		
30	S30/4	0.03	0.12	2.59	1.37	1.14	0.26

(Continued)

Sampling plot no.	Sample	X (ppm)	Q (µg)	C (µg/m3)	ppbv	average	SD
	S31/1	0.01	0.04	0.86	0.46		
	S31/2	0.01	0.04	0.86	0.46		
	S31/3	0.1	0.4	8.64	4.58		
31	S31/4	0.03	0.12	2.59	1.37	1.72	1.96
	S32/1	0.01	0.04	0.86	0.46		
	S32/2	0.01	0.04	0.86	0.46		
	S32/3	0.01	0.04	0.86	0.46		
32	S32/4	0.02	0.08	1.73	0.92	0.57	0.23
	S33/1	0.02	0.08	1.73	0.92		
	S33/2	0.02	0.08	1.73	0.92		
	S33/3	0.03	0.12	2.59	1.37		
33	S33/4	0.02	0.08	1.73	0.92	1.03	0.23
	S34/1	0.31	1.24	26.78	14.2		
	S34/2	0.02	0.08	1.73	0.92		
	S34/3	0.03	0.12	2.59	1.37		
34	S34/4	0.02	0.08	1.73	0.92	4.35	6.57
	S35/1	0.02	0.08	1.73	0.92		
	S35/2	0.02	0.08	1.73	0.92		
	S35/3	0.04	0.16	3.46	1.83		
35	S35/4	0.02	0.08	1.73	0.92	1.14	0.46

(Continued)

Sampling plot no.	Sample	X (ppm)	Q (µg)	C (µg/m3)	ppbv	average	SD
	S36/1	0.02	0.08	1.73	0.92		
	S36/2	0.03	0.12	2.59	1.37		
	S36/3	0.03	0.12	2.59	1.37		
36	S36/4	0.24	0.96	20.74	10.99	3.66	2
	S37/1	0	0	0	0		
	S37/2	0.02	0.08	1.73	0.92		
	S37/3	0.01	0.04	0.86	0.46		
37	S37/4	0.01	0.04	0.86	0.46	0.61	0.37
	S38/1	0.03	0.12	2.59	1.37		
	S38/2	0.03	0.12	2.59	1.37		
	S38/3	0.02	0.08	1.73	0.92		
38	S38/4	0.03	0.12	2.59	1.37	1.26	0.23
	S39/1	0.02	0.08	1.73	0.92		
	S39/2	0.02	0.08	1.73	0.92		
	S39/3	0.03	0.12	2.59	1.37		
39	S39/4	0.02	0.08	1.73	0.92	1.03	0.23
	S40/1	0.14	0.56	12.1	6.41		
	S40/2	0.02	0.08	1.73	0.92		
	S40/3	0.03	0.12	2.59	1.37		
40	S40/4	0.01	0.04	0.86	0.46	2.29	2.77

(Continued)

Sampling plot no.	Sample	X (ppm)	Q (µg)	C (µg/m3)	ppbv	average	SD
	S41/1	0.02	0.08	1.73	0.92		
	S41/2	0.02	0.08	1.73	0.92		
	S41/3	0.02	0.08	1.73	0.92		
41	S41/4	0.01	0.04	0.86	0.46	0.8	0.23
	S42/1	0.03	0.12	2.59	1.37		
	S42/2	0.01	0.04	0.86	0.46		
	S42/3	0.01	0.04	0.86	0.46		
42	S42/4	0.02	0.08	1.73	0.92	0.8	0.44
	S43/1	0.02	0.08	1.73	0.92		
	S43/2	0.02	0.08	1.73	0.92		
	S43/3	0.02	0.08	1.73	0.92		
43	S43/4	0.03	0.12	2.59	1.37	1.03	0.23
	S44/1	0.01	0.04	0.86	0.46		
	S44/2	0.01	0.04	0.86	0.46		
	S44/3	0.01	0.04	0.86	0.46		
44	S44/4	0.02	0.08	1.73	0.92	0.57	0.23
	S45/1	0	0	0	0		
	S45/2	0.01	0.04	0.86	0.46		
	S45/3	0.01	0.04	0.86	0.46		
45	S45/4	0.02	0.08	1.73	0.92	0.61	0.37

(Continued)

Sampling plot no.	Sample	X (ppm)	Q (µg)	C (µg/m3)	ppbv	average	SD
	S46/1	0.02	0.08	1.73	0.92		
	S46/2	0.01	0.04	0.86	0.46		
	S46/3	0.01	0.04	0.86	0.46		
46	S46/4	0.01	0.04	0.86	0.46	0.57	0.23
	Blank1/1	0	0	0	0		
	Blank1/2	0	0	0	0		
	Blank1/3	0	0	0	0		
47	Blank1/4	0.01	0.04	0.86	0.46	0.46	0.23

APPENDIX G

CHROMATOGRAM

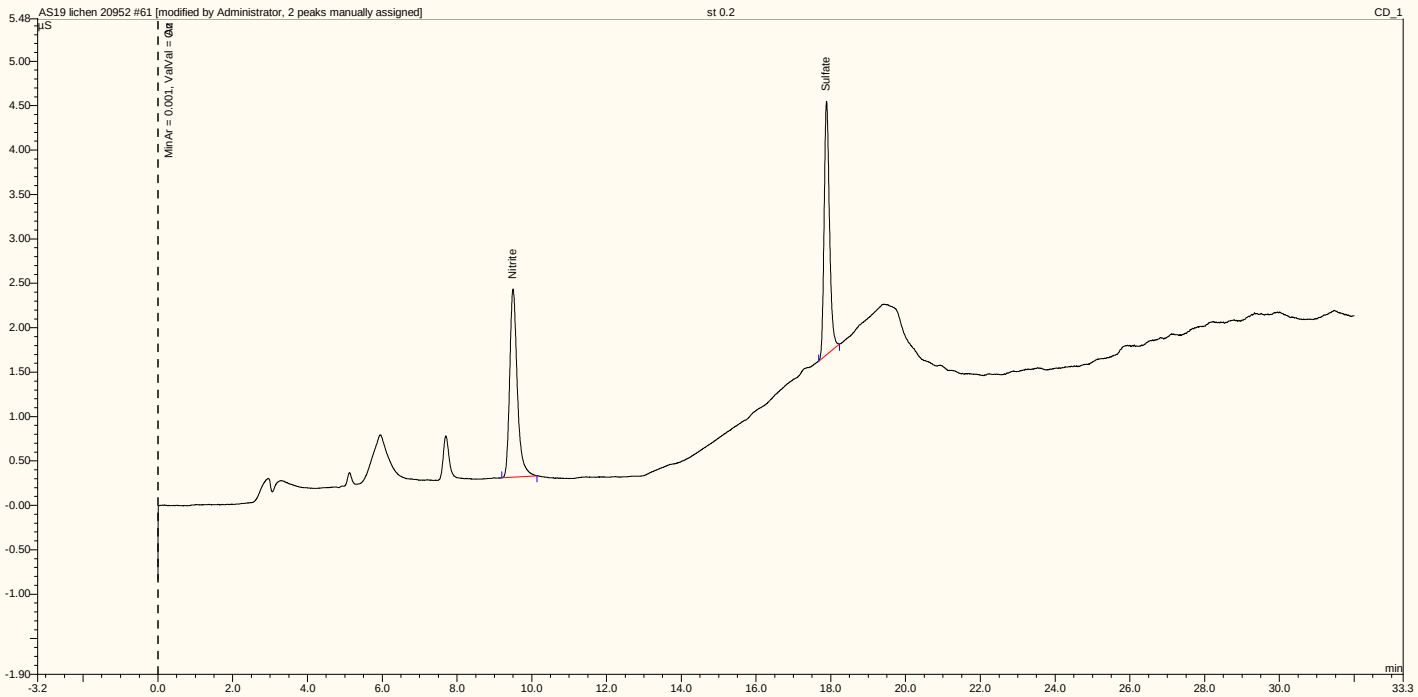


Figure 1 Chromatogram of solution nitrite and sulfate standard 1.0 ppm.

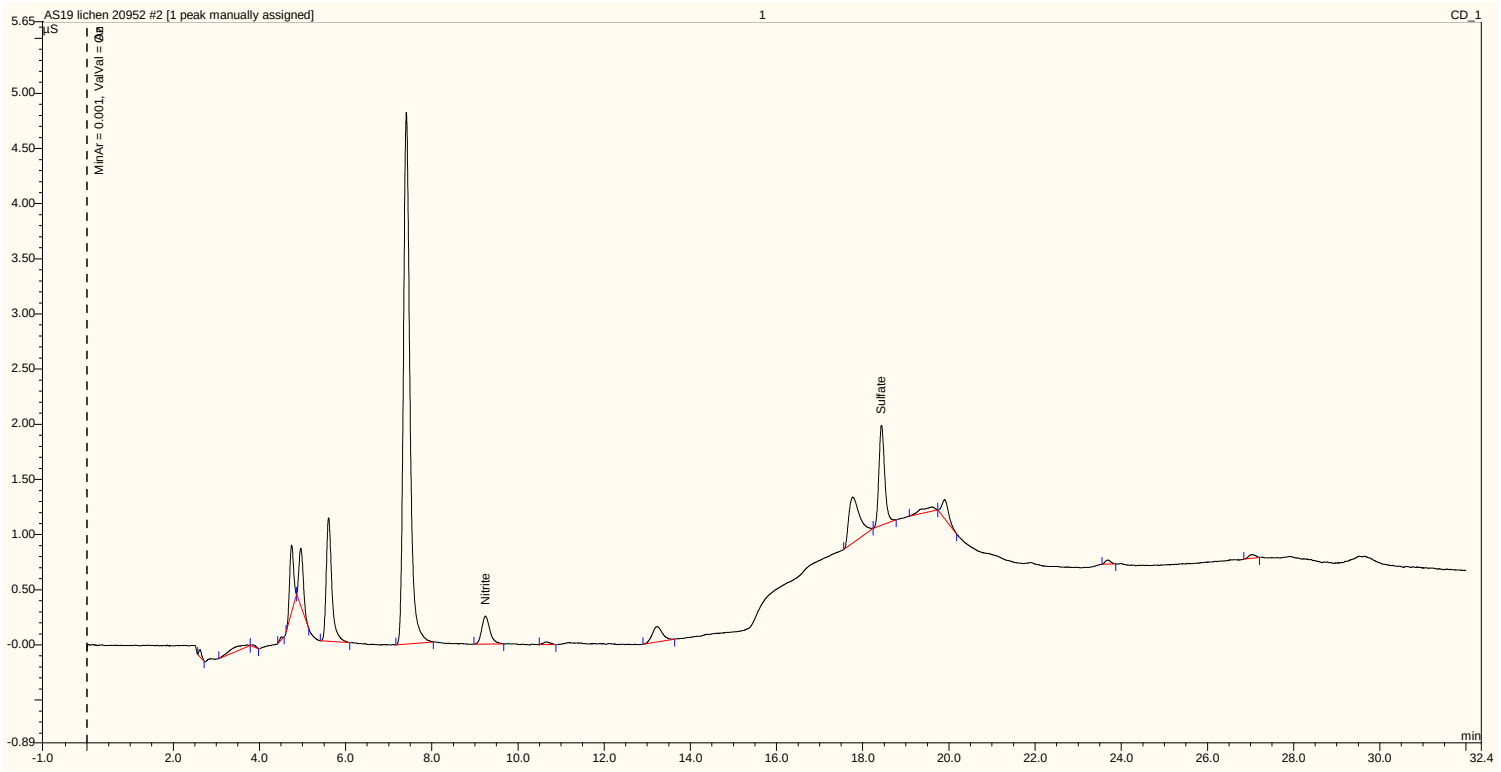


Figure 2 Chromatogram of sample in 15 day.

CURRICULUM VITAE

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Publications

1. Pitakpong, A., Nathawut, T. and Wanaruk, S. (2010). *Use of Lichens as Bioindicators for Air Quality Monitoring in Nakhon Ratchasima Municipality Area.* (Proceedings). **The 3rd Technology and Innovation for Sustainable Development International Conference (TISD2010), Thailand.**
2. Pitakpong, A., Nathawut, T. and Wanaruk, S. (2010)**.** *The Primary Observation of Epiphytic Lichens in Dry Evergreen Forest and Dry Dipterocarp Forest at Sakaerat Environmental Research station, Nakhon Ratchasima province.* (Poster). **The 1st International Conference at Sakaerat Environmental Research station, Nakhon Ratchasima province.**

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