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Original Article

Biomass and selected ecological factors of epiphytic bryophyte along altitudinal gradients in Southern Thailand

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Abstract

Biomass of epiphytic bryophytes was investigated along three altitudinal transects in southern Thailand: Tarutao National Park (25-700 m), Khao Nan National Park (400-1,300 m), and Khao Luang National Park (400-1,500 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 lower 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 lower montane forest (up to 1,500 l/ha) than in the lowland forests. The bark pH of host trees 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.

Keywords: altitudinal belts, biomass, epiphytic bryophytes, tropical rain forest, Thailand

1. Introduction

Epiphytic bryophytes are an important component of tropical rain forests and play a significant role in the water balance (Pócs, 1976, 1980; Veneklaas and 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 and 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 (Edwards and Grubb, 1977; Pócs, 1980; Nadkarni, 1984; Veneklaas *et al.*, 1990; Coxson, 1991; Hofstede *et al.*, 1993). Data on biomass of epiphytic bryophytes in tropical lowland forests are scarce. Moreover, the ecological data on the bryophyte vegetation of tropical forest is rather few.

Southern Thailand 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 (Figure 1). Topographically, there are three main mountain ranges running through the length of the peninsula, the Phuket, the Nakhon Si Thammarat, and the Sankalakhiri Range (Smitinand, 1989).

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 100 mm and mean

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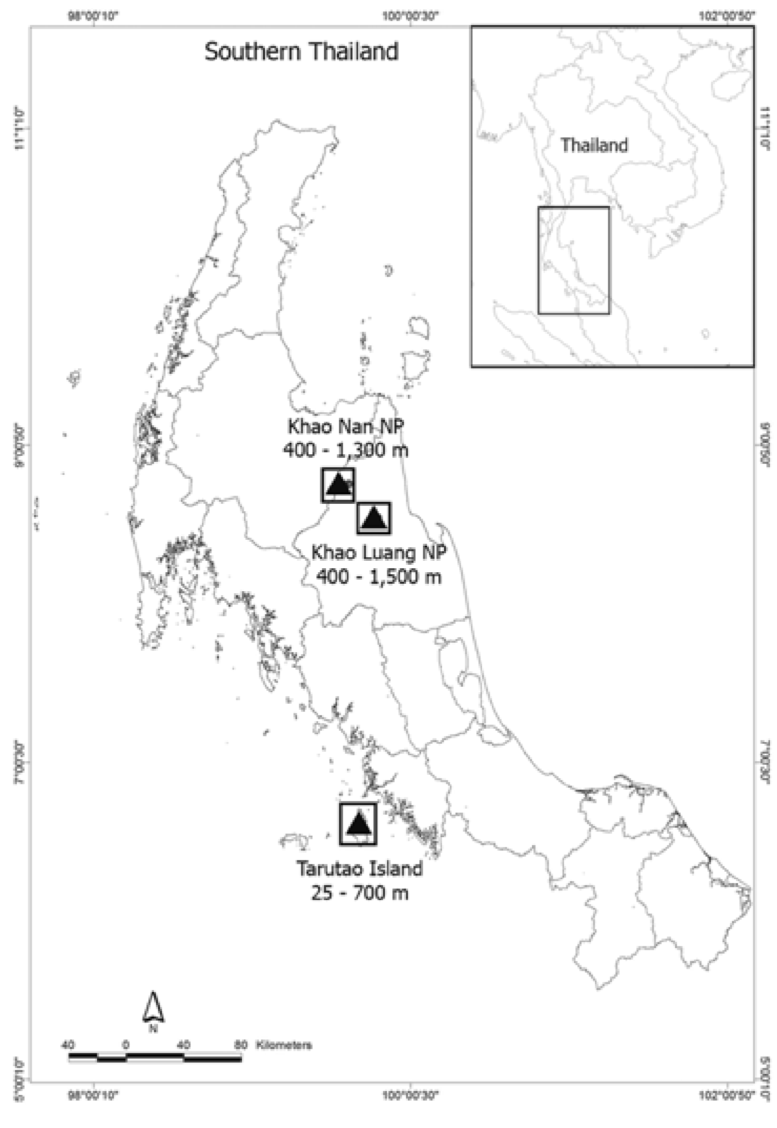

Figure 1. Map of southern Thailand showing the study sites

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 (2-3 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.

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 air temperatures may drop to 18°C. The lowest temperatures are usually recorded in January and February, while the highest temperatures usually occur in March and April.

The vegetation in southern Thailand consists of several forest types (Whitmore, 1990; Maxwell, 2004): 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 (1990), forest types in southern Thailand are mostly tropical lowland and lower montane forests. The tropical lowland evergreen forest is dominated by member of 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).

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).

The aim of the study was to determine and to compare the biomass of the epiphytic bryophytes along altitudinal gradients from lowland to lower montane forests. It was trying to investigate 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.

2. Materials and Methods

The field work was carried out on three altitudinal transects of the tropical forests in different geographical localities in southern Thailand (Figure 1), i.e. Tarutao National Park, 30-700 m above sea level (a.s.l.), a remote island on the west coast, work 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, with work conducted from February to March 2009, and Khao Luang National Park, 400-1,500 m a.s.l., on the mainland peninsula and fieldwork carried out 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 as outlined in the sections below.

2.1 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% relative humidity (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 at each study site. 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.

2.2 Bark pH of host trees

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

2.3 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 general, 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 for 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. Results and Discussion

3.1 Air temperature and relative humidity

The daily temperature and relative humidity fluctuation of the 17 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 1.

Table 1. Results of microclimatic measurements at 17 study plots along three transects in southern Thailand. T = temperature (°C), RH = relative humidity (%).

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	100.00
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
1,000 m	20.44	17.89	24.27	91.09	61.80	100.00
1,200 m	19.05	16.49	22.97	93.15	71.91	99.21
1,300 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
1,000 m	21.46	17.20	24.10	91.17	55.75	100.00
1,200 m	20.06	16.11	23.18	90.64	61.89	100.00
1,400 m	18.91	15.27	21.56	92.09	60.39	100.00
1,500 m	18.93	14.24	24.65	92.65	63.63	100.00

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.

Measurements were taken along Khao Nan National Park transect at 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 altitudinal 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.

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 plots along three transects are shown in Figure 2 to 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

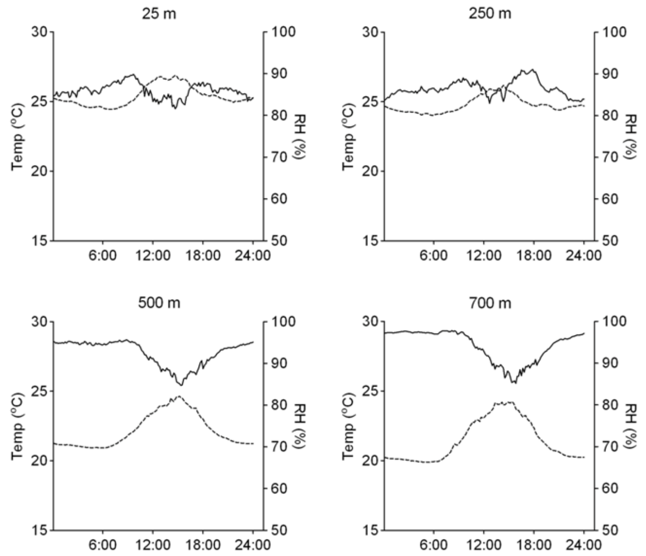

Figure 2. The daily course of temperature (dash line, °C) and relative humidity (dark line, %) at different altitudes from 25 to 700 m, Tarutao Island, based on 10 minute interval readings during 6 day.

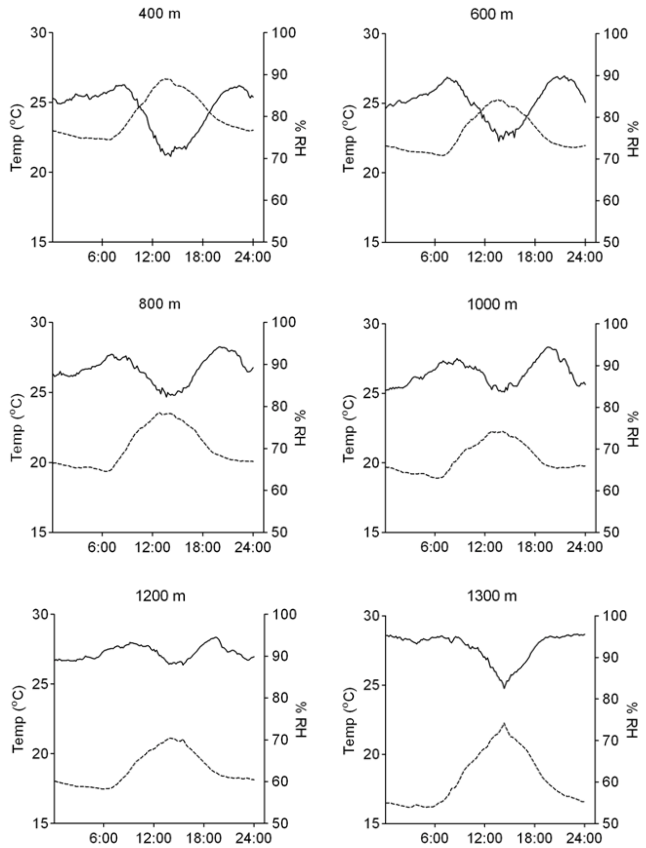

Figure 3. The daily course of temperature (dash line, °C) and relative humidity (dark line, %) at different altitudes from 400 to 1,300 m, Khao Nan National Park, based on 10 minute interval readings during 21 day.

relative humidity values were recorded in the afternoon. This pattern could be interrupted by the rain-fall and the wind.

3.2 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 at different altitude sites along the three transects are presented in Table 2.

Tree bark pH varied considerably at a given altitude site (Figure 5) ranged between 3.19 and 6.27. This has shown a range of an acidic condition. This finding agreed well with

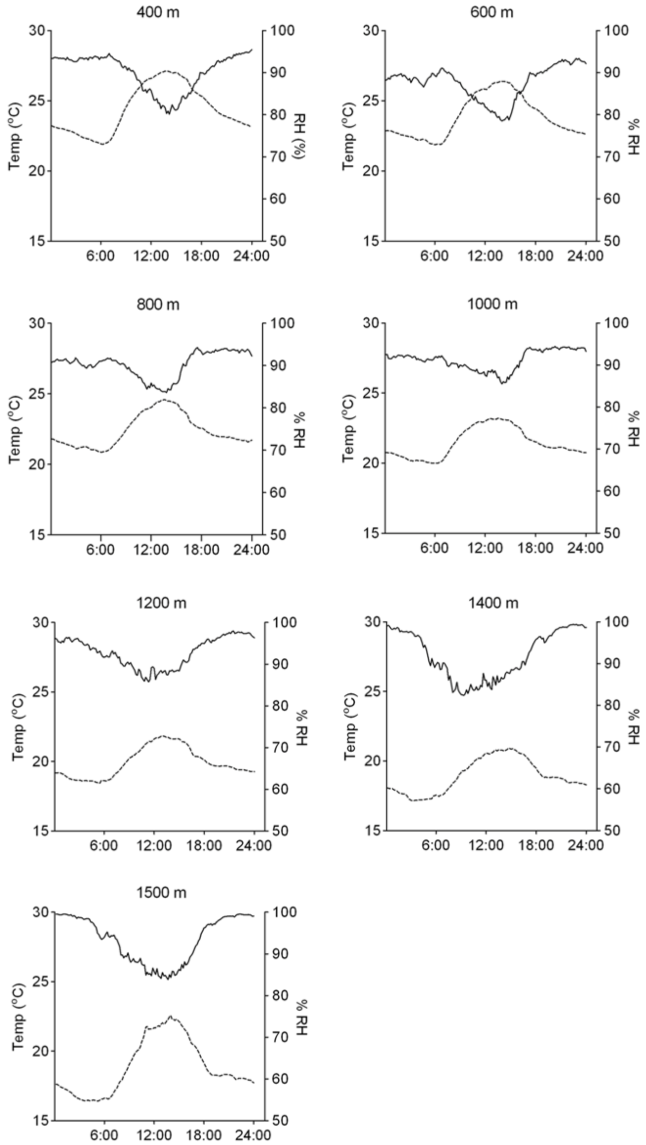

Figure 4. The daily course of temperature (dash line, °C) and relative humidity (dark line, %) at different altitudes from 400 to 1,500 m, Khao Luang National Park, based on 10 minute interval readings during 14 day.

Table 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	-	-	-	-	-	-	-

many previous reports from tropical forests e.g. Amazonian lowlands (Lisboa, 1976), Mt. Kinabalu, Borneo (Frahm, 1990), Colombian montane forest (Wolf, 1993a), Mt. Kahuzi, Zaire (Frahm, 1994), and Costa Rican montane oak forest (Holz and Gradstein, 2005).

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 and Znotiòa, 2006).

The only previous determination of bark pH of host tree in Southeast Asia has been performed by Frahm (1990) 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 = -0.635; p<0.05). A larger amount of humus accumulation on the tree bark at a high altitude may affect pH values. Other environmental factors, such as tree species, soil

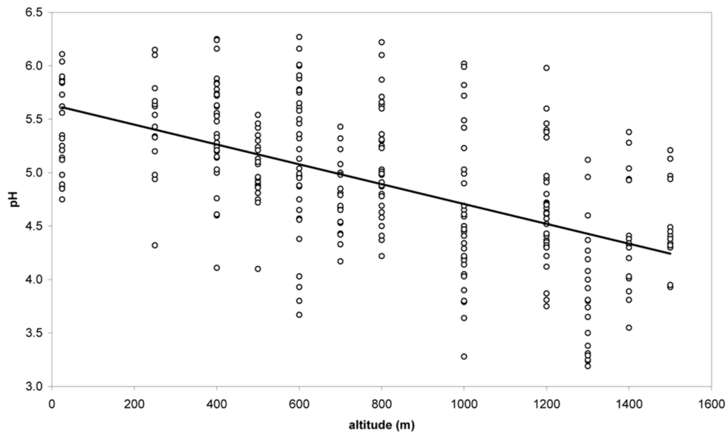

Figure 5. Correlation between values of bark pH and altitude of host tree, shown a negative correlation ($r = -0.635$; $p < 0.05$).

dust, salt spray and rainfall could also affect a value of bark pH.

3.3 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. 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. The dry weight of epiphytic bryophytes per hectare at different altitude, ranged from 2.4 to 620 kg. This is about 300 times from the lowland tropical rain forest to the lower montane forest.

The result showed that the biomass of epiphytic bryophytes increased with higher altitudes from lowland to montane forests at all transects. Generally, this result agree with the quantitative measurements of the bryophyte abundance in the forest understory along altitudinal gradients in many places, e.g. Peru (Frahm, 1987), Borneo (Frahm, 1990), Colombia (Wolf, 1993b) and Zaire (Frahm, 1994). The biomass of bryophytes was rather low in the lowland forest. This might be owing to the microclimatic conditions that did not allow sufficient a net photosynthesis (Frahm, 1987). 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 and to foggy conditions (Pócs, 1980). Moreover, at higher altitudes, the trees are more densely and equally cover with epiphytic bryophytes (Frahm, 1994).

3.4 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. the 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 1,500 l/ha in the montane forest.

Table 3. Biomass (g viz. kg/m^2) dry and wet weight and water storage capacity (l/ha) of epiphytic bryophytes along altitudinal gradients in Southern Thailand.

Study site	dry weight (g/m^2)	wet weight (g/m^2)	wet/dry weight	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
1,000 m	11.08	30.69	2.77	3100	34.35	95.14	60.80
1,200 m	73.85	230.41	3.12	3093	228.42	712.66	484.25
1,300 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
1,000 m	18.31	54.93	3.00	2986	54.67	164.02	109.35
1,200 m	61.87	205.88	3.33	1872	115.82	385.40	269.58
1,400 m	158.48	537.25	3.39	2368	375.28	1,272.20	896.92
1,500 m	145.94	481.60	3.30	4152	605.94	1,999.61	1,393.67

It is considered that 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. According to Frahm (1990), the epiphytic bryophytes could retain the water up to 2,760 l/ha in the forest line. Pócs (1980) found 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), and others.

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