Ecological studies of epiphytic bryophytes along altitudinal gradients in Southern Thailand

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Chapter 1

General Introduction

1.1 Tropical Forest

The tropical forest is an ecosystem found throughout the equatorial region, the area between the Tropics of Cancer and Capricorn (latitudes 23°N and 23°S). This region may be best known for its rain forests: lush, steamy jungles with towering trees, epiphytes, and dense understory of smaller trees, shrubs, and vines, but there are also large areas of mangrove forests, moist forests, dry forests, and savannas.

One of the major characteristics of tropical forests is the constant high temperature, on average 20-25°C throughout the year. The mean temperature of the coldest month is rarely under 18°C, although some tropical montane areas may have colder nights. In the tropical zone, as everywhere, heat decreases in intensity towards higher latitudes, and increasing elevation delimits the warm tropics towards the subtropical and tropical cold climates of the high mountain areas. In the tropics the day is approximately 12 hours all year long. Rainfall is one of the important factors to determine a division into humid and dry tropical forests (Lauer, 1989).

Definitions, names and classification of tropical forest types are myriad. Subdivisions of this ecosystem are determined by seasonal distribution of rainfall, ranging from tropical moist forests or rain forest to the dry forests and savannas. With increasing elevation, tropical forests are changes associated in following forest belts: lowland rain forest belts, submontane rain forest, lower montane rain forest, upper montane rain forest and subalpine rain forest (Frahm & Gradstein, 1991; Whitmore, 1990).

The tropical rain forests, which occupy large areas of the humid tropics, are characterized in general by the complex structure of the canopy which is the top area of the tallest trees. The trees and shrubs are mostly green. Lianas and epiphytes fill the gaps among tree crowns and branches. There are three major tropical forest regions in the world, the largest being the American rain forest followed by the Indo-Malayan or Southeast Asian and African rain forests. This study was carried out in southern Thailand, a part of Southeast Asian rain forest.

1.2 Bryophytes in Tropical Rain Forests

The tropical rain forest is well known for supporting a great diversity of flora and fauna. Because of the complexity of structure and variety of microhabitats, lowland and montane tropical rain forests are the habitat of many bryophytes, holding 25-30% of the world's bryophytes (Gradstein & Pócs, 1989). In fact, Gradstein and Pócs (1989) have stated that the tropical rain forests, including the tropical montane forest, possibly hold more bryophyte species than any other major ecosystems of the world. The bryophyte diversity increases in abundance and species richness ranging from lowland rain forest to lower montane and then to upper montane rain forest (e.g. Frahm, 1990b, d; Frahm & Gradstein, 1991; Gradstein & Pócs, 1989). Gradstein *et al*. (1990) have suggested that the lowland tropical rain forest might have a much richer bryophyte flora than previously believed when the canopy is properly inventoried. Pócs (1982) and Richards (1984) have further inferred that as far as tropical forests and bryophytes are concerned, the humidity of the air, total annual rainfall, and length of dry period are much more important parameters than the prevailing temperature.

According to Gradstein and Pócs (1989), about 90% of the bryophytes of a tropical rain forest belong to only 15 families: Calymperaceae, Dicranaceae, Fissidentaceae, Hookeriaceae, Hypnaceae, Meteoriaceae, Neckeriaceae, Orthotrichaceae, Pterobryaceae and Sematophyllaceae (mosses); and Frullaniaceae, Lejeuneaceae, Lepidoziaceae, Plagiochilaceae and Radulaceae (liverworts).

The Asiatic tropical rain forest is home to a bryoflora quite different from those of tropical America and Africa. On the other hand, the Asiatic tropical rain forest has the highest diversity of bryophytes in terms of genera and families, with a large number of unique moss taxa, as compared to the American and the African tropical rain forests (Buck & Thiers, 1989; Gradstein & Pócs 1989).

1.3 Epiphytic bryophytes

Epiphytes are a characteristic and distinctive component of tropical rain forests and have extraordinarily high species numbers and comprise a substantial part of overall biodiversity. Most of the bryophytes of tropical rain forests are epiphytes (Gradstein *et al*., 2001; Pócs, 1982; Richard, 1984). Due to the high relative humidity throughout the year, tropical rainforests form an excellent habitat for an epiphytic bryophyte species. Although suitable environmental and substrate conditions are even more crucial for this group than for terrestrial species (Frahm 1990a; Frahm *et al*., 2003), they have been able to reach high abundance in submontane and montane rainforests throughout the tropics (Acebey *et al*., 2003; Holz *et al*., 2002; Wolf, 1993b, c).

The massive mats and turfs of epiphytic bryophytes cover forest trees, providing valuable resources such as a growth substrate and nutrition pool to entire communities of vascular epiphytes such as ferns and orchids, and serve as breeding and nesting space for a wide range of birds, amphibians and insects (Nadkarni & Longino, 1990; Pharo *et al*., 1999; Richards, 1984). Furthermore, epiphytic bryophytes have the ability to store high amounts of precipitation water, allowing delayed release and providing time to dissolve nutrients with capillary structures (Clark *et al*., 2005; Köhler *et al*., 2007; Pócs, 1976), thereby contributing to the stability of the forest ecosystem (Frego, 2007).

Due to having no cuticles like vascular plants, bryophytes are particularly sensitive to climatic changes in the environment. They need to compensate for daily fluctuations in temperature and humidity by morphological adaptations to store water (e.g. water sacs, water storage cells, a dense rhizoid, folded leaves) and by their ability to survive short periods of drought by becoming dormant, but having a quick response and fast water absorption and immediate resumption of photosynthetic activity as soon as moisture becomes available again. Canopy openings, brought about by either natural tree falls or after anthropogenic logging and deforestation, causes a major threat to bryophytes, particularly those that prefer the cool and humid habitats that characterize the lower layers of primary, undisturbed rainforests (Acebey *et al*., 2003; Ariyanti *et al*., 2008; Sporn *et al*., 2009). Long periods of severe drought, however, can not be compensated for and lead to definite desiccation (Proctor, 2000). This sensitivity to changes in climatic conditions makes bryophytes a valuable indicator of forest integrity and even of global climate changes (Richards, 1984; Zotz & Bader, 2009). The need to develop strategies to cope with extreme microclimates and to compete successfully for substrate to settle has resulted in various morphological adaptations within the bryophytes.

1.4 Ecological study of epiphytic bryophytes in tropical rain forests

Even though bryophytes are often small and inconspicuous, they are an important component of tropical forests, especially montane ones, and may play a significant role in the water balance and nutrient cycling of these forests (Frahm, 1990; Hofstede *et al*., 1994; Pócs, 1980; Nadkarni, 1984). However, ecological data on the bryophyte ecology of tropical rain forests are sparse. The earliest studies of the ecology of bryophyte in the tropics are the contributions by Giesenhagen (1910) on growth form and Seifritz (1924) on altitudinal zonation in Java. Richard (1954) was the first to describe the different shade and sun bryophytic communities in the neotropics and Tixier (1966) reported on communities in South Vietnam.

Overall, epiphytic bryophytes have received less attention than vascular epiphytes. There are only a few studies dealing with epiphytic bryophytes in tropical ecosystem. Most ecological studies of epiphytic bryophytes have focused on the diversity and ecology of tropical rain forest bryophytes, especially in tropical America and Africa (e.g. Acebey *et al.*, 2003; Frahm, 1987; Frahm, 1994a, b; Kürschner 1995, Kürschner & Parolly 1998, Holz *et al*., 2002; Léon-Vargas *et al.*, 2006; Wolf 1993a, b, c). Many studies have focused on differences in the bryophyte flora in different succession stages in lowland rain forests in the neotropics (e.g. Cornelissen & ter Steege, 1998; Da Costa, 1999). Some comparative studies have also been done between different tropical lowland forest types or different microhabitats within the forests (Cornelissen & Gradstein, 1990; Da Costa, 1999; Dauphin, 1999). However, ecological studies of bryophytes in Southeast Asia are few.

Among the studies from SE Asia is an intensive study along an altitudinal gradient on Mt. Kinabalu, Borneo. Kürschner (1990) showed discontinuities of epiphytic bryophytes within the altitudinal gradient of North Borneo by an ordination study. In another study, life forms, water conduction and water storage structures of epiphytic bryophytes on Mount Kinabalu were studied along an altitudinal transect (Frey *et al*., 1990). Frahm (1990a) performed some ecological studies on the epiphytic bryophytes on Mount Kinabalu, including pH of bark, biomass of bryophytes, water storage capacity and other factors. The altitudinal zonation of bryophytes on Mount Kinabalu was also assessed by Frahm (1990b) using ecological and non-floristical parameters. No other mountain in Southeast Asia has been studied in such detail concerning the ecology and characterization of bryophyte communities.

Recently, Aryanti *et al*. (2008) and Sporn *et al*. (2009a, b) studied the bryophyte diversity of submontane rain forests and cacao plantations of central Sulawesi, Indonesia. These studies have shown the overriding importance of microclimate as a driver of epiphytic bryophyte distribution.

1.5 Aims, outline and contents of the present study

Ecological studies on the epiphytic bryophyte vegetation have been undertaken along altitudinal gradients in southern Thailand. The purpose of the current study was to determine species richness and species composition of epiphytic bryophytes on tree trunks and to correlate them with ecological parameters such as altitude, temperature and air humidity. Phytosociological aspects of the epiphytic vegetation were also considered. In addition, measurements of the pH bark of the host trees were obtained, together with determinations of the biomass and water storing capacity of epiphytic bryophytes along the altitudinal gradients.

The present study is the first to compare diversity and species composition of epiphytic bryophytes in a primary forest along altitudinal gradients in Thailand. It is structured into the following chapters:

Chapter 3 - deals with the biomass of epiphytic bryophytes along altitudinal gradients from lowland to montane forests, examining relations between such factors as microclimates and the pH of the bark of host trees, and the water storing capacity of epiphytic bryophytes and estimations of the biomass and water storing capacity per hectare.

Chapter 4 - examines the patterns of species richness and species composition as well as specific life forms of epiphytic bryophytes on tree trunks along the altitudinal gradient on Tarutao Island in southern Thailand and examines correlations between the epiphytic bryophyte communities and selected aspects of the physical environment of the bryophyte diversity of the tropical lowland forest in Southeast Asia.

Chapter 5 - compares species richness, community composition and ecology of epiphytic bryophytes of different altitudes from lowland forest to montane forest at Khao Nan National Park, southern Thailand. It shows the distribution patterns of epiphytic species and their communities along an altitudinal gradient.

Chapter 2

Study area

Southern Thailand is one of the richest areas in term of biodiversity. This area is located in both the Indo-Burma and Sundaland biodiversity hot spots (Myers *et al*., 2000), and includes areas identified as atransition zone between the Indo-Chinese and Malesian floristic regions (Takhtajan, 1986; Collin *et al.*, 1991). According to van Steenis (1950), 575 genera of flowering plants have their northern or southern range limits near the Thai-Malaysian border. Considering bryophyte diversity alone, more than 50% of currently known Thai bryophytes have been recorded in this area (Sornsamran & Thaithong, 1995), most of which are epiphytes.

2.1 Location and Topography

Southern Thailand (Figure 1) lies between the latitudes of approximately 6° and 10° N, extending south through the Kra Isthmus to the Thailand-Malaysia border, forming a narrow peninsula flanked by the Gulf of Thailand in the east and the Andaman Sea in the west. Topographically, there are three main mountain ranges running through the length of the peninsula, the Phuket, the Nakhon Si Thammarat and the Sankalakhiri ranges (Smitinand, 1989).

Along the western side of the peninsula the Tanao Si (Tenasserim) Range continues north, marking the Thailand-Myanmar border. South of Prachuap Khirikhan province the eastern edge of the Tanao Si levels off to a narrow coastal plain and a further range begins southward, running from northt to south. This range begins in a high mountain (about 1,000 m) but is not continuous in elevation, being hardly 100 m in Chumphon province. At the Pak Chan River it splits into two sections, a western range in Myanmar, and an eastern in Thailand. The eastern, known as the Phuket Range, extends south from the Kra Isthmus and follows the Indian Ocean into Phuket Island. There are numerous granite cores in the Phuket Range, many of them reaching more than 1,100 m altitude.

They are the source of the rich alluvial tin ores of the most important mining districts of Thailand.

On the eastern side, the Nakorn Si Thammarat mountain range stretches from Surat Thani southward to Satun Province which lies at the southwest end of the country. The highest peak, Khao Luang, reaches approximately 1,800 m a.s.l., in the west of Nakhon Si Thammarat province.

Defining the Thai-Malay border for much of its length, the Sankalakhiri mountain range stretches northwest to southeast along the border and then turns southward into Malaysia, with altitudes ranging from 140-1,535 m a.s.l. The highest peak of the Sankalakhiri range on the Thai-Malaysian border is Gunung Ulu Titi Basah.

In general, the east coast of the Peninsula is smooth and regular, with few bays and many long beaches, especially on the shores of Nakhon Si Tharnmarat, Songkhla, and Pattani provinces. A large inland sea, Thalesap Songkla, lies along the east shore in the northeast part of Songkhla province, and the are scattered offshore limestone islands. On the west coast, the shoreline is very irregular and indented with a number of estuaries. There are few beaches, but large areas of mangrove swamps, as the mountains extend down to the sea in many places.

2.2 Climate

According to the Köppen-Geiger classification of climatic regions (Kottek *et al.*, 2006), the general climate of southern Thailand is equatorial monsoon (Am) climate, with mean rainfall of the driest month less than 60 mm and mean temperature of the coldest month above 18°C. The region is under the influence of the southwest and northwest monsoons, which create two distinct seasons, wet and dry. The dry season is observed during December/ January-February/ March (2-4 months), normally with rainfall less than 100 mm per month. The rainy season occurs during March/ April-October/November (8-10 months), when it rains most days and the air is humid. The average annual rainfall is normally above 2,000 mm per year.

Temperatures vary considerably with the season, latitude, and elevation. The monthly average maximum and minimum daily temperatures in the foothills range from 22°C to 35°C. The day temperatures can reach nearly 40°C on sunny days, whereas at night and early morning, the temperatures may drop to 18°C. The lowest temperatures are usually recorded in January and February, while the highest temperatures occur between March and April.

2.3 Vegetation

The vegetation in southern Thailand consists of several forest types (Maxwell, 2004; Whitmore, 1975): tropical lowland rain forest, tropical montane forest, heath forest, forest over limestone, beach vegetation, mangrove forest, brackish-water forest, peat swamp forest and fresh-water swamp forest.

According to Whitmore (1998), forest types in southern Thailand are mostly tropical lowland forest and lower montane forest. The tropical lowland evergreen forest is dominated by the family Dipterocarpaceae, e.g. *Dipterocarpus kerrii* King, *Shorea curtisii* Dyer ex King and *S. roxburghii* G. Don. The species composition of lower montane forest varies locally; it is usually dominated by *Dacrydium elatum* (Roxb.) Wall. ex Hook. (Podocarpaceae); *Lithocarpus* spp., *Quercus* spp. (Fagaceae); *Schima wallichii* (DC.) Korth. (Theaceae); *Rhododendron* spp. and *Vaccinium* spp. (Ericaceae) (Whitmore, 1998).

Unfortunately, the lowland forest has been widely disturbed by human activities over the last 30-40 years, and much has been transformed to various agricultural usages such as rubber and oil palm plantations. Currently, the only undisturbed forests can be found in the mountainous regions where agriculture is not economically viable. It is estimated that approximately 25% of the land is under forest cover, including forest plantations (Maxwell, 2004).

2.4 Study sites

The field work for this study was carried out on three altitudinal transects of the tropical forests in different geographical localities in southern Thailand, i.e. Tarutao National Park (30-700 m a.s.l.), a remote island on the west coast (conducted from April to May and again in December 2008); Khao Nan national Park (400-1,300 m a.s.l.), on the mainland peninsula (conducted from February to March 2009), and Khao Luang National Park (400-1,500 m a.s.l.), on the mainland peninsula (conducted from March to May 2009)..

Tarutao Island

Tarutao National Park is a group of 51 islands in the Andaman Sea, off the southwest coast of peninsular Thailand. The park lies approximately between latitudes 6°30′ - 6°44′ N and longitudes 99°35′ - 99°41′ E, and covers a total area of about 1,500 km^2. Of the 51 islands, only three have an area larger than 10 km^2: Tarutao (151 km^2), Rawi (31 km^2), and Adang (30 km^2).

Tarutao Island lies approximately 26 km off the mainland. The island is 26.5 km long and 11 km across at the widest point. The topography is mostly mountainous (highest point 708 m) with a few broad plains and valleys. Semi-evergreen rain forest covers about 60% of the island, and small patches of mangrove swamp are found in several areas. Long sandy beaches lie along the western coast from Pante Bay to Makham Bay, and at Talo Udang Bay in the south. The east coast consists of craggy limestone rocks, small islands and scattered small patches of mangrove swamp (Cogdon, 1982).

The climatological data from 1999-2008 at the Satun Province Meteorological Station, the nearest meteorological station, shows two distinct seasons. There is a dry season during January-February/ March with less than 100 mm rainfall per month, and a rainy season occurs during March/ April-December, during which it rains most days and the air is humid. Rainfall averages ca. 230 mm per month. The average annual average annual temperature is 27.9°C, while the average maximum temperature is 36.5°C in March and the average minimum temperature is 20.3°C in January. The average annual total rainfall is ca. 2,340 mm, with the highest average monthly rainfall ca. 370 mm in October and the lowest average monthly rainfall ca. 37 mm in January.

The Tarutao transect was established between 25 m and 700 m a.s.l., on the western slope of the island (Figure 2.2). The transect was selected to be representative of the lowland belt, consists of 4 study plots at 25, 250, 500 and 700 m a.s.l.

Khao Nan National Park

Khao Nan National Park is situated in the Nakhon Si Thammarat Mountain Range (Figure 2.3), on the East Coast of peninsular Thailand, and covers an area of approximately 436 km^2. It is marked out, approximately, by the geographical coordinates of 8°41′ - 8°58′ N latitude and 99°30′ - 99°99′ E longitude. It is bounded on the north by Sikead National Park and agricultural lands in Kanchanadit District, Surat Thani Province, to the south by Khao Luang National Park and Plai Kratoon Wildlife Sanctuary, to the east by agricultural lands in Sichon and Tha Sala Districts, and on the west by Tai RomYen National Park, Surat Thani Province. The park, with an altitude ranging from 60 m to 1,438 m (the summit of Khao Nan) provides a heterogeneous habitat which supports a wide range of flora and fauna. A watershed and several streams flowing into waterfalls such as Sunantha Waterfall, Nhan Chong Fah Waterfall, and Klong Klai Waterfall are included within its boundaries.

The transect was established along a trail stretching from Krung Ching waterfall to Sanyen Mountain (Figure 2.3), and included 6 study plots at 400, 600, 800, 1,000, 1,200 and 1,300 m a.s.l. The lower part of the transect was a hilly dipterocarp forest, dominated by Dipterocarpaceae, Euphorbiaceae and Guttiferae. The montane forest was rather dense, found from 1,000 m elevation upwards. It is dominated by *Dacrydium elatum* (Roxb.) Wall. ex Hook. and *Podocarpus* spp. (Podocarpaceae); *Lithocarpus* spp., *Quercus* spp. (Fagaceae); *Schima wallichii* (DC.) Korth. (Theaceae); *Rhododendron* spp. and *Vaccinium* spp. (Ericaceae); *Eugenia* spp. and *Syzygium* spp. (Myrtaceae). Epiphytes are common on trunks and branches of trees and shrubs. Many of them are pteridophytes, Araceae and a number of orchid species: *Bulbophyllum* spp., *Ceologyne* spp., *Dendrobium* spp. etc. These epiphytes usually grow together with a number of mosses and leafy liverworts. Ground floras also include herbaceous species e.g. *Calanthe* spp., Hypoxidaceae, Melastomataceae etc.

Climatological data from 1999 to 2008 at Nakhon Si Thammarat Climatic Station shows an average annual temperature of 27.5°C. The average maximum temperature is about 35.5°C during May and August, and the average minimum approximately 20°C in December and January. The annual precipitation during this period was 2,775 mm. Precipitation in the area was highest from October to January and lowest from February to April with only several rainy days.

Khao Luang National Park

Khao Luang National Park (8°41′44″ N, 99°50′4″ E) is located between 150 m and 1,835 m a.s.l., south of Khao Nan National Park (Figure 2.3), and part of the Nakhon Si Thammarat Mountain Range, It covers an area of approximately 570 km^2 and features a large variety of wildlife and varied natural features including mountains, forests, rivers and waterfalls. The park protects a good representative sample of the flora of the southern forests, including typical Malesian species of Dipterocapaceae together with several species of northern origins. This area is also an important watershed area for the surrounding villages and farms. Park provides a green roof to southern Thailand. It is located within several districts in Nakhon Si Thammarat province e.g. Lansaka, Chawang, Phiboon, Plomkiri, Chang Klang and Nop Pi Dam districts.

Previous field collections of plants in peninsular Thailand have mainly been from this national park (Boonkerd *et al.*, 2008), but most of these collections have been vascular plants. The forest vegetation is similar to the neighboring Khao Nan National Park, and it could be assumed that the climatic data is similar. The transect was chosen along a natural trail to Phamee Mountain, and consisted of seven plots (at 400, 600, 800, 1,000, 1,200 and 1,400 and 1500 m a.s.l.).

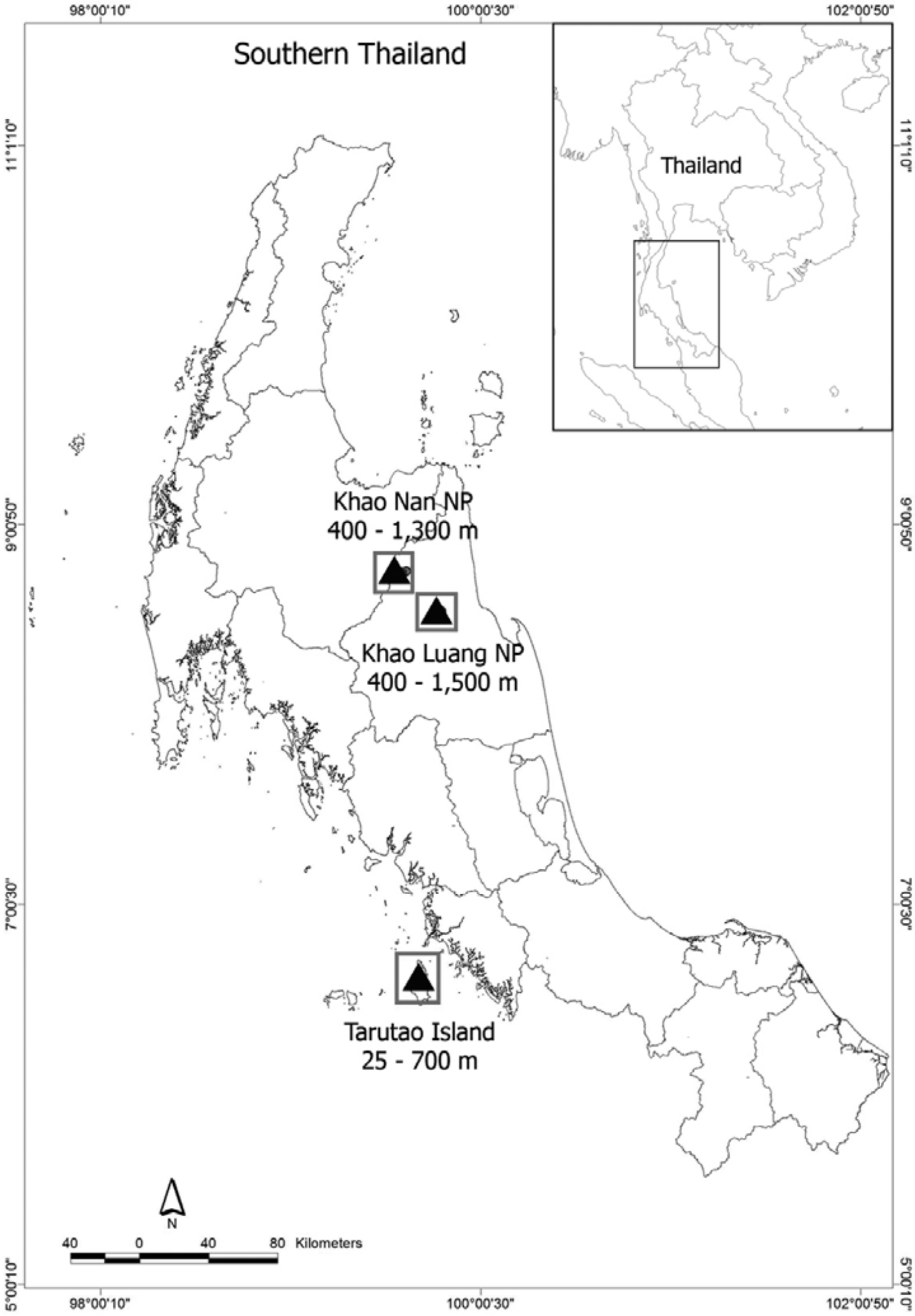


Figure 2.1 Location of the study transects in southern Thailand

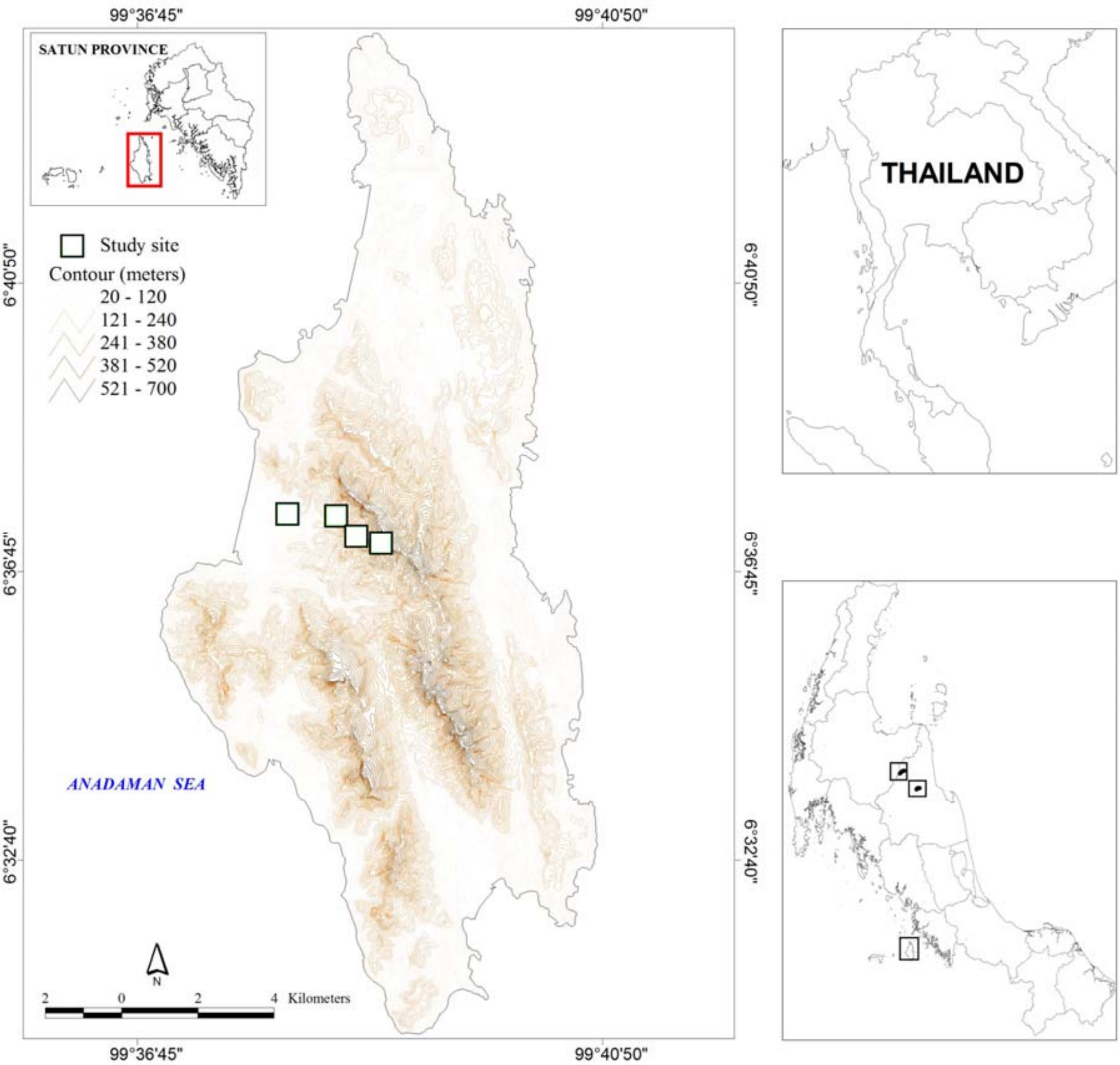


Figure 2.2 Topographic map of Tarutao Island showing the elevations and the location of study sites.

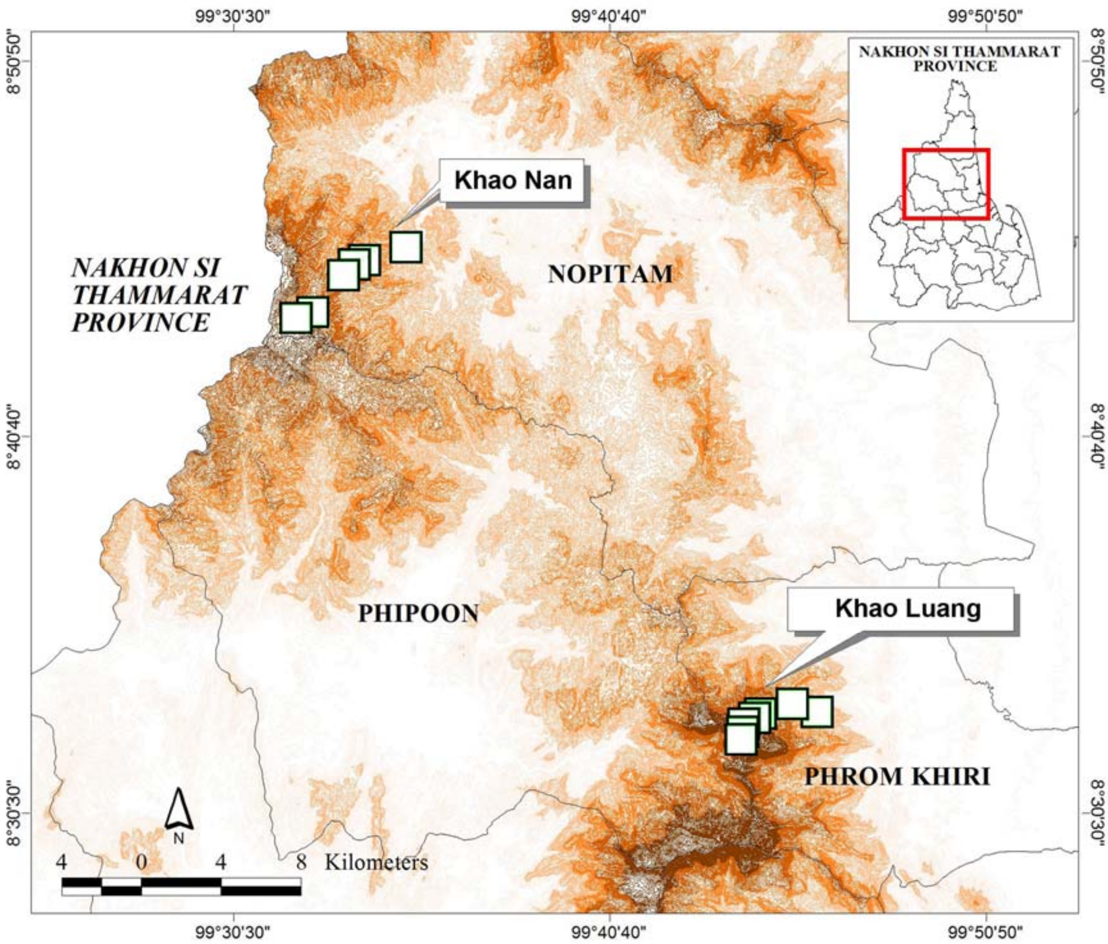


Figure 2.3 Topographic map of Khao Luang and Khao Nan National Park showing the elevations and the location of study sites.

Chapter 3

Biomass and ecology of epiphytic bryophyte along altitudinal gradients in Southern Thailand

3.1 Abstract

Biomass of epiphytic bryophytes was investigated along three altitudinal transects in southern Thailand: Tarutao National Park (25-700 m), Khao Nan national Park (400-1300 m) and Khao Luang National Park (400-1500 m). The dry weight of epiphytic bryophytes per surface area increased from 1.15 g/m^2 in the lowland to a maximum 199 g/m^2 at the montane forests. The estimation of dry weight per hectare increased along transect from 2.4 to 620 kg. The water storing capacity of epiphytic bryophytes was about 1.2 to 2.4 times as dry weight and was generally higher in the montane (up to 1500 l/ha) than in the lowland forests. The bark pH of host trees has been undertaken. All values range between 3.19 and 6.84 and show negative correlation with the altitude ($r = -0.635$, $p < 0.05$). Air temperature gradually decreases with the increasing altitude ca 0.6 °C per 100 m elevation.

3.2 Introduction

Epiphytic bryophytes are an important component of tropical rain forests and play a significant role in the water balance (Pócs, 1976, 1980; Veneklaas & Van Ek, 1990). They also have a significant capability of nutrient retention (Nadkarni 1986; Hofstede *et al.*, 1993), affecting nutrient cycling within forests (Coxson, 1991). Furthermore, they provide shelter for numerous small invertebrates (Gradstein, 1992).

In contrast to vascular epiphytes, epiphytic bryophytes are more diverse particular at the higher elevations (Wolf, 1994; Freiberg & Freiberg, 2000).

Besides the diversity, the epiphytic bryophytes' biomass also changes with altitude in tropical regions (Wolf, 1994), but only few comparative studies had been reported and mostly focused on montane forests (Coxson, 1991; Edwards & Grubb, 1977; Hofstede *et al.*, 1993; Nadkarni, 1984; Pócs, 1980, Veneklaas *et al.*, 1990) or considered only the epiphytic bryophytes on tree trunks in the understorey (Frahm, 1990a; Frahm & Gradstein, 1991). Data on biomass of epiphytic bryophytes in tropical lowland forests are scarce. However, the ecological data on the bryophyte vegetation of tropical forest is so few.

The aim of the study was to determine and to compare the biomass of the epiphytic bryophytes along altitudinal gradients from lowland to montane forests. It was trying to investigat whether the phenomena of the increasing of the biomass of bryophytes along the increasing of the altitudinal gradient would happen in the tropical forest in Southern Thailand. In addition, measurements of air temperature, relative humidity and the pH of the bark of host trees, together with determinations of the water storing capacity of epiphytic bryophytes and estimations of the biomass and water storing capacity per hectare were undertaken.

3.3 Material and Methods

The study area was between the latitudes of approximately 6°N and 10°N, extending southward from the Kra Isthmus to the Thailand-Malaysia border. The mean annual air temperature range from 22°C to 35°C and the average annual rainfall is normally above 2,000 mm.

The study was carried out on three altitudinal transects of the tropical forests in different geographical localities in southern Thailand, i.e. Tarutao National Park (30-700 m a.s.l.), a remote island on the west coast (conducted from April to May and again in December 2008); Khao Nan national Park (400-1,300 m a.s.l.), on the mainland peninsula (conducted from February to March 2009), and Khao Luang National Park (400-1,500 m a.s.l.), on the mainland peninsula (conducted from March to May 2009)..

The seventeen plots of 0.25 hectare (50 × 50 m) were obtained at approximately 200 m altitudinal intervals, along these three transects through the gradient of plant community types from lowland to montane forests. The study plots were selected in only homogenous forest sites in order to obtain a good base for the comparison. Each study site was located within the site of the least disturbed.

Following parameters were determined along those transects:

Microclimate recording

Microclimatic measurements were performed in dry season. At each site, a data logger (HOBO pro V2 RH/Temp, Onset) had recorded the air temperature (°C) and the relative air humidity (%RH) in 10 minute intervals. The data were programmed and read by the software: HOBOware Pro (Onset Hoboware Pro, software for hobo data loggers & devices, Version 2.6). These loggers work within the range of -40 °C to +70 °C (±0.2 °C for values between 0 °C and 50 °C) and 0-100 %RH (±2.5% from 10 to 90% typical, to a maximum of ±3.5%). The data loggers were placed at 1.5 m above the ground in each site study.

Though time of registration was only 1-3 weeks per site, the small seasonal variations in temperature and relative humidity had permitted a good impression of a daily pattern.

Bark pH of host trees

The bark pH of 15-20 trees, where bryophyte collections had been taken, were measured/study site. Pieces of bark had oven-dried at 70 °C, 48 hours then pulverized and diluted in distilled water (1:10, sample : water), after shakening for an hour, the dilution of bark pieces had been pH-measured with a Suntax sp-700 pH meter.

Biomass and water storage

In each study site, the number of phorophytes had been counted within an area of 10×10 m^2. Their girths were measured at 1.5 m from the ground. Bark surface areas had been calculated at the height of 2 m (basal part of tree trunk only – and assumed as a taper cylinder), hence, the calculation of the surface areas of tree base/hectare.

Fresh and dry weight of epiphytic bryophytes on half a square meter was taken from a tree trunk between 0.5 and 2 m height. Bryophytes had been removed from the bark by a knife around the tree base. In gereral, three different trees per plot were studied.

Concerning the calculations, the mean value was used. Each sample was packed in a plastic bag and saturated with water. Afterwards, they were left for half an hour on a wire net until the excess water trickled down. Then, they were weighed on a digital balance before drying at 60 °C, 48 hours in a hot air oven and, then, weighed again. Therefore, the water storage capacity of the epiphytic bryophytes could be calculated.

Furthermore, total epiphytic biomass in the study sites were estimated from the weighed sample by multiplying with the number of phorophytes and trunk surface areas. This gave an estimation of the biomass (kg dry weight/ha) or storage capacity of water (l/ha) and thus a comparison of the ecological function of the epiphytic bryophytes in different elevations of the rainforests. In this way, a rough approximation was obtained.

Biomass in the study was defined as the weight of living plants, excluding accumulated suspended organic soil. Parts of plants were assumed to be living whenever they were recognizable as plant structures and included brownish bryophyte bases.

3.4 Results and Discussions

Air temperature and relative humidity

The daily temperature and relative humidity fluctuations of the seventeen study plots along three transects were recorded as 10 minutes interval readings. The mean, maximum and minimum air temperature and relative humidity of each study sites are summarized in Table 3.1.

Along the Tarutao Island transect in four different elevations, mean annual temperature at the lowest altitude was 25.34 °C and at the highest altitude was 21.36 °C. For the entire transect, the mean temperature decrease with any increasing altitude was about 0.57 °C per 100 m. The relative air humidity values varied between 70 % and 100 %. The mean relative humidity was increased according to the higher altitude from 86 % at 25 m to 94 % at 700 m. The highest fluctuation of climatic data occurred at the highest altitude and was at the lowest point at the middle altitude.

Table 3.1 Results of microclimatic measurements at the seventeen study sites along 3 transects in southern Thailand.

Study site	T_{mean}	T_{min}	T_{max}	RH_{mean}	RH_{min}	RH_{max}
Tarutao Island						
25 m	25.34	23.04	27.85	86.00	70.28	95.57
250 m	24.76	22.85	27.51	86.54	73.56	97.26
500 m	22.11	20.37	26.70	92.72	72.93	99.52
700 m	21.36	19.60	26.55	94.44	72.71	100
Khao Nan National Park						
400 m	23.95	21.68	27.83	85.26	59.64	98.83
600 m	22.76	20.34	26.65	87.44	58.81	99.86
800 m	21.17	18.79	25.65	91.57	68.75	100.00
1000 m	20.44	17.89	24.27	91.09	61.80	100.00
1200 m	19.05	16.49	22.97	93.15	71.91	99.21
1300 m	18.31	13.93	24.97	94.78	69.93	100.00
Khao Luang National Park						
400 m	24.36	19.51	28.82	90.12	61.96	100.00
600 m	23.83	18.84	27.85	87.5	61.93	100.00
800 m	22.36	18.37	25.50	89.78	58.13	100.00
1000 m	21.46	17.20	24.10	91.17	55.75	100.00
1200 m	20.06	16.11	23.18	90.64	61.89	100.00
1400 m	18.91	15.27	21.56	92.09	60.39	100.00
1500 m	18.93	14.24	24.65	92.65	63.63	100.00

Measurements were taken along Khao Nan National Park transect in six different elevations. The highest mean temperature value was recorded at the lowest altitude with 23.95°C. The lowest mean temperature value about 18.3 °C was recorded at the highest altitude. For the entire transect the mean temperature decrease with any increasing altitude was about 0.63 °C per 100 m. The relative air humidity values varied widely between 59 % and 100 %. The mean relative humidity was increased with the altitude from 85.26 % at 400 m to 94.78 % at 1,300 m. The highest fluctuation of the climatic data occurred at the highest altitude and the lowest one occurred at the middle altitude.

Within Khao Luang National Park transect, the climatic data were recorded in seven different altitudes. The mean annual temperature at a lower boundary of this transect was about 24.36 °C. The temperature decrease with altitude was lower than 0.6 °C in different altitudnal site. The relative air humidity values varied between 56 % and 100 %. The mean relative humidity increased according to the altitude, from 87.5 % at 600 m above sea level to 92.65 % at 1,500 m above sea level. The highest fluctuations of the climatic data occurred at the highest altitude.

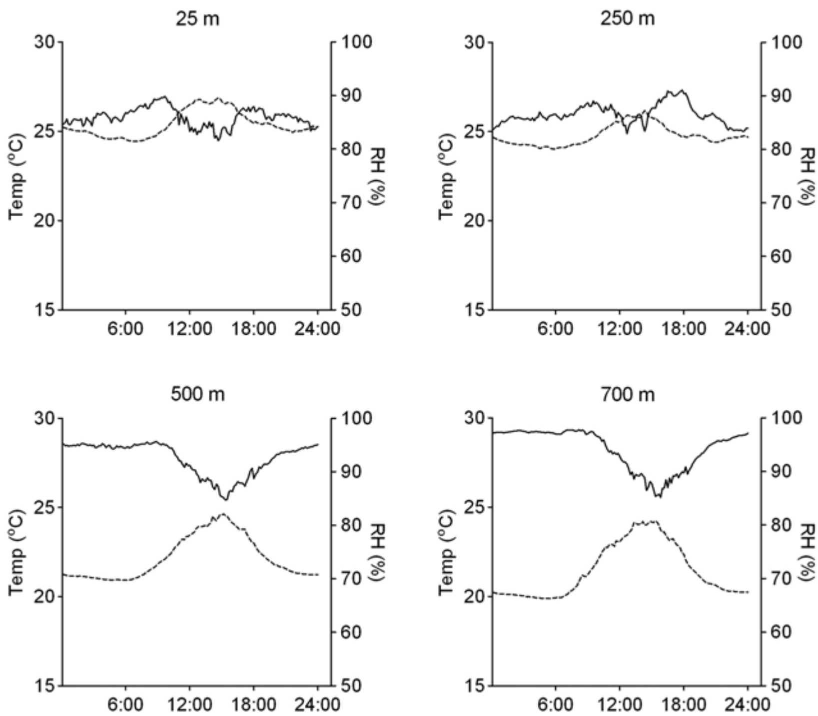


Figure 3.1 The daily course of temperature (dash line, °C) and relative humidity (dark line, %) at different altitudes from 25 to 700 m, Tarutao Island, based on 10 minute interval readings during 6 day.

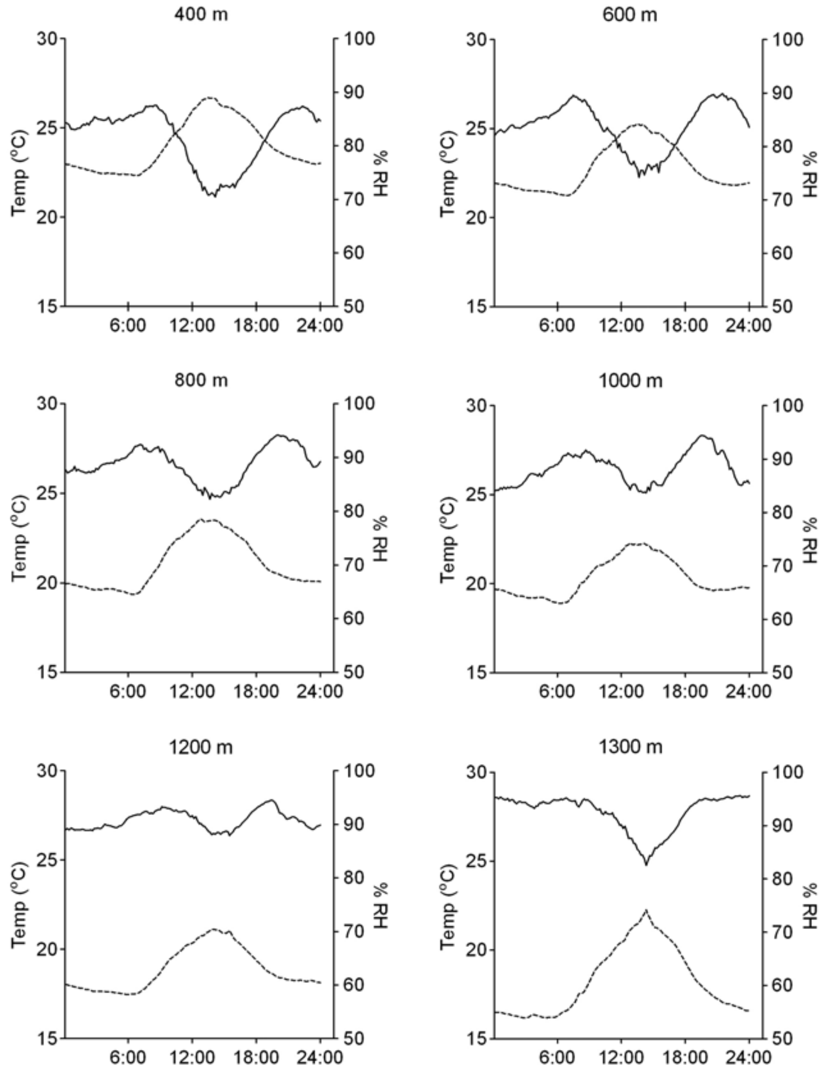


Figure 3.2 The daily course of temperature (dash line, °C) and relative humidity (dark line, %) at different altitudes from 400 to 1,300 m, Khao Nan National Park, based on 10 minute interval readings during 21 day.

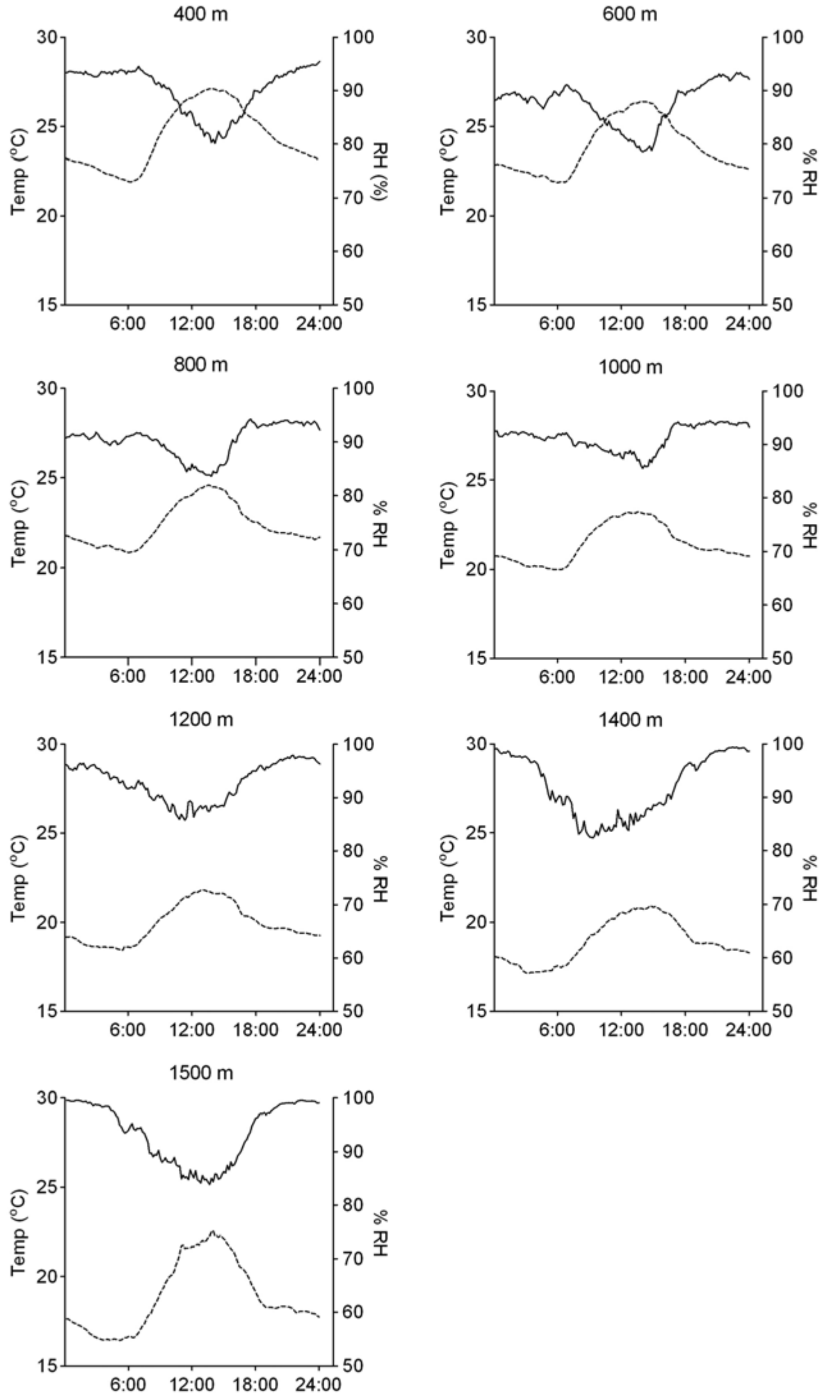


Figure 3.3 The daily course of temperature (dash line, °C) and relative humidity (dark line, %) at different altitudes from 400 to 1,500 m, Khao Luang National Park, based on 10 minute interval readings during 14 day.

During daytime the lowest temperature and the highest relative humidity values were generally recorded at the highest point of the transect. Accordingly, at higher altitudes, between 1,000 and 1,500 m (700 m in the Tarutao transect), there was regular fog or cloud immersion during early morning hours and during late afternoons. This cloud may reduce a large amount of solar radiation. This reduction in solar radiation might reduce the air temperature. This might explain the fact of low temperature and high humidity in the high altitude.

Day climate diagrams of the 17 study sites along 3 transects are shown in Figure 3.1-3.4. The general pattern of the day climate was as follows: the temperature increases quickly at dawn. The relative humidity decreases simultaneously. Highest temperatures were recorded during the first hour in the afternoon. Late in the afternoon, the temperature commenced to decrease again. The cooling was rather quick after sunset for an hour and the temperature decreased slowly afterwards during the rest of the night. The lowest temperatures were recorded during the early morning before sunrise. In contrast to the temperature, the highest relative humidity values were recorded in the early morning, while the lowest relative humidity values were recorded in the afternoon. This pattern could be interrupted by the rain-fall and the wind.

Bark pH of host trees

In the present study, bark pH was measured only once per each tree. The seasonal variations, tree ages, as well as particular tree species were not taken into account. The bark pH values of host trees in different altitude sites along three transects, are presented in Table 3.2.

Tree bark pH varied considerably at a given altitude site (Figure 3.4) ranged between 3.19 and 6.27. This has shown a range of an acidic condition. This has agreed well with many previous reports from tropical forests e.g. Amazonian lowlands (Lisboa, 1976), Mt. Kinabalu, Borneo (Frahm, 1990a), Colombian montane forest (Wolf, 1993b), Mt. Kahuzi, Zaire (Frahm, 1994a) and Costa Rican montane oak forest, (Holz, 2003).

It is to be noticed that in the temperate forests, a correlation between bark pH and community of epiphytic bryophytes had been documented. As community studies have shown that composition of species depends on differences in bark pH (e.g. Barkman, 1958; Mežaka & Znotiņa, 2006).

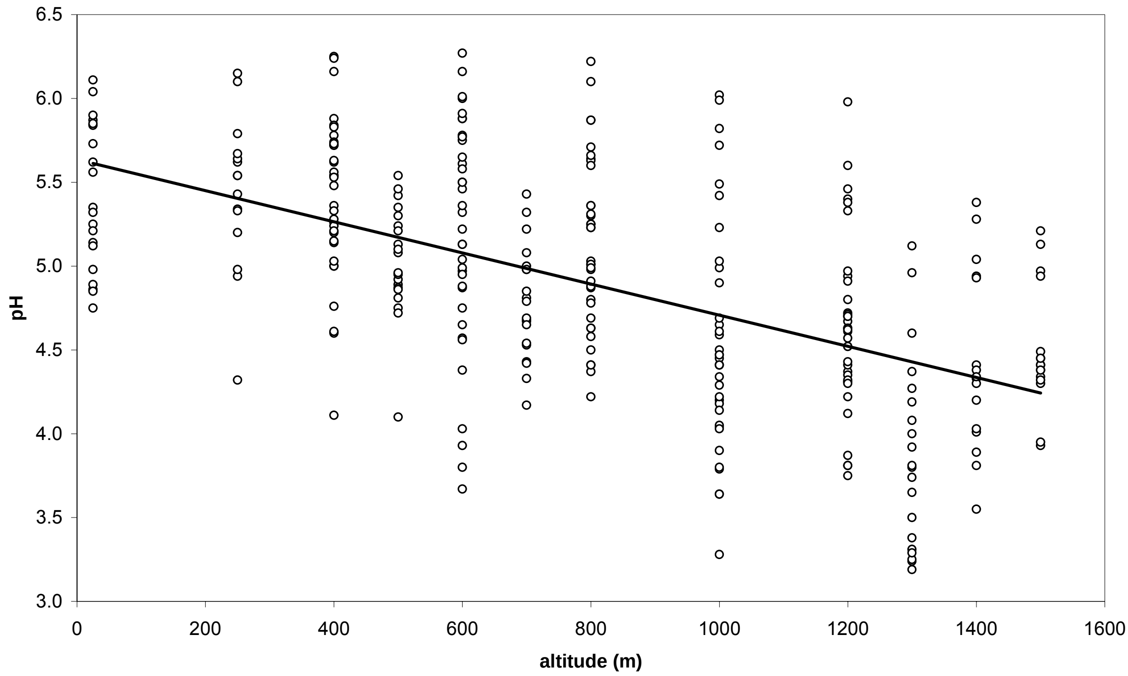


Figure 3.4 Correlation between values of bark pH and altitude of host tree, shown a negative correlation ($r = -0.563$; $p < 0.05$).

The only previous determination of bark pH of host tree in Southeast Asia has been performed by Frahm (1990a) along an altitudinal gradient of Mt. Kinabalu. The pH values range between 3.66 and 6.25. The measurements had been undertaken at altitudes between 20 and 2,900 m, but there is no correlation with the altitude. There is also no correlation with textures of bark and pH values. In contrast to the present study, the bark pH values were negatively correlated with the altitude ($r = -0.563$; $p < 0.05$). Other environmental factors, such as soil dust, salt spray and rainfall could change a value bark pH. A larger amount of humus accumulation on the tree bark at a high altitude may affect pH values.

Table 3.2 Bark pH of host trees

Tree No.	Tarutao Island				Khao Nan National Park						Khao Luang National Park						
	25	250	500	700	400	600	800	1000	1200	1310	400	600	800	1000	1200	1400	1500
1	4.86	4.32	5.35	4.53	4.60	5.61	5.64	4.41	4.31	3.80	5.83	4.88	5.87	5.82	4.43	5.04	4.45
2	4.75	4.94	5.24	4.67	5.26	6.27	4.80	4.65	3.87	3.31	5.20	6.00	4.63	4.22	5.38	4.01	4.30
3	5.14	6.10	5.30	4.81	5.28	4.57	4.50	3.79	4.31	3.19	5.21	4.65	4.91	5.42	4.32	4.20	4.41
4	5.25	5.34	5.13	4.43	5.88	5.88	4.78	3.64	4.22	3.24	5.56	4.38	6.10	3.90	4.12	4.94	4.97
5	5.35	5.79	5.42	4.98	5.54	5.75	4.87	4.50	4.37	3.74	5.00	6.01	5.30	4.41	4.94	4.03	4.49
6	5.87	4.98	5.21	5.08	5.84	5.58	4.63	4.47	4.41	3.25	5.53	4.95	4.69	3.64	4.91	3.55	3.93
7	5.12	5.43	4.89	5.22	5.36	4.87	4.58	4.20	3.81	4.37	5.48	6.16	5.25	4.47	4.52	5.28	4.38
8	4.89	5.20	4.75	5.00	5.00	4.97	5.01	4.04	4.67	3.65	4.61	3.67	5.31	4.69	4.71	4.41	4.34
9	5.84	5.62	4.92	5.32	5.72	4.99	5.87	3.28	4.52	4.08	5.03	3.93	5.36	4.61	3.75	4.33	5.21
10	6.11	5.64	4.95	4.54	5.78	5.65	5.03	3.80	4.35	4.00	5.14	4.03	5.23	6.02	4.30	3.81	5.13
11	5.21	5.33	5.08	4.79	6.25	5.78	4.88	4.05	4.80	5.12	6.16	3.80	5.60	4.34	4.97	5.38	4.32
12	5.32	5.54	5.46	4.68	5.74	5.50	4.41	4.18	5.40	3.92	4.76	5.13	5.25	5.99	4.70	4.38	4.41
13	4.98	6.15	4.81	5.43	5.54	5.04	4.98	4.29	4.63	3.38	4.11	5.32	5.66	5.49	5.98	4.93	3.95
14	5.56	5.67	4.72	4.98	5.62	5.88	6.22	4.99	4.72	4.27	5.15	5.36	5.23	4.41	4.62	4.30	4.45
15	5.73	5.54	4.96	4.42	5.63	5.13	5.01	5.23	4.63	4.60	5.72	4.75	4.41	5.72	5.60	3.89	4.38
16	6.04	-	4.87	4.33	5.24	4.56	5.36	4.14	4.61	3.81	5.73	5.22	5.71	5.03	5.33	4.34	4.94
17	5.62	-	4.10	4.69	5.33	5.46	4.37	4.59	3.81	3.29	-	-	-	-	-	-	-
18	5.90	-	5.10	4.17	6.24	5.77	4.22	4.03	5.46	3.50	-	-	-	-	-	-	-
19	5.85	-	5.54	4.85	-	5.50	5.63	4.90	4.70	4.96	-	-	-	-	-	-	-
20	4.85	-	4.86	4.65	-	5.91	4.99	4.45	4.57	4.19	-	-	-	-	-	-	-

Biomass of epiphytic bryophytes

The determination of the biomass of epiphytic bryophytes per surface area of a tree trunk (g/m^2) and the calculations of the total biomass per hectare (kg/ha) at different elevations along the three transects are shown in Table 3.3.

The dry weight of epiphytic bryophytes per unit surface area of tree trunk at different altitude, ranged from 1.15 to 199.07 g/m^2. They were usually less than 20 g/m^2 in lower elevations (25-1,000 m), and suddenly increased to 60 - 199 g/m^2 at above 1000 m.

Table 3.3 Biomass (g viz. kg/m^2) dry and wet weight and water storage capacity (l/ha) of epiphytic bryophytes along altitudinal transects in southern Thailand.

Study site	dry weight (g/m^2)	wet weight (g/m^2)	Factor	surface area of tree (m^2/ha)	dry weight (kg/ha)	wet weight (kg/ha)	water storage (l/ha)
Tarutao Island							
25 m	1.15	2.83	2.46	2276	2.62	6.44	3.82
250 m	1.19	2.92	2.45	2034	2.42	5.93	3.51
500 m	5.25	16.28	3.10	3074	16.14	50.03	33.89
700 m	18.78	56.34	3.00	2376	44.62	133.86	89.24
Khao Nan National Park							
400 m	2.37	5.26	2.22	1495	3.54	7.87	4.32
600 m	4.49	10.19	2.27	1766	7.93	18.00	10.07
800 m	5.43	13.35	2.46	2856	15.50	38.13	39.32
1000 m	11.08	30.69	2.77	3100	34.35	95.14	60.80
1200 m	73.85	230.41	3.12	3093	228.42	712.66	484.25
1300 m	199.07	682.81	3.43	3115	620.10	2,126.95	1,506.85
Khao Luang National Park							
400 m	1.95	4.10	2.10	2010	3.92	8.23	4.31
600 m	2.65	6.15	2.32	2192	5.81	13.48	7.67
800 m	2.80	6.16	2.20	1886	5.28	11.62	6.34
1000 m	18.31	54.93	3.00	2986	54.67	164.02	109.35
1200 m	61.87	205.88	3.33	1872	115.82	385.40	269.58
1400 m	158.48	537.25	3.39	2368	375.28	1,272.20	896.92
1500 m	145.94	481.60	3.30	4152	605.94	1,999.61	1,393.67

The dry weight of epiphytic bryophytes per hectare at different altitude, ranged from 2.4 to 620 kg. The bryophyte biomass in the cloud forest was about 300 times more than in the lowland forest.

The result showed that the biomass of epiphytic bryophytes increased with higher altitudes from lowland to montane forests at all transects. Generally, this agree with the quantitative measurements of the bryophyte abundance in the forest understory along altitudinal gradients in many places, e.g. Peru (Frahm, 1987c), Borneo (Frahm, 1990a), Colombia (Wolf, 1993) and Zaire (Frahm, 1994a) etc. The biomass of bryophytes were rather low in the lowland forest. This might be owing to the microclimatic conditions that did not allow sufficient a net photosynthesis (Frahm, 1987c). Field studies show that lowland bryophytes have high respiration rates at night, due to high temperatures (Zotz, 1999). High biomass values of bryophyte in montane forest have been attributed to the amount of rainfall more than 100 mm per month (Pócs, 1980) and to foggy conditions (Grubb & Whitmore, 1966; Ellenberg, 1975). Moreover, at higher altitudes, the trees are more densely and equally cover with epiphytic bryophytes (Frahm, 1994a).

Water storage capacity

The determination of the water storage capacity of epiphytic bryophytes at different elevations along three transects were presented in Table 3. The water storage of bryophyte could be distinguished in terms of retention water and interception water, i.e. he retention water is the water stored by the plants and the interception water is the water kept in droplets between individual plants, which could be removed by shaking the bryophyte samples. In the present study, the water storage capacity had been determined by measuring the wet weight (when water is saturated) of the bryophytes. In this way, it was difficult to separate the retention and interception water. The wet weight of the epiphytic bryophytes was 2.2 to 3.4 times as much as the dry weight.

It is similar to the biomass, water storage capacity increased from lowland to montane forests in all transects. The water storage in lowland forest was about

4 l/ha. They ranged between 4 and 10 l/ha in the lowland forest, between 60 and 100 l/ha in sub-montane forest, and 200 and 1500 l/ha in the montane forest.

It is considered that the different life forms of bryophytes were able to store different amounts of interception water. Cushions had a high one, while fans have almost no interception water. Furthermore, water storage of bryophytes was also affected by their morphological and anatomical characters.

Studies of Frahm (1990a) show that the epiphytic bryophytes could retain the water up to 2,760 l/ha in the forest line. Pócs (1980) show that the epiphytic biomass (include vascular and non vascular) can retain the water up to 15,000 l/ha in sub-montane rain forest and even 50,000 l/ha in a mossy forest. However, it is to be concerned here that the differentiation of biomass and water capacity are strongly affected by many factors in general, such as sampling method, forest structure, elevation, climate (annual rainfall, air temperature and air humidity), etc.

Chapter 4

Ecology and community of epiphytic bryophytes along an altitudinal gradient of Tarutao Island, southern Thailand

4.1 Abstract

A comparative study of epiphytic bryophytes on tree trunks was carried out from 25 to 700 m along an altitudinal gradient of Tarutao Island, southern Thailand. A total of 75 quadrats were sampled from four 0.25 hectare plots. In total 61 species of epiphytic bryophytes were recorded including 30 species of liverworts and 31 species of mosses. There is no significant difference of the bryophyte species richness between 25 m and 700 m, however, the species composition changed markedly. Microclimate measurements were carried out at 1.5 m height above ground level. Beside, the altitudinal gradient of 4 study sites proved to be the most important factor in community differentiation of epiphytic bryophytes as indicated by DCA analysis. Microclimate parameters might be the primary factors that correlated to the differences in diversity and species composition of bryophyte assemblages, on the other hand, the similarities of the host plant species are probably minor factors. Furthermore, the distribution of the life form among each bryophyte differs significantly along the altitudinal gradient which might well explain the relationship between each epiphytic bryophyte taxon to its habitat. Based on TWINSPAN analysis, four epiphytic bryophyte community types could be recognized.

4.2 Introduction

The lowland tropical rain forest ecosystem has suffered from intensive pattern of destruction. Most of them has been disturbed by human activities and transferred to agricultural lands, such as rubber and oil palm plantations. The undisturbed forests only persist as separated fragments. Due to the heterogeneity in habitats, the warm and humid tropical lowland rain forest also harbours a rich diversity of bryophytes (Gradstein, 1992). Gradstein *et al*. (1990) had suggested that the lowland tropical rain forest might have a much richer bryophyte flora than previously believed when the canopy is properly inventoried. However, the bryophyte flora of this ecosystem has been less well studied than the other ecosystems (Cornelissen & Ter Steege, 1989). Since bryophytes are potential indicators of the quality of the tropical forest habitats, the study of diversity and ecology may be useful for the conservation of this threatened ecosystem (Buck & Thiers, 1989; Frahm & Gradstein, 1991).

Most of the bryophytes of the tropical rain forests are epiphytes (Pócs, 1982; Richard, 1984; Gradstein *et al*., 2001). They play a significant role in the water balance (Pócs, 1976, 1980; Veneklaas & Van Ek, 1990), and also have a significant capability of nutrient retention (Nadkarni, 1986; Hofstede, *et al*. 1993), which affected the nutrient cycling within forests (Coxson, 1990). Moreover, they provide shelter for numerous small invertebrates as well (Gradstein, 1992). However, it is such a pity that the epiphytic bryophytes have received less attention than the vascular epiphytes. The study of their diversity remains scarce and mostly focused only on the moist habitats (Pharo & Beattie, 1997). Most previous works on the diversity and ecology of bryophytes in tropical lowland rain forest had been done in tropical America (e.g. Cornelisson & Gradstein, 1990; Cornelissen & Ter Steege, 1989; da Costa, 1999; Florschütz-de Waard & Bekker, 1987; Gradstein *et al*., 1990; Richards, 1954). In contrast, the studies from Southeast Asia are very few. More intensive studies had been done in Mount Kinabalu, North Borneo (Frahm, 1990a, b, c; Frey *et al.*, 1990; Frey & Kürschner, 1991; Kürschner, 1990)

The aim of this study was to determine the species richness and to analyze species composition of epiphytic bryophytes as well as the distribution pattern of life forms on tree trunks along the altitudinal gradient on Tarutao Island, Southern Thailand and to seek the correlation, if any, between the epiphytic bryophyte communities and the selected physical environment of the bryophyte diversity of the tropical lowland forest in Southeast Asia.

Tarutao Island has been proved to be a place of a great beauty with relatively undisturbed tropical lowland rain forests, mangrove swamps, littoral vegetation, and forests over limestone (Congdon, 1982). The study of vascular flora and vegetations had been done by Congdon (1982), however, bryophyte study was lacking.

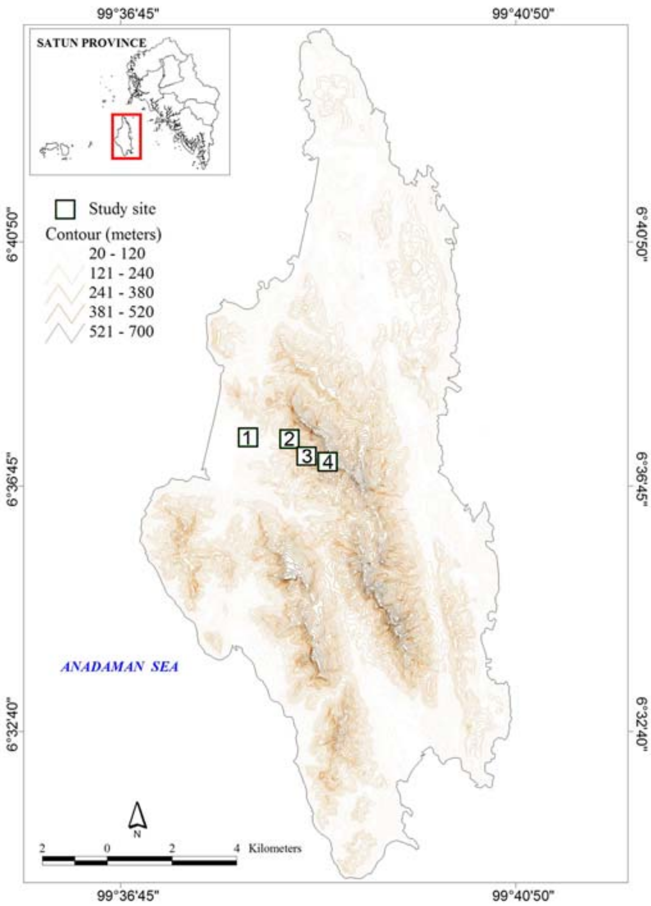


Figure 4.1 Topographic map of Tarutao Island showing the elevations and the location of study sites. Numbers represent study sites. 1, 25 m; 2, 250 m; 3, 500 m, 4, 700 m.

4.3 Material and Methods

Study sites

The field study was conducted on Tarutao Island (6° 35′ 43″ N, 99° 38′ 41″ E), the island off the west coast of the peninsular Thailand in the Andaman Sea (Figure 4.1). The island is 26.5 km long and 11 km across at the widest point. The topography is mostly mountainous (highest point 708 m) with a few broad plains and valleys. Semi-evergreen rain forest covers about 60 percent of the island, and small patch mangrove swamps are found in several areas. Long sandy beaches lie along the western coast from Pante-Malaka Bay to Makham Bay, and at Talo Udang Bay in the south. The east coast consists of craggy limestone rocks, small islands and scattered small patches of mangrove swamp (Cogdon, 1982)

The climate during 1999-2008 displays two distinct seasons (Figure 4.2). The dry season is observed during January-February/ March with rainfall less than 100 mm per month. The rainy season occurs during March/ April-December, it rains almost every day and it is rather humid. Rainfall average is ca. 230 mm per month of those 9/10 months. The average annual temperature is 27.9 °C, while the average maximum temperature is 36.5 °C in March and the average minimum temperature is 20.3 °C in January. The average annual total rainfall is ca. 2,340 mm, while the highest average monthly rainfall is ca.370 mm in October and the lowest monthly rainfall of about 37 mm in January.

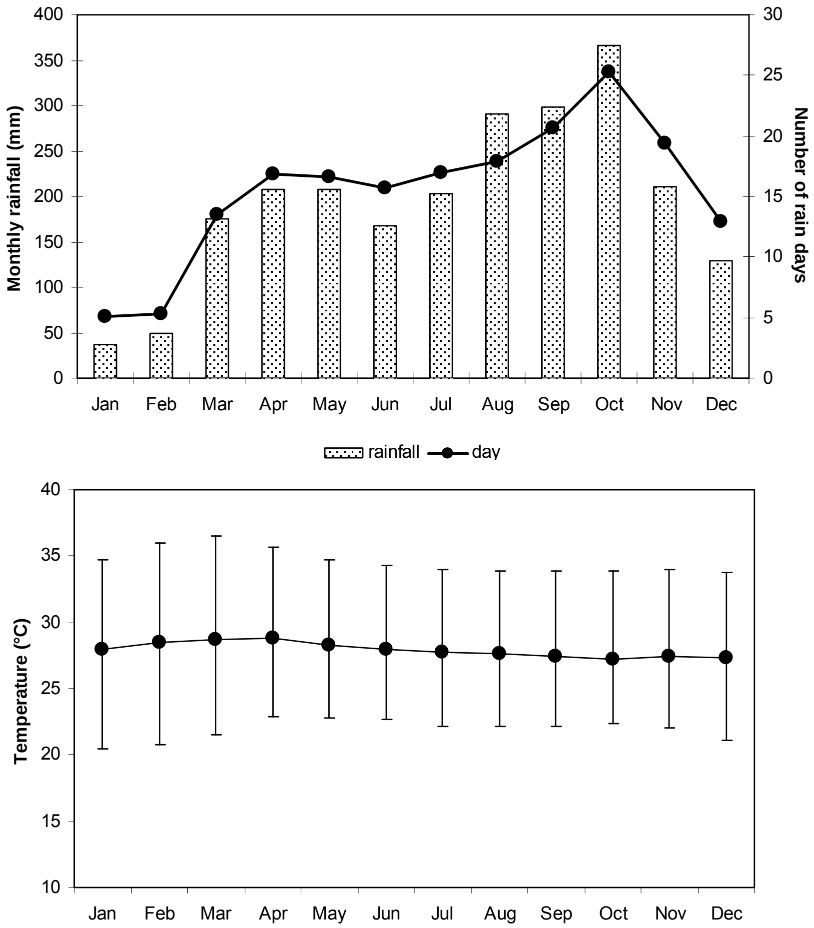


Figure 4.2 Climatological data at Tarutao Island (data collected from Meteorological station of Satun province during the period, 1999-2008)

Microclimate data recording

Microclimatic measurements had been performed in late December 2008 (dry season). At each site, air temperature (°C) and relative humidity (%) were recorded using a data logger Hobo pro V2 RH/Temp, while light intensity (lux) using Hobo pendant Temp/Light data logger. These data were recorded at 10 minute intervals; which are programmed and read by the software HOBOware Pro (Onset Hoboware Pro, software for hobo data loggers & devices, Version 2.6.0). Data loggers were placed 1.5 m above ground level.

Epiphytic bryophytes collecting

Epiphytic bryophytes had been collected along an altitudinal transect between 25 and 700 m above sea level. In this study area, four 0.25 hectare plots (50 × 50 m^2) were studied in approximately 200 m altitudinal intervals (25, 250, 500 and 700 m). They were located on the western slope of Tarutao Island (Fig. 1). A 20 × 20 cm quadrat with 5 vertical and 5 horizontal crosswire was placed on bases of tree trunks between 1.5 and 2 m above the ground. The quadrat was constructed using a semi-rigid frame so that the quadrate could conform to the shaped of tree trunks. Within each 0.25 hectare plot, 15-20 trees with girths more than 30 cm at 150 cm were studied. Each plot was expected to represent the plant community at each altitudinal site along the transect gradient from the foothill to the top of the mountain. One 20 × 20 cm quadrat was selected per tree, however, regardless of the diameter of the trees. Bryophyte samples in this 20 × 20 cm quadrats were collected and identified to the species level. A scale with six classes of percentage cover, modified from Lindlar & Frahm (2002), was used to estimate the abundance of each species within each quadrat.

The collected samples was re-examined microscopically in the laboratory. Thus, many additional bryophyte species, not observed in the field (too small to see without microscope), were able to be detected.

Due to the patchy distribution of bryophytes in general in the structurally heterogeneous rain forest a random sampling method may include many empty quadrats. Tree boles with 40% cover of bryophytes had been selected to set a sample quadrats on.

Pieces of bark of the selected host trees of that quadrats were taken, had been also collected and oven-dried at 70 °C, 48 hours then pulverized and diluted in distilled water (1:10, sample : water), shaken for an hour, afterward the dilution of bark pieces was pH measured with a Suntax sp-700 pH meter.

Life forms classification followed Bates (1998): cushions (c), dendroids (d), fans and tails (f), mats (m), pendants (p), turfs (t) and wefts (w).

Nomenclature and identification

The specimens of epiphytic bryophytes were identified using both keys and descriptions from available taxonomic literatures. Some unidentified taxa were sent and confirmed by specialist (see acknowledgment). The Genus and family classification followed Goffinet *et al*. (2008) for mosses and Crandall-Stotler *et al*. (2008) for liverworts.

The authors citations of plant name and other abbreviations followed Brummitt and Powell (1992) as well as the International Plant Names Index (IPNI). A complete set of voucher specimens was deposited at Prince of Songkla University Herbarium (PSU), with additional duplicates at the Forest Herbarium, Department of National Park Wildlife and Plant Conservation (BKF) and Bonn University herbarium.

Data analysis

For the species richness estimation, the first order jackknife was selected to use here as an implementation in the program computer EstimateS 8.2.0 (Colwell, 2009). Species accumulation curves were computed so as to analyze whether the sampling efforts were adequate to represent the bryophyte communities by non-parametric estimator. The Jackknife1 was calculated as shortcuts to extrapolate from the species number observed to the true number present because this estimator is the most precise and the least biased. The Jackknife1 was calculated as: $S_{est} = S_{obs} + R\ (n\text{-}1/n)$, Where S_{est} is the total estimated number of species, S_{obs} is the observed number of species, R is the number of species that occur in only one sample (singletons), and n is the number of specimens

The Sørensen's similarity index (SSI) was selected here so as to compare the groups of taxa found on the four different altitudes. It was calculated as: SSI = 2w / (m+n), where m is the total number of species in the first sample; n is the total number of species in the second sample, and w is the number of species common to both samples.

Detrended correspondence analysis (DCA) was selected to analyze the variation of specie composition among different forest types. And as to diminish the disproportionate effects of rare species on site scores, epiphytic bryophytes with frequencies < 5% across all sampling quadrats, were excluded. DCA-analysis was undertaken, using low-weighting of rare species, rescaling axes, rescaling threshold value at zero and using 26 segments. Two-Way-Indicator Species Analysis (TWINSPAN; Hill, 1979) was used for further grouping of samples and species. Both analyses were undertaken using the program package PC-ORD for Windows – version 5.19 (McCune & Mefford, 2006). The main data matrix (species covered) consisted of 69 rows (quadrats) and 31 columns (species). The second data matrix consisted of 69 rows (quadrats) and 11 columns, representing the following variables: altitude, air temperature, relative humidity, light intensity, tree diameter, bark type, bark pH, total percent cover, bryophyte richness, mosses richness and liverworts richness.

4.4 Results

Microclimate

The daily fluctuations in microclimate measured at 1.5 m above the ground of the four different altitudinal study sites showed dramatically changes between 6:00 am (- ±8:00 am) to 6:00 pm (- ±8:00 pm) (Figure 4.3). The data in Table 4.1 performed the microclimates of the four study sites with respect to all parameters measured. The highest temperature values were recorded at the 25 m site altitude above sea level, while the lowest ones were recorded at the 700 m site altitude above sea level. From the site at 25 m to the one at 250 m, the temperature had dropped down about 0.58 °C, whereas from 250 m to 500 m it had decreased 2.65 °C, and from 500 m to 700 m it had decreased 0.75 °C. And for the entire transect line from the first lowest site at the foot-hill to the highest site, the mean temperature that had decreased in relation with the increasing altitude, was about 0.57 °C/every 100 m above the sea level.

The relative air humidity values varied between 70 % and 100 %. The mean relative humidity increased from 86 % at the 25 m altitude site to 94 % at the 700 m altitude site. The most fluctuations of the climatic data changes occurred at the 700 m altitude site and at the 250 m altitude site, it showed the least fluctuations.

The light intensity at tree bole of different altitudinal sites had been shown in Figure 3.3c. The highest values were recorded at the 700 m altitude site, then following by those at the 500 and 250 m altitude sites, respectively.

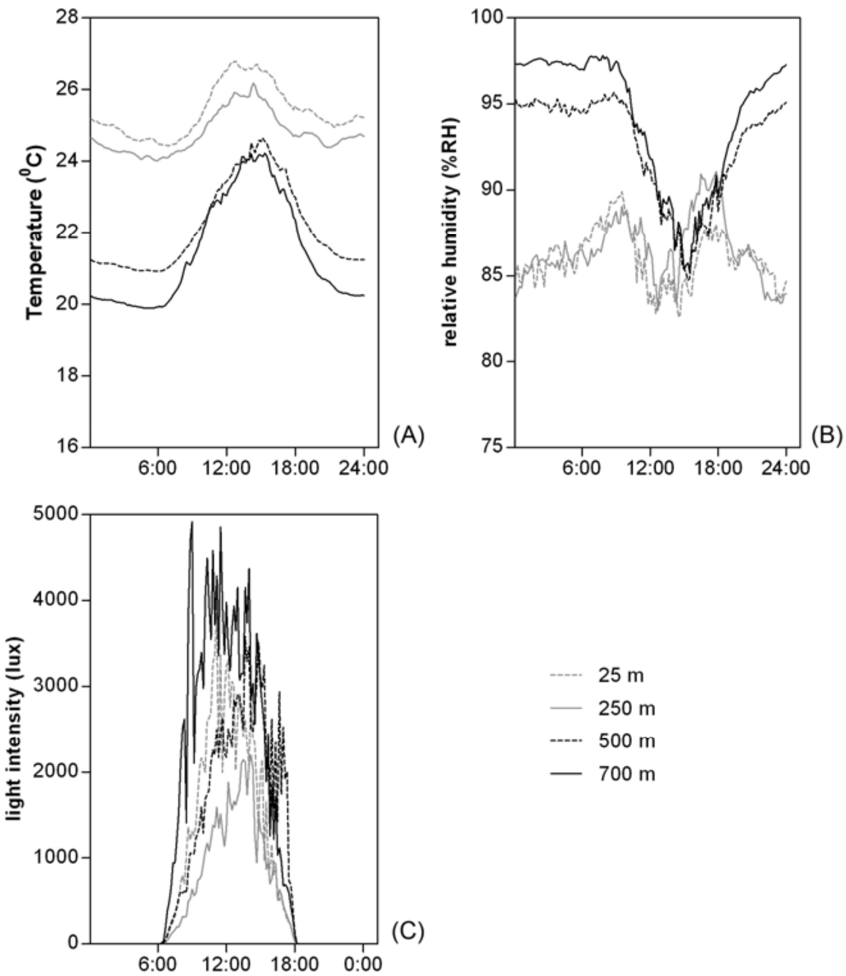


Figure 4.3 Microclimate along an altitude gradient from 25 to 700 m at Tarutao Island. A. daily course of temperature (°C), B. relative humidity (%RH) and C. light intensity (lux).

Table 4.1 Results of air temperature, relative air humidity, and light intensity measurements at the four study sites along an altitudinal transect on Tarutao Island, over a period of 6 days (21-26 December 2008).

6-d mean values	25 m	250 m	500 m	700 m
Daily mean temperature (°C)	25.34	24.76	22.11	21.36
Daily minimum temperature (°C)	23.04	22.85	20.37	19.60
Daily maximum temperature (°C)	27.85	27.51	26.70	26.55
Difference between daily minimum and maximum temperature (°C)	4.81	4.66	6.33	6.95
Daily mean relative humidity (%)	86.00	86.54	92.72	94.44
Daily minimum relative humidity (%)	70.28	73.56	72.93	72.71
Daily maximum relative humidity (%)	95.57	97.26	99.52	100.00
Difference between daily minimum and maximum relative humidity (%)	25.29	23.70	26.59	27.29
Mean light intensity during day times (lux)	1523.38	906.94	1722.27	2447.63

Species richness and floristic similarity

Seventy five quadrats were obtained from the four 0.25 hectare plots and 61 species of the epiphytic bryophytes were identified, that includes 30 species of liverworts (5 families, 19 genera) and 31 (8 families, 16 genera) species of mosses (Table 4.2). Lejeuneaceae is the most common family (in terms of species numbers), with 22 species and also a dominant group at every altitudinal site study (Figure 4.4). The second and third common families are Calymperaceae and Sematophyllaceae, with 15 and 8 species, respectively.

The observed and estimated species richness of epiphytic bryophytes in the study sites are shown in Table 3.3. They varied from site to site, ranging from 17 to 35 species and 19 to 48 species, respectively. The total possible number of species of epiphytic bryophytes in Tarutao Island is ± 71 species. Figure 4.4 shows species area curves for the appropriated quadrats in the each altitudinal site.

Table 4.3 Observed (S_{obs}) and estimated (S_{est}) species richness and percent sampling completeness per study sites and overall in Tarutao Island.

Altitude	S_{obs} s	S_{est}	Sampling completeness (%)
25 m	31	38	82
250 m	17	19	89
500 m	34	46	74
700 m	35	48	73
Overall	61	71	86

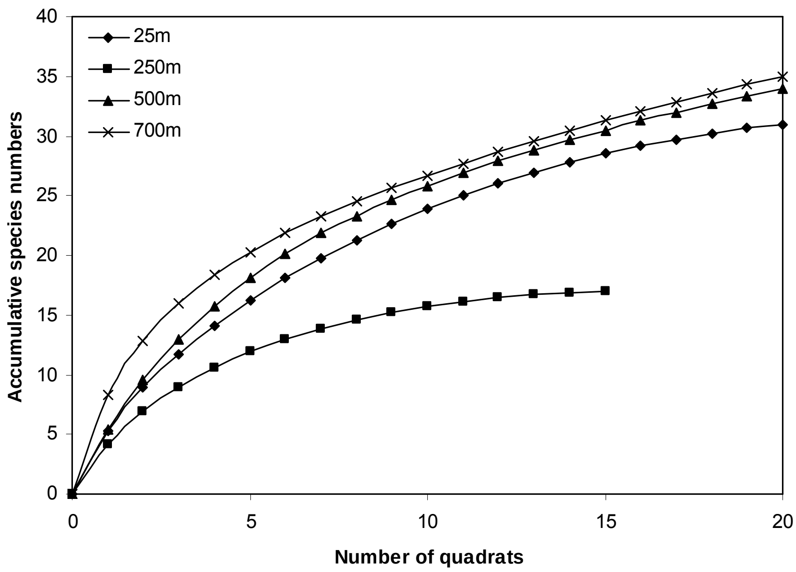


Figure 4.4 Species accumulation curves of epiphytic bryophytes in different altitudinal sites, at Tarutao Island.

The highest species richness per 0.25 hectare plot was found at the 700 m altitude site study with 35 species followed by the 500 m altitude site (34 species) and the 25 m altitude site (31 species). The poorest one was found at the site of 250 m altitude, with 17 species. In any case, the number of mosses was higher than the number of liverworts at every altitudinal site except for the one at 25 m altitude (Figure 4.5).

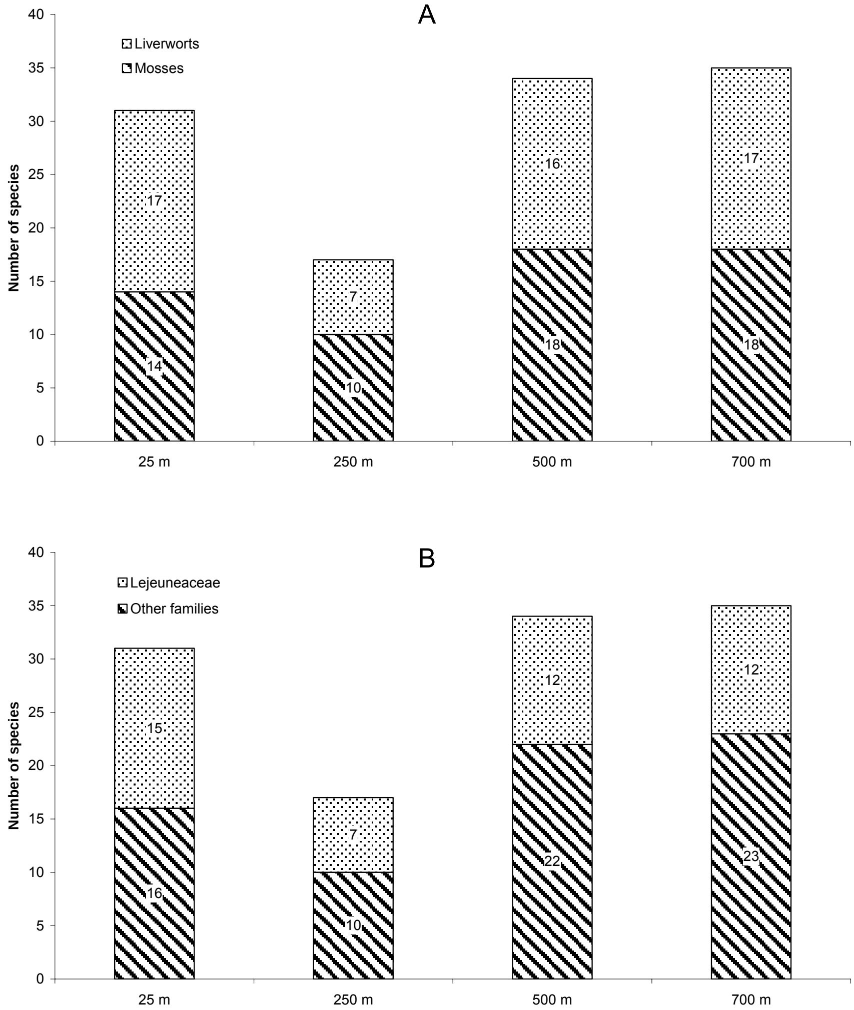


Figure 4.5 A. Number of liverworts and mosses in different altitudes. B. Dominance of Lejeuneaceae along an altitudinal transect on Tarutao Island.

The species numbers per quadrat (20 × 20 cm) ranged from 3-12, with an average of 5.88. The average number of species per quadrat is at the highest point at the 700 m altitude site (8.3), follows by the 500 m altitude site (5.4) and 25 m altitude site (5.25), and the lowest species average number is at the 250 m altitude site (4.13).

The table 4.4 is demonstrating the comparable of similarities between species of epiphytic bryophytes among the four altitudinal sites on Tarutao Island using the Sørensen's similarity index. The most similarity is at the sites of 500 m and 700 m (64%) while the least similarity (23%) is exhibited at the altitudinal range between 250 m and 700 m.

There are 6 – 22 shared species among each altitudinal site study. Among those, 5 common species are at every altitudinal site study along this gradient transect which are 3 species of liverworts i.e. *Cheilolejeunea intertexta* (Lindenb.) Steph., *Lopholejeunea eulopha* (Taylor) Schiffn. and *Metalejeunea cucullata* (Reinw. et al.) Grolle and 2 species of mosses i.e. *Leucophanes octoblepharoides* Brid. and *Trichosteleum* cf. *stigmosum* Mitt.

Eleven species restricted to the 700 m altitudinal site and 8 species were found only at the 25 m site, while the number of restricted taxa at other two altitudinal sites were very low i.e. 3 species at the 500 m altitudinal site and 2 species at the 250 m site, respectively.

Table 4.4 Number of shared species and Sørensen's Similarity Index between the four altitudes.

Altitude	25 m	250 m	500 m	700 m
	Number of shared species			
25 m	-	14	17	12
250 m	0.58	-	11	6
500 m	0.52	0.43	-	22
700 m	0.36	0.23	0.64	-
	Sørensen's similarity index			

Life forms

Six different life forms of the epiphytic bryophytes were found in the present study i.e. cushion, fan, mat, pendant, turf and weft. The most common one is mat form (66%) followed by turf form (20%), cushion form (7%) and weft form (5%), while fan form and pendant form are scarce, there are less than 5% cover of the epiphytic bryophytes of both life forms in each study site (Figure 4.5).

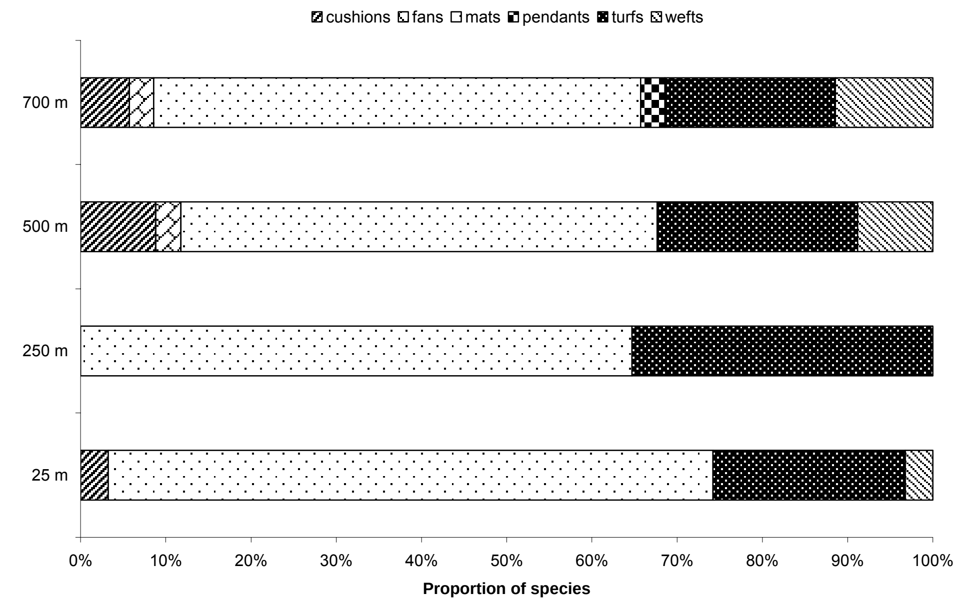


Figure 4.6 Distribution of life forms (in percentages) along an altitudinal transect on Tarutao Island.

Table 4.5 Pearson's Correlations computed between the axes of the DCA ordination and the values of the quantitative environmental variables.

	Axis 1	Axis 2
Altitude	-0.864	0.281
Temperature	0.880	-0.322
Relative humidity	-0.892	0.336
Light intensity	-0.890	0.378
Tree bark	0.320	0.042
Tree diameter	0.384	-0.100
Bark pH	0.622	-0.364
% cover	-0.388	0.262
Bryophytes richness	-0.677	0.196
Mosses richness	-0.414	0.238
Liverworts richness	-0.506	0.045

Floristic ordination

The DCA ordination of 69 quadrats and 31 species yielded the first two axes with eigenvalues of 0.72 and 0.43. The ordination of quadrats is in Figure 4.7 (Axis 1 and 2) and the species ordination is presented in Figure 4.8 (Axis 1 and 2) as well. Pearson's Correlations computed between the samples axes (Table 4.5) had indicated following relationships: *Axis 1* reflecting mainly the altitudinal gradient, exhibits negative correlation with the relative humidity and the light intensity, but positive correlation with the temperature.

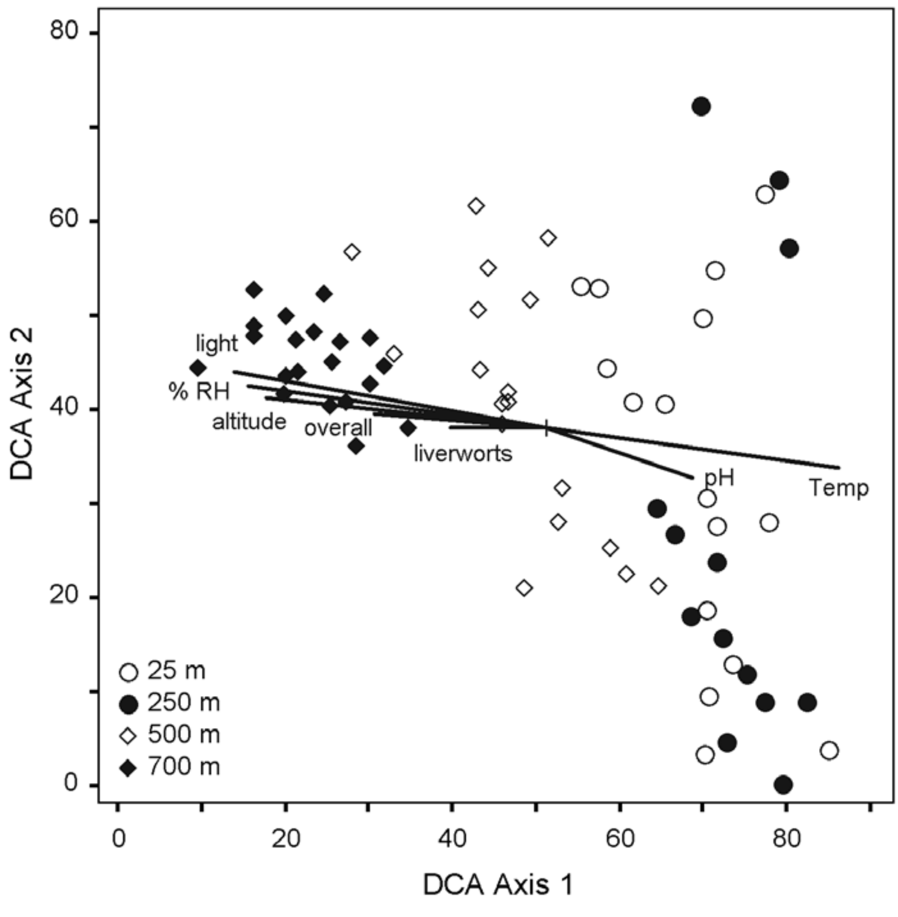


Figure 4.7 DCA Ordination of a vegetation of epiphytic bryophyte at Tarutao Island for 69 quadrats. The first axis goes from cool and wet environment of the higher altitude to a hot and dry condition of the lower one.

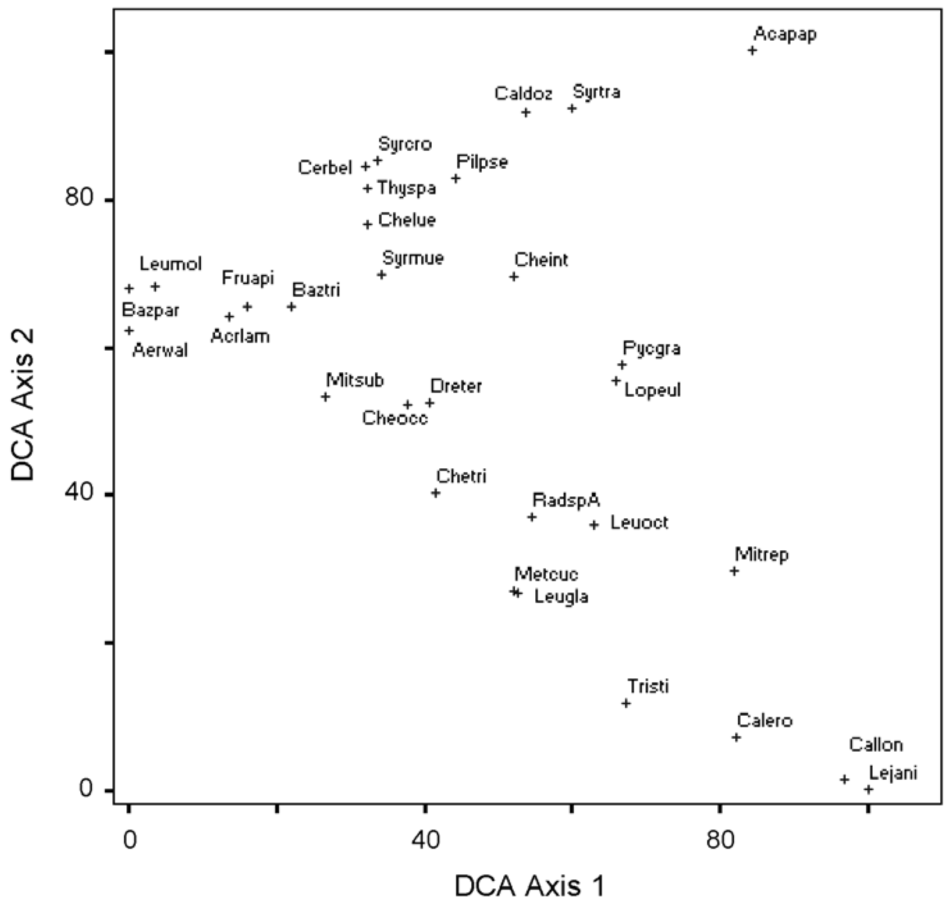


Figure 4.8 DCA ordination of a vegetation of epiphytic bryophyte at Tarutao Island for 31 species (abbreviations as in Table 4.2). The first axis goes from cool and wet environment of the higher altitude to a hot and dry condition of the lower one.

Samples are ordinated on the first axis with respect to their position on the altitudinal gradient and microclimatic condition. Samples from higher altitudes are ordinated towards the left-end point of the first axis. As far as the second ordination axis is concerned, the samples tend to be ordinated not clearly depicted. Samples are not ordinated with respect to the ordination of tree diameter, bark type and total percent cover.

Ordination of species by using DCA is shown in Figure 3.8.Species recorded only at higher altitudes are ordinated close to the left end-point (e.g. *Acroporium lamprophyllum* Mitt., *Aerobryopsis wallichii* (Brid.) M. Fleisch., *Bazzania paradoxa* (Sande Lac.) Steph., *Frullania apiculata* (Reinw. et al.) Nees and *Leucoloma molle* (Müll. Hal.) Mitt.), while species records only at lower altitudes are ordinate close to the right end-point of the first axis (e.g. *Acanthorrhynchium papillatum* (Harv.) M. Fleisch., *Calymperes erosum* Müll. Hal., *Calymperes lonchophyllum* Schwägr., *Lejeunea anisophylla* Mont. and *Mitthyridium repens* (Harv.) Robinson).

Community classification

Based on TWINSPAN cluster analysis, the 69 quadrats and 31 species of bryophytes occurring in the natural forests of Tarutao Island were divided into four community groups, A-D.

In groups A and B, *Acroporium lamprophyllum* Mitt., *Frullania apiculata* (Reinw. *et al.*) Nees and *Mitthyridium subluteum* (Müll.Hal.) N.H. Nowak are major components of most quadrats at 700 m (20 out of 25).

Group A was discriminated by the present of *Mitthyridium subluteum* (Müll.Hal.) N.H. Nowak and *Acroporium lamprophyllum* Mitt. They occurred in 18 quadrats of 700 m and 2 quadrats of 500 m.

Group B was separated by the present of *Cheilolejeunea intertexta* (Lindenb.) Steph., *Cheilolejeunea occlusa* (Herzog) T. Kodama & N. Kitag. And *Cheilolejeunea trifaria* (Reinw. et al.) Mizut. They occurred in 5 qudrats.

Groups C and D were mostly composed of *Mitthyridium repens* (Harv.) Robinson. They occurred in the forests of the medium and low altitude sites.

Group C was characterized by *Calymperes dozyanum* Mitt., *Piloecium pseudorufescens* (Hampe) Müll. Hal. and *Syrrhopodon trachyphyllus* Mont. They occurred in 6 qudrats at 500 m altitude site and 1 quadrat at 250 m altitude site.

Group D was characterized by *Pycnolejeunea grandiocella* Steph. and *Mitthyridium repens* (Harv.) Robinson. The biggest group occurred in lower altitude sites.

3.5 Discussion

Species richness and composition

In the present study, 13 families, 34 genera and 61 species of epiphytic bryophytes were recorded. The observed number of species might be underestimated due to the under-sampling of some (local) rare species. According to the extrapolation of species accumulation or species area curves, it was estimated that there were 71 species of epiphytic bryophyte in this island. In comparison with tropical lowland rain forests (Cornelissen & Ter Steege, 1989, Da Costa, 1999; Florschütz-de Waard & Bekker, 1987), the number of epiphytic bryophyte species in Tarutao Island is relatively low. However, it is to be concerned here that the variations in species richness are strongly affected by many factors in general, such as sampling method, sampling size, forest structure (height of trees, tree density), elevation, climate (annual rainfall, air temperature and air humidity), etc.

Species richness of liverworts and mosses in the present study was quite similar at all altitude sites. This dose not agree with the finding of higher species richness of liverworts than mosses in tropical rain forest from other previous studies. (Acebey *et al.*, 2003; Ariyanti *et al.*, 2008; Cornelissen & Gradstein, 1990; Cornelissen & Ter Steege, 1989; Da Costa, 1999; Florschütz-de Waard & Bekker, 1987; Gradstein *et al.*, 2001; Holz *et al.*, 2002; Sporn *et al.*, 2009). However, mosses are particularly common on the tree base, whereas liverworts cover most of the upper trunk and also much of the thick branches of the lower canopy (Cornelissen & Ter Steege, 1989) and due to the fact that the samplings were done, in this study, on the tree base only, therefore, it might explain the rather similar species richness between liverworts and mosses in the present study.

In terms of species numbers, Lejeuneaceae is the most common family with 22 species and dominant at every altitudinal site. The second and third common families are Calymperaceae (15 species) and Sematophyllaceae (18 species), respectively. All of these are among the 15 main families of the bryophytes in the tropical rainforest (Gradstein & Pócs, 1989). In any case, the common species found, such as *Acroporium lamprophyllum* Mitt., *Mitthyridium repens* (Harv.) Robinson, *Cheilolejeunea intertexta* (Lindenb.) Steph., *Lopholejeunea eulopha* (Taylor) Schiffn., *Metalejeunea cucullata* (Reinw. et al.) Grolle, *Pycnolejeunea grandiocella* Steph. and *Thysananthus spathulistipus* (Reinw. et al.) Lindenb. agree well with the description of the bryophytes community of lowland tropical forests of Kürschner (1990, 1998).

According to the vertical zones on the bole of any individual tree, the tree base has represented the lowest intensity of light-habitat with relative high humidity for any epiphyte. In additions, they perform the transition zone between the forest floor (logs, soil, and stones) and the tree trunk as well.

The increase of relative air humidity and light intensity, but decrease of air temperature in the forest from the lower altitude toward the upper altitude are in general agreement with microclimate readings of other rain forest studies (e.g. Frahm, 1987, 1990; Kürschner, 1990; Wolf, 1994). The species richness peak at 700 m site might suggest the optimal conditions for the bryophyte growth in this altitude site. In other lower altitudinal sites, bryophyte establishment may have been limited by the insufficient light and moisture, but higher temperature. Besides the microclimate conditions, bark structure, affecting nutrient and water flows on the tree might be the important factors determining species richness. In spite of the fact that the comparable of the bark texture and the bark pH from selected host trees had been achieved, other bark factors, i.e. hardness, water holding capacity, or chemical differences in solutions excreted by the host tree should have also been undertaken as they might influence the bryophyte occurrence as well as its species richness.

It was found here also that species richness was decreasing with altitude (from 31 to 17 species) between 25 m and 250 m, however, increases again (from 17 to 35 species) between 250 m and 700 m. This pattern is unexpected in tropical rain forest, while the general pattern species richness increases with altitude (e.g. Frahm, 1987, 1990a, 1994; Pócs, 1982; Van Reenen & Gradstein, 1983; 1984). Considering comparisons of species richness between 25 m site and 250 m site, the higher of species richness observed in 25 m site might be the result of the higher light intensity. It was found that species richness between 25 m site and 700 m site did not differ, but species composition was changed markedly.

Minimum area and species area curve

The concept of minimal area was based on the methodology of vegetation studies. Its accurate delimitation was an indispensable prerequisite for any subsequent analysis and interpretation of the recorded data. In the present study the number of quadrats (selected trees) was fixed at 15 or 20 per study site. The species area curve for the accumulated quadrats in different study sites were drawn (Figure 4.4). They show a more or less steady increase in species numbers, although not perfectly off. The forms of curves indicate that more than 70 % of the species were found in every altitude sites. The reliability of the obtained data may be tested by a comparison of the estimated species numbers of the entire plots. This shows that all study sites were quite well represented by these selected quadrats with values ranging mainly from 73 to 89 percent of the completeness estimated of each site.

Life form distribution

In the study area, the microclimatic data had shown a gradient distribution from a hot and dry condition of the lower altitude site to a cool and wet environment of the higher ones. Epiphytic bryophytes with different life forms might be the indicators of the habitats where they occurred, because of their potential of strict reliance on the water supplies, e.g. mat and turf life forms were dominated the lower altitudes. Because of both life forms are compacts and close to the substrate, these might help to reduce the desiccation rate.

The data presented here shown that fan, pendant and weft life forms had a clear preference for the humid habitats. Fan and pendant were restricted to the higher altitude sites (500 m and 700 m), where had high relative humidity. While weft like form was also more frequency at higher altitude.

The strong correlation of life forms with moisture and light conditions had been repeatedly discussed (Bates, 1998; Proctor, 1990; Thiers, 1988). According to Gimingham and Birse (1957), cushions, mats and turf could be roughly considered as xeric life forms with increasing drought- tolerance. Furthermore, dendroids, fans, pendants, and wefts are life forms characteristics of wet environments.

Altitudinal zonation

In the present study, the similarity analysis showed a high degree of dissimilarity (β-diversity) between 25 m altitudinal site and 700 m altitudinal site. Indeed, there were very few epiphytic bryophyte species widely occurring in all four altitudinal sites. It ought to be interpreted by the fact that a complex ecological factor with different the altitudes (e.g. forest structure, relative humidity, temperature and light availability) might be the limiting factor, determining the species composition of epiphytic bryophyte communities. The results of DCA have confirmed that the distribution and the composition of epiphytic bryophytes were affected by the altitude gradient. Moreover, the result of TWINSPAN shows that the communities of epiphytic bryophytes are clearly altitudinal grouping. Based on those results and microclimatic data along the altitudinal gradient, two different altitude zonations could be divided on Tarutao Islalnd, i.e. the tropical lowland forest (0-500 m) and the submontane forest (500-700 m). The 500 m altitudinal site could be considered to be a transitional zone between lowland forest and submontane forest.

Table 4.2 Species list of epiphytic bryophytes at Tarutao Island, southern Thailand. Species are listed ordered by family; families and species within families are given in alphabetical order. Life-form: c: cushions; f: fans; m: mats; p: pendants; tu: turfs; w: wefts.

Family	Species	Species Code	Altitude (m)				Total occurrence	Life form
			25	250	500	700		
Liverworts								
Frullaniaceae	1. *Frullania alstonii* Verd.	Fruals	X	-	X	-	3	m
Frullaniaceae	2. *Frullania apiculata* (Reinw. *et al.*) Nees	Fruapi	-	-	-	X	19	m
Lejeuneaceae	3. *Acrolejeunea pycnoclada* (Taylor) Schiffn.	Acrpyc	X	-	-	-	1	m
Lejeuneaceae	4. *Archilejeunea planiuscula* (Mitt.) Steph.	Arcpla	-	X	-	-	2	m
Lejeuneaceae	5. *Ceratolejeunea belangeriana* (Gottsche) Steph.	Cerbel	X	-	-	X	7	m
Lejeuneaceae	6. *Cheilolejeunea intertexta* (Lindenb.) Steph.	Cheint	X	X	X	X	29	m
Lejeuneaceae	7. *Cheilolejeunea luerssenii* (Steph.) Mizut.	Chelue	X	-	X	X	15	m
Lejeuneaceae	8. *Cheilolejeunea occlusa* (Herzog) T. Kodama & N. Kitag.	Cheocc	-	-	X	X	6	m
Lejeuneaceae	9. *Cheilolejeunea trifaria* (Reinw. *et al.*) Mizut.	Chetri	-	-	X	X	9	m
Lejeuneaceae	10. *Cheilolejeunea vittata* (Steph. ex G.Hoffm.) R.M. Schust. & Kachroo	Chevit	X	-	-	-	1	m
Lejeuneaceae	11. *Chondriolejeunea chinii* (P. Tixier) Kis & Pócs	Chochi	X	-	-	-	2	m
Lejeuneaceae	12. *Drepanolejeunea ternatensis* (Gottsche) Steph.	Dreter	X	-	X	X	6	m
Lejeuneaceae	13. *Drepanolejeunea teysmanii* Steph.	Dretey	X	X	-	-	3	m
Lejeuneaceae	14. *Lejeunea anisophylla* Mont.	Lejani	X	X	-	-	8	m
Lejeuneaceae	15. *Lejeunea flava* (Sw.) Nees	Lejfla	-	-	-	X	2	m
Lejeuneaceae	16. *Lejeunea tuberculosa* Steph.	Lejtub	-	-	-	X	2	m
Lejeuneaceae	17. *Lepidolejeunea bidentula* (Steph.) R.M. Schust.	Lepbid	-	-	X	X	2	m
Lejeuneaceae	18. *Lopholejeunea ceylanica* Steph.	Lopcey	-	-	X	-	1	m
Lejeuneaceae	19. *Lopholejeunea eulopha* (Taylor) Schiffn.	Lopeul	X	X	X	X	26	m

Family	Species	Species Code	Altitude (m)				Total occurrence	Life form
			25	250	500	700		
Lejeuneaceae	20. *Lopholejeunea subfusca* (Nees) Schiffn.	Lopsub	X	-	X	-	2	m
Lejeuneaceae	21. *Mastigolejeunea indica* Steph.	Masind	X	-	-	-	2	m
Lejeuneaceae	22. *Metalejeunea cucullata* (Reinw. *et al.*) Grolle	Metcuc	X	X	X	X	24	m
Lejeuneaceae	23. *Pycnolejeunea grandiocella* Steph.	Pycgra	X	X	X	-	25	m
Lejeuneaceae	24. *Thysananthus spathulistipus* (Reinw. *et al.*) Lindenb.	Thyspa	X	-	X	X	14	m
Lepidoziaceae	25. *Acromastigum curtilobum* A. Evans	Acrcur	-	-	X	X	2	w
Lepidoziaceae	26. *Bazzania paradoxa* (Sande Lac.) Steph.	Bazpar	-	-	-	X	10	w
Lepidoziaceae	27. *Bazzania tridens* (Reinw. *et al.*) Trevis.	Baztri	-	-	X	X	10	w
Lophocoleaceae	28. *Heteroscyphus splendens* (Lehm. & Lindenb.) Grolle	Hetspl	-	-	-	X	1	m
Radulaceae	29. *Radula javanica* Gottsche	Radjav	X	-	-	-	1	m
Radulaceae	30. *Radula* sp.	Radsp	-	-	X	-	5	m
Mosses								
Calymperaceae	31. *Calymperes dozyanum* Mitt.	Caldoz	X	X	X	-	6	tu
Calymperaceae	32. *Calymperes erosum* Müll. Hal.	Calero	X	X	X	-	5	tu
Calymperaceae	33. *Calymperes lonchophyllum* Schwägr.	Callon	X	X	-	-	5	tu
Calymperaceae	34. *Leucophanes glaucum* (Schwägr.) Mitt.	Leugla	-	X	X	X	6	tu
Calymperaceae	35. *Leucophanes octoblepharoides* Brid.	Leuoct	X	X	X	X	10	tu
Calymperaceae	36. *Mitthyridium fassiculatum* (Hook. & Grev.) Robinson	Mitfas	-	-	-	X	1	m
Calymperaceae	37. *Mitthyridium flavum* (Müll. Hal.) Robinson	Mitfla	-	-	X	X	2	m
Calymperaceae	38. *Mitthyridium repens* (Harv.) Robinson	Mitrep	X	X	X	-	28	m
Calymperaceae	39. *Mitthyridium subluteum* (Müll.Hal.) N.H. Nowak	Mitsub	-	-	X	X	16	ta
Calymperaceae	40. *Octoblepharum albidum* Hedw.	Syrcon	X	-	-	X	2	c
Calymperaceae	41. *Syrrhopodon confertus* Sande Lac.	Syrcro	X	-	-	-	15	tu

Family	Species	Species Code	Altitude (m)				Total occurrence	Life form
			25	250	500	700		
Calymperaceae	42. *Syrrhopodon croceus* Mitt.	Syrmue	X	-	X	X	9	tu
Calymperaceae	43. *Syrrhopodon muelleri* (Dozy & Molk.) Bosch &	Syrspi	-	-	X	X	2	tu
Calymperaceae	44. *Syrrhopodon spiculosus* Hook. & Grev.	Syrtra	-	-	X	X	10	tu
Calymperaceae	45. *Syrrhopodon trachyphyllus* Mont.	Leumol	X	X	X	-	9	tu
Dicranaceae	46. *Leucoloma molle* (Müll. Hal.) Mitt.	Isoalb	-	-	-	X	1	tu
Hypnaceae	47. *Isopterygium albescens* (Hook.) A. Jaeger	Leuadu	-	-	-	X	2	m
Leucobryaceae	48. *Leucobryum aduncum* Dozy & Molk.	Leujav	-	-	X	-	2	c
Leucobryaceae	49. *Leucobryum javense* Brid.	Leusan	-	-	X	X	1	c
Leucobryaceae	50. *Leucobryum sanctum* (Brid.) Hampe	Aerwal	-	-	X	-	8	c
Meteoriaceae	51. *Aerobryopsis wallichii* (Brid.) M. Fleisch.	Octalb	-	-	-	X	3	p
Pylaisiadelphaceae	52. *Taxithelium nepalense* (Schwägr.) Broth.	Taxnep	-	X	-	-	2	m
Rhizogoniaceae	53. *Pyrrhobryum spiniforme* (Hedw.) Mitt.	Pyrspi	-	-	-	X	1	tu
Sematophyllaceae	54. *Acanthorrhynchium papillatum* (Harv.) M. Fleisch.	Acapap	X	X	-	-	10	m
Sematophyllaceae	55. *Acroporium convolutifolium* Dixon	Acrcoi	-	-	X	-	1	m
Sematophyllaceae	56. *Acroporium johnnis-winkleri* Broth.	Acrjoh	X	-	-	-	2	m
Sematophyllaceae	57. *Acroporium lamprophyllum* Mitt.	Acrlam	-	-	X	X	21	m
Sematophyllaceae	58. *Acroporium secundum* (Reinw. & Hornsch.)	Acrsec	-	-	-	X	2	m
Sematophyllaceae	59. *Piloecium pseudorufescens* (Hampe) Müll. Hal.	Pilpse	X	-	X	X	9	m
Sematophyllaceae	60. *Sematophyllum subpinnatum* (Brid.) Brid.	Semsub	X	-	-	-	2	m
Sematophyllaceae	61. *Trichosteleum* cf. *stigmosum* Mitt.	Tristi	X	X	X	X	8	m

Chapter 5

Diversity, distribution and ecology of epiphytic bryophytes on tree trunk along an altitudinal gradient in Southern Thailand

5.1 Abstract

Studying of the impact of the altitudinal change from lowland to montane forest on species richness, species composition and ecology of epiphytic bryophytes was carried out along an altitudinal gradient at Khao Nan Nantional Park, Southern Thailand. Epiphytic bryophytes were collected from tree trunk at 1.5-2 m height from sampling quadrats within an altitudinal range from 400 m to 1,300 m a.s.l. A total of 118 quadrats were sampled from six 0.25 hectare plots. In total 138 species of epiphytic bryophytes were recorded including 83 species of liverworts and 55 species of mosses. Species richness of epiphytic bryophytes have increased with an increasing altitude. In addition, the species composition has changed significantly between altitudes. Microclimate measurements were carried out at 1.5 m height above ground level. Besides, the altitudinal gradient of 6 study sites had proved to be the most important factor in community differentiation of epiphytic bryophytes as indicated by DCA analysis. Moreover, the microclimate parameters might be the primary factors that correlated to the differences in diversity and species composition of bryophyte assemblages, on the other hand, the characteristics of the host plant species (tree diameter, bark roughness) are probably minor factors. Furthermore, the distribution of the life forms among each bryophyte differs significantly along the altitudinal gradient which might well explain the relationship between each epiphytic bryophyte taxon to its habitat. Fan life form was mostly found in low land forest, whereas wefts were the most species rich in a montane forest. Based on TWINSPAN analysis, five epiphytic bryophyte community types could be recognized.

5.2 Introduction

Even though bryophytes are, mostly, small and inconspicuous, they are important components of tropical forests, especially montane ones, and may play a significant role in the water balance and nutrient cycling of these forests (Frahm, 1990a; Hofstede *et al*., 1994; Pócs, 1980; Nadkarni, 1984). Due to the high relative humidity throughout the year, tropical rainforests form excellent habitats for an epiphytic bryophyte species.

Indeed, epiphytic bryophytes have received less attention than any other vascular epiphytes. There are only few studies dealing with epiphytic bryophytes in any ecosystem. Most of the ecological studies of epiphytic bryophytes have been done on the diversity and some ecological aspects of tropical rain forest, especially, in tropical America and Africa (e.g. Acebey *et al*., 2003; Frahm, 1987, 1994; Kürschner 1995, Kürschner & Parolly 1998, Holz *et al*., 2002, 2005; Léon-Vargas *et al*., 2006; Wolf 1993a, b, c).

Studies of bryophytes from Southeast Asia are few. More intensive studies were done along an altitudinal gradient on Mt. Kinabalu, Borneo. Kürschner (1990) had shown discontinuities of epiphytic bryophytes within the altitudinal gradient of North Borneo by means of ordination. Life forms, water conducting and water storing structures of epiphytic bryophytes on Mount Kinabalu were studied along the altitudinal transect (Frey *et al*., 1990). Frahm (1990a) had done some ecological studies on the epiphytic bryophytes on Mount Kinabalu, including pH of bark, biomass of bryophytes, water storage capacity and microclimatic correlation. The altitudinal zonation of bryophytes on Mount Kinabalu was also assesses by Frahm (1990b) using ecological and non-floristically parameters. There has been no other mountain in Southeast Asia that has been studied in such details in ecology and bryophytes community characterization. Recently, Aryanti *et al*. (2008) and Sporn *et al*. (2009a, b) studied the bryophyte diversity of submontane rain forests and cacao plantations of central Sulawesi, Indonesia. These studies have shown the overriding importance of microclimate as a driver of epiphytic bryophyte distribution.

Southern Thailand is one of the richest areas in biodiversity, a part of Indo-Burma and Sundaland biodiversity hot spots (Myers *et al*., 2000). This includes the transition zone between Indo-Chinese and Malesian floristic regions

(Takhtajan, 1986; Collin *et al*., 1991). According to van Steenis (1950), 575 genera of flowering plants have their northern or southern range limits near Thai-Malaysian border. Unfortunately, the lowland forests on mainland have been seriously threatened by human activities and transferred to agricultural lands, such as rubber and oil palm plantations. Only scattering small parts of forests remain, mostly at higher elevation in the mountains, and are preserved in protected areas. Now a day, it is estimated that approximately 25% of the land is under forest cover, including forest plantations (Maxwell, 2004).

Considering the bryophyte diversity, more than 50 % of Thai bryophytes were recorded in Peninsular Thailand (Sornsamran & Thaithong, 1995). Most of them are epiphytes. However, there have been no studying of how do the epiphytic bryophytes distribute along an altitudinal gradient and how do the potential environmental variables regulate their distributions. The information of diversity and altitudinal gradient distributions of epiphytic bryophytes in Peninsular Thailand might, then, provides a comprehensive understanding of epiphytic bryophyte communities in tropical rain forest of South-east Asia in general.

The present study had focused only on epiphytic bryophytes on tree trunks. And it is to be noticed that this is the first comparative study on the epiphytic bryophyte in Thailand and probably first time of such study on South-east Asian mainland as well. The aim of the present study is to compare the diversity and distribution of epiphytic bryophytes on tree trunks along an altitudinal gradient and to assess how any selected environmental variables affect the distribution of those epiphytic bryophytes.

5.3 Material and Methods

Study sites

Khao Nan National Park is situated in the Nakhon Si Thammarat Mountain Range on the East Coast of Peninsular Thailand (Figure 5.1), and covers an area of approximately 436 km^2. It is marked out, approximately, by the geographical coordinates of 8°41′ - 8°58′ N latitude and 99°30′ - 99°99′ E longitude. The park, with an altitude range from 60 to 1,438 m (summit of Khao Nan Mt.), provides heterogeneous habitats for various flora and fauna. In the Park, there are a watershed and streams which flow into many waterfalls such as Sunantha Waterfall, Nhan Chong Fah Waterfall, and Klong Klai Waterfall.

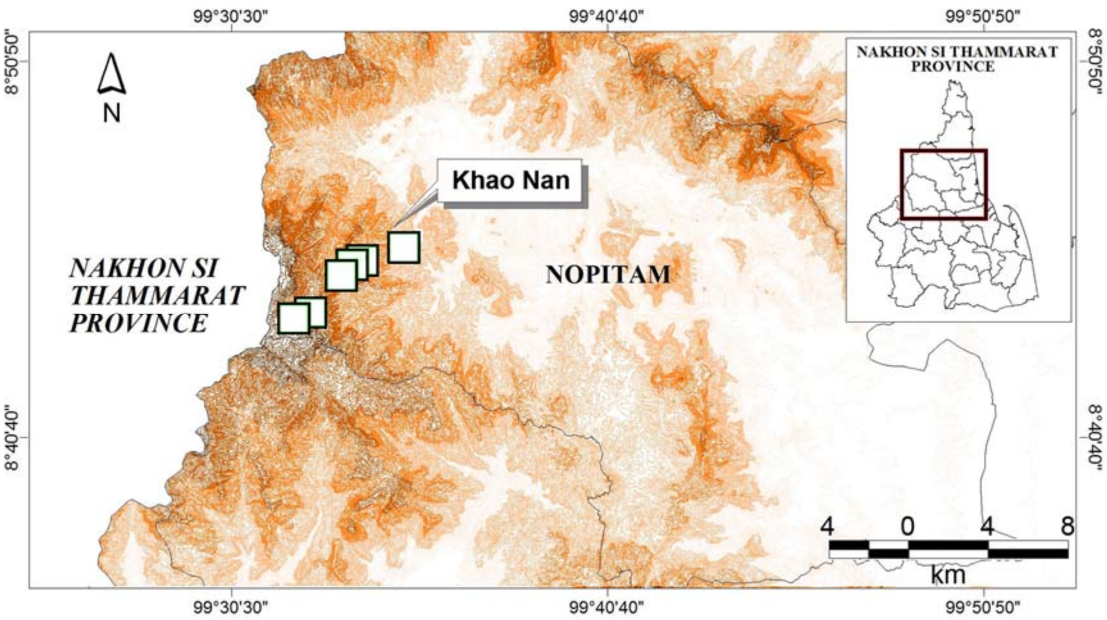
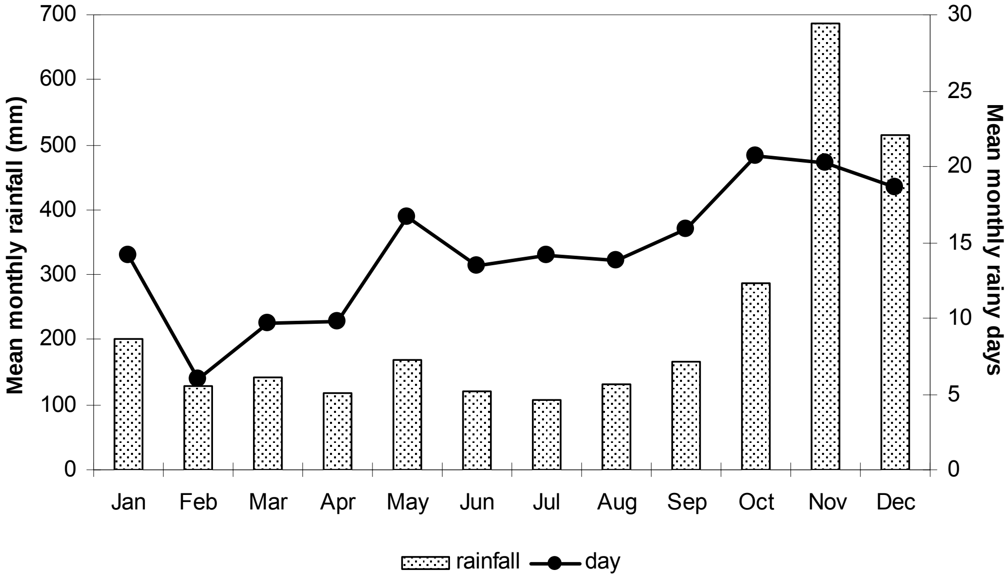


Figure 5.1 Topographic map of Khao Nan Nationpark, Nakhon Si Thammarat Province, Thailand, showing the elevations and the location of study sites.

Field works were carried out along an altitudinal transect from Krung Ching waterfall to Sanyen Mountain (400-1,300 m) (Figure 4.1). The lower part of a transect is a hill-dipterocarp forest, dominated by Dipterocarpaceae, Euphorbiaceae and Guttiferae, respectively. From 1,000 m upwards, the forest type gradually changes to be a montane forest, which. It is usually dominated by *Dacrydium elatum* (Roxb.) Wall. ex Hook. and *Podocarpus* spp. (Podocarpaceae); *Lithocarpus* spp., *Quercus* spp. (Fagaceae); *Schima wallichii* (DC.) Korth. (Theaceae); *Rhododendron* spp. and *Vaccinium* spp. (Ericaceae); *Eugenia* spp. and *Syzygium* spp. (Myrtaceae). Epiphytes are common on trunks and branches of trees and shrubs. Many of them are pteridophytes, aroid plants and a number of orchids. These epiphytes usually grow together with a number of mosses and leafy liverworts.

Climatologically data from 1999 to 2008 at Nakhon Si Thammarat Climatic Station (Figure 5.2) indicated an average annual temperature of 27.5 °C. The average maximum temperature was about 35.5 °C during May and August, and the average minimum, approximately 20 °C, occurred in December and January. Annual precipitation during this period was 2,775 mm. Precipitation in the area was at the highest point from October to January and at the lowest one from February to April with continual several rainy days.



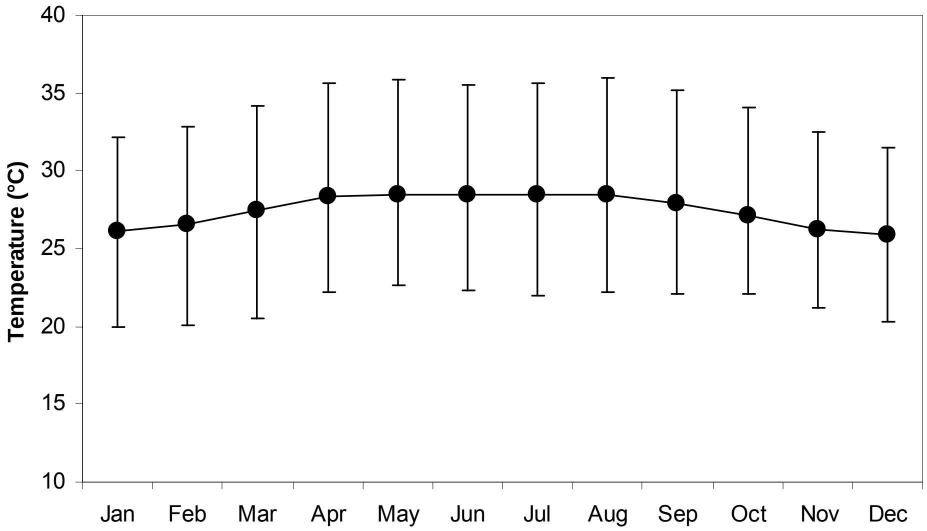


Figure 5.2 Climatological data at Khao Nan National Park (data collected from Meteorological station of Nakhon Si Thammarat Province during the period, 1999-2008)

Microclimate data recording

Microclimatic measurements had been performed during from 17 February 2009 to 12 March 2009 (dry season). At each site, air temperature (°C) and relative humidity (%) were recorded using a data logger Hobo pro V2 RH/Temp. These loggers worked within the range for -40 °C to +70 °C (± 0.2 °C for values between 0 °C and 50°C) and 0-100 %RH (±2.5% from 10 to 90% typical, to a maximum of ±3.5%). The data were recorded at 10 minute intervals; which are programmed and read by the software HOBOware Pro (Onset Hoboware Pro, software for hobo data loggers & devices, Version 2.6.0). Data loggers were placed 1.5 m above ground level.

Epiphytic bryophytes collecting

Epiphytic bryophytes had been collected along an altitudinal transect between 400 and 1,300 m above sea level. In this study area, six 0.25 hectare plots (50 × 50 m) were established in approximately 200 m altitudinal intervals: 400 m, 600 m, 800 m, 1,000 m, 1,200 m and 1300 m. They were located along a transect from Krung Ching waterfall to Sanyen Mountain ridge (Figure 5.1). A 20 × 20 cm quadrat with 5 vertical and 5 horizontal crosswire was placed on bases of tree trunks at around 1.5 to 2 m above the ground. As a quadrat was constructed using a semi-rigid frame, so that it could conform to a shape of tree trunks. Within each 0.25 hectare plot, 15-20 trees which had girths more than 30 cm at 150 cm, were studied. Each plot was expected as a representative of the plant community at each altitudinal site along the transect gradient from the foothill to the top of the moutain. One 20 × 20 cm quadrat was selected per tree, however, regardless of the diameter of the trees. Bryophyte samples in these 20 × 20 cm quadrats were collected and identified to the species level. A scale with six classes of percentage cover, modified from Lindlar & Frahm (2002), was applied to estimate the abundance of each species within each quadrat.

The collected samples had been re-examined microscopically in the laboratory. Thus, many additional bryophyte species, not observed in the field (too small to see without microscope), were able to be detected.

Generally, due to the patchy distribution of bryophytes in the structurally heterogeneous rain forest, a random sampling method had included many empty quadrats. Only the tree boles with 40% cover of bryophytes had been selected to set a sample quadrat on.

Pieces of bark of the selected host trees that quadrats were taken, had been also collected and oven-dried at 70 °C for 48 hours, then pulverized and diluted in distilled water (1:10, sample : water), shaken for an hour, afterward the dilution of ark pieces had been pH measured with a Suntax sp-700 pH meter.

As life forms are not only morphological but also physiological adaptations to conditions of different habitats and elevations. They are especially important for water uptake, water storage and gas exchange. In this study, the life forms of epiphytic bryophytes were classified following Bates (1998): cushion (c), dendroid (d), fan and tail (f), mat (m), pendant (p), turf (t) and weft (w).

Nomenclature and identification

The specimens of epiphytic bryophytes were identified using both keys and descriptions from available taxonomic literature. Some unidentified taxa were sent and confirmed by specialist (see acknowledgments). The Genus and family classification followed Goffinet *et al*. (2008) for mosses and Crandall-Stotler *et al*. (2008) for liverworts.

The author citations of plant name and other abbreviations followed Brummitt and Powell (1992) as well as the International Plant Names Index (IPNI). A complete set of voucher specimens was deposited at Prince of Songkla University Herbarium (PSU), with additional duplicates at the Forest Herbarium, Department of National Park Wildlife and Plant Conservation (BKF) and Bonn University herbarium.

Data analysis

For the species richness estimation, the “first order jackknife” was selected to use here as an implementation in the program computer EstimateS 8.2.0 (Colwell, 2009). Species accumulation curves were computed so as to analyze whether the sampling efforts were adequate to represent the bryophyte communities by non-parametric estimator. The “Jackknife1” was calculated as shortcuts to extrapolate from the species number observed to the true number present due to the fact that this estimator is the most precise and the least biased. The “Jackknife1” was calculated as: $S_{est} = S_{obs} + R$ (n-1/n), Where S_{est} is the total estimated number of species, S_{obs} is the observed number of species, R is the number of species that occur in only one sample (singletons), and n is the number of specimens

Beta diversity or between-habitat diversity is the measure of the change in species diversity between habitats or communities. It is usually expressed in terms of a similarity index between communities or as a species turnover rate. In this study the former is computed with Sørensen’s similarity index for qualitative data and the latter with Whittaker’s index for beta diversity (Whittaker, 1960).

The Sørensen’s similarity index (SSI) was selected here so as to compare the groups of taxa found on the four different altitudes. It was calculated as: SSI = 2w / (m+n), where m is the total number of species in the first sample; n is the total number of species in the second sample, and w is the number of species common to both samples.

Detrended correspondence analysis (DCA) was selected to analyze the variation of specie composition among different forest types. And as to diminish the disproportionate effects of rare species on site scores, epiphytic bryophytes with frequencies < 5% across all sampling quadrats, were excluded. DCA-analysis was undertaken, using low-weighting of rare species, rescaling axes, rescaling threshold value at zero and using 26 segments. Two-Way-Indicator Species Analysis (TWINSPAN; Hill, 1979) was used for further grouping of samples and species. Both analyses were undertaken using the program package PC-ORD for Windows – version 5.19 (McCune & Mefford, 2006). The main data matrix (species covered) consisted of 118 rows (quadrats) and 114 columns (species). The second data matrix consisted of 118 rows (quadrats) and 10 columns, representing the following variables: altitude, air temperature, relative humidity, tree diameter, bark type, bark pH, total percent cover, bryophyte richness, mosses richness and liverworts richness.

5.4 Results

Microclimate

The daily fluctuations in microclimate measured at 1.5 m above the ground of the six different altitudinal study sites showed dramatically changes between 6:00 am to 6:00 pm (Figure 5.3). The data in table 5.1 performed the microclimates of the six altitudinal sites with respect to all parameters measured. The highest temperature values were recorded at the 400 m site altitude a.s.l., while the lowest ones were recorded at the 1,300 m site altitude a.s.l. For the entire transect line from the first lowest site at the foot-hill to the highest one, the mean temperature that had decreased in relation with the increasing altitude, was about 0.63 °C/every 100 m above the sea level.

The relative air humidity values varied between 60 % and 100 %. The mean relative humidity had increased from 85 % at the 400 m altitude site to 95 % at the 1,300 m altitude site.

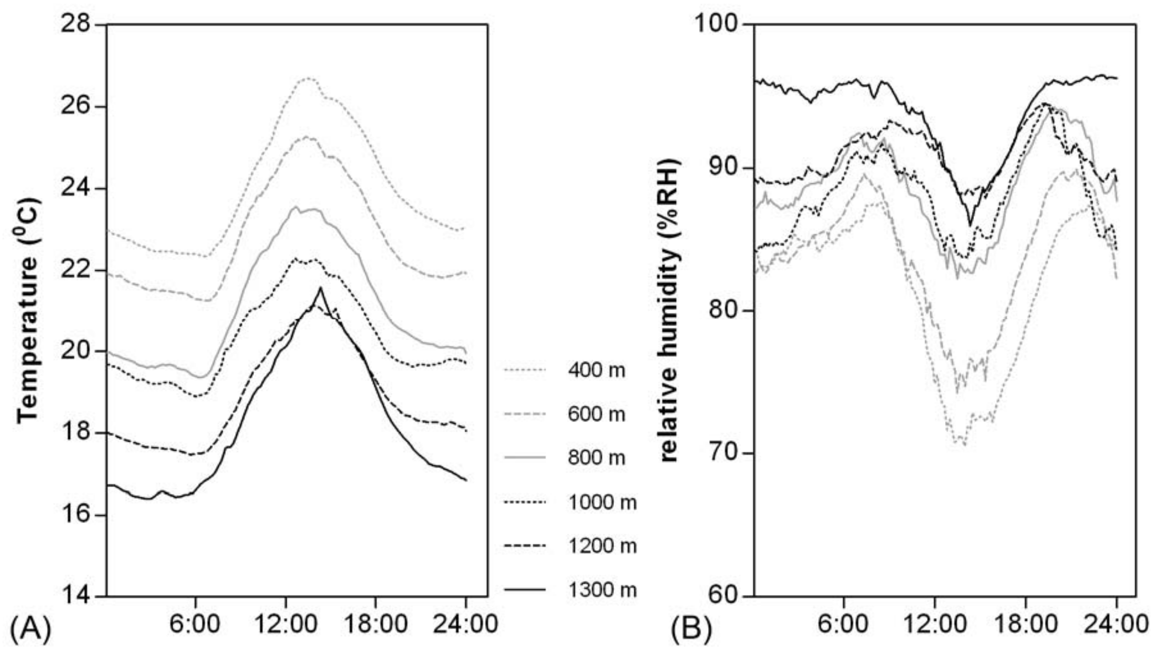


Figure 5.3 Daily course of temperature (°C, A) and relative humidity (%RH, B) along an altitude gradient from 400 to 1300 m at Khao Nan National Park, Southern Thailand. The values are averages over a period of 21 days (17 February to 10 March 2009).

Table 5.1 Results of air temperature and relative air humidity measurements at the six study sites along an altitudinal transect at Khao Nan National Park, Southern Thailand, over a period of 21 days (17 February to 10 March 2009).

21-d mean values	400m	600m	800m	1000m	1200m	1300m
Daily mean temperature (°C)	23.95	22.76	21.17	20.44	19.05	18.31
Daily minimum temperature (°C)	21.68	20.34	18.79	17.89	16.49	13.93
Daily maximum temperature (°C)	27.83	26.65	25.65	24.27	22.97	24.97
Difference between daily minimum and maximum temperature (°C)	6.15	6.31	6.86	6.38	6.48	11.04
Daily mean relative humidity (%)	85.26	87.44	91.57	91.09	93.15	94.78
Daily minimum relative humidity (%)	59.64	58.81	68.75	61.80	71.91	69.93
Daily maximum relative humidity (%)	98.83	99.86	100.00	100.00	99.21	100.00
Difference between daily minimum and maximum relative humidity (%)	39.19	41.05	31.25	38.20	27.30	30.07

Floristic richness and taxonomic diversity

In total, 118 quadrats were obtained from the six 0.25 hectare plots and 138 species of epiphytic bryophytes were identified. Species list is shown in Table 4.2. Among these, 13 families, 29 genera and 83 species are liverworts, while 19 families, 35 genera and 55 species are mosses. Four families of liverworts namely Lejeuneaceae, Lepidoziaceae and Plagiochilaceae are among the most common families. Lejeuneaceae had included 29 species in 12 genera while Lepidoziaceae and Plagiochilaceae had included 19 species in 5 genera and 11 species in 2 genera, respectively. Within mosses, Calymperaceae, Neckeraceae and Sematophyllaceae are the most common families. Calymperacceae had included 11 species in 5 genera while Neckeraceae and Sematophyllaceae had included 9 species in 5 genera and 8 species in 3 genera. Of these, ten species are newly recorded for Thailand, i.e. *Cheilolejeunea luerssenii* (Steph.) Mizut., *Cheilolejeunea occlusa* (Herzog) T. Kodama & N. Kitag., *Cheilolejeunea verrucosa* Steph., *Stenolejeunea apiculata* (Sande Lac.) R.M. Schust., *Zoopsis liukiuensis* Horik., *Plagiochila dendroides* (Nees) Lindenb., *Plagiochila sandei* Dozy ex Sande Lac., *Radula ventricosa* Steph., *Distichophyllum jungermannioides*

(Müll. Hal.) Bosch & Sande Lac. and *Mitthyridium subluteum* (Müll.Hal.) N.H. Nowak.

Among the ten most frequently recorded species (Table 5.2), five are liverworts (*Metalejeunea cucullata* (Reinw. *et al*.) Grolle, *Lejeunea tuberculosa* Steph., *Radula javanica* Gottsche, *Bazzania tridens* (Reinw. *et al*.) Trevis. and *Drepanolejeunea teysmanii* Steph.) and five are mosses (*Leucoloma molle* (Müll. Hal.) Mitt., *Homaliodendron exiguum* (Bosch & Sande Lac.) M. Fleisch., *Isocladiella surcularis* (Dixon) B.C. Tan & Mohamed, *Homaliodendron flabellatum* (Sm.) M. Fleisch. and *Pyrrhobryum spiniforme* (Hedw.) Mitt.). Twenty six species were present in only one of the quadrat, seventeen liverworts (e.g. *Calypogeia angusta* Nees & Mont., *Herbertus armitanus* (Steph.) H.A. Maill., *Ceratolejeunea belangeriana* (Gottsche) Steph., *Cheilolejeunea verrucosa* Steph., *Radula cavifolia* Hampe ex Gottsche *et al*.) and nine mosses (e.g. *Mitthyridium subluteum* (Müll.Hal.) N.H. Nowak, *Syrrhopodon japonicus* (Besch.) Broth., *Dicranoloma braunii* (Müll. Hal.) Paris).

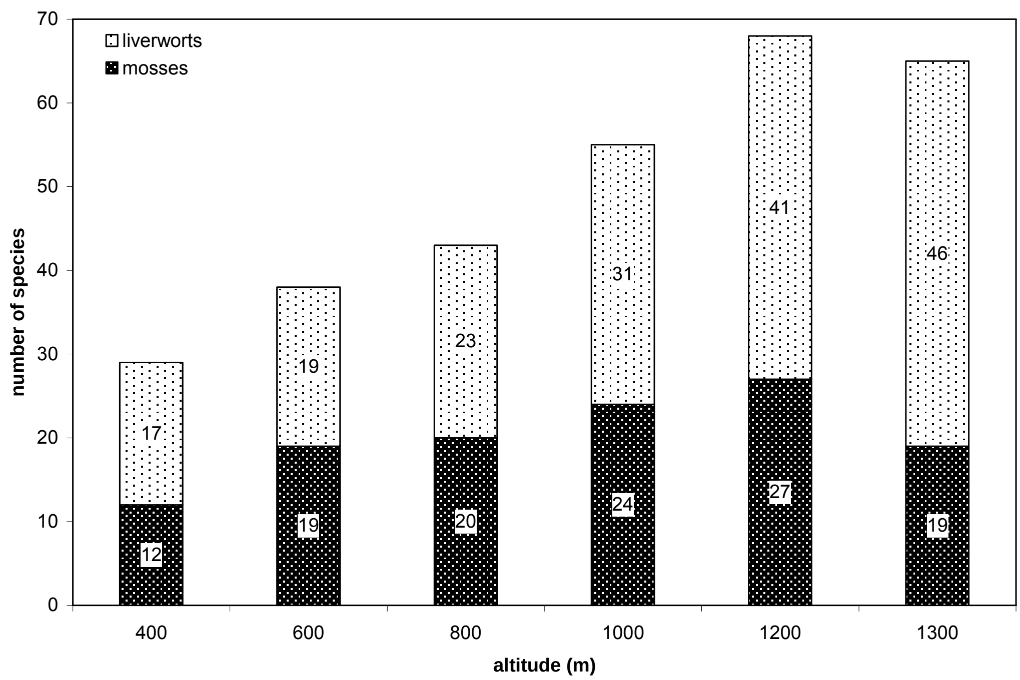


Figure 5.4 Number of liverworts and mosses in different altitudes along a line transect at Khao Nan National Park, Southern Thailand.

The highest species richness per 0.25 hectare plot was found at the 1,200 m altitude site study with 68 species, followed by 1300 m, 1000 m, 800 m and 600 m altitude sites with 65, 55, 43 and 38 species respectively. The poorest one was found at the site of 400 m altitude, with 29 species. In any case, the number of liverworts was higher than the number of mosses at every altitudinal site except for the one at 600 m altitude (Figure 5.4).

The species richness per quadrat (20×20 cm) ranged from 3-24 species, with a mean of 10.7 species and a rather high standard deviation of 5.1. The average number of species per quadrat was at the highest point at 1200 and 1300 m altitude sites: 16.0 and 16.5 species respectively and the lowest species average number was at the 400 m altitude site (5.6 species).

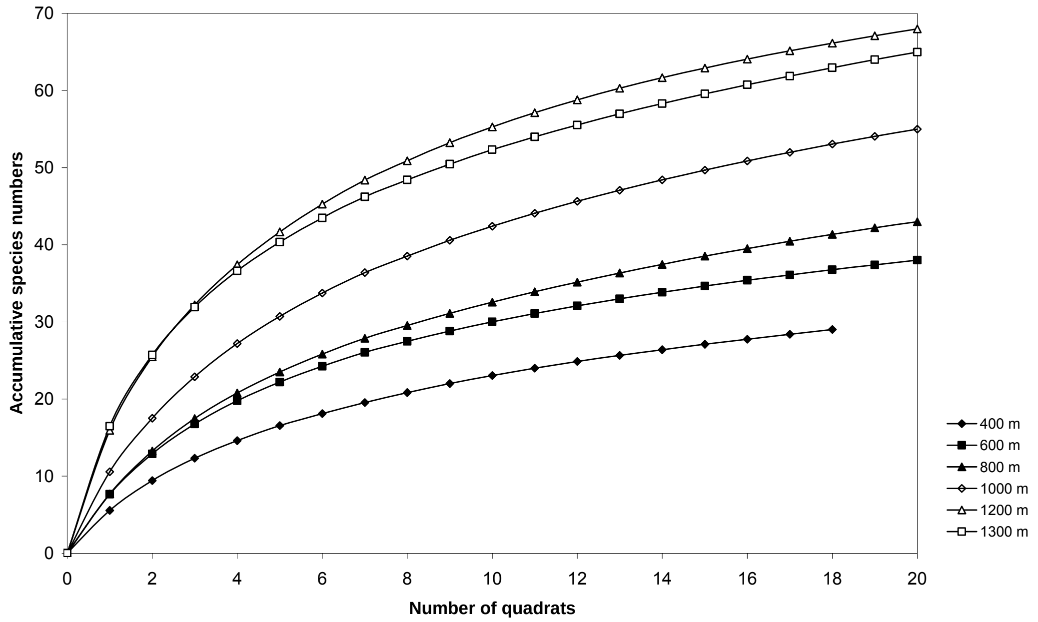


Figure 5.5 Species accumulation curves of epiphytic bryophytes in different altitudinal sites, at Khao Nan National Park, Southern Thailand.

Species accumulation curve

The species accumulation curves of epiphytic bryophytes from the six different study plots were shown in Figure 5.5, which is the correlation between the mean numbers of species against the number of quadrats. In the present study, the number of quadrats (from selected trees) had been fixed at 18 or 20 per a study site. The results had shown an increase in average number of species with an increase in the number of quadrats. Species accumulation curves had shown that in the 1,200 m altitude site, there were the most diverse species numbers, whereas at the 400 m altitude site was the least diverse. Although the rate of species accumulation that decreased as increasing numbers of samples, were successively added to the total, neither of the curves had reached an asymptote.

Species richness estimation

In the present study, the “first order Jackknife” species richness estimator was applied to indicate the species richness estimation. The observed (S_{obs}) and estimated species richness (S_{est}) of epiphytic bryophytes in the study sites are shown in Table 4.3. The number of estimated species was higher than the observed species for all study plots. They varied from site to site, ranging from 29 to 68 species and 39 to 85 species, respectively. Comparison of the number of species observed and the “first order Jackknife” estimated had shown that 74-80% of the species have been collected from each study site. The total estimation number of species of epiphytic bryophytes in this area was 164 species.

Table 5.3 Observed (S_{obs}) and estimated (S_{est}) species richness and percent sampling completeness per study sites and overall at Khao Nan National Park, Southern Thailand.

Altitude	S_{obs}	S_{est}	Sampling completeness (%)
400 m	29	39	74
600 m	38	49	78
800 m	43	58	74
1000 m	55	73	75
1200 m	68	85	80
1300 m	65	84	77
Overall	138	164	84

Beta diversity and species similarity

Beta diversity of epiphytic bryophytes, expressed as the number of species observed divided by the mean number of species (Whittaker's index) on tree trunks in 6 different altitudinal sites along the line transect, is presented in Table 5.4. This index of beta diversity is a measurement of the species turnover or the degree of change in species composition. The highest beta diversity was found at 800 m altitude site (5.6) and therefore, high species turnover, followed by sites at 400 m, 1000 m and 600 m with 5.2, 5.2 and 5.0, respectively. The poorest ones were found at the sites of 1,200 m and 1,300 m altitude, with 4.3 and 4.0 and therefore, low species turnover. Beta diversity of overall altitude sites was very high (12.9). This had reflected the wide range of habitats sampled.

The table 4.5 is demonstrating the comparable of similarities between species of epiphytic bryophytes among the six altitudinal sites at Khao Nan National Park using the Sørensen's similarity index. The most similarity is at the sites of 400 m and 600 m altitude (0.69) while the least similarity (0.02) is exhibited at the altitudinal ranges between 400 m and 1,300 m.

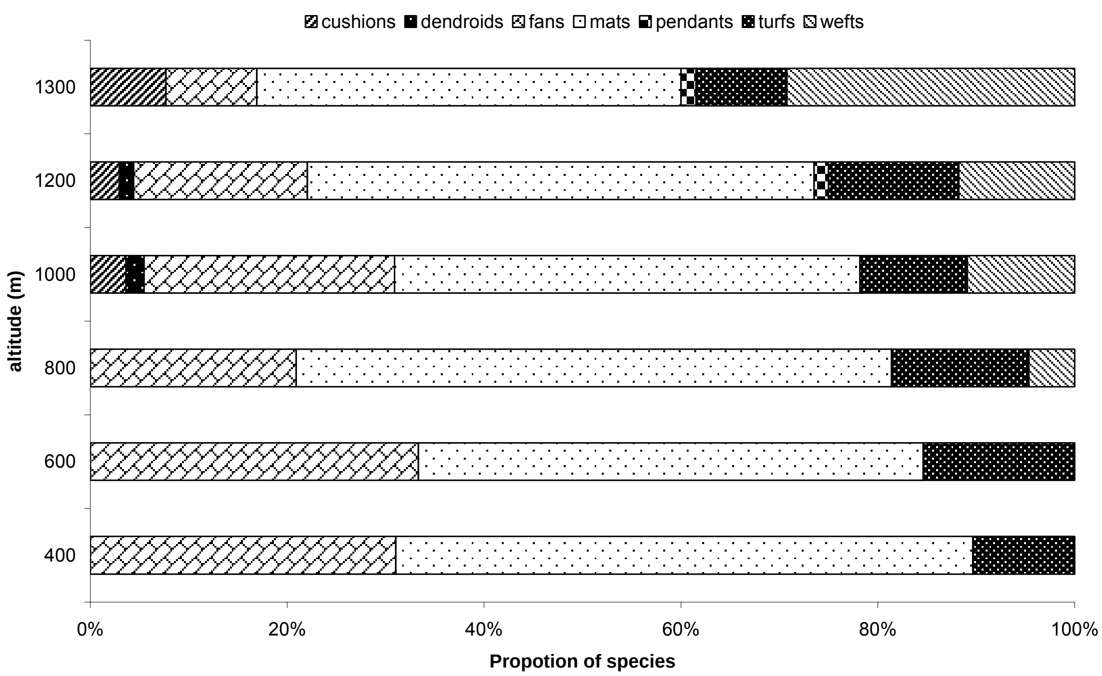


Figure 5.6 Distribution of life forms (in percentages) along an altitudinal transect at Khao Nan National Park, Southern Thailand.

Table 5.4 Species diversity overall and broken down by groups of bryophytes. Beta diversity was measured as Whittaker's index of diversity.

Study site	Number of species (S)	Mean number of species per quadrat (SD) (α)	Beta diversity (S/α)
400 m	29	5.6 (2.5)	5.2
600 m	38	7.7 (2.7)	5.0
800 m	43	7.7 (2.3)	5.6
1000 m	55	10.6 (2.7)	5.2
1200 m	68	16.0 (4.0)	4.3
1300 m	65	16.5 (3.3)	4.0
Overall	138	10.7 (5.1)	12.9

Table 5.5 Number of shared species and Sørensen's Similarity Index between the six altitudes, at Khao Nan National Park, Southern Thailand.

Altitude	400 m	600 m	800 m	1000 m	1200 m	1300 m
	Number of shared species					
400 m	-	23	15	14	7	1
600 m	0.69	-	25	23	13	6
800 m	0.42	0.62	-	32	21	12
1000 m	0.33	0.50	0.65	-	35	21
1200 m	0.14	0.24	0.38	0.57	-	36
1300 m	0.02	0.12	0.22	0.35	0.54	-
	Sørensen's similarity index					

Life forms

Distribution of life forms of epiphytic bryophytes on tree trunks over the different altitudes is shown in Figure 4.6. Seven life forms were found: cushions, dendroids, fans, mats, pendants, turfs and wefts. Fans, mats and wefts were the most common types of life forms, occurring in high frequencies in all altitude sites, but there was no wefts life-form at 400 and 600 m altitude sites. There were only three life forms found in all altitudes i.e. fans, mats and turfs. Cushions had been represented by a few species (*Herbertus armitanus* (Steph.) H.A. Maill. and *Leucobryum* spp.). Only one species of pendants life forms was found namely

Aerobryopsis wallichii (Brid.) M. Fleisch. And *Plagiochila dendroides* (Nees) Lindenb. was the only dendroid life form species and occurred at 1000 and 1200 m altitude sites.

Floristic ordination

The DCA ordination of 118 quadrats and 102 species yielded the first two axes with eigenvalues of 0.80 and 0.40. The ordination of quadrats is in Figure 5.7 (Axis 1 and 2) and the species ordination is presented in Figure 5.8 (Axis 1 and 2) as well. Pearson's Correlations computed between the samples axes (Table 5.6) had indicated the following relationships: *Axis 1* is reflecting mainly the altitudinal gradient. This exhibits negative correlation with the relative humidity, total percent cover, over all species richness and liverwort species richness. On the other hand, it exhibits positive correlation with the temperature and bark pH. Therefore, most of the variation in the DCA ordination could be explained by the first axis.

Samples are ordinal on the first axis with respect to their position on the altitudinal gradient and microclimatic condition. Samples from higher altitudes are ordinal towards the left-end point of the first axis. As far as the second ordination axis is concerned, the samples tend to be ordinal in an unclear depiction. Samples are not ordinal with respect to the ordination of tree diameter and bark type.

Table 5.6 Pearson's Correlations computed between the axes of the DCA ordination and the values of the quantitative environmental variables.

	Axis 1	Axis 2
Altitude	-0.883	-0.341
Temperature	0.884	0.345
Relative humidity	-0.865	-0.329
% cover	-0.613	-0.229
DBH	0.099	0.270
Bark pH	0.805	-0.085
Bark types	-0.300	-0.099
Total species richness	-0.643	-0.416
Moss species richness	-0.229	-0.359
Liverwort species richness	-0.668	-0.331

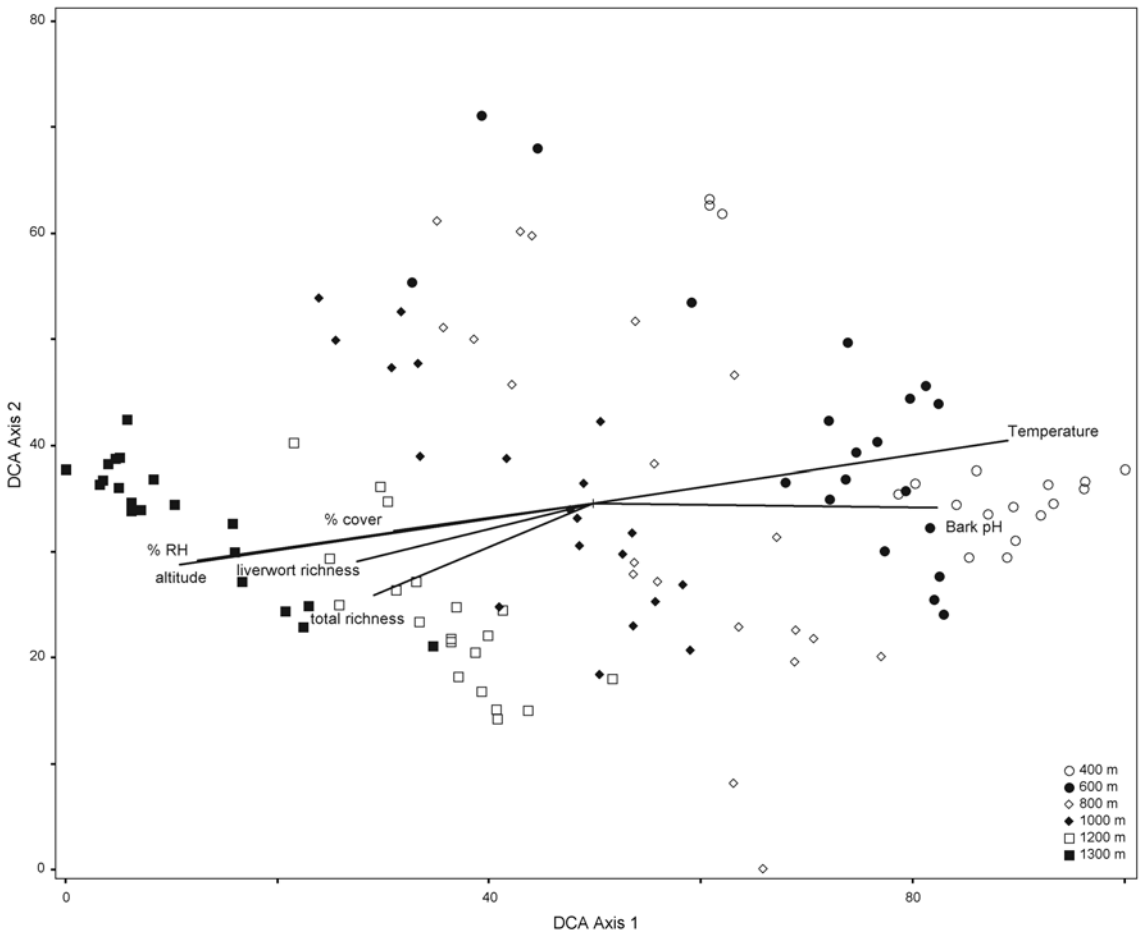


Figure 5.7 DCA Ordination of a vegetation of epiphytic bryophyte at Khao Nan National Park for 118 quadrats. The first axis goes from cool and wet environment of the higher altitude to a hot and dry condition of the lower one.

Ordination of species by using DCA is shown in Figure 3.8. Species recorded only at higher altitudes are ordinal close to the left end-point (e.g. *Acromastigum curtilobum* A. Evans, *Bazzania erosa* (Reinw. *et al*.) Trevis., *Bazzania paradoxa* (Sande Lac.) Steph., *Bazzania uncigera* (Reinw. *et al*.) Trevis, *Bazzania vittata* (Gottsche) Trevis., *Zoopsis liukiuensis* Horik., *Acroporium stramineum* (Reinw. & Hornsch.) M. Fleisch. and *Trismegistia rigida* (Mitt.) Broth.), while species recorded only at lower altitudes are ordinal close to the right end-point of the first axis (e.g. *Caduciella mariei* (Besch.) Enroth, *Calymperes taitense* (Sull.) Mitt., *Floribundaria walkeri* (Renauld & Cardot) Broth. and *Radula bornensis* Steph.).

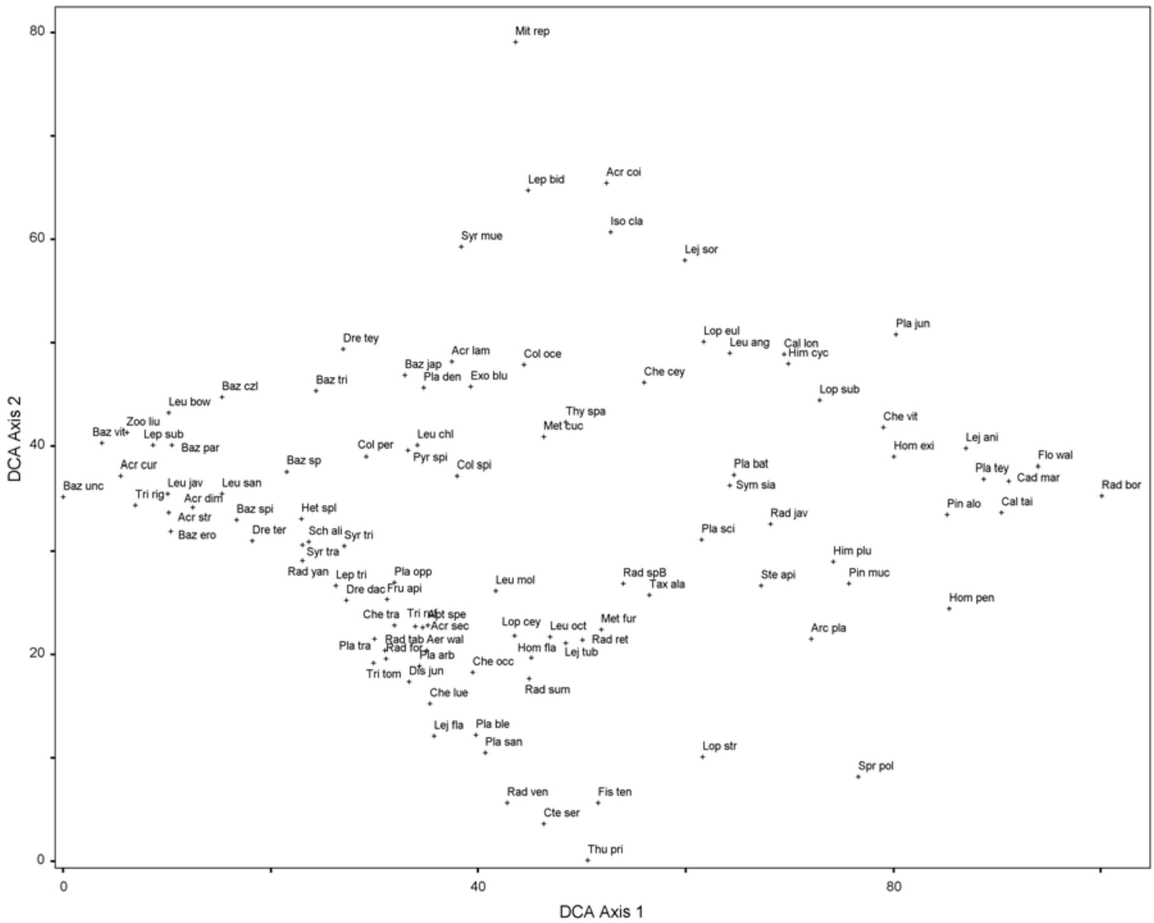


Figure 5.8 DCA ordination of a vegetation of epiphytic bryophytes at Khao Nan National Park for 102 species (abbreviations as in Table 5.2). The first axis goes from cool and wet environment of the higher altitude to a hot and dry condition of the lower one.

Community classification

Based on TWINSPAN cluster analysis, the 118 quadrats and 102 species of epiphytic bryophytes occurring along altitudinal transect at Khao Nan National Park had been divided into five community groups.

Group A included 15 quadrats at 400 m altitude site and 6 quadrats at 600 m site. This group was discriminated by the present of *Caduciella mariei* (Besch.) Enroth and *Lejeunea anisophylla* Mont. Other positive preferential species included *Plagiochila sciophila* Nees ex Lindenb. and *Radula javanica* Gottsche.

Group B included 31 quadrats at a lower altitude from 400-1,000 m, 13 quadrats at 800 m site followed by 11 quadrats at 600 m site, 4 and 3 quadrats at 1,000 and 400 m site, repectively. This group was characterized by the presence of Metalejeunea cucullata (Reinw. *et al*.) Grolle and Leucophanes angustifolium Renauld & Cardot. Other positive preferential species included Cheilolejeunea ceylanica (Gottsche) R.M. Schust. & Kachroo, Lejeunea tuberculosa Steph., Stenolejeunea apiculata (Sande Lac.) R.M. Schust., Plagiochila batamensis (Reiwn. *et al*.) Mont. and Lopidium struthiopteris (Brid.) M. Fleisch.

Group C is the smallest group included 6 quadrats at 800 m site and 2 quadrats, each at 600 and 1000 m sites. This group was characterized by the presence of *Drepanolejeunea teysmanii* Steph., *Isocladiella surcularis* (Dixon) B.C. Tan & Mohamed and *Mitthyridium repens* (Harv.) Robinson. Other positive preferential species was *Lepidolejeunea bidentula* (Steph.) R.M. Schust.

Group D is the biggest one that included 37 quadrats, mainly at 1,200 m site (20 quadrats) and at 1,000 m site (13 quadrats). This group was characterized by the presence of *Homaliodendron flabellatum* (Sm.) M. Fleisch. and *Leucoloma molle* (Müll. Hal.) Mitt. The liverworts *Metzgeria furcata* (L.) Dumort., *Plagiochila arbuscula* (Brid. ex Lehm. & Lindenb.) Lindenb., and *Plagiochilion oppositum* (Reinw. *et al*.) S. Hatt. and the mosses *Leucophanes octoblepharoides* Brid. and *Pyrrhobryum spiniforme* (Hedw.) Mitt. were also common in this group.

Group E was a homogenous group that included 19 quadrats at 1300 m altitude site. This group was discriminated by the presence of *Acroporium stramineum* (Reinw. & Hornsch.) M. Fleisch.. The members of liverworts in the family Lepidoziaceae were the most common species in this group. The other common species had included *Plagiochilion oppositum* (Reinw. *et al*.) S. Hatt. *Schistochila aligera* (Nees & Blume) J.B. Jack & Steph., *Acroporium diminutum* (Brid.) M. Fleisch. *Trismegistia rigida* (Mitt.) Broth. and *Drepanolejeunea* spp.

5.5 Discussion

Floristic richness

In the present study, 32 families, 64 genera and 138 species of epiphytic bryophytes were recorded. Among these, 13 families, 29 genera and 83 species were liverworts, while 19 families, 35 genera and 55 species were mosses. The observed number of species might be underestimated due to the under-sampling of some (local) rare species. According to the extrapolation of species accumulation or species area curves, it was estimated that there were 164 species of epiphytic bryophyte in this study area. It shows that the line transect from Krung Ching waterfall to Sanyen Mountain ridge(400-1,300 m) is rather rich in epiphytic bryophyte diversity, compared with other regions of similar habitat type in Thailand, e.g. Huai Yang National Park (Chantanaorrapint *et al*., 2004) and Khao Yai, Khao Nan National Park (Sukkharak & Seelanan, 2008). However, it is to be concerned here that the variations in species richness were strongly affected by many factors, such as sampling methods, sampling sizes, forest structure (height of trees, tree density), elevation, climate (annual rainfall, air temperature and air humidity), etc.

In terms of species numbers, Lejeuneaceae, Lepidoziaceae and Plagiochilaceae were among the common families of liverworts, included 29, 19 and 11 species, respectively. Among mosses, Calymperaceae, Neckeraceae and Sematophyllaceae were the most common families, included 11, 9 and 8 species, respectively. It was not surprising that these families were species-rich as most of them are the largest families in the Thai Bryo-flora (see He, 1998; Lai *et al*., 2008). Furthermore, all of these are among the 15 main families of the bryophytes in the tropical rainforest (Gradstein & Pócs, 1989). The largest family of epiphytic bryophytes in this study was Lejeuneaceae. This family is the largest family of liverworts with more than 1,600 species (Gradstein *et al*., 2001) and there are about 25 genera and 123 species, accounting for 32% of the total number of liverwort species in Thailand (Lai *et al*., 2008). The members of family Lepidoziaceae are prominent in cloud forest, especially *Bazzania* and *Lepidozia* (Gradstein *et al*., 2001), while several species of the Plagiochilaceae and Radulaceae are also the commonest ones in the tropical montane forest (Pócs, 1982). However, it is interesting to note here that there were only two species of Meteoriaceae found in the present study. This was contrast with the data from other studies (e.g. Chantanaorrapint *et al*, 2004; Wen–Zhang *et al*., 2009), since Meteoriaceae is one of the most species-rich family of the epiphytic bryophytes in tropical forest (Gradstein & Pócs, 1989). Probably due to the fact that they are often abundant on higher branches and twigs, while the present study had focused on the tree trunks.

In the current study, it was found that the number of liverworts species were more than that of mosses species. Liverworts are important elements, in terms of species numbers concerning epiphytic bryophytes. They performed a maximum in species richness between 1,200 m and 1,300 m a.s.l. Mosses: liverworts variety ratio has been related to a humid condition. It could be confirmed here that the general hypothesis of an increase in species numbers of liverworts with an increase of humidity, cloud cover and mist, along the transect line. These results have agreed with the finding of higher species richness of liverworts to mosses in tropical rain forest from other previous studies as well. (Ah-Peng *et al*., 2007; Acebey *et al.*, 2003; Cornelissen & Gradstein, 1990; Gradstein *et al.*, 2001; Holz *et al*., 2002; Sporn *et al.*, 2009; Wolf, 1993c). Moreover, Frahm (1994b) has noticed that liverworts were more numerous in oceanic regions and less common in continental ones. This study area is also oceanic regions as southern Thailand formed a narrow peninsula that flanked by the Gulf of Thailand in the east and the Andaman Sea in the west.

The diversity (in terms of richness and abundance) of epiphytic bryophytes was dependant on the microclimate. The increase of relative air humidity and light intensity vs. the decrease of air temperature in the forest from the lower altitude toward the upper one were, generally, in agreement with microclimate readings of many other rain forest studies (e.g. Frahm, 1987, 1990; Kürschner, 1990; Wolf, 1994). It was found that the species diversity has increased with altitude (from 29 to 65 species) between 400 m and 1,300 m, respectively. The species richness reaching the peak at 1,200 m and 1,300 m might suggest the optimal conditions for the bryophyte growth in this particular altitude site. In other lower altitudinal sites, bryophyte establishment may have been limited by the insufficient light and moisture, but higher temperature. Beside the microclimate conditions, bark structure, affecting nutrient and water flows on trees might be the important factors which determined species richness. However, the present study showed that bark type and tree size are minor factors that affected the bryophyte occurrence as well as its species richness and species composition.

New records

It is interesting to note here that a high number of new records (10 species) were recognized in the present study. Most of them are indigenous species of Malesian region (*Cheilolejeunea luerssenii*, *Cheilolejeunea occlusa*, *Distichophyllum jungermannioides*, *Plagiochila sandei*, *Mitthyridium subluteum* and *Radula ventricosa*) or wide distributed from south China to Malesian region (*Cheilolejeunea verrucosa*, *Stenolejeunea apiculata*, *Plagiochila dendroides* and *Zoopsis liukiuensis*). It could be confirmed here that Thailand is a transitional region between the Malesian and Sino-Japanese floras of bryophytes (Lai *et al*., 2008). Chantanaorrapint *et al.* (2004) and Sukkharak *et al*. (2009) also reported many new bryophytes recorded from southern Thailand. More new records of bryophytes in Thailand could be expected when other parts of Thailand would be more explored.

Sample size sufficiency

The concept of minimal area of sampling plot was based on the methodology of general vegetation studies. Its accurate delimitation was an indispensable prerequisite for any subsequent analysis and interpretation of the recorded data. In the present study, the number of quadrats (on selected trees) was fixed at 18 or 20 per study site. Sufficiency of sampling could be evaluated using species accumulation curves and by comparing the values of various species richness estimators. Sampling was said to be sufficient when the species accumulation curve reach a horizontal asymptote (Soberón & Llorente, 1993). The species accumulation curve for the accumulated quadrats in different study sites were drawn (Figure 5.4). They show a more or less steady increase in species numbers, although not perfectly off. The forms of curves indicate that more than 75 % of the species were found in every altitude sites. The reliability of the obtained data may be tested by a comparison of the estimated species numbers of the entire plots. This shows that all study sites were quite well represented by these selected quadrats with values ranging mainly from 74 to 80 percent of the completeness estimated of each site.

Distribution pattern and altitude zonation

The altitudinal distribution of 138 epiphytic bryophytes was present in Table 4.3. It was found that the species diversity increased with altitude (from 29 to 65 species) between 400 m and 1,300 m, respectively. Derived bryophyte richness pattern along the transect line seems to be linear or monotonic increase with increasing altitude. The results of this survey are in general agreement with Frahm and Ohlemüller (2001). Brun *et al*. (2006) also observed a monotonic increase in diversity of liverworts within the altitudinal gradient of 250 m to 1,525 m. Wolf (1993) showed a different pattern of bryophyte distribution along the altitude, he found a maximum of species richness at a mid-altitudinal in Columbia. However, his study transect ranged widely from 1,000 m to 4,130 m (lower montane to alpine forests). According to Bhattarai *et al*. (2004), they suggested that peak diversity coincided with high moisture levels, the maximum number of rainy days and the cloud zone. In this area, the formation of cloud from humid oceanic air was dominated around 1,000 m to 1,300 m. That particular condition is ideal for the development of bryophytes. It could be confirmed here that the maximum diversity of epiphytic bryophyte would be within the region of 1,000-1,300 m. However a hump-shaped curve of bryophyte species diversity could also be expected with a monotonic decrease above cloud zone where climatic conditions has evolved towards increasing evaporation and irradiance.

In the present study, the similarity analysis showed a high degree of dissimilarity (β-diversity) between 400 m and 1,300 m. Indeed, there were no epiphytic bryophyte species widely occurring in all altitudinal sites. It ought to be interpreted by the fact that a complex ecological factors in different the altitudes (e.g. forest structure, relative humidity, temperature and light availability) might be the limiting factors determining the species composition of epiphytic bryophyte communities. The results of DCA have confirmed that the distribution and the composition of epiphytic bryophytes were affected by the altitudinal gradient. Moreover, the result of TWINSPAN shows that the communities of epiphytic bryophytes were clearly altitudinal grouping. Based on those results of bryophyte species diversity and microclimatic data along the altitudinal gradient, three different altitudinal zones could be divided at Khao Nan National Park, i.e. the lowland forest (0-600 m), the submontane forest (800-1,000 m) and the montane forest (1,200-1,300 m).

In lowland forest, there are much higher canopies and denser understory layers than the upper ones, which has also richer woody climber species. The bryophyte communities on tree trunks were dominated by Lejeuneaceae, Calymperaceae and Neckeraceae. There are more than 50 % of the total species richness.

The submontane forest has lower canopy than the lowland forest with small woody climbers. The number of bryophyte species was higher than the lowland one and also dominated by those three families with more members of Plagiochilaceae and Radulaceae. The bryophyte communities were rather high and it varied from tree to tree. It is not surprising that many species of the lowland and montane forest were found in this_zone. This zone could be considered to be a transitional zone between lowland forest and montane forest.

In the montane forest, the tree canopy was lower and dominated by Fagaceae and Myrtaceae. The bryophyte community of montane forest was strongly dominated by liverworts (e.g. Lepidoziaceae, Plagiochilaceae, Radulaceae) and species richness of liverwort was more than twice as much as a number of mosses. *Acroporium stramineum* (Reinw. & Hornsch.) M. Fleisch. and *Trismegistia rigida* (Mitt.) Broth. were the only epiphytic mosses that reached the highest abundance here. The high species diversity and abundance of epiphytic bryophytes of montane forest was presumably explained by more cloud layer and the cooler temperature as these elevation was much different from the lower ones.

Life form distribution

Epiphytic bryophytes with different life forms could be indicators of the habitats where they occurred due to their potential of strict reliance on the water supplies, gas exchanges and light ability. In the present study, mat and turf life forms species were most common at all altitudes. Fan-like species were significantly most common in lowland forest (low light intensity condition) whereas weft life form was dominant in the montane forest (high light intensity condition). The results have shown that fan life form has been succeeded by weft life form at higher altitude.

The strong correlation of life forms with moisture and light conditions had been repeatedly discussed (Bates, 1998; Proctor, 1990; Sporn *et al*., 2009b;

Thiers, 1988). According to Gimingham and Birse (1957), cushions, mats and turf could be roughly considered as xeric life forms with increasing drought- tolerance. Furthermore, dendroids, fans, pendants, and wefts are life forms characteristics of wet environments.

Beta diversity and species similarity

A total beta diversity of epiphytic bryophytes along the line transect at Khao Nan National Park was very high (12.9) reflecting the wide range of habitats sampled. When the quadrats were divided into more homogenous groups, beta diversity of epiphytic bryophytes was much lower. A large number of rare species (36 species occurred only once or twice) also contributed to the high beta diversities. On the other hand, the beta diversity of epiphytic bryophytes at 1,200 m and 1,300 m were low with 4.3 and 4.0 respectively, due to the fact that the bryophytes communities in these altitudes were rather homogenous in different trees. While at mid-elevations (800 m and 900 m), It showed higher beta diversity and more different bryophyte species from tree to tree.

The results showed that the similarity index was correlated to the distance of study sites. The Sørensen's similarity index decreased with increasing altitudinal distance. It might be concluded that the community composition of bryophytes gradually changed with altitudinal distance.

Table 5.2 Occurrence of epiphytic bryophytes species into six altitudinal sites at Khao Nan Nantional Park, southern Thailand. Species are listed ordered by family; families and species within families are given in alphabetical order. Life-form: c: cushions; d: dendroids; f: fans; m: mats; p: pendants; tu: turfs; w: wefts.

Taxon	Species Code	Altitude (m)						Total occurrence	Life forms
		400	600	800	1000	1200	1300		
Liverworts									
Calypogeiaceae									
1. *Calypogeia angusta* Nees & Mont.	Cal ang	0	0	0	0	0	1	1	m
Frullaniaceae									
2. *Frullania apiculata* (Reinw. et al.) Nees	Fru api	0	0	0	1	9	9	19	m
3. *Frullania meyeniana* Lindenb.	Fru mey	0	0	1	0	0	0	1	m
Herbertaceae									
4. *Herbertus armitanus* (Steph.) H.A. Maill.	Her arm	0	0	0	0	0	1	1	c
Lejeuneaceae									
5. *Archilejeunea planiuscula* (Mitt.) Steph.	Arc pla	1	5	5	0	0	0	11	m
6. *Ceratolejeunea belangeriana* (Gottsche) Steph.	Cer bel	1	0	0	0	0	0	1	f
7. *Cheilolejeunea ceylanica* (Gottsche) R.M. Schust. & Kachroo	Che cey	1	1	6	4	0	0	12	m
8. *Cheilolejeunea luerssenii* (Steph.) Mizut.	Che lue	0	0	0	0	3	0	3	m
9. *Cheilolejeunea occlusa* (Herzog) T. Kodama & N. Kitag.	Che occ	0	0	0	2	9	0	11	m
10. *Cheilolejeunea trapezia* (Nees) Kachroo & R.M. Schust.	Che tra	0	0	0	0	2	2	4	m
11. *Cheilolejeunea verrucosa* Steph.	Che ver	1	0	0	0	0	0	1	m
12. *Cheilolejeunea vittata* (Steph. ex G.Hoffm.) R.M. Schust. & Kachroo	Che vit	3	1	0	0	0	0	4	m
13. *Cololejeunea cf. ocelloides* (Horik.) S. Hatt.	Col oce	0	0	1	2	1	0	4	m
14. *Cololejeunea peraffinis* (Schiffn.) Schiffn.	Col per	0	0	0	1	0	2	3	m

Taxon	Species Code	Altitude (m)						Total occurrence	Life forms
		400	600	800	1000	1200	1300		
15. *Cololejeunea spinosa* (Horik.) Pandé & Misra	Col spi	0	0	1	0	2	1	4	m
16. *Drepanolejeunea dactylophora* (Nees et al.) Schiffn.	Dre dac	0	0	0	0	7	9	16	m
17. *Drepanolejeunea pentadactyla* (Mont.) Steph.	Dre pen	0	0	0	0	1	0	1	m
18. *Drepanolejeunea ternatensis* (Gottsche) Steph.	Dre ter	0	0	0	0	2	12	14	m
19. *Drepanolejeunea teysmanii* Steph.	Dre tey	0	2	5	3	3	15	28	m
20. *Lejeunea anisophylla* Mont.	Lej ani	9	5	1	0	0	0	15	m
21. *Lejeunea flava* (Sw.) Nees	Lej fla	0	0	0	0	3	3	6	m
22. *Lejeunea sordida* (Nees) Nees	Lej sor	2	2	2	1	0	0	7	m
23. *Lejeunea tuberculosa* Steph.	Lej tub	0	2	9	7	14	8	40	m
24. *Lepidolejeunea bidentula* (Steph.) R.M. Schust.	Lep bid	0	0	2	2	0	0	4	m
25. *Lopholejeunea ceylanica* Steph.	Lop cey	0	0	6	4	12	3	25	m
26. *Lopholejeunea eulopha* (Taylor) Schiffn.	Lop eul	6	1	0	2	2	0	11	m
27. *Lopholejeunea nigricans* (Lindenb.) Schiffn.	Lop nig	0	0	0	0	1	0	1	m
28. *Lopholejeunea subfusca* (Nees) Schiffn.	Lop sub	1	4	0	1	0	0	6	m
29. *Metalejeunea cucullata* (Reinw. et al.) Grolle	Met cuc	0	5	14	20	17	7	63	m
30. *Spruceanthus polynorphus* Verd.	Spr pol	0	1	2	0	0	0	3	m
31. *Stenolejeunea apiculata* (Sande Lac.) R.M. Schust.	Ste api	0	3	8	0	0	0	11	m
32. *Thysananthus retusus* (Reinw. et al.) B. Thiers & Gradst.	Thy ret	0	0	1	1	1	0	3	m
33. *Thysananthus spathulistipus* (Reinw. et al.) Lindenb.	Thy spa	1	0	0	3	2	0	6	m
Lepidoziaceae									
34. *Acromastigum curtilobum* A. Evans	Acr cur	0	0	0	0	0	14	14	w
35. *Bazzania calcarata* (Sande Lac.) Schiffn.	Baz czl	0	0	0	1	2	5	8	w
36. *Bazzania erosa* (Reinw. et al.) Trevis.	Baz ero	0	0	0	0	1	7	8	w

Taxon	Species Code	Altitude (m)						Total occurrence	Life forms
		400	600	800	1000	1200	1300		
37.*Bazzania japonica* (Sande Lac.) Lindenb.	Baz jap	0	0	0	2	1	0	3	w
38. *Bazzania loricata* (Nees) Trevis.	Baz lor	0	0	0	0	0	1	1	w
39. *Bazzania paradoxa* (Sande Lac.) Steph.	Baz par	0	0	0	1	1	9	11	w
40. *Bazzania praerupta* (Nees et al.) Trevis.	Baz pra	0	0	0	0	0	2	2	w
41. *Bazzania spiralis* (Nees) Meijer	Baz spi	0	0	0	0	5	12	17	w
42. *Bazzania cf. subtilis* (Sande Lac.) Trevis	Baz sub	0	0	0	0	0	1	1	w
43. *Bazzania tridens* (Reinw. et al.) Trevis.	Baz tri	0	0	2	5	8	16	31	w
44. *Bazzania uncigera* (Reinw. et al.) Trevis	Baz unc	0	0	0	0	0	7	7	w
45. *Bazzania vittata* (Gottsche) Trevis.	Baz vit	0	0	0	1	0	12	13	w
46. *Bazzania* sp.	Baz sp	0	0	0	0	0	3	3	w
47. *Kurzia lineariloba* Mizut.	Kur lin	0	0	0	0	0	2	2	m
48. *Lepidozia holorhiza* (Reinw. et al.) Gottsche et al.	Lep hol	0	0	0	0	0	1	1	w
49. *Lepidozia subintegra* Lindenb.	Lep sub	0	0	0	0	0	3	3	w
50. *Lepidozia trichodes* (Reinw. et al.) Nees	Lep tri	0	0	0	0	1	3	4	w
51. *Lepidozia wallichina* Gottsche	Lep wal	0	0	0	0	0	2	2	w
52. *Zoopsis liukiuensis* Horik.	Zoo liu	0	0	0	0	0	4	4	m
Lophocoleaceae									
53. *Heteroscyphus argutus* (Reinw. et al.) Schiffn.	Het arg	1	1	0	0	0	0	2	m
54. *Heteroscyphus coalitus* (Hook.) Schiffn.	Het coa	0	0	0	0	1	0	1	m
55. *Heteroscyphus sarawaketanus* Piippo	Het sar	0	0	0	0	0	2	2	m
56. *Heteroscyphus splendens* (Lehm. & Lindenb.) Grolle	Het spl	0	0	0	0	3	6	9	m
Mastigophoraceae									
57. *Mastigophora diclados* (Brid.) Nees	Mas dic	0	0	0	0	0	1	1	w

Taxon	Species Code	Altitude (m)						Total occurrence	Life forms
		400	600	800	1000	1200	1300		
Metzgeriaceae									
58. *Metzgeria furcata* (L.) Dumort.	Met fur	1	3	1	9	8	1	23	m
59. *Metzgeria lindbergii* Schiffn.	Met lin	0	1	0	0	0	0	1	m
Plagiochilaceae									
60. *Plagiochila arbuscula* (Brid. ex Lehm. & Lindenb.) Lindenb.	Pla arb	0	0	0	2	15	6	23	f
61. *Plagiochila batamensis* (Reiwn. et al.) Mont.	Pla bat	1	11	6	6	0	0	24	f
62. *Plagiochila blepharophora* (Nees) Lindenb.	Pla ble	0	0	0	0	5	0	5	f
63. *Plagiochila dendroides* (Nees) Lindenb.	Pla den	0	0	0	5	4	0	9	d
64. *Plagiochila junghuhniana* Sande Lac.	Pla jun	0	4	0	0	0	0	4	f
65. *Plagiochila sandei* Dozy ex Sande Lac.	Pla san	0	0	0	0	3	0	3	f
66. *Plagiochila sciophila* Nees ex Lindenb.	Pla sci	3	5	0	8	2	0	18	f
67. *Plagiochila teysmanni* Sande Lac.	Pla tey	3	0	0	0	0	0	3	f
68. *Plagiochila trabeculata* Steph.	Pla tra	0	0	0	0	1	4	5	f
69. *Plagiochilion oppositum* (Reinw. et al.) S. Hatt.	Pla opp	0	0	0	2	11	11	24	f
70. *Plagiochilion therionatanum* (Steph.) Inoue	Pla the	0	0	0	0	0	1	1	f
Pseudolepicolaceae									
71. *Pseudolepicolea* sp.	Pse sp	0	0	0	0	0	1	1	w
Radulaceae									
72. *Radula cf. acutiloba* Steph.	Rad bor	0	0	1	0	0	0	1	m
73. *Radula bornensis* Steph.	Rad cav	3	0	0	0	0	0	3	m
74. *Radula cavifolia* Hampe ex Gottsche et al.	Rad for	0	0	0	0	0	1	1	m
75. *Radula formosa* (Meissn.) Nees	Rad acu	0	0	0	0	0	3	3	m
76. *Radula javanica* Gottsche	Rad jav	9	10	8	1	4	0	32	m

Taxon	Species Code	Altitude (m)						Total occurrence	Life forms
		400	600	800	1000	1200	1300		
77. *Radula retroflexa* Taylor	Rad ret	0	0	1	6	3	1	11	f
78. *Radula sumatrana* Steph.	Rad sum	0	0	1	3	6	0	10	m
79. *Radula cf. tabularis* Steph.	Rad tab	0	0	0	0	3	0	3	m
80. *Radula ventricosa* Steph.	Rad ven	0	0	0	0	6	0	6	m
81. *Radula yangii* Yamada	Rad yan	0	0	0	0	0	4	4	m
82. *Radula* sp.	Rad sp	0	0	1	5	0	0	6	m
Schistochilaceae									
83. *Schistochila aligera* (Nees & Blume) J.B. Jack & Steph.	Sch ali	0	0	0	2	4	18	24	ta
Trichocoleaceae									
84. *Trichocolea tomentella* (Ehrh.) Dumort.	Tri tom	0	0	0	0	1	2	3	w
Mosses									
Calymperaceae									
85. *Calymperes lonchophyllum* Schwägr.	Cal lon	2	1	1	0	0	0	4	tu
86. *Calymperes taitense* (Sull.) Mitt.	Cal tai	3	1	0	0	0	0	4	tu
87. *Exostratum blumii* (Nees ex Hampe) L.T. Ellis	Exo blu	0	3	0	1	8	0	12	tu
88. *Leucophanes angustifolium* Renauld & Cardot	Leu ang	4	11	1	5	1	0	22	tu
89. *Leucophanes octoblepharoides* Brid.	Leu oct	0	0	2	7	9	0	18	tu
90. *Mitthyridium repens* (Harv.) Robinson	Mit rep	1	2	2	1	0	0	6	m
91. *Mitthyridium subluteum* (Müll.Hal.) N.H. Nowak	Mit sub	0	0	0	0	1	0	1	ta
92. *Syrrhopodon japonicus* (Besch.) Broth.	Syr jap	0	0	0	0	0	1	1	tu
93. *Syrrhopodon muelleri* (Dozy & Molk.) Bosch & Sande Lac.	Syr mue	0	2	4	9	0	0	15	tu
94. *Syrrhopodon trachyphyllus* Mont.	Syr tra	0	0	0	0	0	4	4	tu
95. *Syrrhopodon tristichus* Nees ex Schwägr.	Syr tri	0	0	0	0	6	5	11	tu

Taxon	Species Code	Altitude (m)						Total occurrence	Life forms
		400	600	800	1000	1200	1300		
Daltoniaceae									
96. *Distichophyllum jungermannioides* (Müll. Hal.) Bosch & Sande Lac.	Dis jun	0	0	0	0	3	1	4	tu
Dicranaceae									
97. *Dicranoloma braunii* (Müll. Hal.) Paris	Dic bra	0	0	0	0	1	0	1	tu
98. *Leucoloma molle* (Müll. Hal.) Mitt.	Leu mol	0	0	7	15	17	4	43	tu
Fissidentaceae									
99. *Fissidens ceylonensis* Dozy & Molk.	Fis cey	0	0	2	0	0	0	2	f
100. *Fissidens tenellus* Hook.f. & Wils. var. *australiensis*	Fis ten	0	0	0	3	3	0	6	f
Hylocomiaceae									
101. *Ctenidium serratifolium* (Cardot) Broth.	Cte ser	0	0	0	0	5	0	5	m
Hypnaceae									
102. *Hypnum* sp.	Hyp sp	0	0	0	0	0	1	1	m
Hypopterygiaceae									
103. *Lopidium struthiopteris* (Brid.) M. Fleisch.	Lop str	0	2	9	6	3	0	20	ta
Leucobryaceae									
104. *Leucobryum bowringii* Mitt.	Leu bow	0	0	0	1	0	6	7	c
105. *Leucobryum chlorophyllosum* Müll. Hal.	Leu chl	0	0	0	3	5	3	11	c
106. *Leucobryum javense* Brid.	Leu jav	0	0	0	0	1	7	8	c
107. *Leucobryum sanctum* (Brid.) Hampe	Leu san	0	0	0	0	0	6	6	c
Meteoriaceae									
108. *Aerobryopsis wallichii* (Brid.) M. Fleisch.	Aer wal	0	0	0	0	3	1	4	p
109. *Floribundaria walkeri* (Renauld & Cardot) Broth.	Flo wal	4	0	0	0	0	0	4	f
110. *Trachypus humilis* Lindenb.	Tra hum	0	0	0	1	0	0	1	m

Taxon	Species Code	Altitude (m) 400	600	800	1000	1200	1300	Total occurrence	Life forms
Myuriaceae									
111. *Oedicladium cf. rufescens* (Reinw. & Hornsch.) Mitt.	Oed ruf	0	0	0	0	1	0	1	m
Neckeraceae									
112. *Caduciella mariei* (Besch.) Enroth	Cad mar	10	6	0	0	0	0	16	f
113. *Himantocladium cyclophyllum* (Müll. Hal.) M. Fleisch.	Him cyc	0	9	0	1	0	0	10	f
114. *Himantocladium plumula* (Nees) M. Fleisch.	Him plu	9	5	8	2	0	0	24	f
115. *Homalia pennatula* (Dixon) He & Enroth	Hom pen	0	3	0	0	0	0	3	f
116. *Homaliodendron exiguum* (Bosch & Sande Lac.) M. Fleisch.	Hom exi	11	15	4	1	0	0	31	f
117. *Homaliodendron flabellatum* (Sm.) M. Fleisch.	Hom fla	0	1	1	11	15	1	29	f
118. *Pinnatella alopecuroides* (Hook.f.) M. Fleisch.	Pin alo	2	1	0	0	0	0	3	f
119. *Pinnatella anacamptolepis* (Müll. Hal.) Broth.	Pin ana	0	0	0	1	0	0	1	f
120. *Pinnatella mucronata* (Bosch & Sande Lac.) M. Fleisch.	Pin muc	3	8	5	0	0	0	16	f
Pilotrchaceae									
121. *Actinodontium rhaphidostegum* (Müll. Hal.) Bosch & Sande Lac.	Acr rha	0	0	0	0	2	0	2	tu
Pterobryaceae									
122. *Symphysodontella siamensis* Dixon	Sym sia	0	6	4	5	0	0	15	f
Pylaisiadelphaceae									
123. *Aptychella speciosa* (Mitt.) P. Tixier	Apt spe	0	0	0	0	12	0	12	m
124. *Isocladiella surcularis* (Dixon) B.C. Tan & Mohamed	Iso cla	3	7	9	8	4	0	31	m
125. *Taxithelium alare* Broth.	Tax ala	0	0	1	2	0	0	3	m
126. *Trismegistia rigida* (Mitt.) Broth.	Tri rig	0	0	0	0	0	11	11	m
Racopilaceae									
127. *Racopilum cuspidigerum* (Schwägr.) Ångström	Rad cus	0	0	1	1	0	0	2	m

Taxon	Species Code	Altitude (m)						Total occurrence	Life forms
		400	600	800	1000	1200	1300		
Rhizogoniaceae									
128. *Pyrrhobryum spiniforme* (Hedw.) Mitt.	Pyr spi	0	1	2	5	13	5	26	tu
Sematophyllaceae									
129. *Acroporium convolutifolium* Dixon	Acr coi	1	1	3	0	0	0	5	m
130. *Acroporium convolutum* (Sande Lac.) M. Fleisch.	Acr cou	0	0	0	1	0	0	1	m
131. *Acroporium diminutum* (Brid.) M. Fleisch.	Acr dim	0	0	0	0	1	14	15	m
132. *Acroporium lamprophyllum* Mitt.	Acr lam	0	0	1	7	3	1	12	m
133. *Acroporium secundum* (Reinw. & Hornsch.) M. Fleisch.	Acr sec	0	0	0	0	4	0	4	m
134. *Acroporium stramineum* (Reinw. & Hornsch.) M. Fleisch.	Acr str	0	0	0	0	0	17	17	m
135. *Radulina hamata* (Dozy & Molk.) W.R. Buck & B.C. Tan	Rad ham	0	0	0	0	1	1	2	m
136. *Trichosteleum ruficaule* (Thwait. & Mitt.) B.C. Tan	Tri ruf	0	0	0	0	2	1	3	m
Symphyodontaceae									
137. *Chaetomitrium setosum* Broth. & Dixon	Cha set	0	0	0	0	1	0	1	m
Thuidiaceae									
138. *Thuidium pristocalyx* (Müll. Hal.) A. Jaeger	Thu pri	0	0	2	1	5	0	8	w

Summary

Southern Thailand is one of the richest areas in terms of biodiversity. It is a part of the Indo-Burma and Sundaland biodiversity hot spots. It also included the transition zone between Indo-Chinese and Malesian floristic regions. However, there is no data on bryophytes, despite the fact that it is an important component of epiphytic community. Even though bryophytes are, mostly, small and inconspicuous, they are important components of tropical forests, especially the montane ones, and might play the significant role in the water balance and nutrient cycling of such type of forest. As different bryophyte species might have their particular patterns of distributions along the different altitudinal areas vertically and they might have different habitat preferences due to the different potential environmental variables. In spite of that, there have been poorly studying of how do the epiphytic bryophytes distribute along an altitudinal gradient, particularly, in the paleo-tropical forests like those in the South-east Asia Mainland and how do the potential environmental variables regulate their distributions.

The present dissertation is containing results of a study on diversity and ecology of epiphytic bryophytes along altitudinal gradients in Southern Thailand. The purpose of this study is to determine species richness and community composition of epiphytic bryophyte and to correlate them with some selected ecological parameters such as altitude, temperature and air humidity. In additions, the measurements of pH bark of the host trees had been achieved together with the determinations of the biomass, water storing capacity and covered percentage of epiphytic bryophytes along the altitudinal gradients in some selected less-disturbed tropical forest patches in Peninsular Thailand. It is to be noticed that this is the first comparative study on the epiphytic bryophyte in Thailand and the first study of such issue on the South-east Asian mainland as well.

The first part (Chapter 3) is dealing with the biomass of epiphytic bryophytes along the altitudinal gradients from lowland to montane forests. In additions, the microclimate and the pH of the bark of host trees were measured, together with the determinations of water storing capacity of epiphytic bryophytes as well as the estimations of the biomass and water storing capacity per hectare.

Biomass of epiphytic bryophytes was investigated along three altitudinal transects in Southern Thailand. i.e. Tarutao National Park (25-700 m), Khao Nan national Park (400-1300 m) and Khao Luang National Park (400-1500 m). The results had demonstrated that the dry weight of epiphytic bryophytes per surface area increased from 1.15 g/m^2 in the lowland to a maximum of 199 g/m^2 in the montane forests. The estimation of dry weight per hectare had increased along the transect from 2.4 to 620 kg. The water storing capacity of epiphytic bryophytes was about 1.2 to 2.4 times as much as a dry weight and was generally higher in the montane (up to 1500 l/ha) than in the lowland forests. The result showed that the biomass and water storing capacity of epiphytic bryophytes had increased with higher altitudes from lowland to montane forests at all transects.

The bark pH values of host trees ranged between 3.19 and 6.84 and showed negative correlation with the altitude ($r = -0.635$, $p < 0.05$).

The microclimatic measurements were performed in dry season (December to April). At each site, a data logger had placed at 1.5 m above the ground and recorded the air temperature (°C) and the relative air humidity (%RH) in 10 minute intervals. Air temperature gradually had decreased with the increasing altitude ca 0.6 °C per 100 m elevation, but the relative humidity had increased with the increasing altitude. The general pattern of the day climate was as follows: the temperature increased quickly at dawn (±6:00 am). The relative humidity decreased simultaneously. The highest temperature was recorded during the first hour in the afternoon (±1:00 pm). Late in the afternoon, the temperature had commenced to decrease again. The cooling period was rather quick after sunset for an hour (±6:00 pm) and the temperature had decreased slowly afterwards, during the rest of the night. The lowest temperatures were recorded during the early morning before sunrise. In contrast to the temperature, the highest relative humidity values were recorded in the early morning, while the lowest relative humidity values were recorded in the afternoon. This pattern may be interrupted by rainfalls and wind.

The second part (Chapter 4) is paying attention to the species richness and the species composition as well as the distribution patterns of life forms of epiphytic bryophytes on tree trunks in lowland forest along the altitudinal gradient on Tarutao Island, and seeking the correlation, if any, between the epiphytic bryophyte communities and the selected physical environments concerning the bryophyte diversity of the tropical lowland forest.

Epiphytic bryophytes had been collected along an altitudinal transect between 25 and 700 m a.s.l. In this study area, four 0.25 ha sampling plots were laid in approximately 200 m altitudinal intervals. A 20 × 20 cm quadrat with 5 vertical and 5 horizontal crosswire was placed on the bases of tree-trunks between 1.5 and 2 m above the ground. Within each 0.25 hectare plot, 15-20 trees with girths more than 30 cm up to 150 cm were studied. In total 61 species of epiphytic bryophytes were recorded from 75 quadrats which included 30 species of liverworts and 31 species of mosses. There is no significant difference of the bryophyte species richness between 25 m and 700 m a.s.l., however, the species composition changed markedly. Besides, the altitudinal gradient of 4 study sites had proved to be the most important factor in community differentiation of epiphytic bryophytes as indicated by DCA analysis. On one hand, the microclimate parameters might be the primary factors that correlated to the differences in diversity and species composition of bryophyte assemblages. On the other, the similarities of the host plant species were probably minor factors. Moreover, the result of TWINSPAN had shown that the communities of epiphytic bryophytes were clearly altitudinal grouping and four community types could be recognized. Furthermore, the distribution of the life forms among each bryophyte differed significantly along the altitudinal gradient. This might well explain the relationship between each epiphytic bryophyte group to its habitat.

The third part (Chapter 5) is comparing the species richness, community composition and the ecology of epiphytic bryophytes in different altitudes from the lowland forest to the montane one at Khao Nan National Park, southern Thailand. It had demonstrated the distribution pattern of epiphytic bryophyte species as well as the epiphytic bryophyte communities along a given altitudinal gradient.

As the same sampling method which had been explained in Chapter 3, epiphytic bryophytes were collected along an altitudinal gradient, ranged from 400 m to 1,300 m a.s.l. A total of 118 quadrats were sampled from six 0.25 ha plots. In total 138 species of epiphytic bryophytes were recorded including 83 species of liverworts and 55 species of mosses. Species richness of epiphytic bryophytes had increased with an increasing altitude. In addition, the species composition had changed significantly between altitudes. Liverworts were the important elements in terms of species numbers concerning epiphytic bryophytes. The number of liverwort species was more than that of moss species in almost all altitudes, except at the 600 m one. They performed a maximum species richness between 1,200 m and 1,300 m a.s.l.

Mat and turf life forms species were the most common at all altitudes. Fan-like species were significantly the most common in a lowland forest (with low light intensity condition), whereas weft life form was a dominant one of the epiphytic bryophyte in a montane forest (with high light intensity condition). The results had shown also that the fan life form was succeeded by the weft life form at higher altitude.

A quantitative analysis of the vegetation environment relationships consistently showed that the distributions of epiphytic bryophytes were affected by a complex set of factors, related to the altitudinal gradient, such as light intensity, air temperature and relative humidity. The microclimate parameters might be the primary factors that correlated to the differences in diversity and species composition of bryophyte assemblages. On the other hand, the characteristics of the host plant species (tree diameter, bark roughness) were probably minor factors. In fact, the zonation along the altitudinal gradient was clearly important in the TWINSPAN analysis with five community types could be recognized. The Sørensen’s similarity index had decreased with increasing the altitudinal distance. It is to be convinced here that the community composition of bryophytes gradually changed with the altitudinal distance.

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List of abbreviations

a.s.l.	Above sea level
BKF	The Forest Herbarium, Department of National Park Wildlife and Plant Conservation
DBH	Diameter at breast height
DCA	Detrended correspondence analysis
p	Probability value associated with a statistical test
PSU	Herbarium of Prince of Songkla University
SD	Standard deviation
S_{est}	Estimated species richness
S_{obs}	Observed species richness
SSI	Sørensen’s similarity index
TWINSPAN	Two-Way-Indicator Species Analysis

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