ECOLOGICAL STUDIES ON BRYOPHYTES ALONG ALTITUDINAL ZONATIONS IN GENTING HIGHLANDS, PENINSULAR MALAYSIA

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Abstract

The present research investigated the species richness of epiphytic and terrestrial bryophytes along an altitudinal gradient on a mountain in Peninsular Malaysia. Bryophyte communities found at different elevations and their association with various ecological factors was analyzed. Study plots were laid along the altitudinal gradient at 300 m intervals, resulting in six different elevation zones, from the foothills to the summit of Gunung Ulu Kali (1758 m), in the Genting Highlands. A total of 453 bryophyte species comprising 283 liverworts and 170 mosses were recorded from 18 study plots of 0.04 hectare each, with three study plots at each elevation zone. A total of 106 liverwort species reported in the present study are new to Peninsular Malaysia, of which 54 species are new to the country (including Peninsular Malaysia, Sabah and Sarawak). In general, liverworts were more diverse than mosses in all elevation zones. Epiphytic bryophytes were largely represented by Calymperaceae, Lejeuneaceae, Lepidoziaceae, Lophocoleaceae, Plagiochilaceae, and Sematophyllaceae, whereas ground bryophytes were mainly Aneuraceae, Lejeuneaceae, Lepidoziaceae, Lophocoleaceae, and Sematophyllaceae. A few species were recorded exclusively at certain zones or even particular study plots, and could be good indicators where they occurred. In general, epiphytic bryophytes showed higher species evenness than ground bryophytes, and most of the bryophyte species, both epiphytic and terrestrial, were found to occupy only small areas, or present at low abundances. Epiphytic liverworts dominated the montane forests, especially the summit region, whereas epiphytic mosses were more abundant in the lowlands. A similar difference was observed for ground bryophytes species, except at the summit zone where both liverwort and moss coverage values were very similar in two of the study plots. Statistical analyses showed that host-epiphyte or substrate preferences for bryophytes were not important factors most of the time, suggesting that bryophyte assemblages within a forest were principally influenced

by microclimatic conditions. Cluster dendrograms revealed that the bryophyte communities investigated in the present study were clustered according to the different forest types present along an altitudinal gradient, viz., the lowland forest, transition between lowland and lower montane forests, the lower montane forest, and the upper montane forest. Ambient temperature and relative humidity are apparently important factors in determining the distribution of different bryophyte species.

Abstrak

Kajian ini menyelidik kekayaan spesies briofit epifit dan daratan sepanjang kecerunan altitud atas satu gunung di Semenanjung Malaysia. Komuniti briofit yang dijumpai pada ketinggian yang berlainan dan perhubungan mereka dengan pelbagai faktor ekologi telah dianalisa. Beberapa plot kajian dengan selangan ketinggian 300 m telah didirikan sepanjang kecerunan altitud membentuk enam zon altitud yang berbeza, dari kaki bukit ke puncak Gunung Ulu Kali (1758 m) di Genting Highlands. Sejumlah 453 spesies briofit yang terdiri daripada 283 spesies lumut hati dan 170 spesies lumut jati telah direkodkan dari 18 plot kajian yang masing-masing 0.04 hektar, dengan tiga plot kajian pada setiap satu zon ketinggian. Sejumlah 106 spesies lumut hati yang dilaporkan dalam kajian ini merupakan rekod baru bagi Semenanjung Malaysia, di mana 54 spesies ini adalah rekod baru untuk negara ini (termasuk Semenanjung Malaysia, Sabah dan Sarawak). Secara umumnya, lumut hati adalah lebih pelbagai daripada lumut jati di semua zon ketinggian. Briofit epifit sebahagian besarnya diwakili oleh Calymperaceae, Lejeuneaceae, Lepidoziaceae, Lophocoleaceae, Plagiochilaceae dan Sematophyllaceae manakala kebanyakan briofit daratan adalah daripada Aneuraceae, Lejeuneaceae, Lepidoziaceae, Lophocoleaceae, dan Sematophyllaceae. Sebilangan spesies dilaporkan secara eksklusif kepada zon atau plot kajian tertentu, dan boleh dijadikan penunjuk yang baik di mana mereka ditemui. Secara umumnya, briofit epifit menunjukkan kesamarataan spesies yang lebih tinggi daripada briofit daratan dan kebanyakan briofit spesies, bagi kedua-dua epifit dan daratan, adalah ditemui menduduki kawasan yang kecil, atau hadir pada kelimpahan yang rendah. Lumut hati epifit mendominasi hutan gunung, terutamanya di kawasan puncak manakala lumut jati mempunyai kelimpahan yang lebih tinggi di hutan tanah rendah. Perbezaan ini juga dicerap bagi briofit daratan kecuali di zon puncak, di mana liputan kedua-dua lumut jati dan lumut hati adalah sangat serupa di dua plot kajian. Analisa statistik menunjukkan perumah-epifit atau

keutamaan substrat bagi briofit selalunya merupakan faktor yang kurang penting, mencadangkan bahawa keadaan mikroiklim adalah pengaruh utama himpunan briofit dalam satu hutan. Dendrogram berkelompok menunjukkan bahawa komuniti briofit yang dikaji dalam kajian ini dikelompok mengikut perbezaan jenis hutan yang wujud di sepanjang kecerunan altitud, iaitu, hutan tanah rendah, zon peralihan di antara hutan tanah rendah dan hutan gunung rendah, hutan gunung rendah dan hutan gunung tinggi. Suhu dan kelembapan relatif dengan jelasnya adalah faktor penting yang menentukan taburan briofit spesies yang berlainan.

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%	percentage
°C	degree Celcius
a.s.l.	above sea level
am	*ante meridiem*
ca.	*circa*
cm	centimetre
cm^2	square centimetre
e.g.	*exempli gratia*
et al.	*et alia*
etc.	*et cetera*
h	hour
ha	hectare
km	kilometre
m	metre
mm	millimetre
pm	post meridiem
spp.	species
viz.	*videlicet*
vs	versus

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CHAPTER 1

INTRODUCTION

1.1 The evergreen tropical rainforest and bryophytes diversity

Over 31% of the world's land surface is covered with forests. Of these, approximately 47% are categorized as tropical rainforests (Taylor, 2011). Tropical rainforests lie between the Tropic of Cancer and the Tropic of Capricorn (23.5°N and 23.5°S). Almost all rainforests are located near the equator. There are three major blocks of tropical rainforests in the world (Corlett & Primack, 2011; Whitmore & Burnham, 1984). Of these, the largest is the American rainforest, centered in the Amazon basin, followed by the Indo-Malayan rainforest and the African rainforest, which is centered in the Congo basin. It has been estimated that more than half of the entire world's plant and animal species is found within the tropical rainforest (Myers, 1988). In addition to that, the tropical rainforest has more species of trees than any other area in the world.

The tropical rainforest experiences year-round warmth with temperatures ranging between 20 °C and 34 °C. Some tropical montane forests may experience colder nights but remain frost-free. Rainfall is relatively evenly distributed, reaching 2000 mm or more per year. Relative humidity could reach up to 75 to 90%. All these factors combine to make an equable climate favouring fast and luxuriant plant growth, including big trees with high canopies. The complex variation in site conditions over the forest floor, coupled with vertical variation in environmental variables such as light and humidity, and changes overtime due to plant growth, damage and mortality, together create a myriad of habitats and niches to which species can adapt. The resulting richness in many plant and animal groups seems correlated to this dynamic environment in which competition and adaptation, as well as environment change, influence ecological outcomes.

Tropical rainforests, especially montane forests, are extremely rich in bryophytes (e.g., Frahm and Gradstein (1991); Pardow and Lakatos (2013); Wolf (1993)). Pristine rainforests provide optimal conditions for the development of specialized bryophyte assemblages and the maintenance of high levels of biodiversity (Sporn *et al.*, 2009). The complexity of the structure and great variety of microhabitats ideally provide shelter to many bryophytes (Gradstein, 1992). Bryophytes are said to be the most successful group of plants other than angiosperms in terms of their number of species, wide geographical distribution and habitat diversification (Slack, 2011). They are found almost everywhere from the tropics to the Arctic and Antarctica regions, being absent only from the ocean (Tan & Pócs, 2000). It is not surprising that bryophytes are especially diverse in tropical regions, and particularly so at mid- to higher elevations that have cooler and moister environments than the lowlands. Enroth (1990) reported 424 bryophyte species (204 liverworts and 220 mosses) from tropical rainforests of Huon Peninsula, Papua New Guinea at 0–3400 m, with the highest diversity recorded at 2200–2300 m. In African rainforest, Pócs (1994) documented 540 bryophyte species (188 liverworts and 352 mosses) from Mount Kilimanjaro, Tanzania, ranging from 750 m to 5050 m, with highest species diversity at 2200 m and 2700 m.

Mosses along with liverworts and hornworts were the earliest terrestrial green plants representing the oldest lineages among extant land plants (Buck & Goffinet, 2000). They can thrive on tree branches, leaves, boulders, rocks, and even roof tops and abandoned fabrics when there is ample moisture. Shady areas which are wet and humid generally permit most bryophytes to grow. Nevertheless, there are also sun-loving and heat-tolerant bryophytes which are able to grow in extreme environments (Richards, 1954).

Most studies of bryophytes have been taxonomic or floristic in nature. Little, if any attention has been given to the ecology of bryophytes, particularly in tropical environments.

1.2 An urgency for bryophyte ecological studies

Tropical forests are among the biologically richest ecosystems on Earth, yet are facing serious destruction in the hands of humans (Gradstein, 1992; Laurance *et al.*, 2011). In the Lindquist *et al.* (2012) report on Forest Resources Assessment (FRA), it was shown that the extent of tropical forests had dwindled to 1.7 billion hectares, from 1.9 billion hectares in 1990. This indicates an average loss of 9.5 million hectares per year over that period. This implies that all tropical forests could be destroyed by the middle of this century if the rate of deforestation is maintained at such a pace. With such rapid deforestation, extinction has become of special concern.

Malaysia, a tropical country that lies between 1° and 7° N and 100° and 119° E, is a tropical rainforest country that has been recognized as one of 17 megadiverse countries in the world, with high endemism at both the species and higher taxonomic levels (Mittermeier *et al.*, 1997). Hansen *et al.* (2013) stated that Malaysia experienced a greater percentage of loss of forest cover compared to Brazil and Indonesia and ranked Malaysia 9th among all countries in the world by total loss of tree cover from 2000 to 2012. Malaysia was also placed 10th in terms of as the acceleration of tree cover loss, with 6.1% increase in annual forest loss per year. This finding has shown that deforestation in Malaysia is occurring at alarming rate. Therefore, there is an urgency to conduct more studies in this region especially to better understand and characterize pristine forests. Given that the diversity of plants is fundamental to understanding total tropical forest diversity, inventory and monitoring of plant diversity and forest structure are key prerequisites for understanding and managing forest ecosystems (Tang *et al.*, 2011)). The scanty information on bryophytes compared to higher plants in Malaysian forests has inspired the present study on the ecological distribution of bryophytes.

The knowledge we have from the current literature on Malaysian bryophytes is scanty. There are a few comprehensive checklists on mosses (Dixon, 1935; Suleiman & Akiyama, 2007; Touw, 1978; Yong *et al.*, 2013) and hepaticae and anthocerotae (Chuah-Petiot, 2011) but these are still insufficient for interpreting bryophyte ecology and their relative importance in different communities, as well as inter- and intra-species relationships. Most inventory studies that have been carried out have merely focused on mosses, e.g., Damanhuri and Maideen (2001b), Damanhuri *et al.* (2005f), Mohamed and Mohamad (1987), Mohamed and Yong (2005), Yong *et al.* (2006) , from different mountain ranges in Peninsular Malaysia. Reports by Mohamed (1995), Mohamed *et al.* (2003), Suleiman and Edwards (2002) and Suleiman and Akiyama (2007) regarding the diversity of bryophytes in Sabah and Sarawak have also emphasized mosses. The hepatic flora in Peninsular Malaysia has long been neglected, and the very first checklist on this group of plants was only recently published (Chuah-Petiot, 2011); subsequently, other work on selected hepatic groups or new country records have also been published, e.g., Lee (2013), Pócs *et al.* (2014), Cheah and Yong (2016).

There have been insufficient published insights into the ecology of bryophytes in Malaysia. The earliest study on bryophyte ecology was contributed by Johnson (1969) based on a forest quadrat in Taman Negara (National Park) in Peninsular Malaysia, comparing different terrains. More than three decades later, Damanhuri *et al.* (2005a) was the first to compare the diversity of mosses found in 1 ha plots between a highland forest (Fraser’s Hill, Pahang) and a lowland forest (Sungai Lalang, Selangor).

Elsewhere, there have been large-scale ecological studies on bryophytes along altitudinal gradients in the Andes in Central Colombia (1980-1983) and Sierra Nevada de Santa Marta (1977) during the ECOANDES expeditions. The inventory has contributed several important publications on the bryoflora of the neotropical forest (Gradstein *et al.*, 1989; van Reenen & Gradstein, 1983, 1984). Further ecological studies involving bryophytes have been carried out in the tropical montane forest of tropical America (Acebey *et al.*, 2003; Cornelissen & ter Steege, 1989; Corrales *et al.*, 2010; Gradstein & Frahm, 1987; Gradstein *et al.*, 2001; Mota de Oliveira *et al.*, 2009; Wolf, 1993).

Thus, there is a paucity of information on ecological studies relating to bryophytes in the Old World tropics, not only Malaysia in particular, but overall for Southeast Asia (Ariyanti *et al.*, 2008; Frahm, 1990a, b, c; Sporn *et al.*, 2009; Sporn *et al.*, 2010) The information so far has shown that the bryophyte floras of the New and Old World tropics are significantly different in term of diversity and composition.

More focused ecological studies are important to implement in order to shed light on some of the following questions before any appropriate conservation approaches may be considered. What kinds of habitats harbour the highest diversity of bryophytes in Malaysia? In which altitudinal zones are bryophytes most abundant and diverse? Do rare species coexist with common species in the same habitats? Can bryophyte diversity patterns be predicted using appropriate parameters?

1.3 Objectives

The present study aims to document the species composition and distribution of bryophytes found at different altitudinal zones on a mountain in Peninsular Malaysia, especially in relation to key environmental factors such as altitude, relative humidity and temperature. Any unique species that occurs within particular elevational zones could be potential indicator species for future environmental monitoring research. A second objective is to better understand any differences in abundance and diversity of epiphytic and terrestrial bryophyte communities in different vegetation along the altitudinal gradient. This study is the first of its kind for Peninsular Malaysia.

The species diversity of bryophytes along altitudinal gradients on mountains would permit subsequent comparisons with that of flowering plants. Thus, would help inform on more effective conservation approaches for the plant life in general. Information generated from the present work would also serve as a baseline for long-term climate change studies and is useful for local authorities in possible conservation programmes for protecting and preserving the rare and endemic bryophyte species on Malaysian mountains.

CHAPTER 2

LITERATURE REVIEW

2.1 Bryophytes in the tropical rainforest ecosystem

Bryophytes constitute an essential component of biodiversity and are also regarded as keystone species in ecosystem monitoring (Sérgio *et al.*, 2011). Gradstein and Pócs (1989) stated that lowland and montane tropical rainforests house an abundance of bryophytes, harbouring 25–30% of the world's bryophytes. They are one of the most prominent components in natural landscapes such as mossy or cloud forests with constant moisture and cover branches, twigs, exposed roots, boulders, rotten logs leaves and even bare ground. The many forms of bryophytes reflect their adaptation to different microclimatic conditions (Mägdefrau, 1982). The formation of mats and cushions of epiphytic bryophytes serve as a breeding and nesting ground for a wide range of birds, amphibians and invertebrates, including snails, worms, nematodes and tardigrades (Nadkarni & Matelson, 1989; Peck, 2006). They not only serve as a growth substrate and retain nutrients for other vascular epiphytes such as ferns and orchids, but also provide bedding material for seed germination and establishment (During & van Tooren, 1990).

Most tropical rainforest bryophytes are epiphytic (Gradstein *et al.*, 2001; Pócs, 1982). Host trees with a variety of architecture and bark features provide different habitats for epiphytic communities, from the tree base to the outer branchlets of the tree canopy (Pardow & Lakatos, 2013; Richards, 1954). It is possible to classify bryophytes into three different groups according to their relationship to sun and shade, viz., the shade-epiphyte, the sun-epiphyte and the generalist (Acebey *et al.*, 2003; Cornelissen & ter Steege, 1989; da Costa, 1999; Gradstein, 1992). In general, bryophyte increases in abundance from lowland rainforest to lower montane forest followed by upper montane forest (Frahm, 1990a; Richards, 1984). However, high abundance may not correlate with a high number of species in the forest. León-Vargas *et al.* (2006) commented that high frequency of precipitation is more important than high annual rainfall for many bryophytes. During the drier season, the canopy bryophytes in cloud forests can survive a drop in relative humidity, provided there are substantial frequencies of 100% humidity from cloud or fog. Proctor (2011) has pointed out that majority of bryophytes can withstand drying to approximately 75% of relative humidity for at least some days. Given the advantage of desiccation tolerance, some bryophytes are able to grow in comparatively xeric environments such as exposed ground, boulders, cliffs and even on volcanic soil. On the other hand, when there is excessive rainfall, the ability of bryophytes to store large amounts of water, allowing delayed release and providing time for nutrients to dissolve contributes to forest ecosystem stability (Proctor, 2009). Bryophytes retain up to 15,000 kg of water per hectare in epiphyte-rich forests, such as temperate and tropical rainforests (Kürschner & Parolly, 2004; Pypker *et al.*, 2006).

Aside from the many epiphytic bryophytes, epixylic species form the second most abundant bryophyte community in tropical rain forests (Silva & Pôrto, 2009). The diversity of terrestrial bryophytes includes epilithic species and others. In general, terrestrial bryophytes are not so abundant at lower elevations due to the greater frequency and amount of leaf fall that contributes to the presence of a thick layer of litter covering the forest floor; nonetheless, they may be conspicuous on the humid soils of montane forests (Gradstein, 1992; Richards, 1954). Weibull and Rydin (2005) regarded boulders as an archipelago of habitat islands in a 'forest sea', providing distinct patchy substrates in the forest and hosting a different set of bryophyte flora compared to the forest floor. They have sometimes been called 'ecosystem engineers' owing to their ability to create, modify, or maintain certain habitats (Vanderpoorten & Goffinet, 2009). In some instances, mosses can succeed a forest community through a process known as paludification (Reiners *et al.*, 1971). This process refers to peat accumulation over previously dry mineral soil, through transition to waterlogged conditions (Lavoie *et al.*, 2005). Thick bryophyte cover may directly hamper the regeneration of herb and shrub layers, thus shifting the whole vegetation towards a moss-dominated swamp community. Some terrestrial bryophytes are found thriving on ever-wet or humid rocks and boulders near riverbanks, e.g., the moss *Fissidens* spp, and the liverworts *Dumortiera hirsuta*, and *Riccardia* spp. Others prefer open sites with higher light levels in montane forests, e.g. *Campylopus* spp and *Marchantia* spp. The humus that forms in soil when plants and animals decay in the summit zone of a mountain also encourages the growth of a great diversity of terrestrial bryophytes, *Sphagnum* spp. in particular. Therefore, terrestrial bryophytes play a distinctive role in the ecosystem and are crucial to understand and monitor in a forest ecosystem.

2.2 Diversity and biogeography

In term of floristic composition the bryophyte flora varies along altitudinal gradients and more or less corresponds to different forest types. In spite of the unique set of plant species in each forest type, Gradstein and Pócs (1989) concluded that approximately 90% of the bryophytes found in a tropical rainforest belong to only 15 bryophyte families. These include Calymperaceae, Dicranaceae, Fissidentaceae, Hookeriaceae, Hypnaceae, Meteoriaceae, Neckeriaceae, Orthotrichaceae, Pterobryaceae and Sematophyllaceae making up the mosses families, whereas Frullaniaceae, Lejeuneaceae, Lepidoziaceae, Plagiochilaceae and Radulaceae are the few liverwort families that are very common in tropical rainforests. Although there are higher chances for encountering bryophytes of the same family in a tropical rainforest, less than 20% of tropical bryophytes are pantropic in distribution (Tan & Pócs, 2000). Bryophyte diversity in the Old World tropics (paleotropics) and the New World tropics (neotropics) is essentially different. Within the paleotropics, the Asiatic tropical rainforest harbours a higher bryophyte diversity in comparison to African tropical rainforests, with a large number of moss taxa endemic to that region (Buck & Thiers, 1989; Gradstein & Pócs, 1989).

The present study focuses on the bryoflora found on a mountain in the Malay Peninsula which is biogeographically part of the Malesian phytogeographical region (van Steenis, 1950). Malesia is the region whereby the well-known Wallace's Line is situated, a biogeographical indication that separates the Asiatic and Australian biotas (Van Oosterzee, 1997; Wallace, 1863; Whitmore, 1981). Despite the conspicuous dissimilarities in animal diversity of the eastern and western Malesian sub-regions, the Wallace's line is somehow less remarkable as a floristic boundary (Whitmore & Burnham, 1984). This implies that more plant groups are shared between Sundaic Malesia to the west and the Gondwanic Malesia to the east. Tan (1984) reported that the Wallace's line does not restrict the crossing of the moss flora between New Guinea, the Philippines and Borneo as a high number of shared taxa, 431 (ca. 26.3%), has been recorded among these territories. Another study reported by Ariyanti and Gradstein (2007) suggested that the greater number of eastern compared to western Malesian liverwort species in Sulawesi (13 *vs* 2) is in accordance with Wallace's line, indicating that this border of Asiatic and Australasian biogeographical regions is also relevant to wind-dispersed organisms such as liverworts. In the case of Peninsular Malaysia, recent floristic data reveals that the moss flora of Peninsular Malaysia and Singapore remains Sundaic in composition with a strong affinity to the moss flora of Sumatra (Ho *et al.*, 2006; Yong *et al.*, 2013).

2.3 Ecological studies of bryophytes along tropical altitudinal gradients

Altitudinal gradients provide an appealing setting for biodiversity research as they offer the potential to test hypotheses of global processes at local scales (Rahbek, 2005). Three predominant patterns of species richness have by far been recognized generally: a monotonic decline in species richness with altitude; a plateau where richness remains high until the mid-altitudes before declining at higher altitudes; and a "humped" distribution with a peak of richness at some intermediate point on the gradient (Grytnes & McCain, 2007; McCain, 2005, 2009; Rahbek, 1995). Rahbek (2005) demonstrated that almost 50% of the examined plant studies depicted a humped pattern, and around 25% had a monotonic decline with elevation. The fraction of hump-shaped patterns increased to about 70% after eliminating studies that did not consider the whole altitudinal gradient.

Different classifications have been proposed for altitudinal belts in tropical mountains either based on climatic factors (Holdridge *et al.*, 1971; Lauer, 1986) or physiognomic characters of the vegetation (Frahm & Gradstein, 1991; Grubb, 1974; Hamilton, 1989; Richards, 1952). Definitions of rainforest belts by climatic factors are of limited practical use as climatic data are often unavailable. Frahm and Gradstein (1991) proposed the use of bryophytes as a tool to describe altitudinal zonation of tropical rainforests based on bryophyte cover, phytomass and species diversity. They distinguished five altitudinal belts of tropical rainforest which include the lowland forest, the submontane forest, the lower montane forest, the upper montane forest and the subalpine forest. The elevational limits of the altitudinal belts vary depending on local humidity conditions, latitude, relief (inclination, rain shadow), substrate and mountain mass elevation (*Massenerhebung* effect) (Bach & Gradstein, 2011).

Many bryological studies conducted in the neotropical region have contributed to the conclusion of Frahm and Gradstein (1991). One of these intensive bryophyte studies was the ECOANDES project, where seven altitudinal transects were laid in the Andean mountains, including northern Colombia (one transect), and on the Sierra Nevada de Santa Marta and central Colombia (six transects), from 1977 to 1983. van Reenen and Gradstein (1984) distinguished five altitudinal bryophyte zones ranging from 500–4100 m elevation along the Santa Marta transect based on percentage cover and relevé cluster diagrams in van Reenen and Gradstein (1983). The authors also found that the cover of liverworts in particular, reached peak values in the so-called 'condensation-zone', present at about 2800–2900 m close to the upper montane forest line. The BRYOTROP project, funded by the German Research Foundation, also successfully conducted several important transects for studies in the mountains of three different continents; South America (Peru), Asia (Borneo) and Africa (Zaire and Rwanda). A total of 478 bryophyte taxa were recorded from the Peruvian Andes with 217 taxa in 109 genera belonging to mosses and 261 taxa in 85 genera of hepaticae. Gradstein and Frahm (1987) reported five distinct bryophyte zonations on the Peruvian Andes, in accordance with the zonations in Sierra Nevada de Santa Marta in Colombia determined by van Reenen and Gradstein (1983). In the case of Mount Kahuzi in Zaire, Africa, four rainforest zones were recognized based on floristic parameters as well as ecological parameters derived from bryophytes, viz., submontane forest, lower tropical montane forest, upper tropical montane forest and subalpine forest (Frahm, 1994b). Peak values of bryophyte floristic discontinuities were found at 1500 m, 1800 m, 2500 m and 3400 m in Zaire which corresponded well with the Peruvian Andes except the 2800 m Andean discontinuity that has no parallel. The third locality, Mount Kinabalu in Borneo, will be discussed in detail in the following section.

Apart from research that has focused on the diversity and distribution of bryophytes on tropical mountains, there are also studies on the relationship between environmental factors and bryophyte abundance, and the interactions among and between bryophytes and phorophytes. One study documented vertical distribution, phorophyte preference and community composition of epiphytic bryophytes and lichens in a lowland rainforest of Guyana (Cornelissen & ter Steege, 1989). Sixteen standing trees were sampled using mountaineering tree-climbing techniques from tree base to outer canopy according to schematic tree height zones formulated by Johansson (1974). It was found that both species richness and life-form diversity increased with increasing height of phorophyte. Two categories of epiphytic species were distinguished, viz., “specialists” and “generalists”. “Specialists” have narrow vertical distribution and are found mostly in the upper canopy whereas “generalists” have broader distribution and nearly all showed no height preference on the phorophyte. Life strategies in terms of interspecific competition, avoidance of competition and rapid colonization proved to be major factors influencing the vertical distribution of the epiphytes. This was shown by Wolf (1993), who investigated species richness, distribution and biomass of epiphytic bryophytes and lichens along an altitudinal transect in the northern Andes in Colombia. The sampling method used included canopy epiphytes and was modified after Cornelissen and ter Steege (1989). It was found that the bryophyte richness showed a maximum between 2550 m and 3190 m whereas lichen richness decreased gradually between 1500 m and 3200 m and substantially at higher altitudes. The species richness of liverworts reached its peak with about 100 taxa per altitudinal interval of ca. 200 m, at the mid-altitudinal range of 2550–3190 m a.s.l. Many bryophytes either reached their lowest or highest point of distribution between 2550 m and 3190 m, indicating that this was the transition zone, where highest species richness was found.

Acebey *et al.* (2003) compared the species diversity and habitat diversification of bryophytes in primary forest and fallows of different ages in Bolivia. They found only about 45% of species were shared between the forest and fallows sites where 35 species exclusive to the forest, and 16 to the fallows. Bryophyte species found in fallow tended to grow appressed to the substrate to avoid desiccation. The distributional shift of forest species to lower heights on trees in the fallows indicated that microclimatic conditions played an important role in determining the distribution of bryophyte species. Eventually, it was found that about half of the forest species, liverworts in particular, may re-establish in 10–15-year-old fallows. This succession of epiphytic bryophytes was mostly made up of drought-tolerant specialists and generalists, with a small number of shade epiphytes. In an investigation of the effect of habitat fragmentation on community structure (abundance, composition, diversity and richness) in the Brazilian Atlantic forest, Alvarenga and Pôrto (2007) found that epiphytic and epiphyllous bryophytes responded negatively to habitat fragmentation either by decreases in abundance (epiphytes) or in richness (epiphyllous bryophytes). On the contrary, larger patch sizes included more generalists but a reduced number of shade and sun specialists. For preserving more bryophyte species, they proposed that the critical forest fragment to be at least 50 ha, and that smaller size must be compensated by low levels of insularization to maintain diversity and abundance.

It is noteworthy to mention that bryophytes have been noticeably well studied on the island of La Réunion situated east of Madagascar (Ah-Peng *et al.*, 2014; Ah-Peng *et al.*, 2012; Arts, 2005; Wilbraham, 2009). Ah-Peng *et al.* (2007) reported 70 species of bryophytes including nine new records along an altitudinal gradient on a lava flow in La Réunion. The liverworts (78.5%) present on lava flow outnumbered mosses. Bryophyte species were structured into six categories based on altitude and microhabitat preferences. In a study comparing two altitudinal gradients, continental (Nevado del

Ruiz, 5321 m a.s.l., Colombia) versus island (Piton des Neiges, 3069 m a.s.l., Réunion Island), Ah-Peng *et al.* (2012) suggested that the difference is likely caused by contemporary and historical effects, which interplayed in shaping local diversity patterns. Réunion is a relatively young island of 2.1 million years old, where recent colonization history may be continuing to shape its diversity, whereas the Colombian gradient could be the equilibrium outcome of different processes such as colonization, extinction, immigration and speciation.

Although the Indo-Malayan region is one of the richest rainforest regions in the world, ecological studies on bryophytes there, in particular Southeast Asia, remain scarce. As mentioned earlier, the BRYOTROP transect on Mount Kinabalu remains the most important reference for ecological studies in this region. Subsequently, Ariyanti *et al.* (2008) and Sporn *et al.* (2009) have compared the species diversity and composition of bryophytes in cacao agroforests, selectively logged forests and natural forests in central Sulawesi, Indonesia. Surprisingly, their findings revealed that bryophyte species richness do not differ between natural forest and the other habitat types but species composition changed markedly in different habitat types. Sporn *et al.* (2010) commented that assessments of bryophyte diversity in tropical forests were insufficient when understory trees and tree crowns were excluded. In an attempt to elucidate the bryophyte diversity on tree trunks in the montane rainforest of central Sulawesi, Gradstein and Culmsee (2010) found that trunk-base bryophyte species diversity was increasingly dissimilar with geographical distance and was approximately 25% (consisting of only 7 bryophyte species) in common with that of the lower montane forest on Mount Kinabalu, Borneo, and nearly completely different across continents, e.g., Africa and South America. Their findings subsequently showed that phorophyte trees with rough and fissured bark are often richer in species than those with smooth bark. The diameter of phorophyte trees however correlated with the distribution of a few bryophyte species but not with community composition or species richness.

Chantanaorrapint (2010), on the other hand, made an extensive ecological study along altitudinal gradients at a few locations in southern Thailand, in the Tarutao National Park (25–700 m.) and Khao Nan National Park (400–1300 m). The findings also suggested that microclimatic parameters might be the primary factors that correlate to species diversity and composition of bryophyte assemblages. Based on the grouping of epiphytic bryophyte communities, two different altitude zonations were proposed for Tarutao Island, viz., tropical lowland forest (0–500 m) and submontane forest (500–700 m). A transition zone occurred at 500 m elevation between lowland and submontane forest. On Khao Nan National Park, however, three different altitudinal zonations based on bryophyte communities were recognized, namely the lowland forest (0–600 m), submontane forest (800–1000 m) and montane forest (1200–1300 m).

2.4 Bryological studies along altitudinal gradients in Malaysia

In Malaysia, extensive collections of bryophytes have been carried out on Borneo Island, particularly on Mount Kinabalu and forests in the state of Sabah. Studies on the bryophyte flora of Borneo have been carried out since early days, e.g., Bartram (1936), Dixon (1935, 1941), Iwatsuki and Noguchi (1975), Noguchi (1971), Noguchi and Iwatsuki (1972). However, the only reported ecological research was the BRYOTROP project conducted on Mount Kinabalu in 1986, for a period of six weeks and resulted in a series of publications on mosses and liverworts, e.g., Menzel (1988, 1992), Tan (1994), Váňa (1993), Yamada (1989). Besides their checklist of mosses and liverworts of Mount Kinabalu (Frahm *et al.*, 1990), Frahm (1990a) made ecological studies based on several parameters, such as cover of epiphytes, life form, phytomass, abundance of bryophytes on different substrates etc. to elaborate the altitudinal zonation of bryophytes on Mount Kinabalu. Five different altitudinal zonations of tropical rainforests in northern Borneo were distinguished: lowland forest, submontane forest, lower montane forest, upper montane forest and subalpine forest. Likewise, Kitayama (1992) also conducted an altitudinal transect study on tree species from 600 to 3400 m a.s.l. and recognized four distinct altitudinal vegetation zones, viz., the lowland, lower montane, upper montane and subalpine zones based on floristic vegetation analysis and correlated with soil profile. Frey and Kürschner (1991), on the other hand, reported nine dominant life strategies of epiphytic bryophyte communities in the tropical lowland and montane rainforests of Mount Kinabalu. These life strategies include colonists with sexual reproduction; colonists with vegetative reproduction; colonists with vegetative and sexual reproduction; perennial shuttle species with sexual reproduction; perennial shuttle species with vegetative reproduction; perennial shuttle species with passive reproduction; perennial shuttle species with sexual and vegetative reproduction; perennial stayers with sexual reproduction; and perennial stayers with passive reproduction. They found that perennial stayers with passive reproduction (e.g., *Lepidolejeunea bidentula*) and perennial shuttle species with vegetative reproduction (e.g., *Bazzania tridens* and *B. uncigera*) are the most prominent life strategies for epiphytic bryophyte communities on Mount Kinabalu. Epiphytic bryophytes with these two life strategies are important components of tropical rainforests and are interchangeable between them as climatic conditions change along an altitudinal gradient in the tropics. Colonists, however, act as an indicator of disturbed vegetation in epiphytic bryophyte communities.

In the case of Peninsular Malaysia, many expeditions have explored less-visited forested areas after 2000. Studies were focused merely on mosses which left the hepatic flora largely undocumented (see Table 2.1). Most of the published reports are in the form of species checklists with minimum information about the abundance and ecology of the collected mosses. Below we summarize some relevant studies, including the scanty knowledge on bryophyte documented before 2000.

There are few studies on plant diversity and distribution along elevational gradients in Peninsular Malaysia. These studies were based on vascular plant species, and information on bryophyte species is generally lacking. The earliest report of altitudinal variation in forests in Peninsular Malaysia was that by Whitmore and Burnham (1969). They categorized the vegetation on the Main Range near Kuala Lumpur into lowland rainforest (up to 750 m), lower montane rainforest (750–1500 m) and upper montane rainforest (1500–1770 m). In conjunction with this altitudinal sequence, they found that the first notable soil change with accumulation of peat occurred in the upper part of lower montane rainforest and that the boundary between lower and upper montane rainforests more or less coincided with a second notable soil change, which is the development of a mineral-leached layer and an underlying iron pan (Whitmore & Burnham, 1969). After that, a summary of the distribution and altitudinal zonation of birds and small mammals by Medway (1972) together with descriptions of the forest zones of Gunung Benom by Whitmore (1972) were published after the Royal Society expedition to Gunung Benom in 1972. Kochummen (1982) discussed the effects of elevation on vegetation in Gunung Jerai, Kedah, where he recognized four different zones: lowland dipterocarp forest, hill dipterocarp forest, montane myrtaceous forest and the montane ericaceous forest, based on tree species similarities along the altitudinal gradient. The ratios of stems to species, genera, families, as well as the total basal area showed a marked increase at approximately 750 m, then decreased gradually as the elevation increased, indicating the existence of a transitional zone at this altitude. Nakashizuka *et al.* (1992) on the other hand, studied the composition and structure of tree species along an altitudinal gradient in Genting Highlands and suggested four forest types, viz., lowland forest (below 700 m), a transition zone (700–1100 m), lower montane forest (1100–1500 m) and the upper montane forest (1500–1700 m). Obviously, bryophytes have never been ecologically assessed along altitudinal gradients in Peninsular Malaysia. The present study would provide the first investigation for Peninsular Malaysia and a baseline for comparison with the bryophyte communities of neighbouring areas, for instance, Mount Kinabalu and forests of southern Thailand.

2.5 The botanical survey in Genting Highlands

Genting Highlands, due to its close proximity to, and easy access from Kuala Lumpur is often visited by students as well as researchers. Nonetheless, there are limited publications about the rich plant flora of this area, e.g., Ng *et al.* (2012), Piggott (1977), Stone (1981). In general, the flora at the summit of Gunung Ulu Kali in the Genting Highlands has been better documented relative to other elevations. Despite the two reports on the vegetation and general ecology of the area (Nakashizuka *et al.*, 1992; Whitmore & Burnham, 1969), a general checklist of the plant species found below the summit region is still lacking.

Stone (1981) documented two vegetation types, viz., upper montane forest and elfin forest, with more than 460 higher plant species, at the summit region. According to Stone (1981), the upper montane forest indicator-species are made up of *Exbucklandia populnea*, *Garcinia cantleyana* var. *grandiflora*, *Lithocarpus cyclophorus* and *Pandanus klossii* whereas the elfin forest was dominated by *Leptospermum flavescens* and *Dacrydium comosum*. The summit flora of Gunung Ulu Kali was reassessed in 1997, employing similar methodology and after drastic changes in the surrounding landscape and the loss of some forested areas (Chua & Saw, 2001). The results showed a high level of endemicity (47.2% of all enumerated species) within a small area of a forest fragment (two plots of 0.03 ha each). Some species that no longer occured at the summit region of Ulu Kali, such as *Sonerila ramosa* were still found close by in larger forest fragments, suggesting that they could be affected by microclimate changes due to fragmentation. Chua and Saw (2001) concluded that the physical changes had negative impacts on certain less tolerant plant populations, e.g., the tiny filmy ferns of Hymenophyllaceae. Ferns and bryophytes were once being reported abundant at Gunung Ulu Kali (Null, 1972; Whitmore & Burnham, 1984), however, recent reassessment showed that the numbers of these plant groups had decreased (Chua & Saw, 2001). Null (1972) described the summit of Ulu Kali as “tall evergreen orthophyll savannah” and also “gnarled evergreen mossy forest” (with abundant bryophytes and epiphytes). According to him, flowering plants species such as *Lepidosperma chinense*, *Leptospermum flavescens*, *Dacrydium comosum*, *Nepenthes macfarlanei* and *Argostemma acuminata* as well as fern species such as *Matonia pectinata*, *Dipteris conjugata* and *Gleichenia microphylla*, are the dominant species at the summit region with Importance Value Index (IVI) values of more than 10 (Null, 1972).

A total of 101 species of 11 families of ferns were documented at the same summit region (between 1500 m to the summit of Gunung Ulu Kali) by Piggott (1977). Rapid development at the summit region had caused changes in habitat and subsequently changes in the composition and the distribution of fern flora in Gunung Ulu Kali (Piggott, 1981). In the latter assessment, pioneer species such as *Goniophlebium subauriculatum*, *Hypolepis brooksiae* and *Pseudophegopteris rectangulare* were commonly found in mountain clearings, covering the exposed edges of the forest (Piggott, 1981). To some extent, the changes in habitat encouraged either heat-tolerant or sun-loving species to colonize the exposed sites but these displaced the shade-loving species that preferred damp places with low light levels. A total of 27 fern species were newly documented for the mountain by (Piggott, 1981). In a more recent orchid inventory at Genting Highlands, Ng *et al.* (2012) recorded 134 species, of which 33 were endemic to Peninsular Malaysia and classified 47 species as threatened with extinction using IUCN criteria. A number of orchid species were reported new to Genting Highlands and most of them were found only in small populations. Their observations indicated that the on-going development at the summit and neighbouring area have also created favourable conditions for lowland species to migrate or invade.

In spite of the high floral diversity and endemism known for the Genting Highlands, in particular the summit region, the bryophyte flora is still to a large extent unknown. Manuel (1981a, b) reported only six bryophyte species from the Genting Highlands, viz., *Breutelia arundinifolia*, *Fissidens subangustus*, *Philonotis mollis* and *Philonotis speciosa*, *Telaranea major* and *Zoopsis liukiuensis*. Later, Lee (2013), who worked solely on the genus *Lejeunea* (Lejeuneaceae), documented 15 species and a single variety of *Lejeunea* the from Genting Highlands.

Table 2.1 A summary of bryophyte inventories in Peninsular Malaysia and Singapore after 2000.

Location by state	Species and varieties			References
	moss	liverwort	hornwort	
Johor				
Southwestern Endau-Rompin National Park	122			Mohamed and Yong (2005)
Kedah				
Gunung Jerai	166			Yong *et al.* (2006)
Langkawi Islands	139		1	Mohamed *et al.* (2005)
Ulu Muda Forest Reserve	110			Damanhuri *et al.* (2005f)
Kelantan				
Bachok and adjacent forest	23			Lim *et al.* (2010)
Gunung Stong	159			Damanhuri *et al.* (2005e)
Lojing Highlands	104			Suleiman *et al.* (2010)
Negeri Sembilan				
Kenaboi Forest Reserve, Jelebu	126			Mohamed *et al.* (2009)
Pahang				
Cameron Highland	249			Gunaseelan (2001)
Endau Rompin State Park	95			Damanhuri *et al.* (2004)
Fraser's Hill	110			Damanhuri and Nizam (2001)
Krau Wildlife Reserve	116			Lee and Damanhuri (2008)
Pulau Tioman	92			Mohamed *et al.* (2008)
Sungai Bebar Peat Swamp Forest	38			Damanhuri *et al.* (2005c)
Taman Rimba Kenong	114			Damanhuri *et al.* (2007)
Perak				
Belum Forest Reserve	67			Damanhuri (2000)
Matang Mangrove Forest Reserve	10			Damanhuri *et al.* (2005d)
Pulau Pangkor	53			Maideen and Damanhuri (2000)

Table 2.1, continued

Location by state	Species and varieties			References
	moss	liverwort	hornwort	
Perlis				
Wang Kelian State Park	72			Damanhuri and Maideen (2001b)
Wang Mu Forest Reserve	58			Yong *et al.* (2002)
Selangor				
Ayer Hitam Forest Reserve	44			Damanhuri and Maideen (2001a)
Gunung Nuang	118			Yong and Damanhuri (2005)
Lembangan Langat	82			Damanhuri *et al.* (2005b)
North Selangor peat swamp forest	23			Yong and Cheah (2013)
Terengganu				
Bukit Bauk Urban Forest	68			Damanhuri *et al.* (2008)
Gunung Gagau	120			Damanhuri *et al.* (2011)
Gunung Mandi Angin	143			Damanhuri *et al.* (2006)
SINGAPORE				
Nee Soon Swamp Area	13	21		Wong *et al.* (2013)
Singapore		73	1	Piippo *et al.* (2002)

CHAPTER 3

MATERIALS AND METHODS

3.1 Sampling Sites

The Genting Highlands are nestled among several mountain peaks within the Titiwangsa Main Range at the border between the states of Pahang and Selangor. It is located some 50 km from Kuala Lumpur, the capital of Malaysia. The summit region of Genting Highlands comprise of Bukit Genting Chin Chin, Gunung Lari Tembakau, Gunung Mengkuang (Lebah), Gunung Ulu Kali and Gunung Purun, and are in large part destroyed by increasing development of hotel and amusement park complexes. More forested areas were exploited for construction of new buildings even up to the present day at the summit region. As a result, this region is considered as one of the most disturbed cloud forests in Malaysia. The forests of Genting Highlands vary according to altitude, from lowland dipterocarp forest at the foothills, to the hill dipterocarp at higher elevation, followed by lower montane and finally upper montane forest near the summit of Gunung Ulu Kali (1758 m) (Medway, 1968; Nakashizuka *et al.*, 1992; Whitmore & Burnham, 1969).

Data of this study were collected at elevations ranging from 250 m to 1700 m a.s.l. in the Genting Highlands. The elevation range of the mountain was divided into six altitudinal zones viz. 1–300 m, 301–600 m, 601–900 m, 901–1200 m, 1201–1500 m, and 1501–1700 m, with three study plots laid randomly within each zone. The terrains around 900 m a.s.l. are mostly steep and largely disturbed, hence, study plots were laid at a lower elevation that still representing the vegetation common to the zone, 601–900 m at the Main Range. The present study sites are identified with Global Positioning System (GPS) coordinates and altitude in Table 3.1.

Table 3.1: Details of all the study sites and sampling plots at the Genting Highlands.

Altitudinal zone (m a.s.l.)	Plot	Location (according to GPS)	Actual elevation (m a.s.l.)
1–300	A1	N 03°19’ 06” E 101°44’ 00”	250
	A2	N 03°18’ 56” E 101°44’ 00”	200
	A3	N 03°19’.129’ E 101°43.912’	245
301–600	B1	N 03°21.063’ E 101°46.538’	650
	B2	N 03°21.034’ E 101°46.544’	610
	B3	N 03°21.019’ E 101°46.534’	570
601–900	C1	N 03°25.690’ E 101°45.591	770
	C2	N 03°25.719’ E 101°45.593’	775
	C3	N 03°21.230’ E 101°46.499’	785
901–1200	D1	N 03°24.504’ E 101°47.256’	1160
	D2	N 03°24.483’ E 101°47.272’	1200
	D3	N 03°24.484’ E 101°47.277’	1190
1201–1500	E1	N 03°24’53.6” E 101°47’18.9”	1545
	E2	N 03°24’55.1” E 101°47’20.5”	1550
	E3	N 03°26.510’ E 101°47.013’	1500
1501–1700	F1	N 03°25.733’ E 101°47.362’	1675
	F2	N 03°26.480’ E 101°46.987’	1725
	F3	N 03°26.521’ E 101°47.035’	1755

3.2 Sampling of bryophytes

Study plots measuring 20 × 20 m were set up within the natural forested sites, either undisturbed or of minimum disturbances, and as far as possible from perceived human activity. Selection criteria were based on the presence of at least 15 mature or preferable big size trees with a diameter at breast height (dbh) above 20 cm. The study plots were located at least 50 m apart from any water source such as stream, river and waterfall. This was to ensure the recording of general microclimatic data at each study site would not be unduly influenced by proximity to a river or waterfall. Within each study plot, all mature trees (dbh≥20 cm) were mapped and given individual codes. A total of 15 trees were picked randomly from each study plot for investigation. Epiphytic bryophytes were sampled in 20 × 30 cm quadrats positioned at each cardinal direction (North, South, East, and West) from tree base at least 0.5 m above ground to approximately 1.5 m high on the tree trunk. In total, an area of 2400 cm^2 (equivalent to four quadrats) on each tree was studied. As bryophytes could be patchily distributed within the structurally heterogeneous rain forest, it was expected that a random sampling may record some empty quadrats. The percentage cover of every epiphytic bryophyte species that could be readily distinguished was traced on a piece of transparent sheet sized 30 × 20 cm. Bryophytes from every quadrat were then sampled and brought back to laboratory for further identification. Additional taxa subsequently detected from microscopic scrutiny of collections made from each quadrat were designated a cover of 0.5% of 600 cm^2 (Tng *et al.*, 2009). Canopy bryophytes were excluded for this study due to inaccessibility and inadequate funding to hire tree climbers and helpers. Epiphyllous species were also excluded, so that our study focused only on tree base and terrestrial bryophytes.

A minor modification in the sampling plot and method was applied to the three study plots laid at the summit region of Gunung Ulu Kali, which is mainly made up of narrow and sharp ridges where relative flat areas are less than 20 m wide. Therefore, study plots in rectangular shape measuring 40 × 10 m, instead of 20 × 20 m, were laid at different locations along the ridge to sample bryophytes. It is important to note that those trees growing in this summit forest were mostly stunted, hardly exceeding 5 m in height and also many had dbh less than 15 cm. Fifteen trees, were still randomly selected from each study plot but the cardinal positions of each sampling quadrat were not strictly adhered to due to the small sized trunks. Bryophytes were sampled from different branches of the same tree where the area of the branches would be sufficient to fit the 30 × 20 cm quadrat.

The terrestrial bryophytes (referring to those grow on substrates on forest ground, such as rocks, soil, rotten logs and humus) were sampled by utilizing the same study sites as for epiphytic bryophytes. The ground area of each study plot was evenly divided into 16 subplots (5 × 5 m each), of which 12 subplots were randomly selected for sampling. A quadrat measuring 0.25 m^2 (50 × 50 cm) was laid at the center of each randomly selected subplot. Bryophytes found within the quadrat were examined and harvested for later identication. As for epiphytic bryophytes, additional taxa subsequently detected from microscopic scrutiny were designated a cover of 0.5%.

Sampling was carried out from March 2012 to July 2013. A total of 18 study plots in the six different altitudinal zones, or three plots at each altitudinal zones were laid to sample the epiphytic and terrestrial bryophytes. Samplings of both epiphytic and terrestrial bryophytes of each study plot were completed within the same visit. Bryophytes were collected and separated according to species in the field, and then placed into different collecting envelopes. Authentication of collected materials was carried out in the laboratory by referring to various popular and recent taxonomic treatments, e.g., Eddy (1988, 1990, 1996), Gradstein (2011) and through comparison with herbarium materials. Familial nomenclature follows Crandall-Stotler *et al.* (2009) for liverworts and Goffinet and Buck (2004) for mosses. Voucher specimens were deposited in the herbarium of the University of Malaya (KLU), Kuala Lumpur.

3.3 Microclimatic measurements and other parameters

Onset HOBO data loggers Pro v2 U23-001 were installed in each study zone to record the local weather information, particularly the ambient temperature and relative humidity. The data loggers were set to document the weather information once every two hours for a period of eight weeks. In total, six data loggers were placed, each at one of the three study plots and at every altitudinal zones from 29th of October 2014 to 24th of December 2014.

Other parameters that might affect the distribution and composition of bryophytes in the forest, viz., bark texture, cardinal directions and ground habitat were taken into account in the present study. The bark texture of all selected trees was recorded by designating textural qualifications such as fissured, flaking, rough and smooth bark. Cardinal directions on phorophyte however, denoting by north, south, east and west were documented to examine the effect of directions on bryophyte occurrence. As for terrestrial bryophyte, ground habitats including rock, soil, rotten log and humus were recorded for all terrestrial bryophyte samples.

3.4 Statistical Analysis

The bryophyte community structure and composition in tree and ground habitats were compared using the following parameters: (i) species richness per site; (ii) coverage of liverwort and moss species per site; and (iii) ratio of liverwort to moss species per altitudinal zone (Tng *et al.*, 2009). Species rarefaction curves for each site based on the accumulated species richness of epiphytic and ground bryophytes at every study plot were computed using PAST Version 3.08 (Hammer *et al.*, 2001) to evaluate the sampling efficiency. A Chao-1 estimator with bias corrected was employed to obtain an estimation of total number of species per site:

$$\text{Chao-1} = S + \frac{F_1(F_1-1)}{2(F_2+1)}$$

where S = number of taxa per study plot

F_1 = number of singleton species

F_2 = number of doubleton species

In addition, a rank abundance curve or Whittaker plot was generated for all study plots in the six altitudinal zones to demonstrate relative species abundance, species richness and species evenness with reference to the percentage coverage of each bryophyte species samples in this study. All species were ranked in descending order by their percentage coverage in each study plot. The Shannon entropy (H′) and the Gini-Simpson index (λ) were calculated to explain the diversity for each study plot. Nonetheless, it is noted that both indices do not reflect the true diversity of the plot as they are nonlinear in nature and their values are therefore not directly comparable. Hence, the results from both the indices were further translated into effective number of species, which is number of equally abundant species necessary to produce the observed value of diversity (Jost, 2006). Converting indices to true diversities grants them a set of common behaviours and properties, thus, comparable (Jost, 2006). Comparison could then be made between the observed species richness (D^0) and Shannon effective number of species (D^1) as well as the Gini-Simpson effective number of species (D^2). The following are equations of indices and conversion to effective number of species:

Shannon entropy, $H' = -\sum_{i=1}^{S} p_i \ln p_i$

Shannon effective number of species, $D^1 = \exp(H')$

Gini-Simpson index, $\lambda = 1 - \sum_{i=1}^{S} p_i^2$

Gini-Simpson effective number of species, $D^2 = 1/1 - \lambda$

where S = number of taxa per study plot

P_i = proportion of individuals belonging to the *i*th species

Habitat preference has been regarded as an important factor in determining the distributional pattern of bryophytes (Berg *et al.*, 2002). Two aspects, viz., cardinal direction and bark texture were given attention for all epiphytic bryophytes except for zone F, the summit region where cardinal direction was difficult to strictly adhered to owing to small sized tree trunks. Total occurrences of epiphytic bryophytes on the respective direction of tree trunk were recorded and summed for every study plot. The chi-squared test was employed, with prior assumption that the ratio of total occurrences of all four directions on tree trunk recorded for every plot would be of the same value, or in another term, no preference. In terms of bark texture (fissured, flaking, rough or smooth), the extent of occurrence of each epiphytic species with each recorded bark texture was summed for further analysis. The same procedure was applied to investigate the bryophyte preference on ground substrates (rock, soil, rotten log or humus). The Kruskal-Wallis test was first employed to evaluate the similarity between medians of all four tested variables, of bark textures for epiphytic species and substrates for bryophytes on ground. Subsequently, a Draftsman's plot was performed to demonstrate the correlation between variables for both liverworts and mosses. Above analyses were performed using R package, R version 3.2.3 (R Development Core Team, 2013).

The relationship between study plots were depicted in a cluster dendrogram based on data of total coverage and total number of occurrences of each species of recorded epiphytic and ground bryophytes. Analysis was performed using Ward's method of Euclidean distance for all eighteen plots from the six altitudinal zones. Heatmaps were generated to summarize the total coverage and total occurrences of different bryophyte species, each for epiphytic and terrestrial species, respectively. The information in the heatmaps was aligned according to the clusters resolved in the dendrogram, and colour tones were used to indicate the weight of each data. Only the top 15% of bryophyte species with highest coverage across all sampling plots was presented for both epiphytic and ground bryophytes, respectively, to lessen the disproportionate effects of rare species on the general picture. Pie charts of liverwort and moss proportions were generated for better visualization and comparison. An additional colour key denoting the six altitudinal zones was constructed to relate the clustering with reference to different altitudes and temperatures (results from the data loggers). Above analyses were performed using an R package, gplots with R Version 3.2.3 (R Development Core Team, 2013).

CHAPTER 4

RESULTS

4.1 Microclimate

The monthly mean air temperature provided by The Resort World Sdn. Bhd. adjacent to the summit of Gunung Ulu Kali for 1994–1995 was 19.7 ℃ and the mean relative humidity was 53.7% and mean annual rainfall 3534 mm (Chua & Saw, 2001). Recent meteorological data by Kamarulzaman *et al.* (2009), using an Automated HOBO Weather Station installed near the forested summit of Ulu Kali; however, recorded mean temperature of 16.5 ℃ with mean relative humidity of 91.3% and mean annual rainfall of 2339 mm. In the present study, the ambient temperature and relative humidity of all six zones (A–F) at the Genting Highlands were recorded daily over a period of eight weeks from 1200 h, 29 October 2014, until 1200 h, 24 December 2014. Figure 4.1 illustrates the daily changes of the two measured parameters at two hours intervals within each zone over eight weeks. In general, temperature decreases with increasing altitude. A drop of 1–2 ℃ was recorded in every subsequent zone from the lowest to the highest elevation (Figure 4.1). Mean daily relative humidity was constantly high and did not fluctuate much at higher elevations beginning from 900 m until 1700 m above sea level. The lower zones, however, demonstrated low humidity during the day (lowest around 1200–1500 h) compared to morning and at night. Highest temperature recorded around 1200–1500 h at zone A and B was when the relative humidity was the lowest (Figure 4.1). All zones experienced an optimum relative humidity, or 100% humid, in at least part of the day, throughout the eight weeks which subsequently contributed to the very high daily mean relative humidity ranging from 94% to 99.7% (Table 4.1).

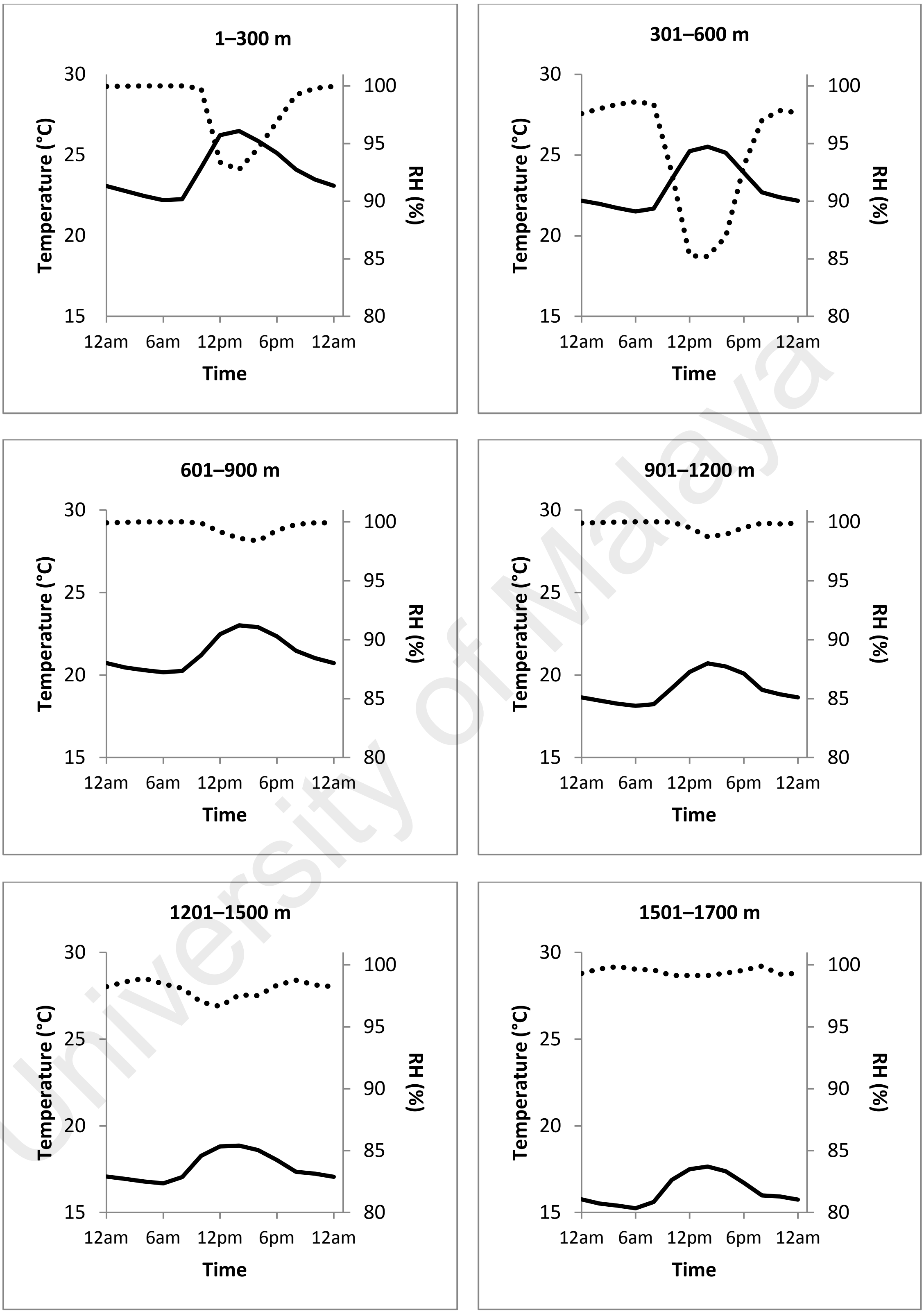


Figure 4.1: The average daily temperature (solid line) and average relative air humidity (dotted line) recorded at different study zones on Genting Highlands, based on readings at 2 hours intervals over eight weeks (29 October 2014 to 24 December 2014).

Table 4.1: Summary of daily temperature and daily relative humidity at six altitudinal zones on Genting Highlands over eight weeks from 29 October 2014 until 24 December 2014.

Study zones	Daily temperature (℃)				Daily relative humidity (%)			
	Minimum	Maximum	Mean	Range (max – min)	Minimum	Maximum	Mean	Range (max – min)
A	21.22	29.84	24.03	8.62	64.75	100.00	98.03	35.25
B	20.29	29.44	23.12	9.15	61.81	100.00	94.09	38.19
C	18.94	25.50	21.36	6.56	83.55	100.00	99.57	16.45
D	16.92	23.91	19.19	6.99	85.44	100.00	99.69	14.56
E	15.70	21.22	17.64	5.52	56.83	100.00	98.05	43.17
F	13.52	19.15	16.30	5.63	63.48	100.00	99.46	36.53

A summary of the climate conditions for all six altitudinal zones is presented in Table 4.1. At zone A, 1–300 m elevation, daily mean temperature was the highest (24.03 ℃) among all zones. Mean relative humidity recorded at this zone was 98% over eight weeks despite the expectation of being the lowest among all zones. This could be caused by dense lowland forests with constant mist episodes from the highlands brought by wind. Daily mean temperature decreased slightly at zone B, 301–600 m elevation with mean relative humidity reaching 94%. That is the lowest mean humidity record among all zones, indicating that is the driest site. As for zone C, at 601–900 m elevation, daily mean temperature dropped to 21 ℃ with daily mean humidity reaching 99.6%. These conditions allowed the growth of many epiphytic plants including bryophytes as the forest remained ever-wet and cool. Another drop of 2 ℃, from 21 ℃ to 19 ℃ in daily mean temperature was recorded when ascending from zone C to zone D, at 901–1200 m elevation. The daily mean relative humidity recorded for this zone, 99.7% was the highest among all zones, which could be considered as an extremely wet condition. Rainfall visited this zone frequently as observed during fieldwork. In zone E, at 1201–1500 m elevation, daily mean temperature dropped to 17.6 ℃ but a downtrend was observed for daily mean humidity, reaching 98%. An extremely low relative humidity reading, 56.8%, was recorded at this zone during the eight weeks, implying that there could be very dry episodes for particular days even at this highly humid zone. The highest zone, F, at 1501–1700 m elevation, yielded the lowest daily mean temperature of all zones, 16.3 ℃. The temperature at this zone could drop as low as 13.5 ℃ during the night till just before dawn. Daily mean humidity recorded was high, reaching 99.5%. Many bryophytes grow at this zone, which the vegetation at this zone is aptly called the mossy forest. Although high light intensity is common to the summit area, mist and rainfall were frequent, which provided a favourable condition for bryophytes to thrive.

4.2 Assessing sampling adequacy and species evenness

A total of 9447 identifications of species in 5096 samples collected from the Genting Highlands study plots yielded records of 453 bryophyte species. Sampling completeness was analyzed despite the great number of samples and species recorded. According to the Chao-1 statistic, a species richness estimator with bias corrected, the estimated species richness for epiphytic bryophytes (Table 4.2a) and ground bryophytes (Table 4.2b) fitted a sigmoidal pattern across the altitudinal gradient, with the highest richness estimated for plot C2 for epiphytic species and also being exceptionally high in estimation of ground bryophyte richness for the same plot. Estimated sampling completeness is as high as 66.4–100% (for epiphytic bryophytes) and 40–88.2% (for ground bryophytes), suggesting that adequate sampling intensity was conducted in present study (Table 4.2). In general, epiphytic bryophyte species (average 82.2% completeness) were better sampled in relative to ground bryophyte species (average 65.7% completeness). Interestingly, study plot C3 exhibited a perfect sampling effort for epiphytic bryophytes and the highest sampling completeness for ground bryophytes, in spite of the fact that the lowest epiphytic diversity was recorded in this plot, and ground diversity was the second lowest among all study plots. For comparison, the species rarefaction curve expressed as a function of occurrences for the pooled data set (sample-based rarefaction curves) was generated (Figure 4.2 & 4.3). None of the species rarefaction curves, for both epiphytic and ground bryophytes species, reached a clear plateau even though some of them ended with prolonged gentle slopes that approached an asymptote (Figure 4.2 & 4.3). Higher evenness is equated to a steeper rarefaction curve (Ludwig & Reynolds, 1988). For example, plot D3 demonstrated low sampling completeness (66.4%) for epiphytic bryophytes because of the high number of singletons (species occurring only once) recorded, which resulted in a steeper rarefaction curve (Figure 4.2). Likewise, plots with sampling completeness lower than

Table 4.2: Observed (S_{obs}) and Estimated (S_{Chao1}) species richness and percentage of sampling completeness (S_{obs} / S_{Chao1} $\times$ 100%) for: a) epiphytic bryophyte, b) ground bryophyte, in Genting Highlands.

a)

Sampling sites	Observed species richness (S_{obs})	Chao-1 Estimator (S_{Chao1})	Sampling Completeness (%)
A1	38	45	84.4
A2	36	40	90.0
A3	21	24	87.5
B1	27	33	81.8
B2	24	35	68.6
B3	24	29	82.8
C1	88	96	91.7
C2	120	153	78.4
C3	18	18	100
D1	103	124	83.1
D2	96	123	78.0
D3	89	134	66.4
E1	94	129	72.9
E2	82	101	81.2
E3	126	143	88.1
F1	117	128	91.4
F2	107	130	82.3
F3	96	137	70.1

b)

Sampling sites	Observed species richness (S_{obs})	Chao-1 estimator (S_{Chao1})	Sampling Completeness (%)
A1	8	18	44.4
A2	21	51	41.2
A3	20	27	74.1
B1	16	23	69.6
B2	14	17	82.4
B3	16	22	72.7
C1	47	68	69.1
C2	44	110	40
C3	15	17	88.2
D1	54	99	54.5
D2	46	54	85.2
D3	53	76	69.7
E1	41	65	63.1
E2	50	91	54.9
E3	86	135	63.7
F1	91	166	54.8
F2	72	96	75
F3	57	71	80.3

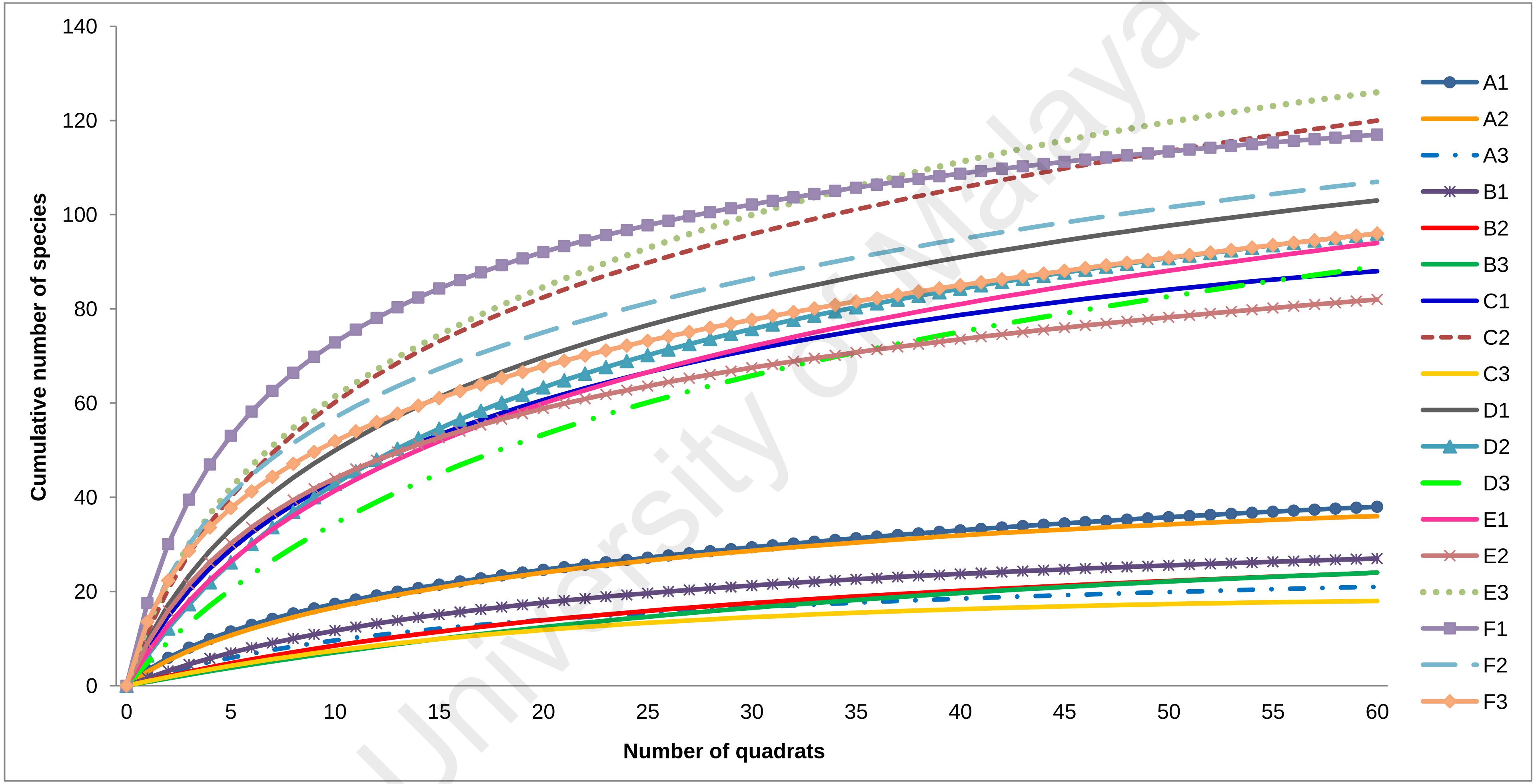


Figure 4.2: Species rarefaction curves for epiphytic bryophytes in all eighteen study plots in Genting Highlands.

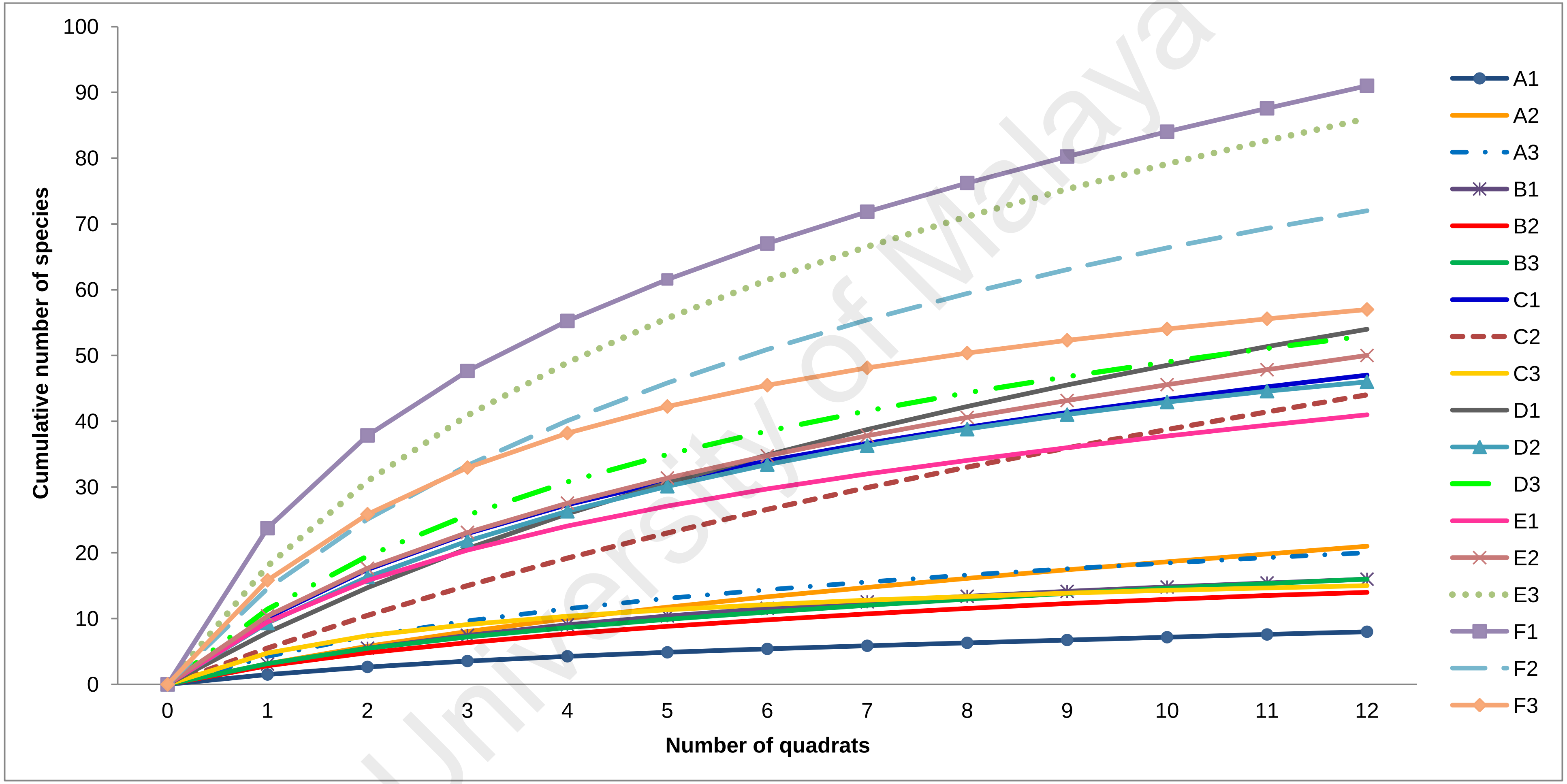


Figure 4.3: Species rarefaction curves for ground bryophytes in all eighteen study plots in Genting Highlands.

60% for ground bryophytes, viz., A1, A2, C2, D1, E2 and F1, possessed greater Chao-1 species richness values compared to observed species richness, due to high evenness in these plots with fewer dominant species. All these plots showed steeper rarefaction curves compared to plot A1 (Figure 4.3), as this plot yielded only 8 bryophyte species.

There are minor differences in estimated species richness when comparing with the observed richness, or in the rarefaction curves (Table 4.2, Figure 4.2 & 4.3). According to the Chao-1 species richness estimator, plot C2 is estimated with the highest richness of the epiphytic bryophyte species, while plot E3 is estimated to be the second richest, followed by plot F3 (Table 4.2a). The most number of epiphytic species was, however, obtained from plot E3, followed by plot C2 and then plot F1 (Table 4.2a, Figure 4.2). Similarly, for the ground bryophytes, plot F1 and plot E3 are the two plots with the highest species richness according to both Chao-1 species richness estimators and actual sampling, as well as in rarefaction curves, but plot C2 turned out to be the third richest in estimated species diversity according to the Chao-1 estimator instead of plot F2 as observed (Table 4.2b, Figure 4.3). The differences were mainly because of the occurrences of many rare species in plot C2, which caused a higher estimated number of species. Despite many rare species recorded in plots E3, F1 and F2, the dominant species were equally abundant, which resulted the observed species richness for these three plots lower than the total richness estimated for plot C2 using Chao-1 species richness estimator.

4.3 General bryophyte diversity in Genting Highlands

Overall, 453 bryophyte species were collected from 18 study plots laid at six different altitudinal zones in the Genting Highlands. The location and the list of bryophyte species documented in the present study are provided in Appendix A. They are belonging to 283 liverwort species in 67 genera and 24 families, together with 170 moss species in 65 genera and 26 families (Table 4.3). Hornwort was somehow absent from all sampling sites. It is worth mentioning that a total of 106 liverwort species recorded in present study are new to Peninsular Malaysia with 54 of them new to the country. These new records for Peninsular Malaysia and Malaysia are listed in Table 4.4 and Table 4.5, respectively.

Species richness demonstrated a sigmoid curve pattern for epiphytic bryophytes but a decrease then gradual increase for ground bryophytes (Figure 4.4). In general, total species richness is relatively low at lower elevations, increases gradually with elevation until it reaches a peak at zone E, viz., at 1201–1500 m elevation, then decreases at the highest elevation, or near the summit of the highlands, at 1700 m elevation. Nonetheless, the total richness recorded near the summit of mountain was still significantly high, in relation to elevation below 600 m. It is noted that the total species richness decreased from zone A (1–300 m) to zone B (301–600 m), resulting in a sigmoid curve instead of a common bell-shaped curve or monotonic decline with altitude. Both the epiphytic and ground bryophytes generally follow the above- mentioned richness pattern. The only exception was that the richness of ground bryophytes continued to rise until the summit zone or the highest elevation, but not reaching a peak at zone E (1201–1500 m) (Figure 4.4).

Liverworts outnumbered mosses in most of the study plots, with the exception of plots A2 and B2 for epiphytic bryophytes, and plots A1, A2, A3, B1, B3, C1, C3 and D1 for ground bryophytes (Figure 4.5 and 4.6). The proportion of liverworts was approximately 70% or more of total richness at plots E3, F1, F2 and F3, for both epiphytic and ground bryophytes. Liverworts apparently have their greatest diversity at higher elevations, particularly in zones E and F (Figure 4.7). The probability of

Table 4.3: A summary of liverworts and mosses recorded from Genting Highlands.

Family	Genera	Species
Liverworts		
Aneuraceae	2	23
Balantiopsidaceae	1	2
Calypogeiaceae	2	3
Cephaloziaceae	3	3
Cephaloziellaceae	1	3
Frullaniaceae	1	8
Geocalycaceae	1	3
Herbertaceae	2	4
Jamesoniellaceae	2	2
Jubulaceae	1	1
Jungermanniaceae	1	1
Lejeuneaceae	21	96
Lepicoleaceae	1	2
Lepidoziaceae	7	50
Lophocoleaceae	3	18
Mastigophoraceae	1	1
Metzgeriaceae	1	6
Pallaviciniaceae	2	2
Plagiochilaceae	4	17
Pleuroziaceae	2	2
Radulaceae	1	18
Scapaniaceae	4	8
Schistochilaceae	2	8
Trichocoleaceae	1	2
Mosses		
Brachytheciaceae	1	1
Bryaceae	1	1
Calymperaceae	6	36
Daltoniaceae	3	10
Dicranaceae	5	10
Diphysciaceae	1	1
Fissidentaceae	1	10
Hypnaceae	6	15
Hypnodendraceae	2	2
Hypopterygiaceae	3	4
Leucobryaceae	2	8
Leucomiaceae	1	1
Meteoriaceae	1	3
Mniaceae	1	1
Neckeraceae	5	6
Pilotrichaceae	1	2
Polytrichaceae	1	1
Pottiaceae	1	1
Pterobryaceae	2	2
Pylaisiadelphaceae	7	14
Rhizogoniaceae	2	3
Sematophyllaceae	8	29
Sphagnaceae	1	5
Symphyodontaceae	1	1
Thuidiaceae	1	2
Trachylomataceae	1	1
Total	132	453

Table 4.4: New liverwort records for Peninsular Malaysia.

No.	Taxon	Family
1	*Acrolejeunea arcuata*	Lejeuneaceae
2	*Anastrophyllum revolutum*	Scapaniaceae
3	*Anastrophyllum squarrosum*	Scapaniaceae
4	*Cephalozia hamatiloba*	Cephaloziaceae
5	*Ceratolejeunea belangeriana*	Lejeuneaceae
6	*Ceratolejeunea singapurensis*	Lejeuneaceae
7	*Cheilolejeunea decursiva*	Lejeuneaceae
8	*Cheilolejeunea lindenbergii*	Lejeuneaceae
9	*Chiloscyphus ciliolatus*	Lophocoleaceae
10	*Chiloscyphus muricatus*	Lophocoleaceae
11	*Cololejeunea platyneura*	Lejeuneaceae
12	*Cololejeunea schmidtii*	Lejeuneaceae
13	*Drepanolejeunea ternatensis*	Lejeuneaceae
14	*Frullania gaudichaudii*	Frullaniaceae
15	*Frullania trichodes*	Frullaniaceae
16	*Harpalejeunea filicuspis*	Lejeuneaceae
17	*Herbertus armitanus*	Herbertaceae
18	*Herbertus dicranus*	Herbertaceae
19	*Heteroscyphus wettsteinii*	Lophocoleaceae
20	*Kurzia abbreviata*	Lepidoziaceae
21	*Kurzia abietinella*	Lepidoziaceae
22	*Kurzia borneensis*	Lepidoziaceae
23	*Kurzia geniculata*	Lepidoziaceae
24	*Kurzia lineariloba*	Lepidoziaceae
25	*Lejeunea apiculata*	Lejeuneaceae
26	*Lepicolea rara*	Lepicoleaceae
27	*Lepidolejeunea integristipula*	Lejeuneaceae
28	*Lopholejeunea ceylanica*	Lejeuneaceae
29	*Lopholejeunea nigricans*	Lejeuneaceae
30	*Mastigolejeunea humilis*	Lejeuneaceae
31	*Metzgeria albinea*	Metzgeriaceae
32	*Metzgeria lindbergii*	Metzgeriaceae
33	*Mnioloma fuscum*	Calypogeiaceae
34	*Nowellia borneensis*	Cephaloziaceae
35	*Plagiochila bicornuta*	Plagiochilaceae
36	*Plagiochila blepharophora*	Plagiochilaceae
37	*Plagiochila javanica*	Plagiochilaceae
38	*Plagiochila junghuhniana*	Plagiochilaceae
39	*Plagiochila sandei*	Plagiochilaceae
40	*Plagiochila sciophila*	Plagiochilaceae
41	*Plagiochila singularis*	Plagiochilaceae
42	*Psiloclada clandestina*	Lepidoziaceae
43	*Radula amentulosa*	Radulaceae
44	*Radula apiculata*	Radulaceae
45	*Radula tabularis*	Radulaceae
46	*Riccardia albo-maginata*	Aneuraceae
47	*Riccardia elata*	Aneuraceae
48	*Riccardia fruticosa*	Aneuraceae
49	*Riccardia grollei*	Aneuraceae
50	*Riccardia heteroclada*	Aneuraceae
51	*Riccardia planiflora* var. *aequatorialis*	Aneuraceae
52	*Schistochila reinwardtii*	Schistochilaceae

Table 4.5: New liverwort records for Malaysia.

No.	Taxon	Family
1	*Acromastigum echinatiforme*	Lepidoziaceae
2	*Acroscyphella tjiwideiensis*	Balantiopsidaceae
3	*Andrewsianthus bidens*	Scapaniaceae
4	*Bazzania tricrenata*	Lepidoziaceae
5	*Cephaloziella stephanii*	Cephaloziellaceae
6	*Chandonanthus hirtellus*	Scapaniaceae
7	*Cheilolejeunea imbricata*	Lejeuneaceae
8	*Cheilolejeunea krakakammae*	Lejeuneaceae
9	*Cheilolejeunea serpentina*	Lejeuneaceae
10	*Chiloscyphus coadunatus*	Lophocoleaceae
11	*Chiloscyphus cuspidatus*	Lophocoleaceae
12	*Chiloscyphus minor*	Lophocoleaceae
13	*Chiloscyphus schiffneri*	Lophocoleaceae
14	*Cololejeunea denticulata*	Lejeuneaceae
15	*Cololejeunea dinghuiana*	Lejeuneaceae
16	*Cololejeunea drepanolejeuneoides*	Lejeuneaceae
17	*Cololejeunea grossepapillosa*	Lejeuneaceae
18	*Cololejeunea plagiophylla*	Lejeuneaceae
19	*Cololejeunea spinosa*	Lejeuneaceae
20	*Colura inuii*	Lejeuneaceae
21	*Gottschea integerrina*	Schistochilaceae
22	*Hattoriella subscrispa*	Jungermanniaceae
23	*Heteroscyphus tridentatus*	Lophocoleaceae
24	*Kurzia mauiensis*	Lepidoziaceae
25	*Lejeunea dentata*	Lejeuneaceae
26	*Lejeunea ulicina*	Lejeuneaceae
27	*Lopholejeunea latialata*	Lejeuneaceae
28	*Lopholejeunea nicobarica*	Lejeuneaceae
29	*Metzgeria ciliata*	Metzgeriaceae
30	*Mnioloma stamatotonum*	Calypogeiaceae
31	*Plagiochila fusca*	Plagiochilaceae
32	*Plagiochila gracilis*	Plagiochilaceae
33	*Plagiochila salacensis*	Plagiochilaceae
34	*Plagiochila stephanii*	Plagiochilaceae
35	*Radula caduca*	Radulaceae
36	*Radula falcata*	Radulaceae
37	*Radula kurziii*	Radulaceae
38	*Radula lingulata*	Radulaceae
39	*Riccadia diminuta*	Aneuraceae
40	*Riccardia hattorii*	Aneuraceae
41	*Riccardia latifrons*	Aneuraceae
42	*Riccardia multifida*	Aneuraceae
43	*Riccardia multifidoides*	Aneuraceae
44	*Riccardia pumila*	Aneuraceae
45	*Riccardia singapurensis*	Aneuraceae
46	*Saccogynidium irregularospinum*	Geocalycaceae
47	*Schistochila nyamanii*	Schistochilaceae
48	*Symphyogyna similis*	Pallaviciniaceae
49	*Symphyogynopsis gottscheana*	Pallaviciniaceae
50	*Telaranae granulata*	Lepidoziaceae
51	*Telaranea papulosa*	Lepidoziaceae
52	*Telaranea patentissima*	Lepidoziaceae
53	*Thysananthus minor*	Lejeuneaceae
54	*Triandrophyllum heterophyllum*	Herbertaceae

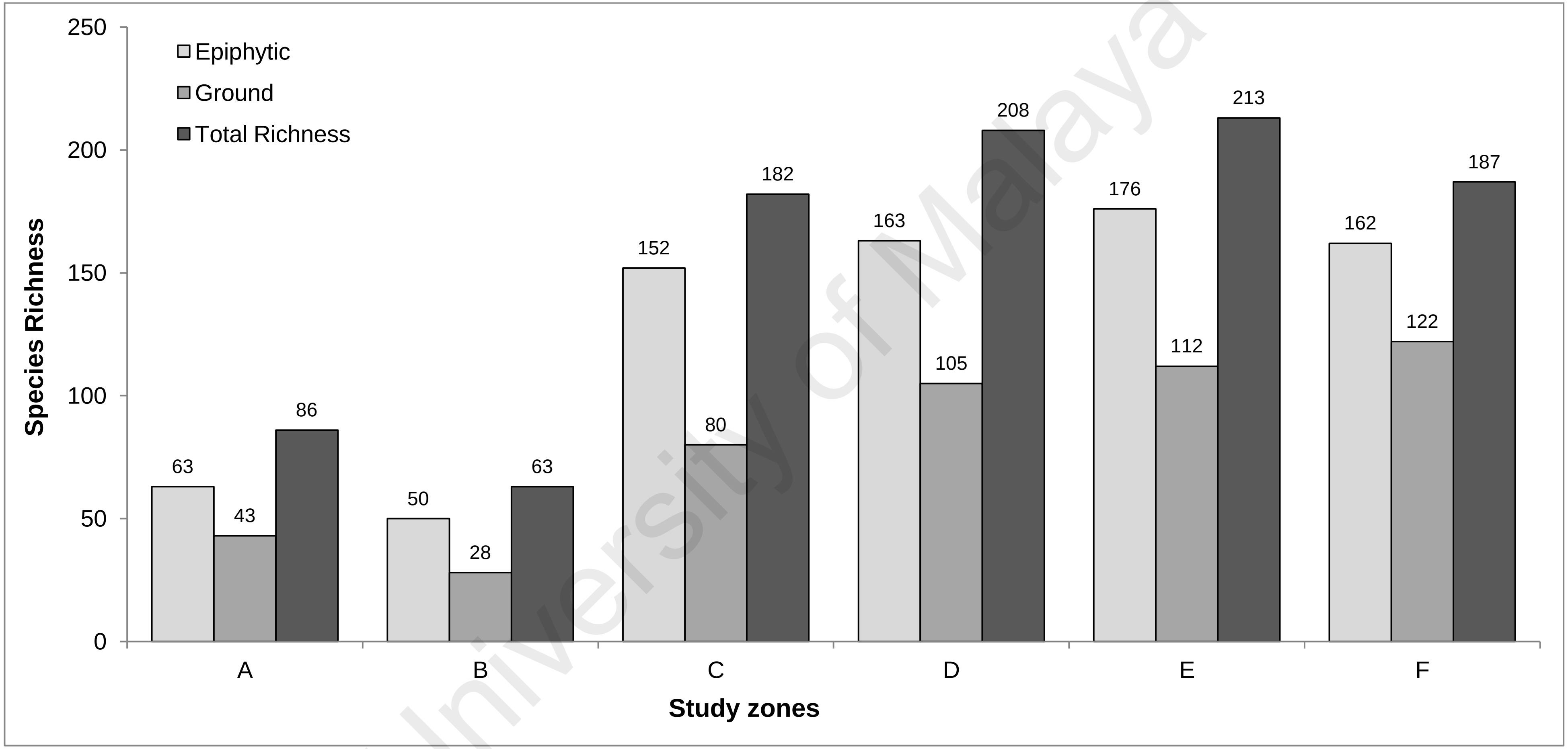


Figure 4.4: Bryophyte diversity recorded for each altitudinal zone at Genting Highlands.

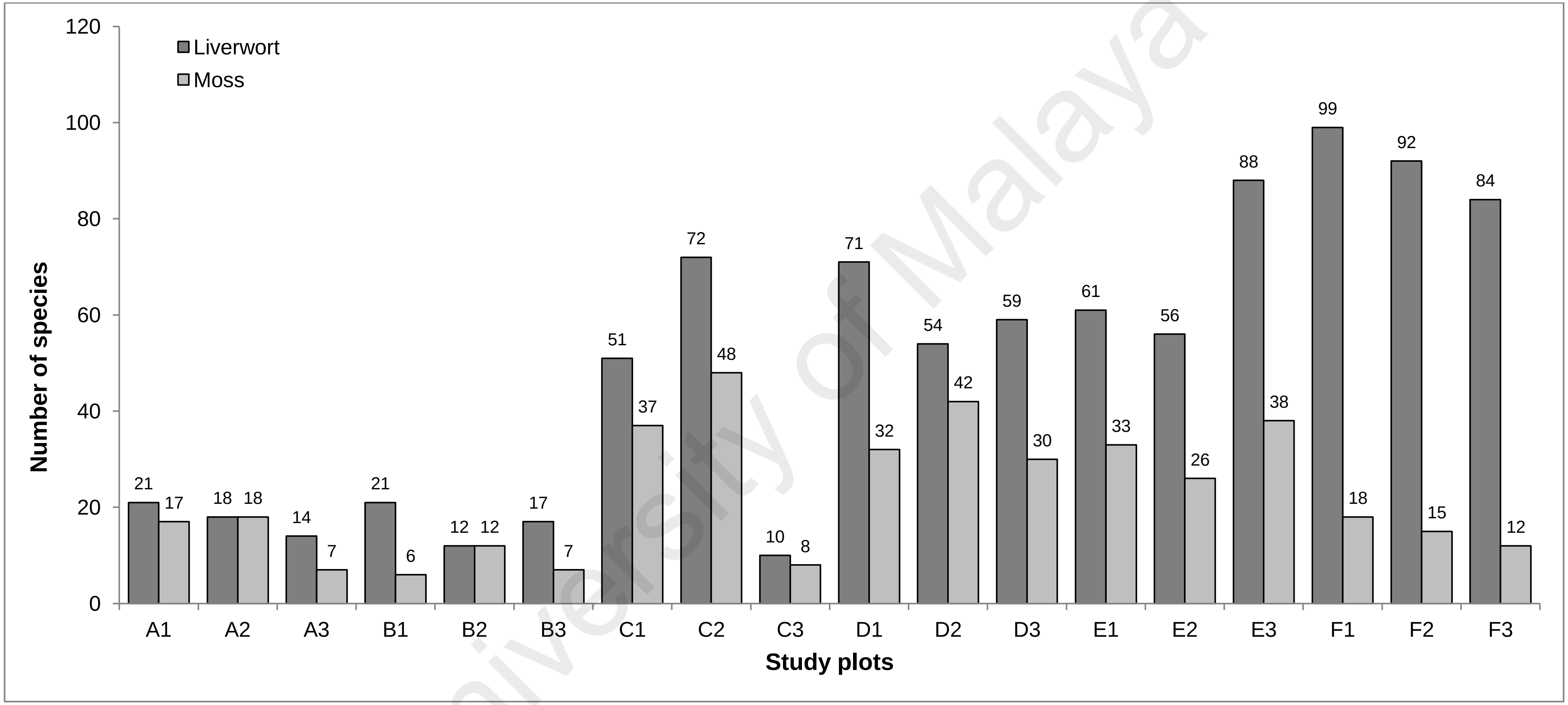


Figure 4.5: Species richness of epiphytic bryophytes at each study plot in Genting Highlands with dark grey bars representing liverworts and light grey bars representing mosses.

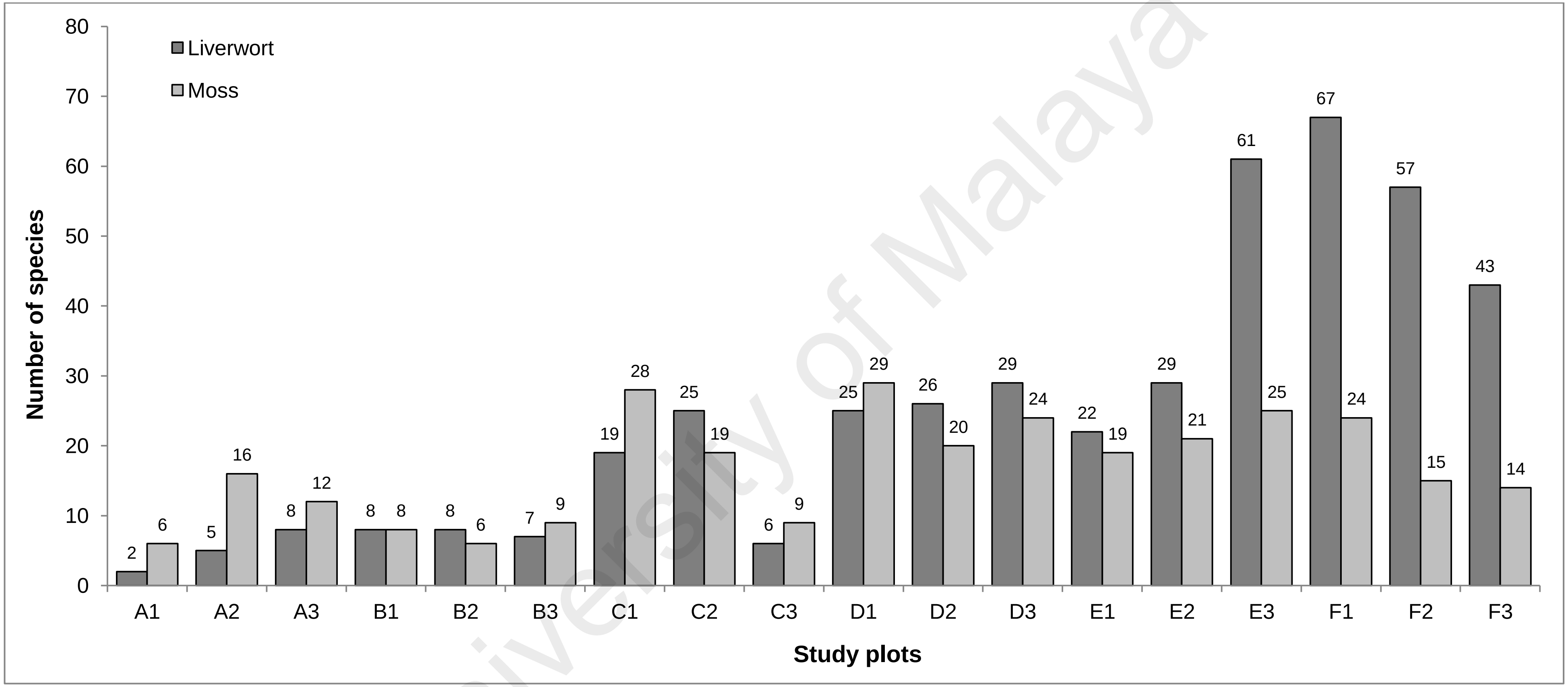


Figure 4.6: Species richness of ground bryophytes at each study plot in Genting Highlands with dark grey bars representing liverworts and light grey bars representing mosses.

collecting a liverwort species on a tree trunk at zones E and F was 0.87 and 0.83, respectively, and of collecting a liverwort species on the ground was 0.68 and 0.77, respectively (Figure 4.7). Mosses, however, are more diverse at lower elevations, especially on the ground when the chance of collecting a moss from the ground in zone A was as high as 0.75 in plots A1 and A2, reaching 0.60 in plot A3 (Figure 4.6). The ratio of liverwort to moss diversity for both epiphytic and ground habitats, at all four lower zones, A–D, is more even, with the ratio ranged merely from 0.54 to 1.60 (Figure 4.7).

The general diversity was summarized in families, with total number of species across all sampling plots for epiphytic bryophytes (Figure 4.8), and ground bryophytes (Figure 4.9) in the present study. Members of Lejeuneaceae contributed the most number of species, accounting for about 24% of the total epiphytic bryophyte species, followed by Lepidoziaceae (12.4%), Calymperaceae (8.8%) and Sematophyllaceae (6.4%). The four above-mentioned families, together with Plagiochilaceae, Lophocoleaceae, Radulaceae, Aneuraceae, Pylaisiadelphaceae and Dicranaceae are the top 10 diverse families, accounted for 73.5% of the total richness observed on tree trunk (Figure 4.8). As for ground bryophyte, Lejeuneaceae and Lepidoziaceae again top the chart, contributing 14.7% and 13.3%, of the total recorded ground bryophyte species in the present study. The subsequent eight families, viz., Sematophyllaceae, Aneuraceae, Lophocoleaceae, Calymperaceae, Hypnaceae, Plagiochilaceae, Radulaceae, and Fissidentaceae, together with the two above-mentioned most diverse families, accounted for about 69.9% of total number of ground bryophyte species (Figure 4.9).

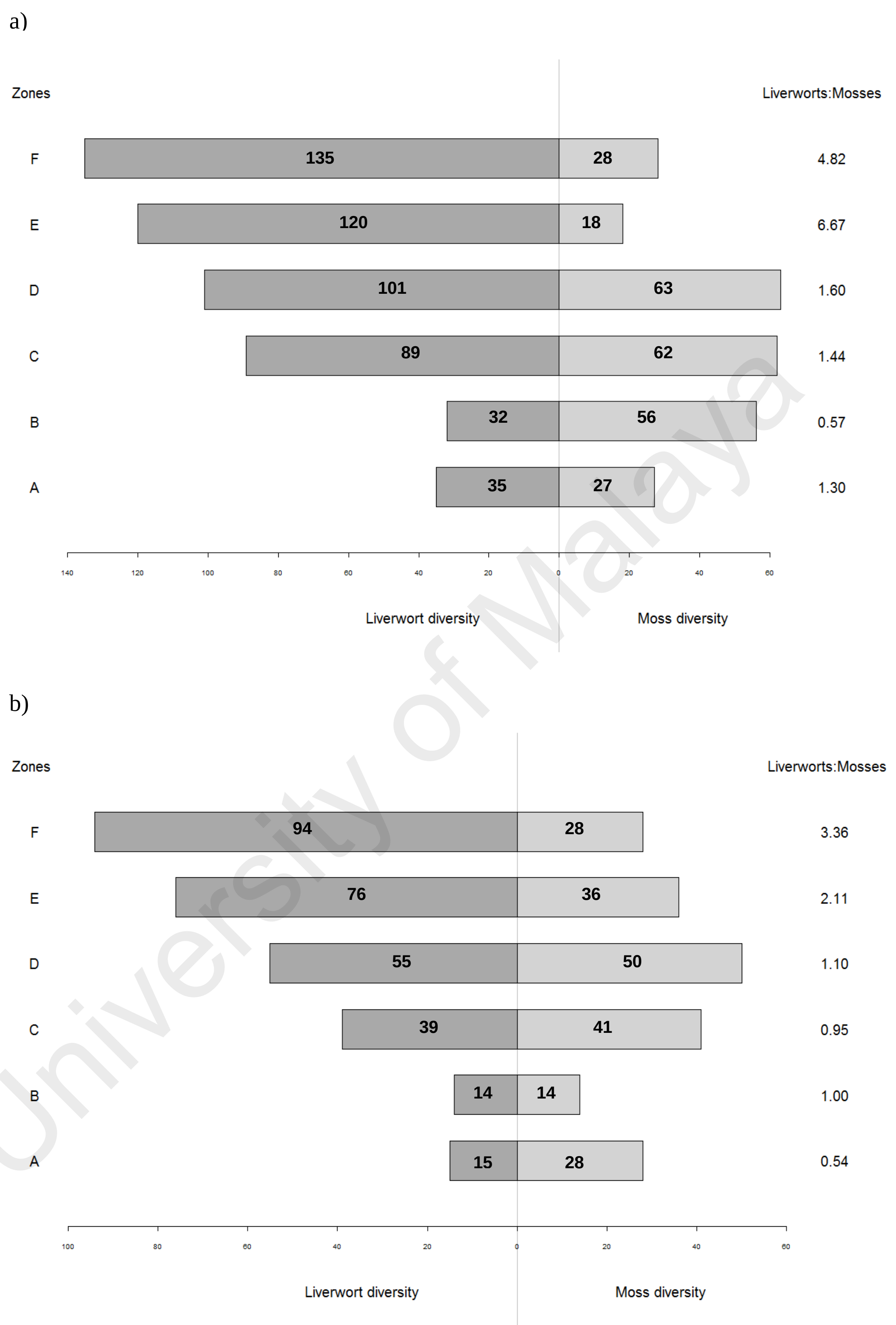


Figure 4.7: Ratio of liverwort and moss species found a) on tree trunks, b) on the ground, in the six elevational zones. Numbers on the right are the ratio of liverworts to mosses at each elevation zone. Horizontal axes indicate the number of liverwort and moss species recorded for each zone.

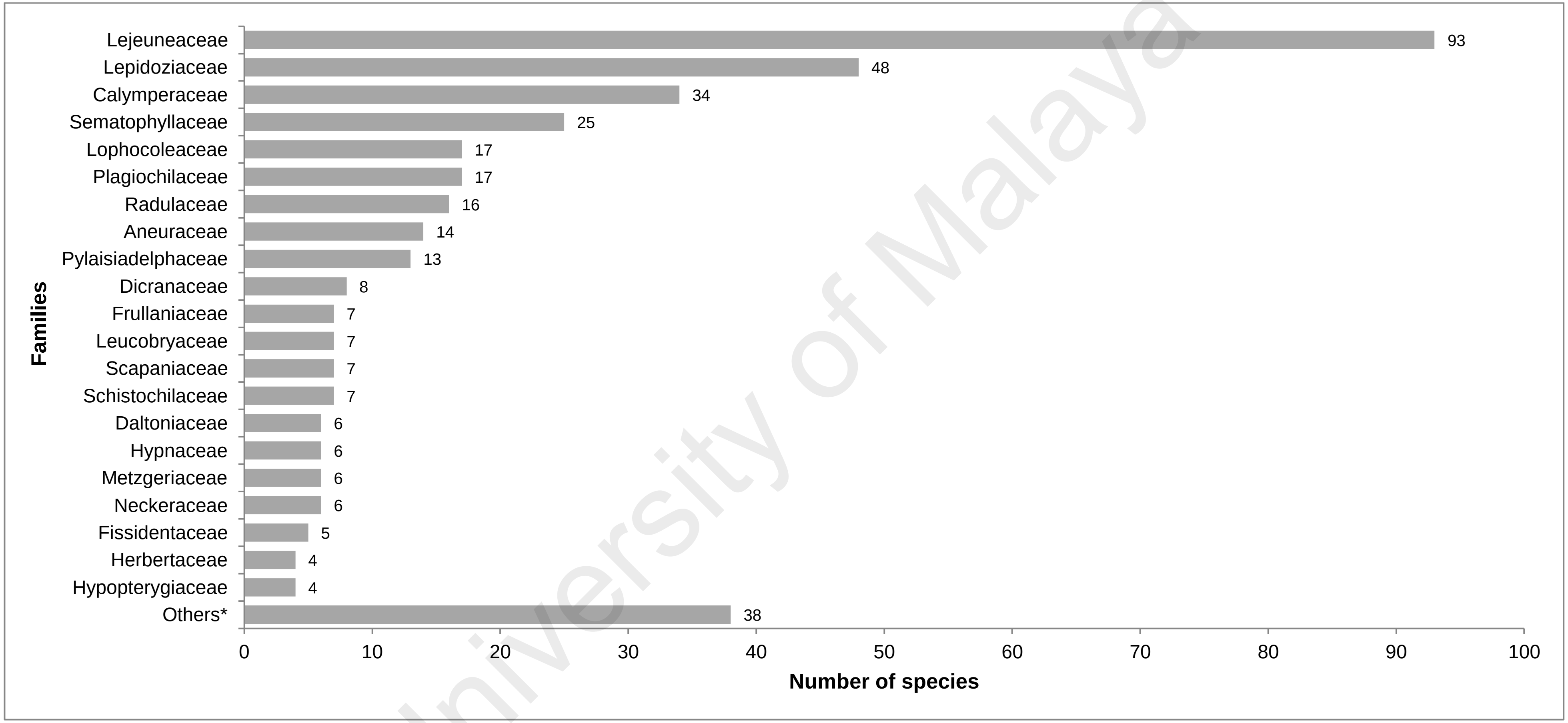


Figure 4.8: Bryophyte families collected from tree trunks in Genting Highlands, arranged according to species richness in descending order. '*' denotes 20 other families with low species richness reported in the present study.

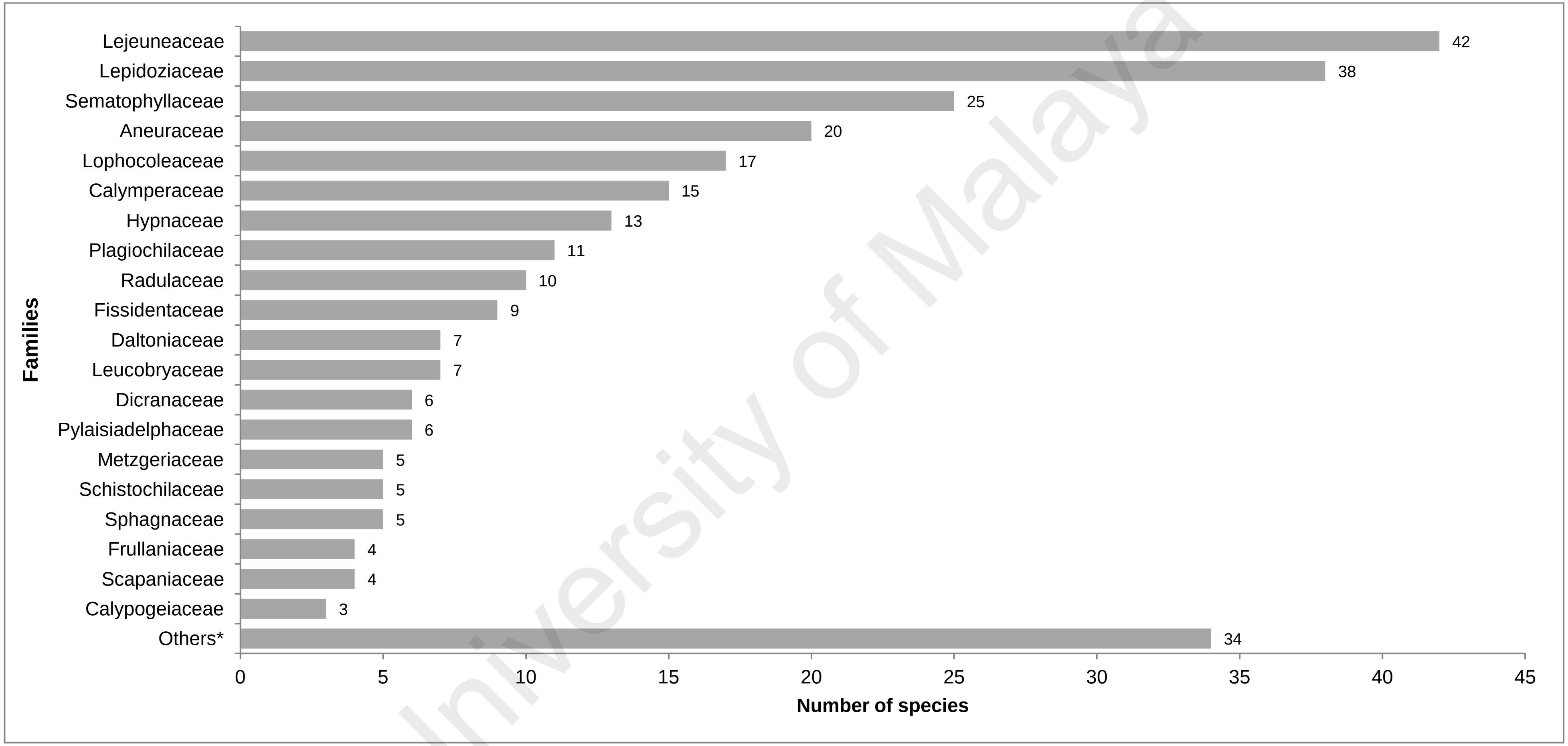


Figure 4.9: Bryophyte families collected from forest ground in Genting Highlands, arranged according to species richness in descending order. ‘*’ denotes 26 other families with low species richness reported in the present study.

4.4 Bryophyte richness and effective number of species

The species rank abundance curves for epiphytic bryophytes from the different study plots of the same elevation zones depicted similar distributional patterns, and in general fitting the log-normal series (Figure 4.10). The curve always starts off with a small number of dominant or common species of a study plot, and then decreases into a gentle slope which generally displays the log-normal distribution (Figure 4.10). The curves for the study plots at zone C (except plot C3 with lower species richness), D, E, and F, have a very broad and gentle slope that eventually tapers off, becoming somewhat linear, indicating many taxa were fairly similar in terms of their relative abundance or indicates a high evenness (Figure 4.10). In summary, species with few or single population and occupying a smaller niche (rare species), are more common than those species that present in many populations and occupying a larger area (dominant species). In the present study, all species rank abundance curves generated for both epiphytic and ground bryophytes have negative species abundance values (y-axis) (Figure 4.10 & 4.11). This implies that many bryophytes occupied a relatively small coverage as compared to the whole sampling area.

The species rank abundance curves based on ground bryophytes were similar to epiphytic bryophytes in their distributional patterns, even though lower species richness was reported for ground bryophytes in every study plot, of respective elevation zone. Likewise, it was found that high evenness, or rare or less abundant species (singletons), were more commonly occurs at higher elevations in the case of ground bryophytes.

In order to better assess the bryophyte richness at different study plots, diversity indices such as the Shannon entropy and the Gini-Simpson index were employed, and the effective number of species were generated for comparison (Table 4.6 & 4.7). The number of equally-common species, also known as the effective number of species,

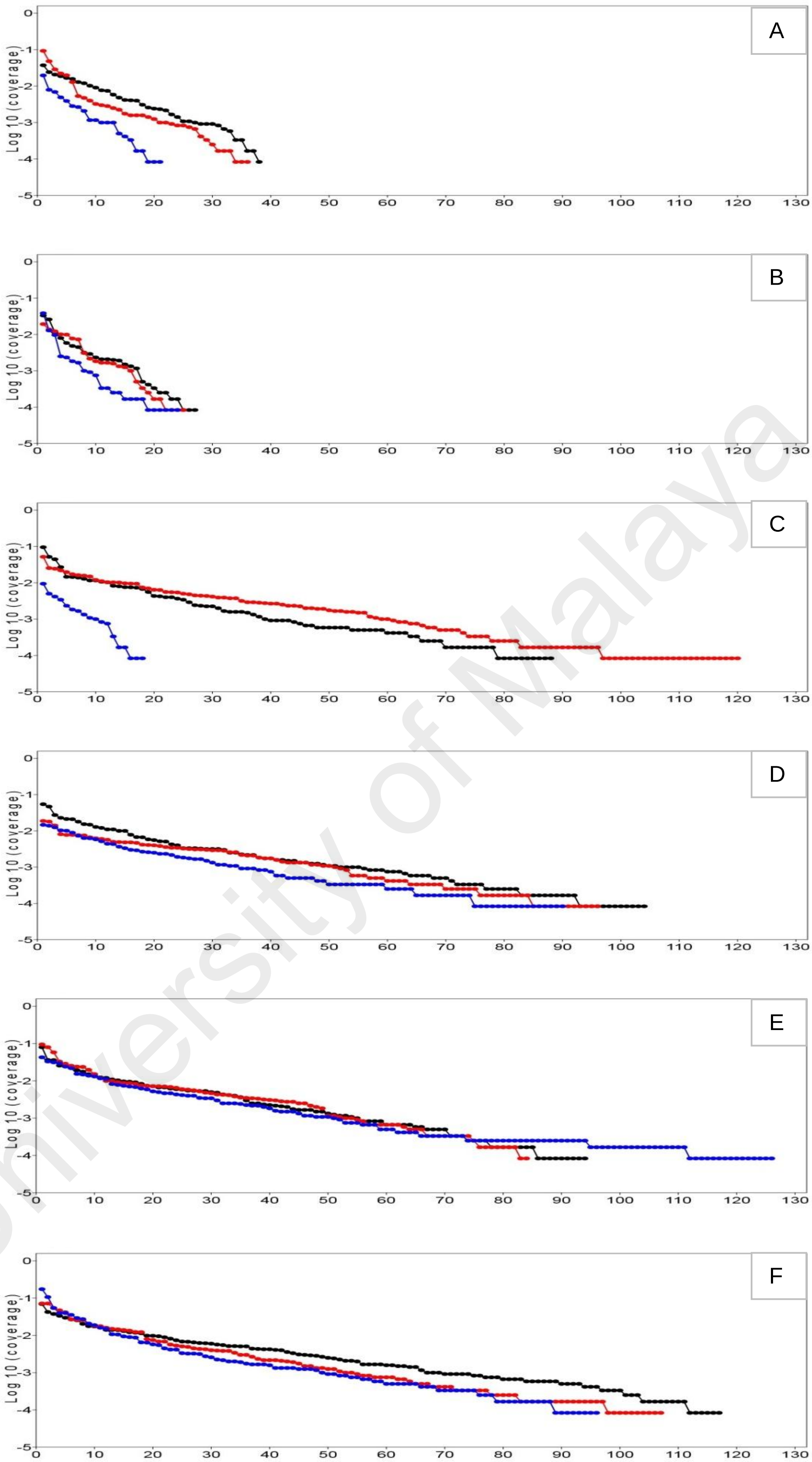


Figure 4.10: Species rank abundance curves for epiphytic bryophytes collected from study plots at zone A (1–300 m), B (301–600 m), C (601–900 m), D (901–1200 m), E (1201–1500 m) and F (1501–1700 m). Black lines indicate Plot 1, red lines indicate Plot 2 and blue lines indicate Plot 3. Horizontal or X-axes are the species rank according to dominance in descending order.

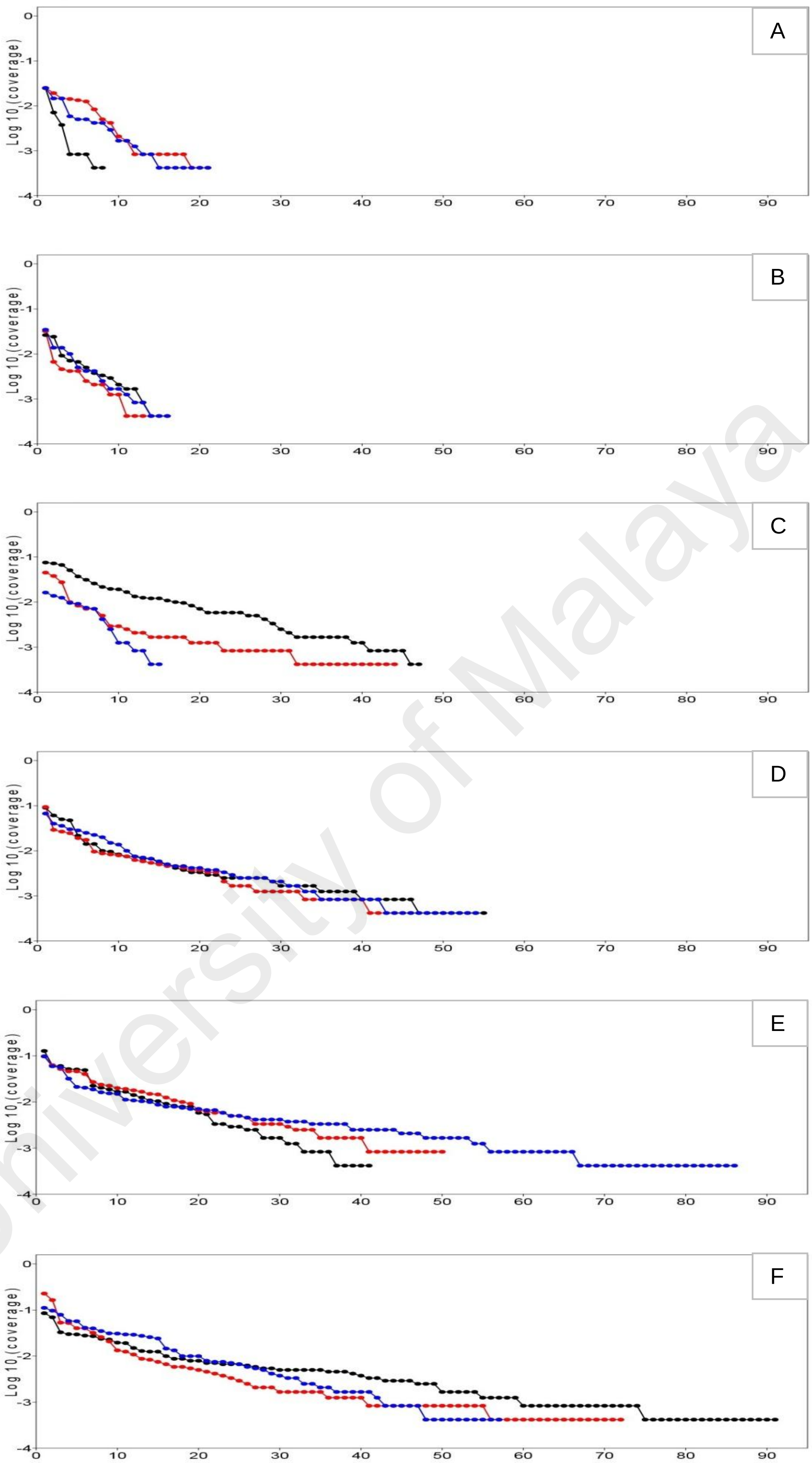


Figure 4.11: Species rank abundance curves for ground bryophytes collected from study plots at zone A (1–300 m), B (301–600 m), C (601–900 m), D (901–1200 m), E (1201–1500 m) and F (1501–1700 m). Black lines indicate Plot 1, red lines indicate Plot 2 and blue lines indicate Plot 3. Horizontal or X-axes are the species rank according to dominance in descending order.

Table 4.6: Summary of epiphytic bryophyte species richness and effective number of species in 18 study plots in the Genting Highlands. Highest values of D^0, D^1 and D^2 are highlighted in bold.

Plot	Total frequency	Total coverage (cm^2)	Relative coverage (%)	Total number of families	Total number of genera	Total number of species, D^0	H′	λ	exp (H'), D^1	1/(1-λ), D^2
A1	198	8658	24.05	5	21	38	3.088	0.9343	22	15
A2	179	9696	26.93	11	23	36	3.079	0.9314	22	15
A3	87	2091	5.81	4	15	21	2.72	0.918	15	12
B1	99	4194	11.65	4	15	27	3.012	0.9393	20	16
B2	63	3519	9.78	7	18	24	2.957	0.9383	19	16
B3	48	2679	7.44	8	19	24	3.035	0.9453	21	18
C1	490	15753	43.76	19	42	88	4.004	0.9749	55	40
C2	682	15987	44.41	22	52	120	4.311	0.9814	75	54
C3	57	1215	3.38	6	13	18	2.719	0.9234	15	13
D1	574	15756	43.77	22	44	103	4.119	0.9767	61	43
D2	386	8370	23.25	21	48	96	4.221	0.9806	68	52
D3	293	6156	17.10	16	37	89	4.114	0.9769	61	43
E1	418	18738	52.05	20	45	94	4.075	0.9763	59	42
E2	537	22608	62.80	24	43	82	3.94	0.9739	51	38
E3	761	15012	41.70	21	50	**126**	4.276	0.9804	72	51
F1	1052	23523	65.34	25	44	117	4.329	0.983	**76**	**59**
F2	798	23586	65.52	26	42	107	4.113	0.9778	61	45
F3	815	26274	72.98	23	40	96	3.939	0.9729	51	37

H′ = Shannon entropy ≡ $-\sum_{i=1}^{S} p_i \ln p_i$; λ = Gini-Simpson index ≡ $1- \sum_{i=1}^{S} p_i^2$

Table 4.7: Summary of ground bryophyte species richness and effective number of species in 18 study plots in the Genting Highland. Highest values of D^{0}, D^{1} and D^{2} are highlighted in bold.

Plot	Total frequency	Total coverage (cm^2)	Relative coverage (%)	Total number of families	Total number of genera	Total number of species, D^{0}	H′	λ	exp (H'), D^{1}	1/(1-λ), D^{2}
A1	18	1162.5	3.88	5	7	8	1.813	0.8025	6	5
A2	38	3812.5	12.71	11	16	21	2.816	0.9252	17	13
A3	51	2712.5	9.04	5	11	20	2.738	0.9204	15	13
B1	37	2875	9.58	10	11	16	2.573	0.9087	13	11
B2	34	1875	6.25	8	10	14	2.341	0.872	10	8
B3	38	2862.5	9.54	11	12	16	2.481	0.8934	12	9
C1	122	18075	60.25	20	31	47	3.59	0.9663	36	30
C2	66	5600	18.67	16	27	44	3.642	0.9692	38	32
C3	57	2625	8.75	9	12	15	2.448	0.8969	12	10
D1	95	12800	42.67	24	34	54	3.809	0.9731	45	37
D2	112	9800	32.67	18	27	46	3.6	0.9664	37	30
D3	137	12075	40.25	17	29	53	3.708	0.9693	41	33
E1	114	18587.5	61.96	16	23	41	3.414	0.9586	30	24
E2	125	19400	64.67	20	27	50	3.603	0.965	37	29
E3	216	17125	57.08	23	41	86	4.187	0.981	**66**	**53**
F1	285	19587.5	65.29	22	38	**91**	4.181	0.9808	65	52
F2	175	24350	81.17	18	30	72	4.005	0.9768	55	43
F3	190	26100	87.00	17	26	57	3.808	0.9735	45	38

H′ = Shannon entropy ≡ $-\sum_{i=1}^{S} p_i \ln p_i$; λ = Gini-Simpson index ≡ $1-\sum_{i=1}^{S} p_i^2$

measures the degree to which proportional abundances are distributed among species, where each species is weighted by its abundance. In general, the value of the Shannon effective number of species (D^1) will be smaller than the observed species richness (D^0) when there is a degree of dominance. The Gini-Simpson effective number of species (D^2), on the other hand, possesses a value that is even smaller than D^1 after a second degree of elimination of less abundant species. Hence, the effective number of species follows $D^0 > D^1 > D^2$, with a higher number of dominants in a community contributing to greater differences between the values of D^0, D^1, and D^2. The value of D^1 is equated to the number of abundant species in a community, whereas the value of D^2 corresponds to the number of very abundant species.

According to Table 4.6 and 4.8a, study plot E3 for epiphytic bryophytes does not exhibit highest effective species richness in D^1 and D^2 even though the highest observed species richness was reported for that plot. Likewise, study plot F1 for ground bryophytes has the highest D^0 but study plot E3 has higher D^1 and D^2 values, suggesting that the latter study plot has more dominant species compared to the former (Table 4.7 & 4.8b). Determination of true species richness of study plots in zones A and B showed greater impact on the relative plot richness compared to higher zones, e.g. zones E and F.

4.5 Floristic composition

Both species coverage and frequency data are commonly used in ecological study, as well in the present study. Total coverage of a species indeed provides the information of how abundant a species within an investigated area, which indirectly implying the degree of dominance of that species. This information has been employed by researchers on bryophyte studies (Alvarenga & Pôrto, 2007; Frahm, 1994a; Stehn *et al.*, 2010; van Reenen & Gradstein, 1984), and other taxonomic groups, including ferns

(Karst *et al.*, 2005; Negishi *et al.*, 2006; Silva & Schmitt, 2015) and lichens (Das *et al.*, 2013; Dymytrova, 2009; Grandin, 2011).

In general, liverworts were more frequently sampled and covered a bigger area in relative to the mosses on the tree trunk in most of the study plots (Figure 4.12). Mosses were more abundant, or with a larger coverage at the lower elevation, as in plots A2, B3, C1, C2 and C3, from elevation 300 m to 900 m a.s.l. In plot D2, epiphytic mosses covered a slightly larger area when compared to the epiphytic liverworts, however, the richness as well as the frequency to encounter a liverwort species is still higher than the moss (Figure 4.5). At higher elevation, liverworts always dominate the trunk-base area, particularly at location closed to or at the summit zone; liverworts occupied 90% of the investigated area in plots E3, F1, F2, and F3 (Figure 4.12). In contrast to tree-trunk inhabiting species, mosses found on the ground were almost as abundant as liverworts although the latter were more diverse (Figure 4.13). Mosses were more abundant and covered more than 50% of the investigated ground area in seven out of nine plots at or below 900 m elevation, viz., A1, A2, A3, B2, C1, C2 and C3, whereas, about equally abundant to the liverworts for plot B1 (Figure 4.13). It is worth noting that liverworts outnumbered mosses and more abundant at higher elevation, but not in two of the plots in zone F, viz., F2 and F3. Members of Sphagnaceae were found to appear in abundance which covered a substantial amount of ground area in these two plots.

The first 20 bryophyte families, viz., 11 liverwort families and 9 moss families, with total coverage beyond 1500 cm^2 on tree trunks are listed in Figure 4.14. These bryophytes constitute a great proportion or about 96% of total coverage documented on tree trunks in the present study. The remaining 21 families which are not detailed in

Table 4.8: Comparison of sequences of study plots in each zone based on values of observed species richness (D^0), Shannon effective number of species (D^1) and Gini-Simpson effective number of species (D^2) for a) epiphytic bryophytes and b) ground bryophytes. Zones with changes in sequence of study plots between D^o, D^1, and D^2 are denoted by '*'. Study plots with highest values in D^o, D^1, and D^2, respectively, are highlighted in bold.

a) Epiphytic bryophytes

Zone	D^o	D^1	D^2
A*	A1 > A2 > A3	[A1 = A2] > A3	[A1 = A2] > A3
B*	B1 > [B2 = B3]	B3 > B1 > B2	B3 > [B1 = B2]
C	C2 > C1 > C3	C2 > C1 > C3	C2 > C1 > C3
D*	D1 > D2 > D3	D2 > [D1 = D3]	D2 > [D1 = D3]
E	**E3** > E1 > E2	E3 > E1 > E2	E3 > E1 > E2
F	F1 > F2 > F3	**F1** > F2 > F3	**F1** > F2 > F3

b) Ground bryophytes

Zone	D^o	D^1	D^2
A*	A2 > A3 > A1	A2 > A3 > A1	[A2 = A3] > A1
B*	[B1 = B3] > B2	B1 > B3 > B2	B1 > B3 > B2
C*	C1 > C2 > C3	C2 > C1 > C3	C2 > C1 > C3
D	D1 > D3 > D2	D1 > D3 > D2	D1 > D3 > D2
E	E3 > E2 > E1	**E3** > E2 > E1	**E3** > E2 > E1
F	**F1** > F2 > F3	F1 > F2 > F3	F1 > F2 > F3

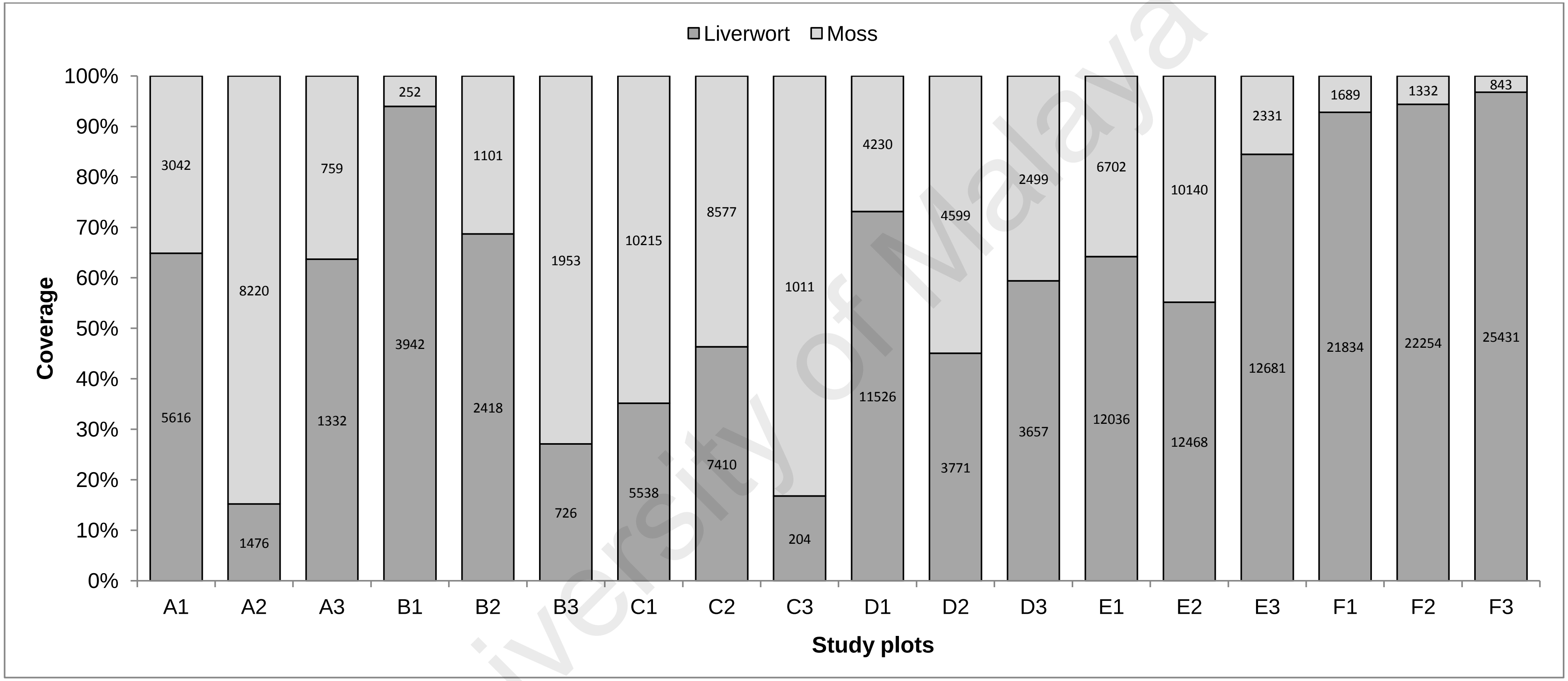


Figure 4.12: Abundance of epiphytic bryophytes, based on the total coverage (in cm²) on tree trunks, with dark grey indicating liverwort and light grey indicating moss. Figure given in the vertical bar is the total coverage recorded for each bryophyte group.

Figure 4.14 make up only 4% of total recorded coverage, less than the area occupied by any of the six families which top the chart. Lepidoziaceae is the most abundant bryophyte family found on tree trunks. Approximately 25% of total area documented in the present study was represented by members of this family, albeit its species richness was only half of the Lejeuneaceae (Appendix C & D). Members of Lejeuneaceae contributed the most number of epiphytic species and were the only family found in all 18 study plots, a frequency not attained by other families (Appendix C & D). Lejeuneaceae (15% of the total estimated coverage) was the second highest in the chart with a drop of 10% in total coverage compared to Lepidoziaceae (25%), followed by Calymperaceae (10.3%), Plagiochilaceae (10%), Sematophyllaceae (7.8%) and Radulaceae (6%) (Figure 4.14). These six families accounted for about 74% of the total coverage recorded on tree trunks. The top 15% (58 species) bryophyte species with highest coverage are summarized in Figure 4.15, and all of them are from the top 20 families depicted in Figure 4.14. These 58 species constituted about 67.8% of total coverage recorded on tree trunks whereas the remaining 32.2% were represented by 330 unlisted bryophyte species where all of them occupied only a small area and were considered as less abundant. *Acromastigum bancanum* (Lepidoziaceae) appeared to be the most abundant species in the present study, representing 5% of the total documented area. The second abundant species is *Acanthorrhynchium papillatum* (Sematophyllaceae), followed by *Chiastocaulon dendroides* (Plagiochilaceae) and *Pyrrhobryum spiniforme* (Rhizogoniaceae) which are among the top four abundant species. The bar chart gradually decreases from the fifth species until the 58th species, creating a “plateau”, indicating little difference in coverage between the two consecutive species. It is worth mentioning that as many as 16 out of 58 species depicted in Figure 4.15 are members of Lepidoziaceae, the most abundant family on tree trunk.

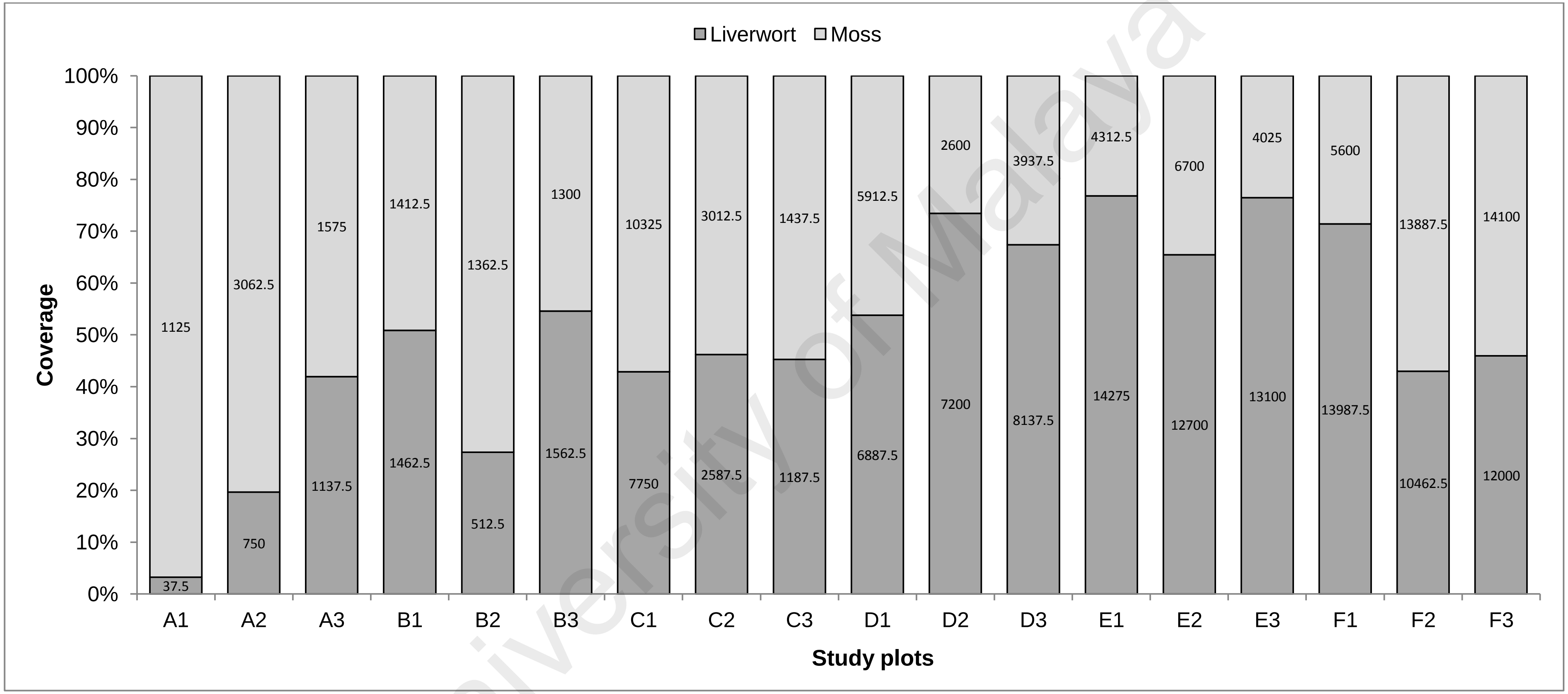


Figure 4.13: Abundance of ground bryophytes, based on the total coverage (in cm^2) on the ground, with dark grey indicating liverwort and light grey indicating moss. Figure given in the vertical bar is the total coverage recorded for each bryophyte group.

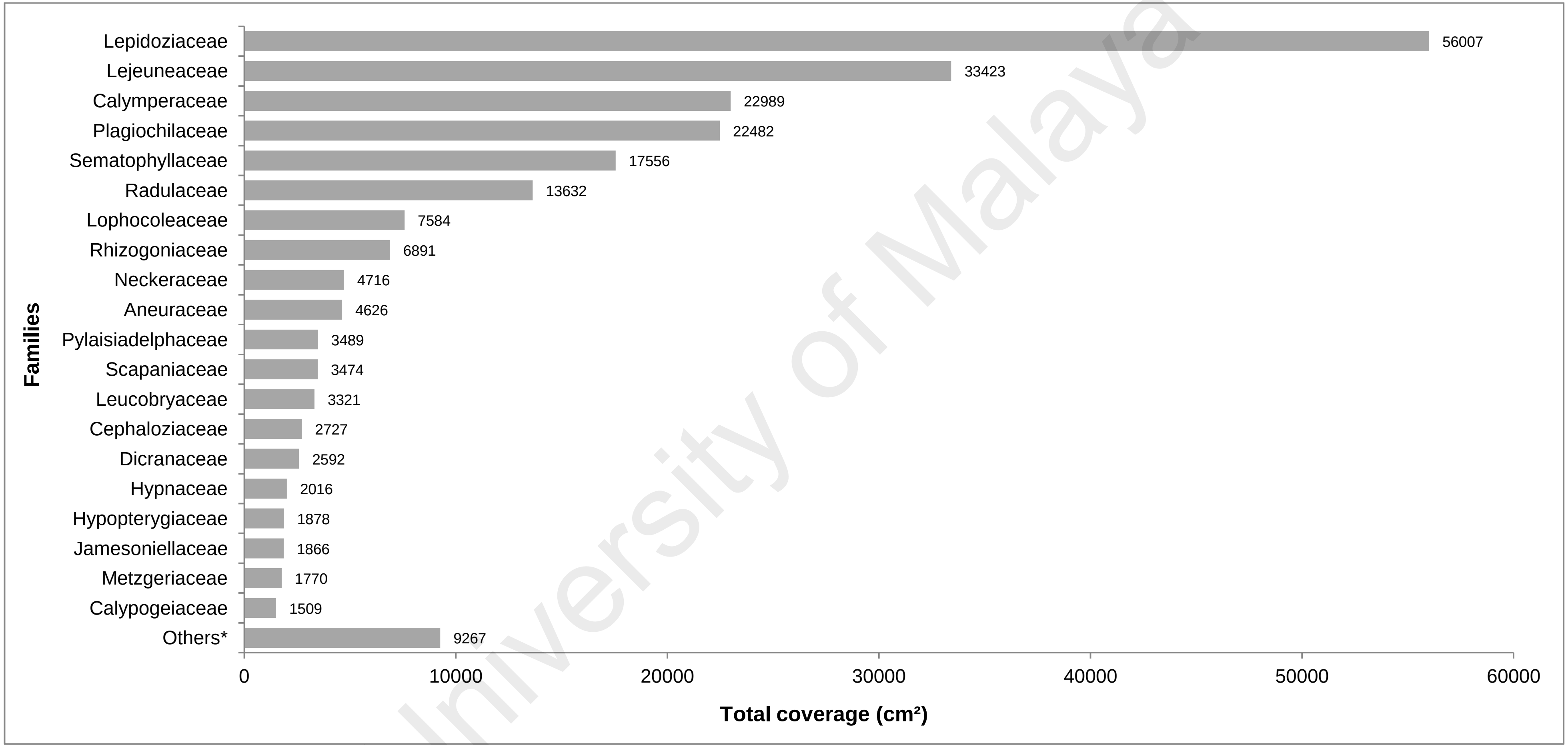


Figure 4.14: Bryophyte families collected from tree trunks in Genting Highlands, arranged according to documented coverage in descending order. '*' denotes 21 other families with low coverage reported in the present study.

The first 20 bryophyte families with total coverage beyond 2000 cm^2 on the ground habitats are listed in Figure 4.16. These families (of 9 liverwort families and 11 moss families) make up 94.8% of the total coverage recorded from the sampling quadrates laid on the forest ground. The remaining 26 families which are not detailed in Figure 4.16 accounting for only 5.2% of the total area, where this is less than the area covered by any of the five families which top the chart. The most abundant family, Lepidoziaceae, took up an area equivalent to 21.6% of the total recorded area, followed by Sphagnaceae (11.7% of the total coverage), after a sheer drop of about 10% (Figure 4.16). The third abundant family is Lophocoleaceae (11.3%), then Aneuraceae (10%) and Sematophyllaceae (9.1%) came after in sequence (Figure 4.16). For the ground bryophyte, Sematophyllaceae is the only family with its members occurred in all 18study plots. These five families constituted 63.6% of the total coverage recorded from the ground bryophytes. It was obvious that the sixth to ninth placed families, viz., Fissidentaceae, Calypogeiaceae, Hypnaceae, and Pylaisiadelphaceae, respectively, are more or less equally abundant on the ground, with total coverage one time higher than Daltoniaceae and the rest (Figure 4.16). Even though Lejeuneaceae is still the most diverse family found on the forest ground, but many of the Lejeuneaceae members covered only a small area on the ground, or of species with small plant size. Among the many ground bryophyte species, *Telaranea wallichiana* (Lepidoziaceae) is the most abundant, accounting for 6.4% of the total coverage of all recorded ground species, together with *Sphagnum perichaetiale* (Sphagnaceae), *Heteroscyphus coalitus* (Lophocoleaceae), *Sphagnum cuspidatulum* (Sphagnaceae) and *Calypogeia arguta* Calypogeiaceae) made up the five most abundant species on the ground (Figure 4.17). Lepidoziaceae had nine members listed in the chart, which made it the most abundant family for recorded ground bryophytes (Figure 4.17). It is worth mentioning that the second most abundant family, Sphagnaceae is only represented by five members in

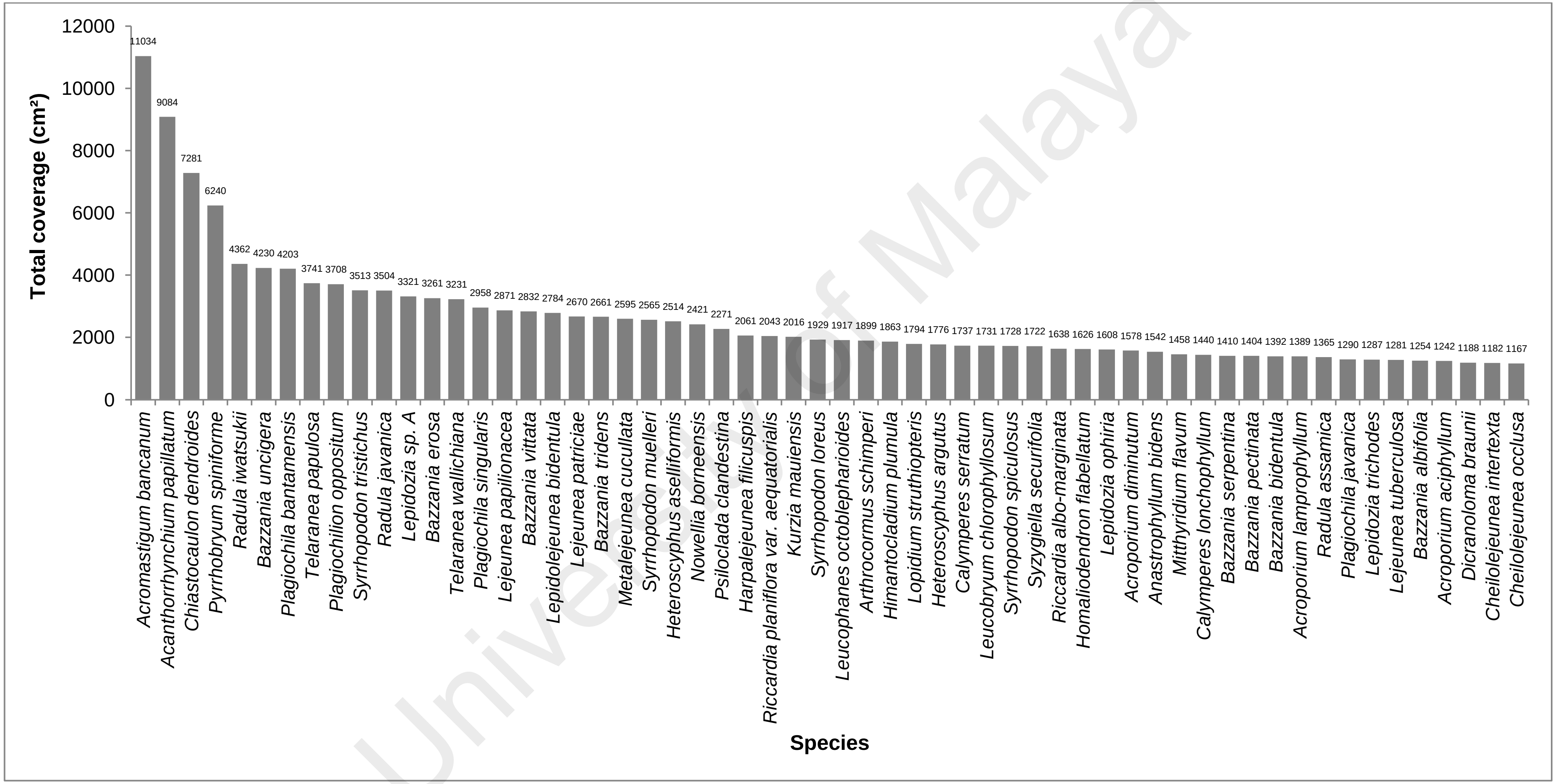


Figure 4.15: Bryophyte species collected from tree trunks in Genting Highlands, ranked according to documented coverage in descending order. Only 15% of the bryophyte diversity, with the highest coverage values, is represented here.

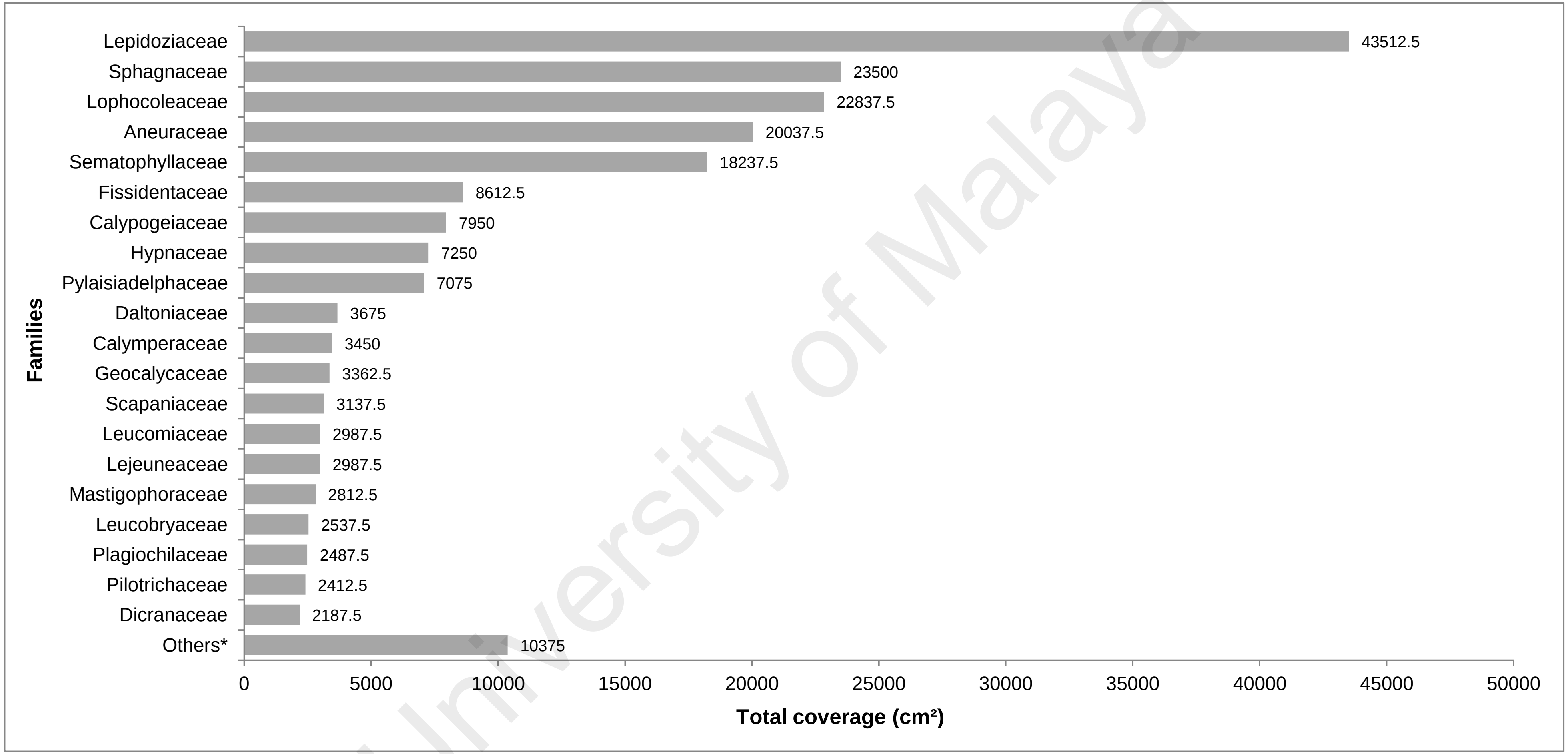


Figure 4.16: Bryophyte families collected from forest ground in Genting Highlands, arranged according to documented coverage in descending order. '*' denotes 26 other families with low coverage reported in the present study.

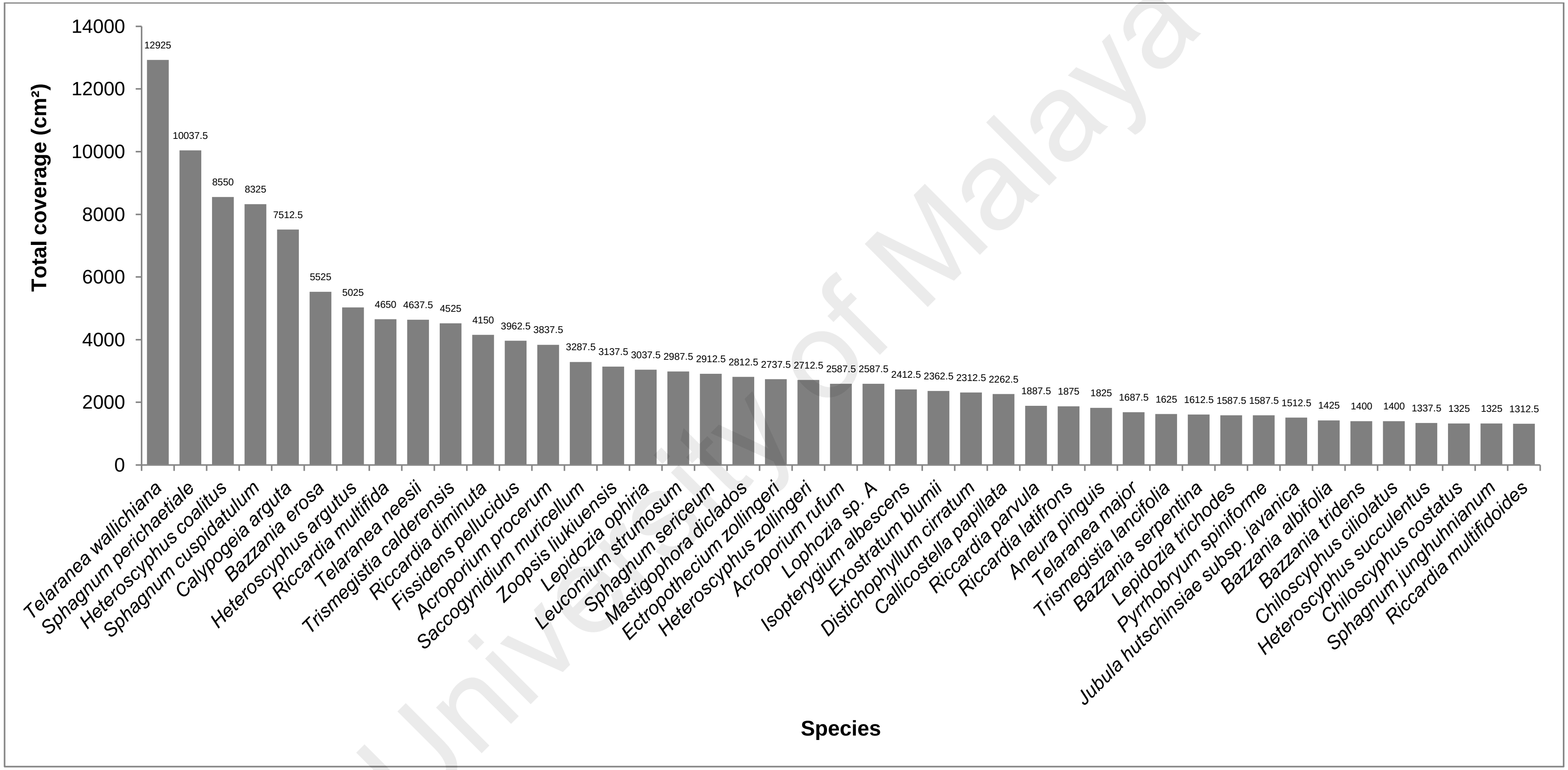


Figure 4.17: Bryophyte species collected from forest ground in Genting Highlands, ranked according to documented coverage in descending order. Only 15% of the total bryophyte diversity, with the highest coverage value, is represented here.

Genting Highlands, where four of them are significant enough in their total coverage and are listed in the chart. Of these, two of them are among the top five abundant species documented in the present study (Figure 4.17). All 43 species listed in Figure 4.17 are members of the top 20 families depicted in Figure 4.16, except for *Pyrrhobryum spiniforme* (Rhizogoniaceae) and *Jubula hutschinsiae* subsp. *javanica* (Jubulaceae). All the listed species in Figure 4.17, accounting for 72.8% of the total coverage for recorded ground bryophyte species. There were 243 unlisted species which constituted the remaining percentage, 27.2% of the total coverage.

4.6 Habitat preferences

The epiphytic bryophytes in the present study were sampled from different cardinal directions on tree trunks and from different bark surfaces. In respect of cardinal direction preference, the chi-squared tests revealed that only bryophytes found in zones B and C have a clear preference on certain directions, whereas the distribution of bryophytes in zones A, D and E were not influenced by cardinal direction (Table 4.9). At the Genting Highlands, day length did not differ much throughout the year. In the northern hemisphere or temperate country, the longer day and shorter night, or otherwise, would promote the establishment of bryophytes on the northern side of a tree as more sunlight hit the southern side of the phorophyte (Franks & Bergstrom, 2000; Trynoski & Glime, 1982). The converse situation occurred in zones B and C where the north and west sides of the phorophyte received a greater amount of sunlight, which could conceivably hinder the growth of bryophytes that prefer a shady and wet habitat.

As for bark texture and ground preference, the Kruskal-Wallis test for equal medians showed a significant difference between medians of four variables in bark texture (Table 4.10a) and ground preference (Table 4.10b), respectively. Hence, a further analysis using Draftsman's plot was employed. Different types of tree bark present a variety of habitats to different bryophytes. In the present study, Draftsman's plot showed that epiphytic moss demonstrated wider distributional range as many species were found occurring on different bark textures instead of holding on to a particular bark type (Figure 4.18). Epiphytic liverwort however, displayed a rather discrete pattern, where less number of species utilizing different bark types. Epiphytic liverworts were more host specify than epiphytic mosses. Nonetheless, it was apparent that many epiphytic liverwort species found on fissured bark were also occurring on flaking bark.

Table 4.9: a) Total occurrences of bryophyte on different faces of tree trunk and b) The Chi-squared test to evaluate the cardinal direction preference of epiphytic bryophytes in five elevation zones. A total of 315 bryophyte species was enumerated from zones A–E.

a)

Zone	North	South	East	West
A	122	128	116	98
B	24	89	53	44
C	266	345	357	263
D	322	335	278	318
E	403	443	433	445
Total	1137	1340	1237	1168

b)

Zone	Chi-square (χ^2)	p-value	significance level of 95%
A	4.345	0.227	not significant
B	42.229	<0.001	**significant**
C	24.561	<0.001	**significant**
D	5.793	0.122	not significant
E	2.617	0.454	not significant

Table 4.10: Non-parametric test for equal medians of all four variables for a) bark texture and b) ground substrate.

a)

Kruskal-Wallis test		
H(chi²):	29.53	
Hc (tie corrected):	31.36	
p(same):	7.122×10^{-7}	($p<0.05$)
		There is **a** significant difference between sample medians

b)

Kruskal-Wallis test		
H(chi²):	194.8	
Hc (tie corrected):	238.9	
p(same):	1.668×10^{-51}	($p<0.05$)
		There is **a** significant difference between sample medians

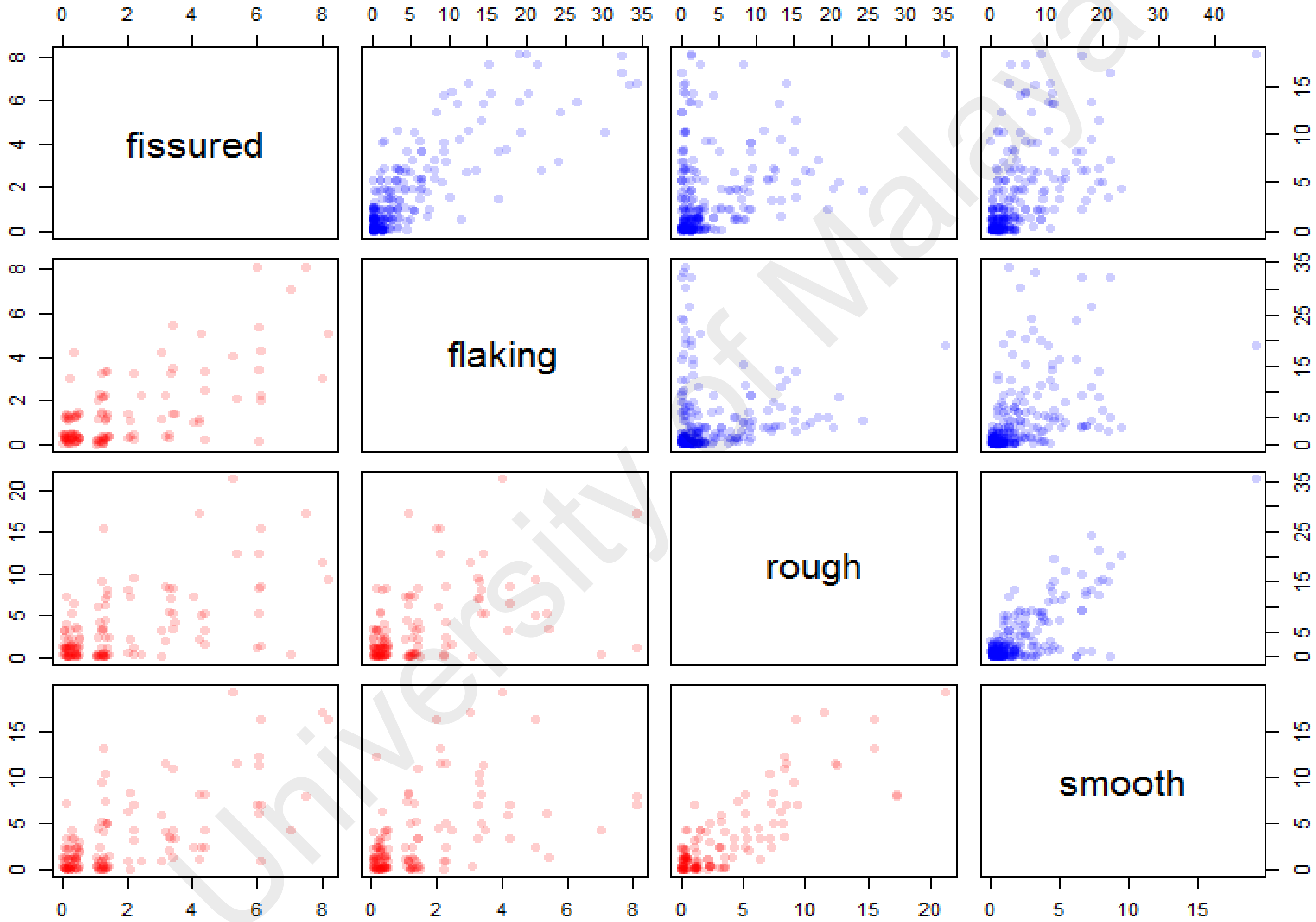


Figure 4.18: Draftsman's plot showing the bark preference for epiphytic bryophytes with red indicating mosses and blue indicating liverworts.

Likewise, epiphytic moss that was found on rough bark could possibly be found on smooth bark.

In the case of terrestrial bryophytes, the Draftman's plot showed that mosses were more host specify than liverwort species. Many moss species were restricted to a particular ground substrate while liverwort species tended to spread across different ground substrates (Figure 4.19). Only few ground liverworts that occurred on rotten log are found growing on soil. Other pairwise ground substrates have substantial number of shared species.

4.7 Relationship between zones and study plots

The similarity between study plots was examined in order to articulate the relationship of different plots. Two sets of results for epiphytic and ground bryophytes were obtained, respectively, based on coverage and frequency data. Four major clusters are apparent from the Dendrogram of Ward's method by employing Euclidean distance of all study plots based on the coverage of both epiphytic bryophytes (Figure 4.20a) and ground bryophytes (Figure 4.20b). Epiphytic bryophytes of zone E and zone F appeared as two distinctive clusters that were separated from other study plots of zones A, B, C and D. Likewise, for ground bryophytes, study plots of zones E and F remained as exclusive clusters except plot F1, which shared close proximity with plots D2 and D3 (Figure 4.20). The dendrograms of all study plots, based on coverage of epiphytic bryophytes and ground bryophytes are depicted in Figure 4.21 and Figure 4.22, respectively, together with the proportion of liverwort and moss diversity in each study plot, as well as a heatmap which shows the top 15% bryophyte species with highest coverage recorded from tree trunks and on ground, respectively. Zone F consists of many unique species with high coverage values, which were mostly not found in the other zones viz., *Acromastigum bancanum, Acroporium aciphyllum, Bazzania erosa, B. uncigera, Heteroscyphys aselliformis, Kurzia mauiensis, Lepidozia ophiria, Lepidozia* sp. A*, L. trichodes, Nowellia borneensis, Radula iwatsukii, Riccardia albo-marginata, R. planiflora* var. *aequatorialis* and *Telaranea papulosa* (Figure 4.21). Similarly, zone E also possessed a set of unique species but with smaller coverage. *Bazzania vittata, Plagicohila javanica, Plagiochilion oppositum* and *Syrrhopodon tristichus* appeared to be common in zone E. Unique species like *Dicranoloma braunii*, found only in plot E2 and in abundance (Figure 4.21). The liverwort species, *Chiastocaulon dendroides*, occurred in abundance in this zone, even though it also presents in zones C and D, but in lower abundance. It was obvious that *Acanthorrhynchium papillatum*, is more abundant at lower elevation, recorded high coverage in study plots A2, C1 and C2, where these three plots happened to resolved in a cluster. *Syrrhopodon loreus* occurred in abundance in plot A2, but not in other study plots, the species seemed to be unique to lower elevation. A number of the epiphytic bryophytes are almost equally abundant and coexisted in two or more zones, usually between the typical lowland and summit vegetation, of from zone C to zone E, viz., *Bazzania albifolia*, *Calymperes serratum, Heteroscyphus argutus, Himantocladium plumula*, *Homaliodendron flabellum*, *Leucobryum chlorophyllosum*, *Leucophanes octoblepharioides*, *Lopidium struthiopteris*, *Pyrrhobryum spiniforme* and *Radula javanica*. Besides that, species which have wide distributional range (occurred at least in five elevation zones), equally abundant from lowland to highland include, *Acroporium lamprophyllum*, *Bazzania tridens*, *Cheilolejeunea intertexta, C. occlusa, Lejeunea papilionacea*, *L. tuberculosa*, *Lepidolejeunea bidentula*, *Metalejeunea cucullata*, *Mitthyridium flavum, Syrrhopodon spiculosus* and *Telaranea wallichiana* (Figure 4.21).

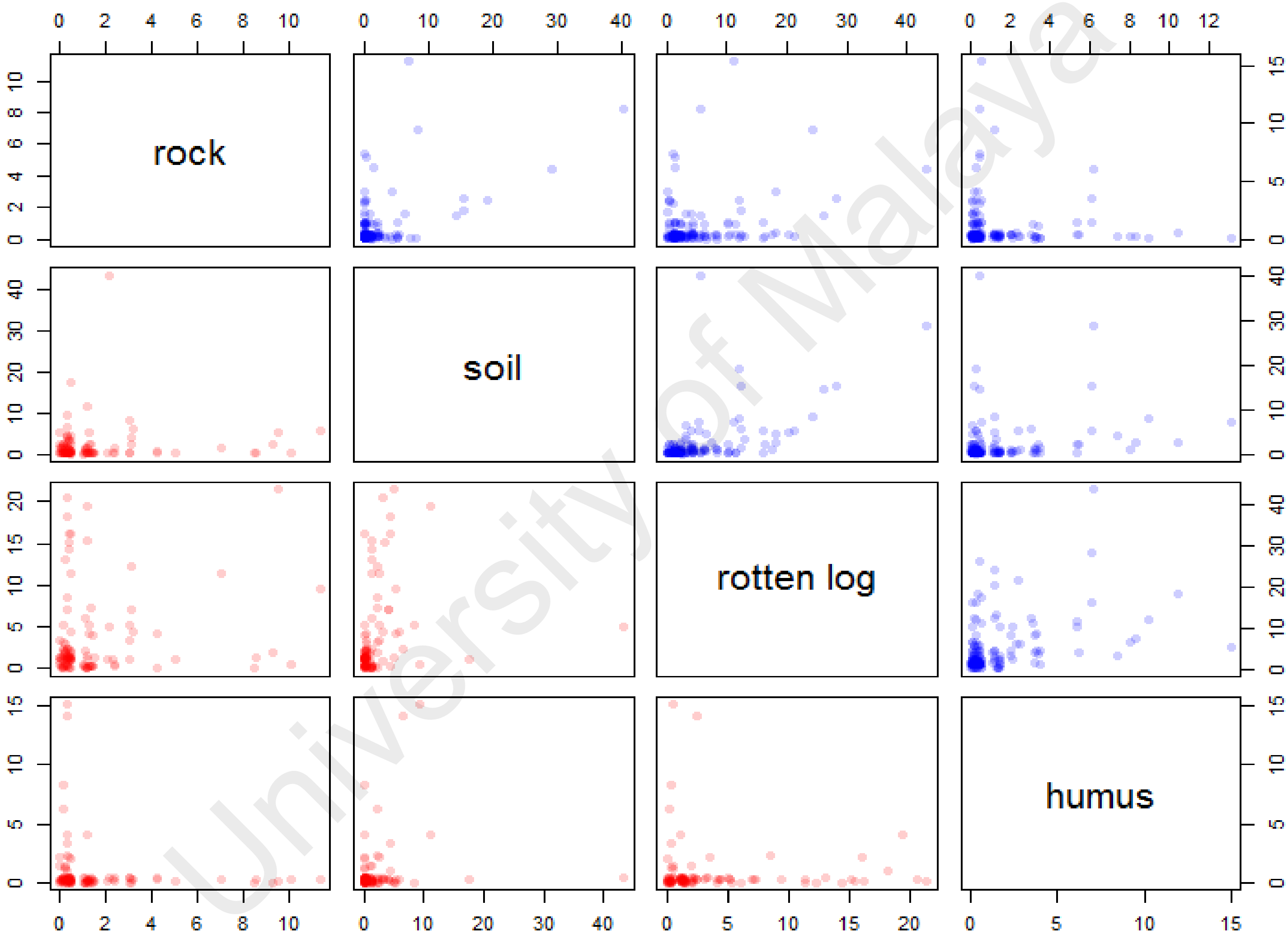
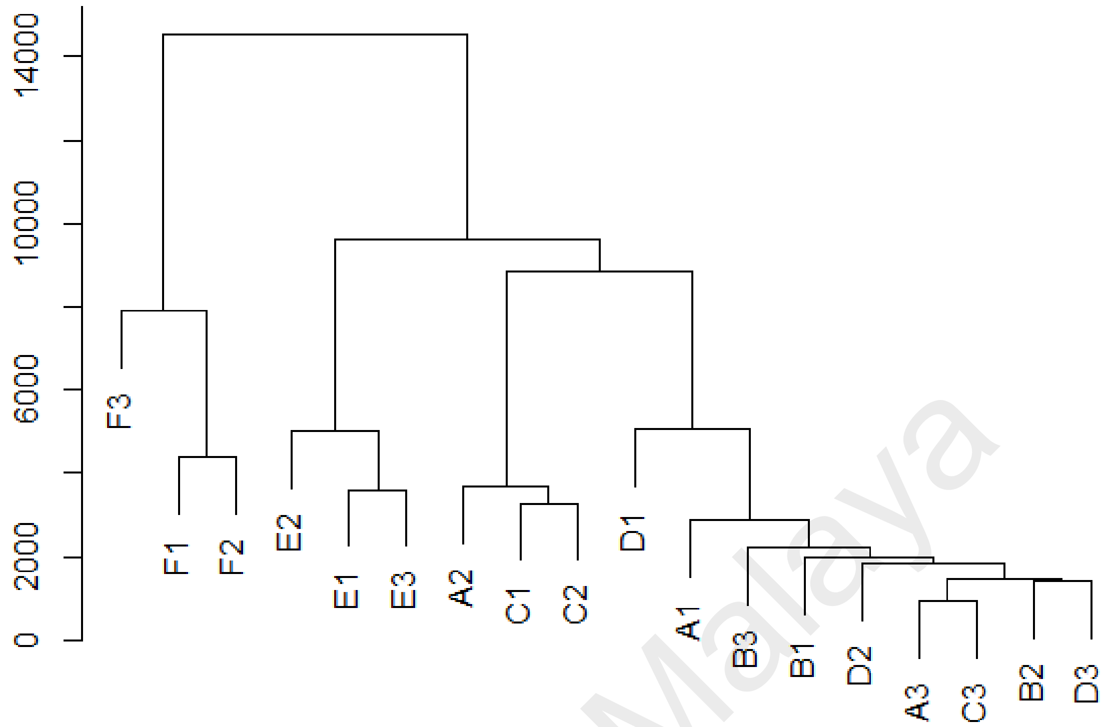


Figure 4.19: Draftsman's plot showing the habitat preference for ground bryophytes with red indicating mosses and blue indicating liverworts.

a)



b)

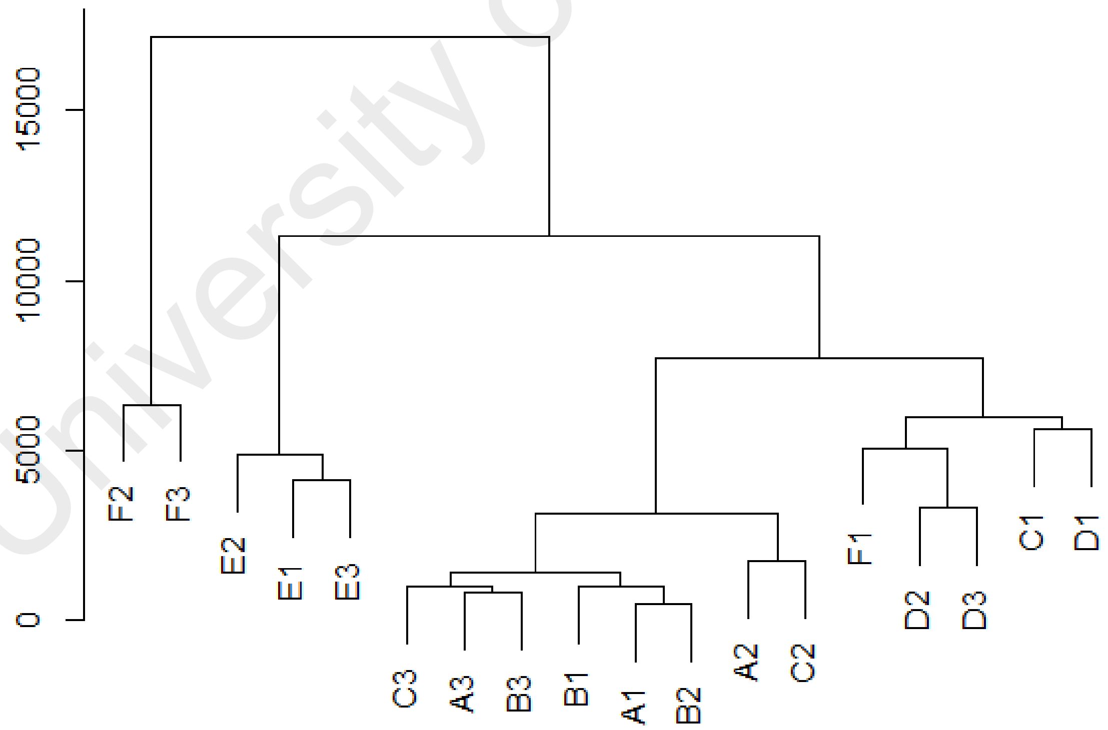


Figure 4.20: Cluster dendrogram of Ward's method using Euclidean Distance of eighteen study plots in the Genting Highlands, based on total coverage of a) epiphytic bryophytes and b) ground bryophytes.

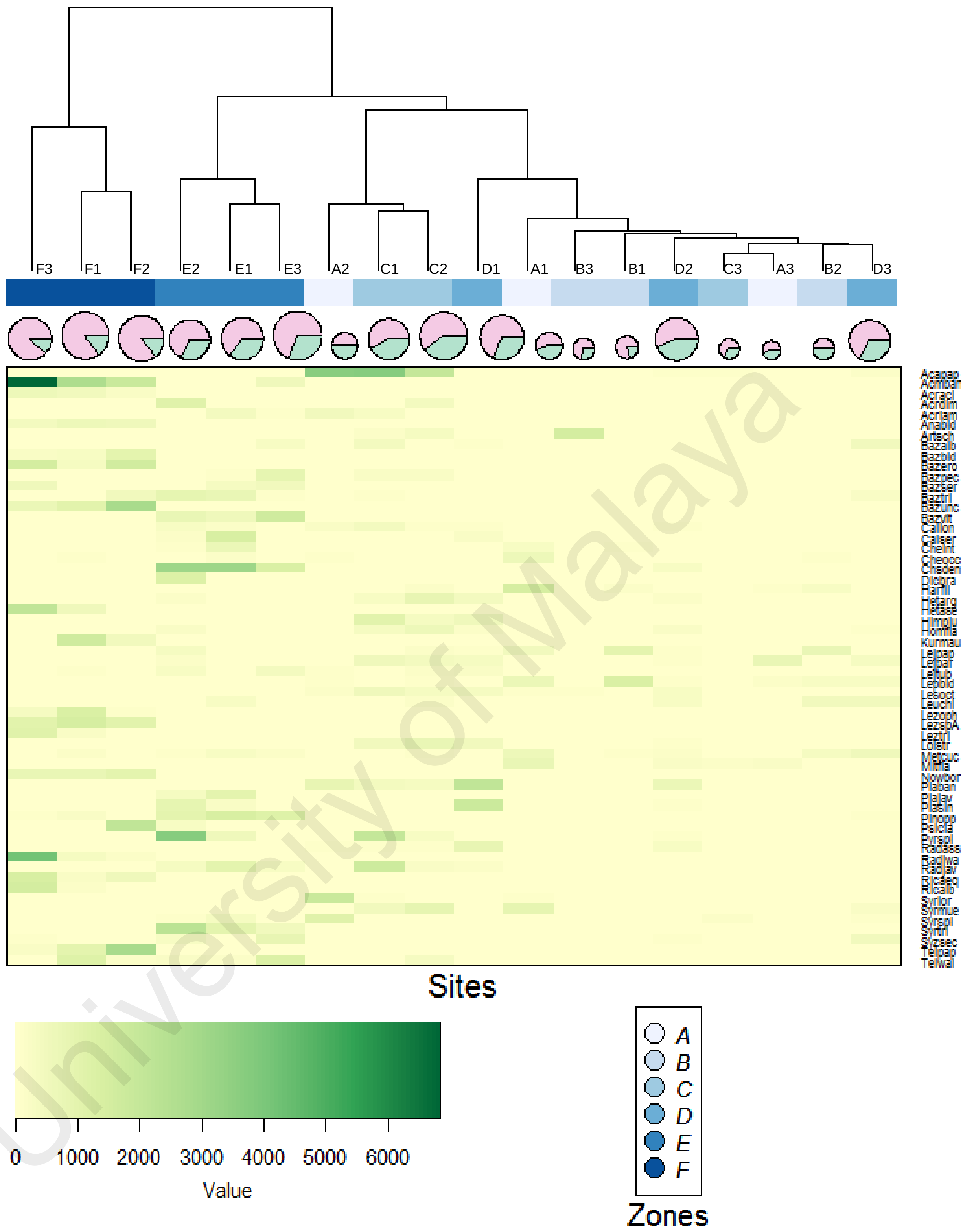


Figure 4.21: The relationship between study plots relative to altitude, bryophyte composition and coverage of epiphytic species. Dendrogram of Ward's method using Euclidean Distance of eighteen study plots in Genting Highlands by total coverage of each species. Pie charts indicate the proportion of liverworts (in pink) and mosses (in green), with size denoting the total diversity in a particular study plot. Heatmap presents the top 15% of recorded species with highest total coverage in alphabetical order.

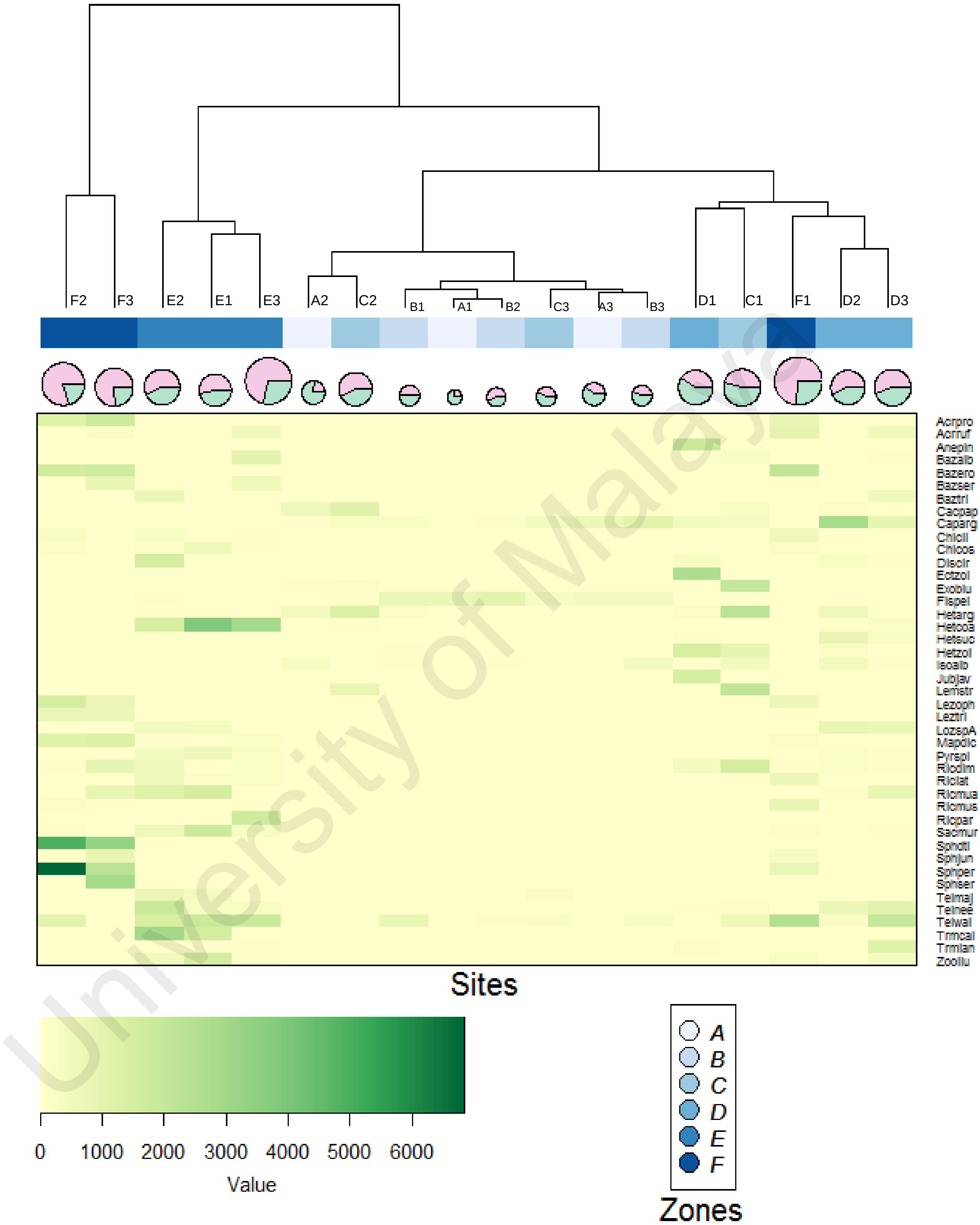
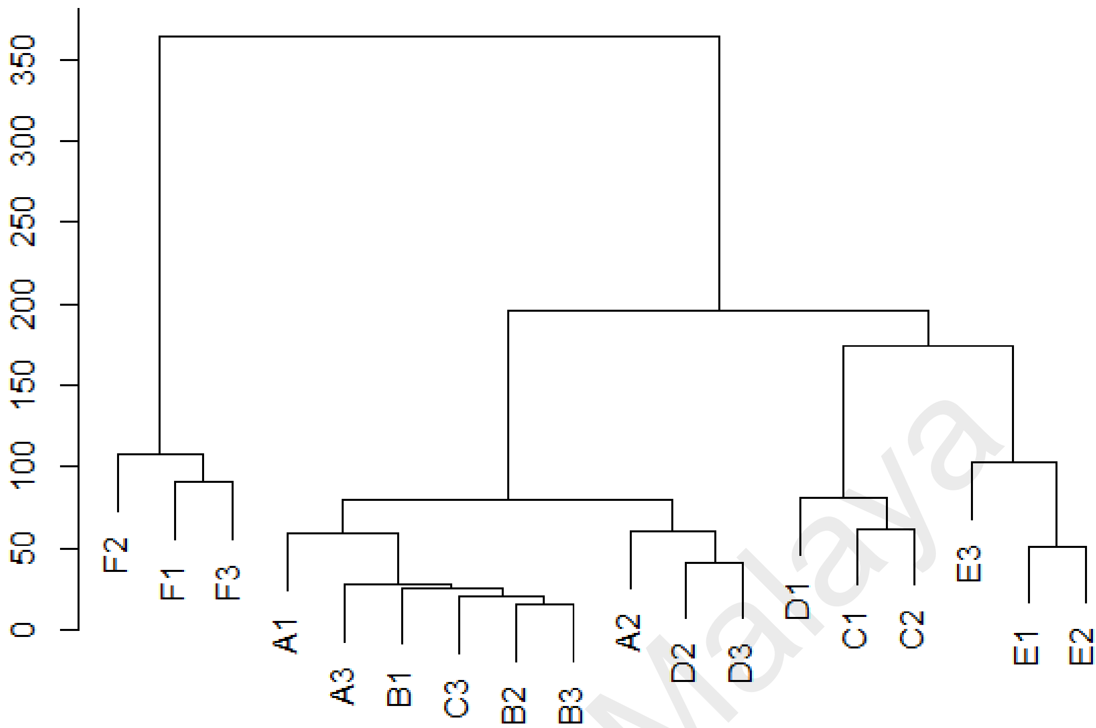


Figure 4.22: The relationship between study plots relative to altitude, bryophyte composition and coverage of ground species. Dendrogram of Ward's method using Euclidean Distance of eighteen study plots in Genting Highlands by total coverage of each species. Pie charts indicate the proportion of liverworts (in pink) and mosses (in green), with size denoting total diversity in a particular study plot. Heatmap presents the top 15% of recorded species with highest total coverage in alphabetical order.

Several distinct ground species that were only found abundant at the summit zone (zone F) include *Acroporium procerum*, *Bazzania erosa*, *Lepidozia ophiria*, *L. trichodes*,*Mastigophora diclados*, *Sphagnum cuspidatulum*, *S. junghuhnianum*, *S. perichaetiale* and *S. sericeum* (Figure 4.22). There are nine species which exhibited high coverage on tree trunk as well as on ground across the sampling sites. They are *Bazzania albifolia*, *B. erosa*, *B. serpentina*, *B. tridens*, *Heteroscyphus argutus*, *Lepidozia ophiria*, *L. trichodes*, *Pyrrhobryum spiniforme*, and *Telaranea wallichiana*. Of these, seven species are members of family Lepidoziaceae. There are few species found in high coverage in zone D, *Aneura pinguis*, *Ectropothecium zolligeri*, *Heteroscyphus succulentus*, *Jubula hutschinsiae* subsp. *javanica* and *Trismegistia lancifolia*. *Leucomium strumosum* is unique to zone C, occurred in abundance in plots C1 and C2, whereas, *Trismegistia calderensis* found abundant in plots E1 and E2, and is unique to zone E. *Callicostella papillata*, *Calypogeia arguta* and *Heteroscyphus argutus* occurred in lowland to mid elevation, zones A–D, but not on ground of higher zones, E and F. Conversely, species which preferred higher zones, ranging from zones D to F include *Acroporium rufum*, *Bazzania tridens*, *Lophozia* sp A, *Riccardia multifida* and *Saccogynidium muricellum*. Members of ground bryophyte with high coverage occurred in between typical lowland and summit vegetation, or zones C–E are *Bazzania albifolia*, *Distichophyllum cirratum*, *Heteroscyphus coalitus*, *Pyrrhobryum spiniforme*, *Telaranea major* and *T. neesii*. Three species have wide distributional range (occurred in at least five elevational zones), viz,. *Isopterygium albescens*, *Riccardia parvula* and *Telaranea wallichiana*. *Fissidens pellucidus* was commonly found in lower zone and also occurred in zone E, but less abundant.

The cluster Dendrogram of Ward's method by Euclidean distance of all 18 study plots, based on total number of occurrences, depicted five major clusters for epiphytic bryophytes (Figure 4.23a) and four main clusters for ground bryophytes (Figure 4.23b). The dendrograms together with the proportion of liverwort and moss diversity in each study plot, as well as a heatmap which shows the top 15% bryophyte species with highest frequency recorded from tree trunks and ground, are depicted in Figure 4.24 and Figure 4.25, respectively. Zones E and F once again displayed as exclusive clusters for epiphytic bryophytes, made up of study plots only from those zones. Plots C1, C2 and D1 resulted in a cluster whereas plots A2, D2 and D3 were resolved in another cluster (Figure 4.23a). Almost all study plots of zone A and zone B (except plot A2), together with plot C3, are the members of the fifth cluster. Members of the fifth cluster formed mostly by study plots of the low elevation, of low species richness (as shown in the pie chart) and low frequency (as shown in the heatmap). Epiphytic bryophyte species with high frequencies which only occurred in zone F include *Bazzania erosa*, *B. uncigera*, *Conoscyphus trapezioides*, *Drepanolejeunea dactylophora*, *Lepidozia trichodes*, *Nowellia borneensis*, *Radula iwatsukii*, *Riccardia albo-marginata* and *R. planiflora* var. *aequatorialis*. Several species with high occurrences in zone E and F were all liverworts, viz., *Acromastigum bancanum*, *Anastrophyllum bidens*, *Bazzania bidentula*, *B. bilobata*, *B. loricata*, *Heteroscyphus aselliformis*, *Kurzia lineariloba*, *Lepidozia* sp. A, *Mnioloma fuscum* and *M. stamatotonum*. There are species which occurred in zones C–F or D–F but most frequent only at particular zone, for example, *Bazzania vittata*, *Drepanolejeunea ternatensis*, *D. teysmannii*, *Gottschea aligera*, *Leucobryum javense*, *Plagiochila singularis*, *Plagiochilion oppositum*, *Syzygiella securifolia* and *Zoopsis liukiuensis*. Species such as *Acanthorrhynchium papillatum*, *Exostratum blumii*, *Harpalejeunea filicuspis*, *Heteroscyphus argutus*, *Leucophanes octoblepharioides*, *Mitthyridium flavum*, *Plagiochila bantamensis*, *Radula assamica* and *Syrrhopodon muelleri* are found in zones A–C or A–D, but often in lower frequency. Two species, *Cheilolejeunea occlusa* and *Metalejeunea cucullata*, occurred from the lowest zone to the highest zone with equally high frequency in all zones. It is worth noting here that species reported with high frequencies were not necessarily present a)



b)

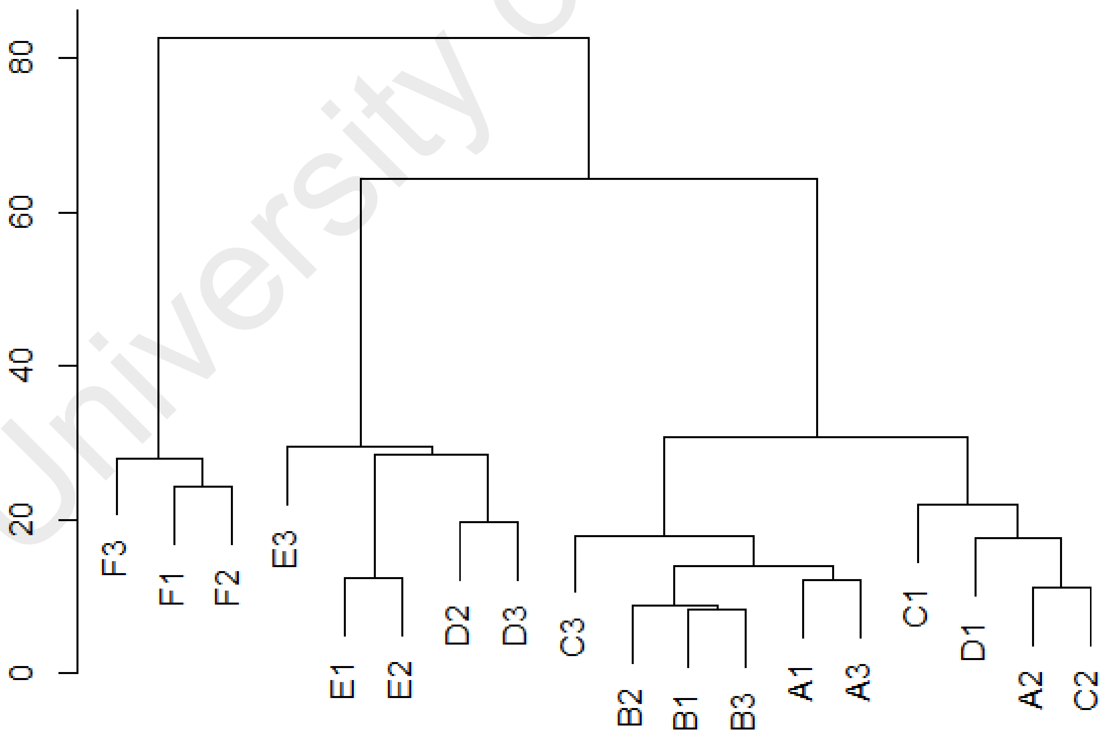


Figure 4.23: Cluster dendrogram of Ward's method using Euclidean Distance of eighteen study plots in the Genting Highlands, based on total occurrences of a) epiphytic bryophytes and b) ground bryophytes.

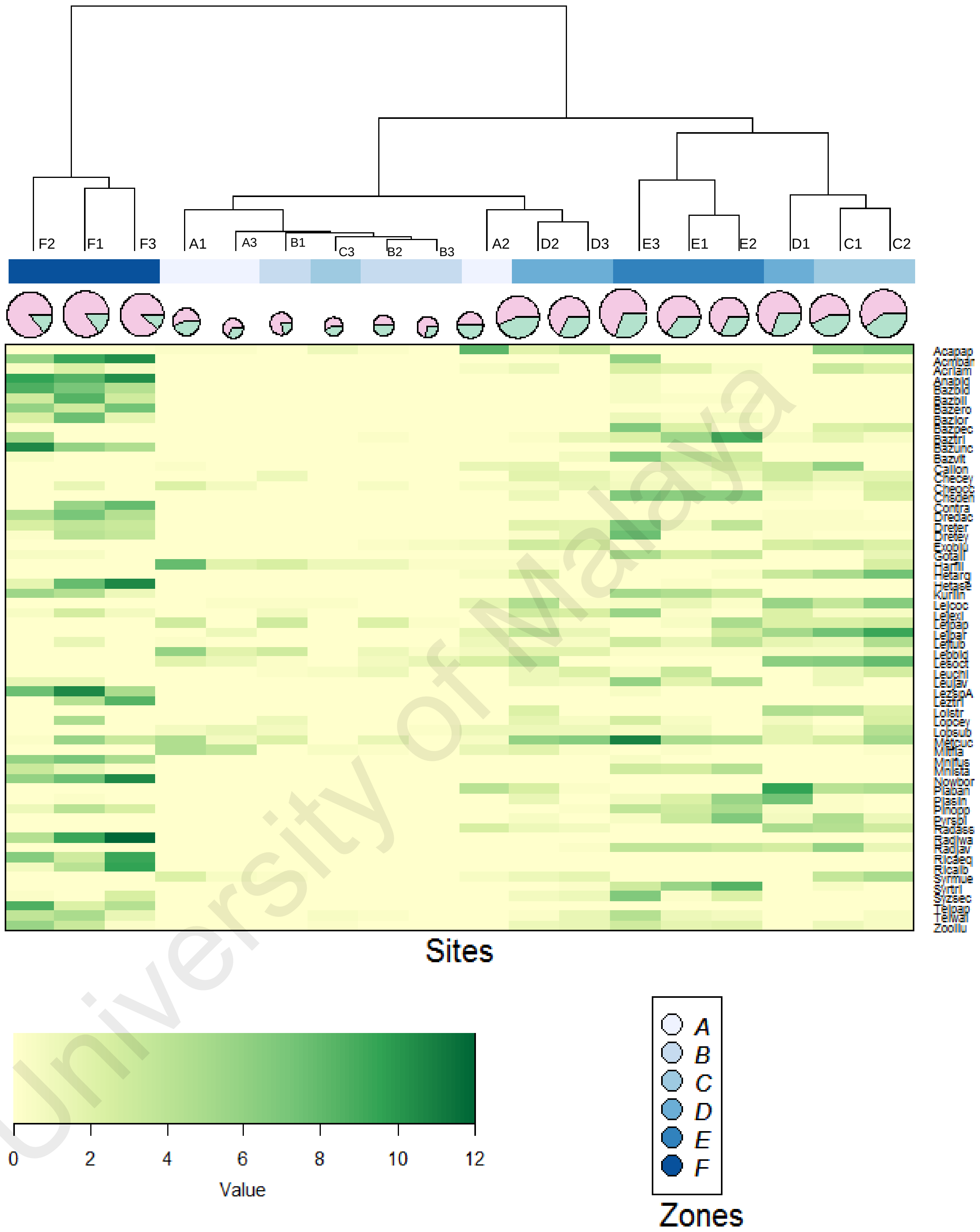


Figure 4.24: The relationship between study plots relative to altitude, bryophyte composition and frequency of epiphytic species. Dendrogram of Ward's method using Euclidean Distance of eighteen study plots in Genting Highlands by total number of occurrences of each species. Pie charts indicate the proportion of liverworts (in pink) and mosses (in green), with size denoting the total diversity in a particular study plot. Heatmap presents the top 15% of recorded species with highest total number of occurrences in alphabetical order.

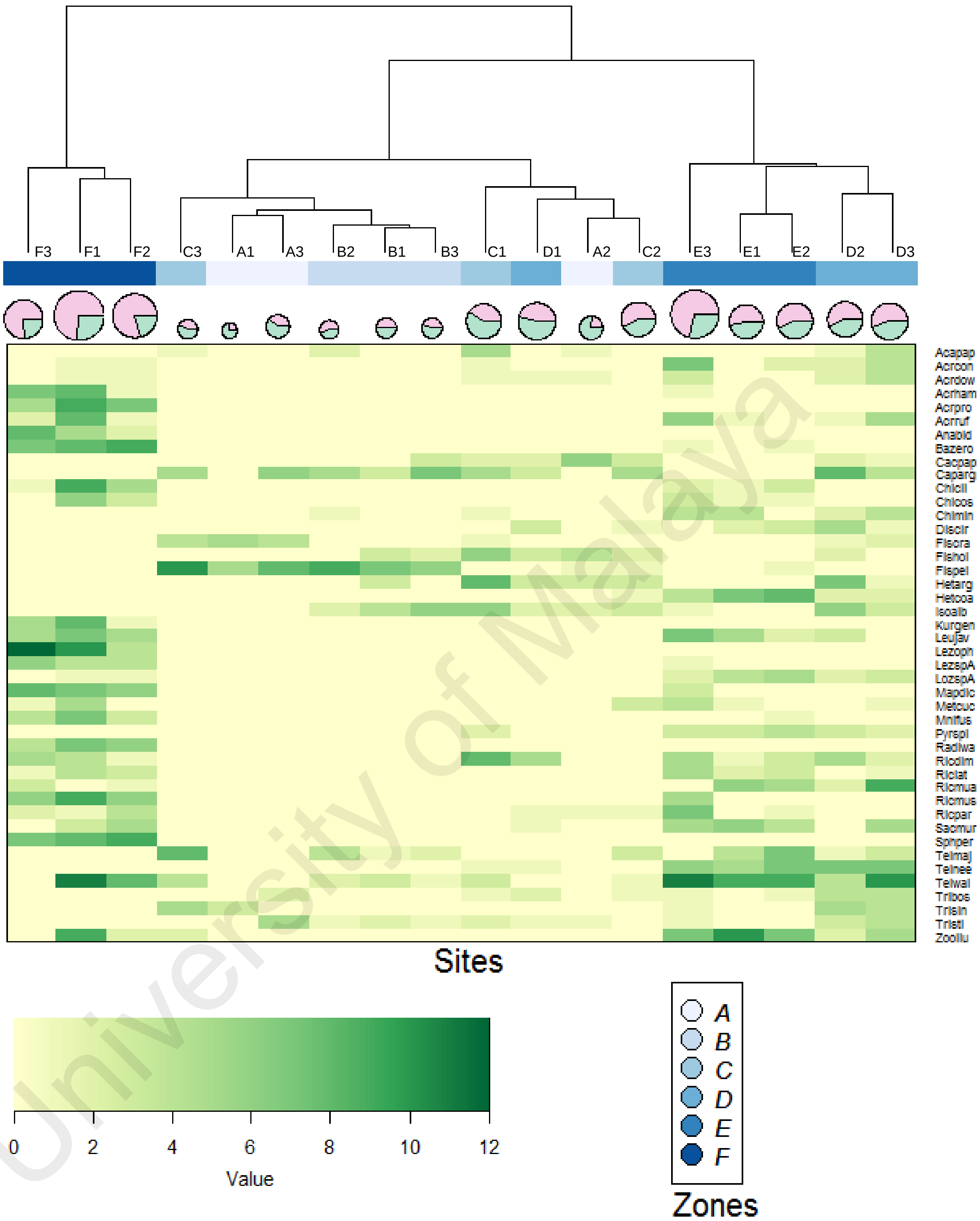


Figure 4.25: The relationship between study plots relative to altitude, bryophyte composition and frequency of ground species. Dendrogram of Ward's method using Euclidean Distance of eighteen study plots in Genting Highlands by total number of occurrences of each species. Pie charts indicate the proportion of liverworts (in pink) and mosses (in green) with size denoting the total diversity in a particular study plot. Heatmap presents the top 15% of recorded species with highest total number of occurrences in alphabetical order.

in abundance in any study plot or elevation zone; examples are *Bazzania bilobata*, *B. loricata*, *Cheilolejeunea ceylanica*, *Conoscyphus trapezioides*, *Drepanolejeunea dactylophora*, *D. ternatensis*, *D. teysmannii*, *Exostratum blumii*, *Gottschea aligera*, *Kurzia lineariloba*, *Lejeunea cocoes*, *L. exilis*, *Leucobryum javense*, *Lopholejeunea ceylanica*, *L. subfusca*, *Mnioloma fuscum*, *M. stamatotonum* and *Zoopsis liukiuensis* (Figure 4.21 & 4.24). Of these, eight of them belong to Lejeuneaceae and four species are members of Lepidoziaceae.

In the case of ground bryophytes, all the study plots in zone F resolved as a distinct cluster, whereas plots D2 and D3 were incorporated into a cluster with all plots from zone E (Figure 4.23b). Plots A2, C1, C2 and D1 formed the third cluster, whereas the last cluster is comprised of the remaining study plots of zones A, B and C (Figure 4.23b). Ground species which occurred exclusively in zone F and with high occurrences, are *Acroporium procerum*, *Anastrophyllum bidens*, *Kurzia geniculata*, *Lepidozia ophiria*, *Radula iwatsukii* and *Sphagnum perichaetiale*. Many species with high frequency coexisted in both zones E and F, viz., *Acromastigum bancanum*, *Bazzania erosa*, *Chiloscyphus ciliolatus*, *Chiloscyphus costatus*, *Lepidozia* sp. A, *Mastigophora diclados*, *Mnioloma fuscum*, *Riccardia latifrons* and *R. multifidoides*. Species which are found at zones C–E, usually with equally high frequency, including *Distichophyllum cirratum*, *Heteroscyphus coalitus*, *Pyrrhobryum spiniforme* and *Telaranea neesii*. Several other species which distributed at zones A–C or A–D, often with fairly uneven frequency, or more common only at particular plot or zone, are *Acanthorrhynchium papillatum*, *Callicostella papillata*, *Fissidens crassinervis*, *F. hollianus*, and *Heteroscyphus argutus*. The liverwort, *Calypogeia arguta* is also found in zones A–D but with equally high frequency across all zones. Species with high occurrences does not conform to high coverage, similar to the case in epiphytic bryophytes, examples are *Acanthorrhynchium papillatum*, *Acroporium convolutum*, *A. downii*, *A. hamulatum*, *Anastrophyllum bidens*, *Chiloscyphus minor*, *Fissidens crassinervis*, *F*. hollianus, *Kurzia geniculata*, *Leucobryum javense, Lepidozia* sp. A, *Metalejeunea cucullata*, *Mnioloma fuscum*, *Radula iwatsukii*, *Trichosteleum boschii*, *T. singapurense* and *T. stigmosum* (Figure 4.22 & 4.25). On the other hand, there are 12 species reported with high frequency not only on ground but also on tree trunk, viz., *Acanthorrhynchium papillatum, Anastrophyllum bidens, Bazzania erosa*, *Heteroscyphus argutus*, *Leucobryum javense*, *Lepidozia* sp. A, *Metalejeunea cucullata*, *Mnioloma fuscum*, *Pyrrhobryum spiniforme, Radula iwatsukii*, *Telaranea wallichiana* and *Zoopsis liukiuensis*.

CHAPTER 5

DISCUSSION

5.1 Sampling adequacy and rarefaction curve

The richness estimate (Chao-1 with bias corrected) suggests that 66.4–100% and 40–88.2% of the epiphytic and ground bryophyte diversity, respectively, were sampled at each study plot in zones A–F (Table 4.2). Richness estimates for both epiphytic and ground bryophytes of all study plots displayed higher values than the observed species richness, except for plot C3 of epiphytic bryophytes, where both estimated and observed richness values coincided. Species rarefaction curves generated based on the epiphytic bryophyte diversity showed that species richness is nearly stable after 15 trees were sampled in almost all the study plots (Figure 4.2). However, the rarefaction curves for ground bryophytes did not reach a clear plateau and had steeper gradients compared to epiphytic bryophytes. This is presumably due to the sampling of many localized rare species in the 'habitat island' as considered by Weibull and Rydin (2005), which contribute to the higher estimated species richness by Chao-1, but a lower sampling completeness.

It is well-known that tropical regions harbour high biodiversity, and sample-based studies often yield rarefaction curves that do not reach a clear plateau, hinting at the number of species that remain unsampled (Ah-Peng *et al.*, 2012). In order to increase the sampling adequacy, Aranda *et al.* (2010) stated that field collection should be conducted in places with similar spatial and habitat characteristics as the ones where new species have been recently discovered. Gradstein *et al.* (2003), on the other hand, proposed that sampling of five trees within a 1-ha plot of forest would allow rapid and representative assessment of epiphyte bryophytes diversity. In the present investigation, study plots of each zone were laid within the same vegetation type. In addition to that, as many as 15 mature trees were sampled in every plot, with four quadrats laid on each tree, totaling 60 quadrats from each study plot (size 0.04 ha) at every zone. Thus, the sampling approach in the present study could be considered as rather robust and well representing the actual bryophyte richness on tree trunks and on the ground, even though not all the species in the forest were sampled. In terms of ground bryophytes (Figure 4.3), the total sampled area is not far different from that sampled for epiphytic bryophytes. Hence, comparison of both is made possible.

For epiphytic bryophytes, the highest species richness with the Chao-1 was estimated for plot C2 instead of plot E3, the plot with the highest number of species collected (Table 4.2a). The significant difference between estimated and observed species richness can be explained by the formulation of the estimator, which considered singletons and doubletons and is consequently sensitive to the large number of rare species in the data set. This suggests that plot C2 has many rare species relative to plot E3, thus resulting in a higher estimated species richness. Likewise, plot C3 possesses no or few rare species, resulting in a perfect sampling effort for epiphytic bryophytes, and the highest sampling completeness for ground bryophytes (Table 4.2).

5.2 Species richness

The present study is the first systematic documentation of terrestrial bryophyte richness along an altitudinal gradient in Malesia, as well as for the Southeast Asian region. The recorded number of 453 species (283 liverworts, 170 mosses) in eighteen 20 × 20 m study plots (totalling 0.72 ha) along the altitudinal gradient is among the highest ever reported for tropical forests in Malesia. Enroth (1990) documented 424 species (204 liverworts and 220 mosses) from the tropical mountain range of the Huon Peninsula, Papua New Guinea, from near sea level up to 3400 m. This is by far the closest species richness compared to the present study. Similar studies on bryophytes distributed along altitudinal gradients on tropical mountains are also available for the African continent. As many as 540 bryophyte species (188 liverworts and 352 mosses) were documented for Mount Kilimanjaro, Tanzania, ranging from 750 m to 5050 m (Pócs, 1994). Ah-Peng *et al.* (2012) reported 265 bryophyte species, comprising 170 liverworts and 95 mosses, from the highest summit (Piton des Neiges, 3069 m) of Réunion Island, where collections were carried out from 350 m to 2750 m. In the neotropical region, Wolf (1993) conducted an extensive field collection in the northern Andes, Colombia and found 295 bryophyte species from the montane forest at 1000–4130 m. On a lower mountain (1200 m) in Darién National Park, Panama, Gradstein and Allen (1992) documented 86 liverworts and 32 mosses along an altitudinal gradient of different forest types. The present results of bryophyte richness are surprisingly high for a rather low mountain (about 1770 m) compared to those surveyed in Africa and the neotropical region.

Many liverwort species are reported as new to Peninsular Malaysia (106 species), as well as to Malaysia as a whole (54 species) (Table 4.4 & 4.5). An account by Chuah-Petiot (2011) listed 764 liverwort species for Malaysia; with current additions, the tally for liverwort species is now 818 species, or an additional 6.6%. This is an adequate reminder that this plant group has long been neglected. Further exploration of other parts of Malaysia would surely continue to contribute to rein in new discoveries.

As shown in the present study, the epiphytic bryophyte species richness in Genting Highlands from the lowest to the highest zones is reflected by a sigmoid curve (Figure 4.4), where total richness rises rather drastically between zones B and C. This difference in total richness generally corresponds to a lower bryophyte richness in the lowland tropical area, relative to the highlands. Similar observations were also reported by dos Santos and da Costa (2010) and Frahm (1994b).

Ground bryophytes richness is somehow similar to that of the epiphytic bryophytes, with minor differences. The richness pattern decreases, and then continues to increase gradually, from zones C to F, but does not show any peak at zone E (Figure 4.4).

The higher species richness recorded at zone A compared to zone B is probably due to the more humid conditions (Table 4.1). It is notable that the highest richness in the present study was recorded in zone E, which suggests that optimal conditions for bryophyte growth exist in this zone (with a mean relative humidity of 98.05% and mean temperature of 17.64 ℃) (Table 4.1). Bryophytes were reported to have its maximum richness at locations with mean relative humidity above 80% and mean temperature around 15 ℃ in the neotropical mountain ranges (Churchill, 1991; Corrales *et al.*, 2010; Wolf, 1993), as well as on Mount Kinabalu, Sabah (Frahm, 1990b) and even at lower mean temperatures, around 10–13 ℃ for the higher Himalayan Range (Grau *et al.*, 2007). In general, low evapotranspiration rates due to high humidity, along with low to moderate temperatures, would encourage the establishment of many bryophyte species (Proctor, 2003).

The higher liverwort richness compared to mosses in the present study appears to accord with findings in the tropical American rainforest (Gehrig-Downie *et al.*, 2013; Romanski *et al.*, 2011; Wolf, 1993). The trees and ground in zones E and F are especially dominated by liverwort rather than moss species (Figure 4.5 & 4.6). In zone E, around 1500 m elevation, liverwort diversity is about six times more than mosses on tree trunks and almost twice the number of moss species on the ground (Figure 4.7). van Reenen and Gradstein (1984) also reported relatively high liverwort to moss ratios in the tropical rainforest of Sierra Nevada de Santa Marta, Colombia, where liverworts were five times more diverse than mosses on tree trunks. Higher liverwort richness on tree trunks is also documented in zones C and D in the present study (Figure 4.7), which is in accordance with findings in submontane forest at 950–1100 m in Central Sulawesi, Indonesia (Sporn *et al.*, 2010). This suggests that more liverwort species prefer cooler environment with relatively high humidity. Nonetheless, mosses are more diverse than liverworts in zone B, particularly on tree trunks, and also on the ground in zone A, indicating that moss species are better adapted to habitats with warmer climate and lower humidity in Genting Highlands (Figure 4.7). In short, above results suggest that the liverwort to moss richness ratio could be an excellent character to distinguish tropical lowland forest from forest of higher elevations.

5.3 Bryophyte distribution and evenness

Whittaker (1965) stated that coverage is one of the best scales used to rank terrestrial plant species due to its independence of the concept of the "individual" and thus a better expression of importance. It is therefore useful for all recorded species of each plot to be ranked from the highest to the lowest coverage for comparison (Figure 4.10 & 4.11) Study plots of zones A and B together with plot C3 exhibit short and oblique curves, denoting a low species diversity of the community with low evenness (Figure 4.10 & 4.11). This is in contrast to study plots of zones D–F and plots C1 and C2 (Figure 4.10 & 4.11), where high evenness is obtained as the rank abundance curves show gentle slopes and eventually level out. Both epiphytic and ground bryophytes behave alike in terms of coverage distribution in zones A–F. This pattern is similar to that of epiphytic and ground bryophytes in the Mount Kinabalu transect, ranging from 20 to 3400 m elevation, where bryophytes are abundant at mid-elevation and near the summit (Frahm, 1990a).

Hill (1973) and Jost (2006) showed that the notion of diversity in ecology corresponds not to the value of the diversity index itself but to its effective number of species. Converting diversity indices to their effective number of species permits the evaluation on the changes in their magnitude, because effective number of species possesses the "doubling" property that characterizes the intuitive concept of diversity (Jost, 2007). This is illustrated by taking two equally large, completely distinct communities (without shared species) that each have diversity χ, so that their combined diversity should be 2χ, which explains the "doubling" property of Hill (1973). The true species richness of all study plots showed some degrees of change after converting diversity indices to effective number of species in the present study. These changes however, are sufficient to displace the sequences (arranged from highest to the lowest richness) of the study plots, based on observed species richness (D^0), or the Shannon effective number of species (D^1) or Gini-Simpson effective number of species (D^2) (Table 4.8). Dominant species are more prominent in the lower zones A and B, thus giving low evenness. The conversion of diversity indices to true species richness also revealed that the highest observed species richness was not in study plot E3 for epiphytic bryophytes (Table 4.8a) and study plot F1 for ground bryophytes (Table 4.8b). This is due to the occurrence of many rare species in E3 and F1 as shown by the long tail of species rank abundance curves (Figures 4.10 & 4.11), which was eliminated following conversion. Dominant species are substantial in these two plots, but rare or less abundant species are also more pronounced, which resulted in the high evenness as shown in species rank abundance curves.

5.4 Species composition

The majority of epiphytic bryophyte species found in the present study belong to Aneuraceae, Calymperaceae, Dicranaceae, Lejeuneaceae, Lepidoziaceae, Lophocoleaceae, Plagiochilaceae, Pylaisiadelphaceae, Radulaceae and

Sematophyllaceae (Figure 4.8). These 10 families have accounted for 73.5% of the total epiphytic diversity in the present study. All of these except Aneuraceae, Lophocoleaceae and Pylaisiadelphaceae are the main bryophyte families in tropical rainforest (Gradstein & Pócs, 1989). Aneuraceae and Lophocoleaceae,both liverworts families are, however, among the dominant families in the Malaysian liverwort flora (Chuah-Petiot, 2011). The moss family Pylaisiadelphaceae was proposed by Goffinet and Buck (2004) to accommodate a few morphologically variable genera that could not be properly placed within Sematophyllaceae. In the case of ground bryophytes, 69.9% of the total recorded species belong to the Aneuraceae, Calymperaceae, Fissidentaceae, Hypnaceae, Lejeuneaceae, Lepidoziaceae, Lophocoleaceae, Plagiochilaceae, Radulaceae and Sematophyllaceae (Figure 4.9). These findings are, again, in line with the major tropical rainforest families recognized by Gradstein and Pócs (1989), except Aneuraceae and Lophocoleaceae. Lejeuneaceae is the most speciose family, represented by 24% of the total epiphytic diversity and 14.7% of the total ground diversity recorded in the present study. Lepidoziaceae comes second with 12.4% and 13.3% of all documented species on tree trunks and ground, respectively. These two families are also among the most diverse families in other tropical rainforests, e.g., Central Sulawesi (Gradstein & Culmsee, 2010), Costa Rica (Holz, 2006) and Southeastern Brazil (dos Santos & da Costa, 2010).

Liverworts not only showed higher richness but also higher coverage compared to mosses in Genting Highlands. This phenomenon is most pronounced at higher elevations, especially near the summit region at zone F, where 90% of the investigated trunk areas are occupied by liverworts (Figure 4.12), presumably due to the frequent occurrence of fog and the cooler temperatures (Figure 4.1 & Table 4.1). The mosses, on the other hand, have larger coverage at the lower zones A–C (Figure 4.12) which is in accordance with the study at the submontane forest of Central Sulawesi (Ariyanti *et al.*, 2008). In the present study, most of the moss species recorded from these zones had tufted and tree-like growth habits which grant higher tolerance to desiccation. Plot D2 has a higher coverage of epiphytic mosses than liverworts even though the latter is more diverse (54 species) than mosses (42 species) in that plot. This could possibly be due to the presence of many big-size moss species occurring in abundance within this plot (e.g., *Homaliodendron flabellatum* and *Symphysodontella cylindracea*), which occupy larger areas compared to the many small size leafy liverworts. In terms of ground bryophytes, mosses have distinctive higher coverage than liverworts in nine study plots (Figure 4.13), which could be explained by the overall more specialistic behaviour of mosses (Wolf, 1993). The terrestrial habitats comprised a mosaic of microhabitats influenced by microtopography, geology, soil and vegetation cover (Mandl *et al.*, 2010), which enhance the establishment of mosses with a stochastic dispersal strategy (Wolf, 1994). At the summit region, zone F, the thick layer of humus and ever-wet conditions promote the growth of *Sphagnum*, which contributes most to moss coverage at this zone.

In the case of epiphytic bryophytes, it is obvious that some of the families with a poor number of species were always found extensively covering a substantial trunk area, thus contributing significantly to the abundance of epiphytic bryophytes in this mountain. Two examples are Neckeraceae and Rhizogniaceae, represented only by six and three species, respectively, but listed among the top 10 abundant bryophyte families on tree trunks (Figure 4.8 & 4.14). Meanwhile, two families that are rich in species, viz., Dicranaceae and Pylaisiadelphaceae, were found at lower abundance (Figure 4.8 & 4.14). Members of these two families could have more refined niches or are regulated by specific environmental factors or in other words, they are mostly ‘specialists’. However, this would require further investigation.

Nonetheless, most of the families with a high number of species still contribute significantly to the abundance of epiphytic bryophytes, and are among the top 10 abundant families in the present study (Figure 4.8 & 4.14). The list of top 20 families (11 liverwort families and 9 moss families) with the highest total coverage values constituted 96% of the total coverage documented on tree trunks in the present study, indicating that these families were the most common and abundant in Genting Highlands (Figure 4.14). However, the remaining 4% of 21 unlisted families suggests a comparably high number of species that occured in small populations and were apparently rare in the study sites. In spike of the highest species richness attained by Lejeuneaceae, which was by far the most prominent bryophyte family in the area, Lepidoziaceae turned out to be the most abundant family, accounting for about 25% of the total area documented in the present study. Lejeuneaceae are mostly small plants which cover little area on tree trunks compared to members of Lepidoziaceae such as *Bazzania*, which often develop large populations engulfing much trunk area. High coverage of Lepidoziaceae on tree trunks was also reported for tropical rainforests in Colombia (van Reenen & Gradstein, 1984) and Panama (Gradstein & Allen, 1992). A small part of the diversity (15%) contributing to more than half of the epiphytic bryophyte abundance (67.8%) is also reported here (Figure 4.15). Among the 15% diversity, or 58 epiphytic bryophytes, 16 of them are members of Lepidoziaceae. The most abundant species, *Acromastigum bancanum* (Lepidoziaceae) is found exclusively in montane forest, at elevations from 1500 m upwards, whereas the second most abundant species, *Acanthorrhynchium papillatum* (Sematophyllaceae), has a wider distributional range, from the lowlands to mid-elevation. *Chiastocaulon dendroides* (Plagiochilaceae) and *Pyrrhobryum spiniforme* (Rhizogoniaceae) were the third and fourth most abundant species in zones C–E.

Among ground bryophytes, Calymperaceae, Lejeuneaceae, Plagiochilaceae and Radulaceae were the top 10 families with the most species, but in lower abundance on the ground (Figure 4.9). In contrast, a number of families with lower diversity were very abundant on the ground, including Calypogeiaceae, Daltoniaceae, Pylaisiadelphaceae and Sphagnaceae (Figure 4.9 & 4.16). According to Holz (2003), Calypogeiaceae and Sphagnaceae are the main contributors of ground bryophytes in the tropical American forest. As much as 94.8% of the total coverage documented on the ground in the present study was contributed by the top 20 bryophyte families listed, whereas the remaining 5.2% was from the 26 unlisted families (Figure 4.16). Again, a considerably high proportion of bryophytes occurring in small populations occupied a small area on the forest floor in Genting Highlands. It is notable that Lepidoziaceae was not just dominat on tree trunks, but was also the most abundant family on the forest floor (21.6%). Ten members of the Lepidoziaceae, viz., *Bazzania albifolia*, *B. erosa*, *B. serpentina*, *B. tridens*, *Lepidozia ophiria*, *L. trichodes*, *Telaranea major*, *T. neesii*, *T. wallichiana* and *Zoopsis liukiuensis* were very abundant, even though several of them were tiny and often occurred in huge populations, forming cushions or mats (Figure 4.17). *Telaranea wallichiana* (Lepidoziaceae), was the most abundant species (6.4%) and had a wide distributional range, occurring in zones B–F. The second most abundant family, Sphagnaceae, contributed 11.7% to the total coverage recorded in this study but was only represented by five species in Genting Highlands. Four of them were very abundant in the study area, viz., *Sphagnum cuspidatulum*, *S. junghuhnianum*, *S. perichaetiale* and *S. sericeum* and made up the very high bryophyte abundance on the forest floor at the summit area (Figure 4.17). The other families which were very abundance on the ground include Lophocoleaceae (11.3%), Aneuraceae (10%), Sematophyllaceae (9.1%), Fissidentaceae (4.3%), and Calypogeiaceae (3.9%). These families were also reported to be abundant in the tropical rainforest of Colombia (Corrales *et al.*, 2010; van Reenen & Gradstein, 1983). Lejeuneaceae was not prominent on the forest floor although it was still the most diverse family (42 species) there (Figure 4.9). This is because Lejeuneaceae on the ground were mostly tiny and found adhering to rotten logs or only occurring among larger bryophytes. If the ground species are ranked according to total area occupied, the top 15%, or 43 species, contributed 72.8% of the total area, whereas the remaining 243 species only occupied 27.2% of the area, and could be considered as less abundant (Figure 4.17). This suggests that most ground species appeared in small populations, which covered a relatively small total area. A number of the bryophytes were equally abundant on tree trunk and forest floor; these were *Bazzania albifolia*, *B. erosa*, *Lepidozia ophiria*, *Pyrrhobryum spiniforme* and *Telaranea wallichiana*.

In some circumstances, a high number of individuals may not correspond to high coverage. This is confirmed in the present study, where, as many as 18 epiphytic species and 17 ground species with high abundance values do not exhibit high coverage in the study plots (Figure 4.21, 4.22, 4.24 & 4.25). Many of these bryophytes are very small and grow among larger species, often from the family Lejeuneaceae (e.g., *Cheilolejeunea ceylanica*, *Drepanolejeunea dactylophora*, *D. ternantensis*, *D. teysmannii*, *Lejeunea cocoes*, *L. exilis*, *Lopholejeunea ceylanica*, *L. subfusca*, *Metalejeunea cucullata*) and Lepidoziaceae (e.g., *Kurzia geniculata*, *K. neariloba*, *Lepidozia* sp. A, *Zoopsis liukiuensis*). Another reason could be the patchy occurrence of a species, often found with only few scattered individuals within a population, but occurred many times within that site. This is true for species like *Acanthorrhynchium papillatum*, *Acroporium convolutum*, *A. downii*, *A. hamulatum*, *Bazzania bilobata*, *B. loricata*, *Chiloscyphus minor*, *Conoscyphus trapezioides*, *Exostratum blumii*, *Fissidens crassinervis*, *F. hollianus*, *Gottschea aligera*, *Leucobryum javense*, *Mnioloma fuscum*, *M. stamatotonum*, *Radula iwatsukii*, *Trichosteleum boschii*, *T. singapurense*, and *T. stigmosum*.

5.5 Habitat preferences

Genting Highlands, Peninsular Malaysia, situated near the equator where there is little distinction in day length, should receive a reasonably even amount of sunlight throughout the year. Therefore, differences in microclimate on the north and south side of a tree trunk are expected to be minor as compared to the tree in temperate countries. The strong influence of east and south directions on composition of bryophyte community in zones B and C is unexpected for the tropics. Trynoski and Glime (1982) reported that south exposure on the phorophyte exhibited the greatest total bryophyte cover in between tree base and breast height (0.6 m from ground) but east exposure is more important at breast height of a trunk (1.2 m from ground), according to a research conducted within the Dow Wilderness Area, Michigan, the United States. The circumferential variation at a given height on the phorophyte tends to be correlated with cardinal directions (Gough, 1975). However, in the tropics, epiphytic bryophytes which show preference for particular cardinal directions on a phorophyte could be responding to local-scale microclimatic conditions.

Bark texture has been regarded as one of the factors moderating the distribution and composition of epiphytic bryophytes in tropical rainforests (Cornelissen & ter Steege, 1989; Frahm, 1990b; Gradstein & Culmsee, 2010; Ma *et al.*, 2009). Although many bryophyte species documented in the present study are habitat generalists, some species appear to have certain preference for paricular bark textures. Trees with dense fissured bark were observed to promote the establishment and growth of epiphytic bryophytes (Znotiņa, 2003). Cornelissen and ter Steege (1989) noticed that many bryophytes preferred fissured than smooth bark in the rainforest of Guyana; likewise, this was also observed in the present study. According to (Frahm, 1990b), bryophytes generally avoided trees with flaking or stripping bark, and no epiphytic bryophytes were reported from the *Leptospermum* forest in the Ultrabasic zone of Mount Kinabalu, Sabah. The present results however, contrast with Frahm (1990b), as many species were collected from trees with flaking bark (including *Leptospermum javanicum*), mostly in the summit zone of Genting Highlands. The fact that more liverworts were found on fissured and flaking bark than on rough and smooth bark could be possibly due to the higher number of liverwort species occurring at the higher zones, E and F, where trees with fissured and flaking bark were also more common. Wolf (1994), however, pointed out that it is the ecological conditions prevailing on trunks that are responsible for the host-epiphyte relationships, and not the identity of phorophyte. It was found that phorophyte conditions were boundlessly unique when more tree species with intermediate bark properties were investigated Holz (2003). Whether bryophytes would exhibit similar bark preferences if the microhabitat conditions were less pronounced, remains unknown.

Most ground bryophytes have a wider distributional range rather than being confined to specific habitats. Humus only becomes distinct in the summit region and ground bryophytes like *Sphagnum* were found abundantly on the forest floor in this zone. (Corrales *et al.*, 2010) stated that bryophyte species showed greater response to microhabitat variation than macroecological features related to a forest type. Ecological parameters such as light intensity, soil pH and leaf litter thickness that defined the type and quality of a microhabitat could have influenced the establishment preference of ground bryophytes in all forest types (Corrales *et al.*, 2010). As an example, a higher preference of bryophyte species, especially mosses, for rotten logs and soil compared to rock in the present study might be due to the substrate water retention capability.

5.6 Relationship between zones and study plots with ecological parameters

In general, three to four prominent groupings were detected using cluster dendrograms according to Ward's method, employing either bryophyte coverage or total number of occurrence for both epiphytic and ground bryophytes (Figure 4.20–4.25). Study plots of zones E and F were well-defined and resolved as two distinctive groups in all analyses. There was no clear separation between zones C and D, either in the cluster dendrogram using total coverage or that using total number of occurrence for both epiphytic (Figure 4.20a & 4.23a) and ground bryophytes (Figure 4.20b & 4.23b). The majority of study plots from zones A and B, of lower elevations, resolved in the same cluster in all analyses, often including one or a few from zones C and D (Figure 4.20–4.25). Meanwhile, study plots from zones C and D either formed a clade together with a plot from a lower elevation (as in Figure 4.20a and 4.23b), or a plot from a higher elevation (as in Figure 4.20b), or were more often found in a clade that was largely made up of study plots from zones A and B, as mentioned above (Figure 4.20–4.25).

Indications from the cluster dendrograms and heatmaps are that the bryophyte diversity in the Genting Highlands apparently assembled according to forest types, where zones E and F were lower montane and upper montane forest, respectively, zones C and D were the transition between lower montane and lowland forest, while zones A and B represented the lowland forest. Nakashizuka *et al.* (1992) recognized four altitudinal zones, based on the similarity of tree diversity along an altitudinal transect in Selangor, Peninsular Malaysia, which includes lowland forest (0–700 m), a transition zone (700–1100 m), lower montane forest (1100–1500 m) and upper montane forest (1500–1700 m), which is similar to the distribution of bryophyte diversity observed in the present study.

Microclimate differed significantly in terms of the mean ambient temperature from lowland to upper montane forest, but mean relative humidity remained high across the altitudinal gradient (Table 4.1). Bryophyte species composition and microclimatic similarities are correlated, indicating that the differences between bryophyte communities increased with increasing microclimatic differences (Sporn *et al.*, 2009). This is confirmed in the present study, where the upper montane forest with lowest mean temperature and high relative humidity has an apparently larger coverage of bryophyte flora, whereas the lowland forest with the highest mean temperature and a considerably high mean humidity harbours fewer bryophytes, in terms of both abundance and diversity. The daily microclimate fluctuation in lowland forest is great, hindering the growth of many bryophytes, especially shade-loving species (Holz *et al.*, 2002; Romanski *et al.*, 2011). Those species that inhabit the lowland forests are mostly desiccation-tolerant species, which are capable of withstanding drying out, e.g., *Acanthorrhynchium papillatum, Fissidens* spp. S*yrrhopodon loreus*. These species possess 'water sacs' for water storage or have leaves densely covered by papillae that reduce desiccation (Ariyanti *et al.*, 2008). The mid-elevation zones, C–E, harbour many specialists which are generally known as desiccation-intolerant species (sensu Gradstein & Pócs, 1989) characteristic of the shaded understory of tropical montane rainforests. The very high recorded mean relative humidity (Table 4.1) in zones C, D and E could possibly help explain the occurrence of high species richness with high abundance at mid-elevations. Cardelús *et al.* (2006) suggested that the peak in species richness at mid-elevation could be the manifestation of environmental influences on richness, because the distribution of species with limited range is only slightly constrained by major domain boundaries. As for the upper montane forest, the constant inundation by fog and cool temperature often promote the growth of bryophytes (Cornelissen & ter Steege, 1989; Gehrig-Downie *et al.*, 2013). Most of the phorophytes found at this zone are short and stunted, which allow exposure of branches and tree bases to more direct sunlight or high radiation. Therefore, those species that thrive on the exposed parts of tree trunks, which are commonly known as sun-epiphytes (sensu Gradstein *et al.*, 2001), could grow abundantly, e.g., *Heteroscyphus aselliformis* and *Radula iwatsukii*. Tng *et al.* (2009) reported that sites with higher humidity exhibit a greater magnitude of bryophyte occurrence inhabiting both tree trunks and ground habitats, which is supported by the current finding that as many as 12 species forming the top 15% of the most frequent species are equally common on both tree trunks and ground habitats (Figure 4.24 & 4.25).

The lowland, lower montane and upper montane forests in the Genting Highlands are dominated by very different bryophyte species. The bryophyte vegetation of the summit zone, F, is much dominated by liverworts (*Bazzania* spp., *Lepidozia* spp.), which is in line with the findings of (Gradstein & Culmsee, 2010) in montane forests of Central Sulawesi, Indonesia. Ground species of the upper montane forest, however, show a higher coverage by mosses (*Acroporium procerum*, *Sphagnum* spp.) than liverworts although the species richness of the latter is more than three times higher (Figure 4.7). Gradstein and Pócs (1989) noted that tropical American rainforests hold a more sizeable liverwort flora, while mosses are more prominent in Asiatic rainforests. Our findings however, show that liverworts are more diverse than mosses in almost every forest type in the Genting Highlands, except the lowland forests, which indicates that the liverwort flora could also be very rich in Asiatic rainforests. On the other hand, the present study shows that montane forests house many unique species compared to the lowland forests. Many species including *Acromastigum bancanum*, *Acroporium aciphyllum*, *Acroporium procerum*, *Bazzania erosa* and *B. uncigera*, *Heteroscyphys aselliformis*, *Kurzia mauiensis*, *Lepidozia ophiria*, *Lepidozia* sp. A, *L. trichodes*, *Mastigophora diclados*, *Nowellia borneensis*, *Radula iwatsukii*, *Riccardia albo-*

marginata, *R. planiflora* var. *aequatorialis*, *Sphagnum cuspidatulum*, *S. junghuhnianum*, *S. perichaetiale*, *S. sericeum* and *Telaranea papulosa* are found only at the summit zone, F, with high coverage. Species like *Bazzania vittata*, *Dicranoloma braunii*, *Plagiochila javanica*, *Plagiochilion oppositum*, *Syrrhopodon tristichus,* and *Trismegistia calderensis* are common and abundant in zone E but not elsewhere. Ground species such as *Aneura pinguis*, *Ectropothecium zolligeri*, *Heteroscyphus succulentus*, *Jubula hutschinsiae* subsp. *javanica* and *Trismegistia lancifolia* are found abundantly in and unique to zone D, while *Leucomium strumosom* is confined to forest floor in zone C. *Syrrhopodon loreus* is likely the only species with high coverage on tree trunks reported as unique to the lowland zone A. Aside from the unique species (confined to a particular zone), several other species have wide distributional ranges, including *Acroporium lamprophyllum*, *Bazzania tridens*, *Cheilolejeunea intertexta*, *C. occlusa*, *Isopterygium albescens*, *Lejeunea papilionacea*, *L. tuberculosa*, *Lepidolejeunea bidentula*, *Metalejeunea cucullata*, *Mitthyridium flavum*, *Riccardia parvula*, *Syrrhopodon spiculosus* and *Telaranea wallichiana*, which are found equally abundantly from lowland to highland. The above-mentioned species could be good indicator species for a particular elevation zone in the Genting Highlands. Hence, future research could address the range expansion or reduction of the above species and investigate potential correlation with any local or regional climate changes.

CHAPTER 6

CONCLUSION

This is the first methodical assessment of composition and diversity of epiphytic and ground bryophytes along an altitudinal gradient in Peninsular Malaysia. The study documented 283 liverwort and 170 moss species, totalling 453 bryophyte species from 18 study plots (0.04 hectare each) laid along an altitudinal transect at Genting Highlands. It amply demonstrated that the Genting Highlands indeed have a rich bryophyte flora and could be nominated as a potential key site for bryophyte conservation in Malaysia. Bryophyte species were distributed according to altitudinal range, from lowland forest, transition between lowland and montane forest, and montane forest comprising lower and upper montane forests. There are significant differences in the composition of bryophytes on tree trunks and forest floor in the study plots in different forest types. Each of the above forest types could be characterized by the presence of a few unique bryophyte species, which can be regarded as indicator species. In general, bryophyte species richness increases with elevation and is richest at the lower montane forest zone. Mosses are found more abundantly in the lowlands and at the lower elevations within the lower montane, while liverworts dominating the higher elevation within the lower montane and the summit region. The lower montane forest has the highest species richness of epiphytic bryophytes. Terrestrial bryophytes, however, show greater species richness in the summit zone. Moreover, epiphytic bryophytes showed higher species evenness than ground bryophytes and most bryophyte species, both epiphytic and terrestrial, were found to occupy only small areas, or were present in low abundances. The cover of epiphytic and ground bryophytes also increased with elevation. Epiphytic liverworts occupied 90% of the investigated area in the summit zone but much less at lower elevations. Epiphytic mosses, on the other hand, were more abundant in the lowlands but not at higher elevation zones. Ground bryophytes also showed similar coverage variation except for the summit zone, where liverworts and mosses were almost equally abundant in two study plots.

The present study reaffirms that climatic conditions such as relative humidity and temperature have an essential role in determining the distributional range of particular bryophyte species. Constantly high humidity and low temperatures promote the growth of many bryophytes in the tropics. On the other hand, most species were found growing on several substrates, both on tree trunks and forest floor, indicating that microhabitat conditions rather than host preferences were more important in shaping bryophyte communities present in the Genting Highlands.

These findings provide fundamental information for future comparative studies as well as further evaluations of species richness and bryophyte ecology on other mountains from similar climatic regions. Such a study could also be the foundation for implementing a future environmental monitoring programme, to access the impacts of various natural changes or anthropogenic disturbances on the growth and development of bryophytes in the montane forest. This is especially appropriate for a location like the Genting Highlands, where extensive development still continues at its higher elevation zone. It would be of definite interest to see if the bryophyte communities could survive another decade in the forests of the Genting Highlands as these highlands probably represent some of the most disturbed and altered tropical montane environments.

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LIST OF PUBLICATION AND PAPER PRESENTED

1. Authors: Cheah, Yih-Horng & Yong, Kien-Thai

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2. Authors: Cheah, Yih Horng & Yong, Kien Thai

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