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# Effect of habitat fragmentation and alteration on arboreal frogs in Sabah, Malaysia

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*Polypedates macrotis*
(photograph by author)

# Abstract

In Southeast Asian tropical rainforests, epiphytes provide safety and favourable microclimatic conditions to many small animals, including frogs. In recent years, the commercial planting of oil palm trees has caused a rapid decline of rain forests, most probably at considerable expense of biodiversity. However, palm trees do carry epiphytes, and there is some hope that they may act as biodiversity refuges. In this master thesis, I compare frog diversity and abundance in epiphytes of the *Asplenium nidus* complex between fragmented secondary forests, oil palm plantations and their edges along the Lower Kinabatangan River, eastern Sabah, Malaysia. More epiphytes were found in secondary forests and edges than in oil palm plantations and edges. Also, epiphyte characteristics differed significantly among habitat types. In the forest and forest edge plots, epiphytes on average occurred higher up the trees, and had a lower temperature and higher relative humidity than in the plantation and plantation edge plots. Mean diameter of the epiphytes was larger in forest plots than in other plot types. The distance between the epiphytes and the nearest water source were closest in plantation plots, but the distance to the Kinabatangan River tended to be larger in plantation edge plots. Epiphytes of plantation plots contained the largest numbers of frogs, but also the lowest species diversity. The likeliness of finding at least one frog in an epiphyte was also higher at night and when it has recently rained. Five frog species of three families were found in epiphytes. *Hylarana raniceps* (Ranidae) was by far the most abundant species, followed by *Polypedates leucomystax* (Rhacophoridae), *Rhacophorus appendiculatus* (Rhacophoridae), *Metaphrynella sundana* (Microhylidae) and *Polypedates macrotis* (Rhacophoridae). All *Polypedates leucomystax* and the majority of *Hylarana raniceps* were found in plantation and edge plantation plots. In line with their reputation as true forest species, *Metaphrynella sundana* and *Polypedates macrotis* were only present in forest plots. *Rhacophorus appendiculatus* was mostly present in forest edge plots. It seems that epiphytes in plantations, do provide opportunities for frogs, but unfortunately are primarily used by ‘disturbance’ species with low conservation value.

*Key words*: biodiversity; secondary forests; oil palm plantations; bird’s nest ferns; arboreal frogs

# Index

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# 1. Introduction

In this master thesis I compare the occurrence and diversity of arboreal frogs in epiphytes between secondary forests, oil palm plantations and their edges in Sabah, Malaysian Borneo. A convenient area for this study is the Lower Kinabatangan Wildlife Sanctuary. This study is a contribution to the knowledge of overall biodiversity loss occurring around the globe, caused mainly by habitat destruction and alteration. In what follows I will briefly outline the issues of deforestation and degradation of tropical forests, the importance of secondary forests for conservation, the effects of oil palm plantations, and the possible role of epiphytes as places of safety for the model animals of this study: arboreal frogs.

## 1.1. Deforestation and degradation of tropical forest

Recent years have witnessed a considerable intensification of agricultural activities. This development is essential for providing the ever-growing world population with food and fibre, but has also caused around 80% of deforestation worldwide (Kissinger et al., 2012). Timber extraction and logging are responsible for about 52% of forest degradation (Hosonuma et al., 2012). The resulting loss and degradation of natural habitats is causing a decline in biodiversity (Baillie et al., 2004). In addition, deforestation releases $CO_2$ into the atmosphere, which contributes to climate warming, especially in the tropics. It thus influences biodiversity in a second, indirect way (Bala et al., 2007). The world's total forest area is just over 4 milliard hectares, which corresponds to an average of 0.6 ha per capita (FAO 2010). In the last decade, each year around 13 million hectares of forest have been converted to other uses or have been lost through natural causes. It used to be 16 million hectares per year in the 1990s (Figure 1.1, FAO 2010). However, according to Target 5 of the Convention on Biological Diversity 2020, the rate of loss, degradation and fragmentation of natural habitats including forests has to be brought close to zero or at least halved to reduce direct pressures on biodiversity and promote sustainable use (Perrings et al., 2012). Globally, the ongoing destruction of tropical rainforests is of major concern because more than half of all known terrestrial plant and animal species live in tropical and subtropical forests (Laurance, 2007). Between 1990 and 1997, 5.8 (± **1.4**) million hectares of humid tropical forest have been lost each year, with a further 2.3 (± 0.7) million hectares of forest visibly degraded (Achard et al., 2002).

Southeast Asia contains the highest mean proportion of country-endemic bird (9%) and mammal species (11%) and has the highest proportion of threatened vascular plant, reptile, bird, and mammal species of all tropical regions of Meso-America, South America, and Sub-Saharan Africa (Sodhi et al., 2009). Southeast Asia could lose 13 to 42% of local populations by 2100, at least 50% of which could represent global species extinction and is therefore of particular conservation concern (Koh & Sodhi, 2010). The biodiversity decline is mainly due to the high rate of deforestation (Achard et al., 2002; Koh & Sodhi 2010; Miettinen et al., 2011). The major reason for deforestation is oil palm agriculture (Fitzherbert et al., 2008; Wilcove & Koh, 2010). In Malaysia alone, 4.6 million hectares of forests have been lost, accounting for a 20% reduction of forested land (Wicke et al., 2011). The State of Sabah has seen a rapid expansion of secondary forests with varying levels of degradation from selective and commercial logging (McMorrow & Talip, 2001).

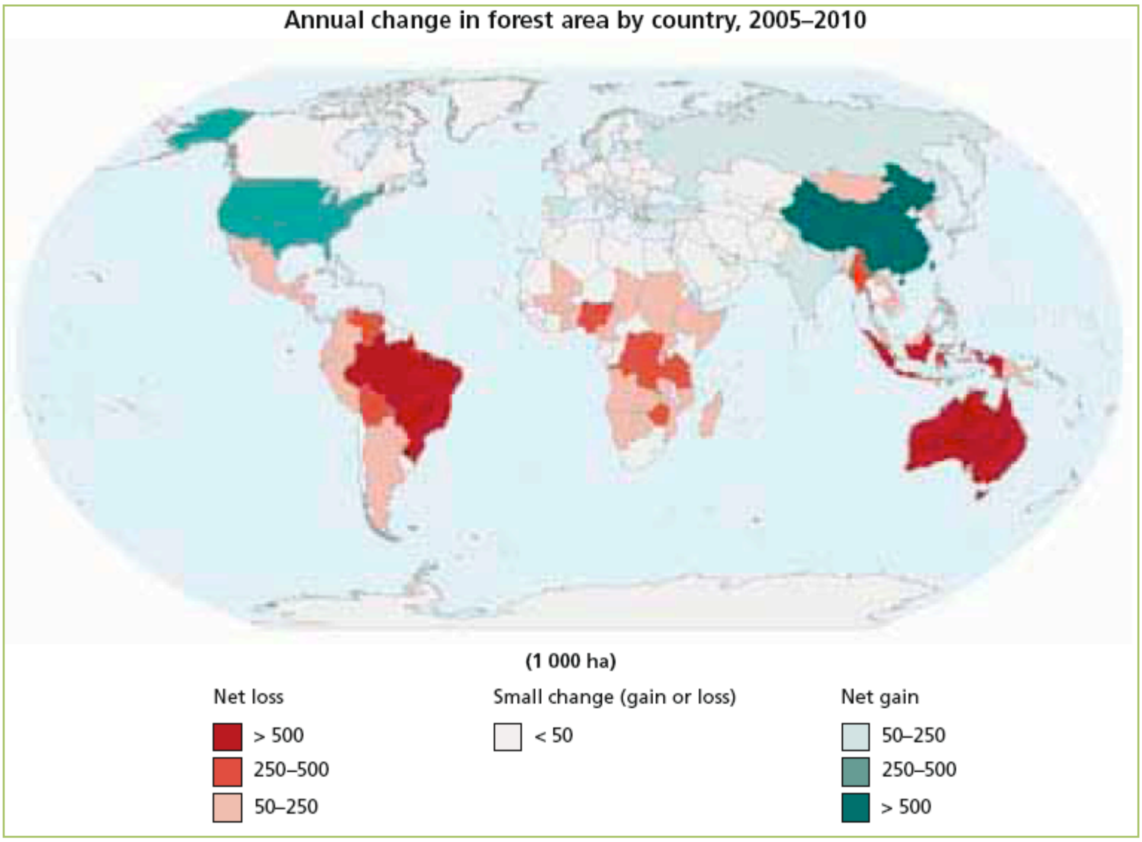


*Figure 1.1. Annual change in forest area by country, 2005–2010. Red means a net loss of forest area, while green is a net gain (taken from FAO 2010)*

## 1.2. Secondary tropical forest

Secondary rain forests (500 million ha) and degraded rain forests (350 million ha) together make up around 60% of the world's tropical forests. Southeast Asia has an estimated 175 million ha of secondary forests and 70 million ha of degraded forests (ITTO, 2002). The Food and Agriculture Organisation (FAO, 2003) defines secondary forests as forests regenerating largely through natural processes after significant removal or disturbance of the original forest vegetation by human or natural causes at a single point in time or over an extended period, and displaying a major difference in forest structure and/or canopy species composition with respect to pristine primary forests (Figure 1.2). Secondary forests are mostly located in more accessible areas in the vicinity of human settlements and provide valuable goods and services at local, national and international levels (ITTO, 2002). Forest degradation implies thinning of the canopy and loss of carbon in remaining forests, where damage is not associated with a change in land use and where, if not hindered, the forest is expected to re-grow (Hosonuma et al., 2012). A degraded forest delivers a reduced supply of goods and services from a given site and maintains only limited biological diversity. It has lost the structure, function, species composition and/or productivity normally associated with the natural forest type expected at that site (ITTO, 2002).

*Figure 1.2. View on secondary forest from a platform in lot 6 of the Lower Kinabatangan Wildlife Sanctuary (photograph by author)*

Although protecting primary forests should remain a priority because of higher biodiversity (Clough et al., 2011; Gibson et al., 2011), secondary forests might be pivotal for the conservation of biodiversity in tropical areas (Ficetola et al., 2007; Barlow et al., 2007). One of the most typical characteristics of secondary forests is the high floristic heterogeneity among stands only short distances apart, at the level of both the canopy and the undergrowth (ITTO, 2002). The conservation value of a secondary forest is expected to increase over time (Chazdon et al., 2009) and the rate of change depends on the frequency and intensity of disturbance, and the availability of seed parents (FAO 2003). The presence of old growth forests in the immediate vicinity is also a factor (Dent & Wright, 2009; Chazdon et al., 2009). Turner et al. (1997) concluded that even after a century of colonization, tree species diversity in secondary forests was still significantly less than in primary forest. A meta-analysis of several plant and animal taxa revealed that on average many more species were unique to primary forests than secondary forests and secondary forests held more primary forest species than plantations (Barlow et al., 2007). Dent and Wright (2009) reviewed 65 studies on faunal diversity and concluded that secondary forests are primarily inhabited by species that are widespread, occur in high densities and are habitat generalists. Still, at least for some taxa (including amphibians, Gillespie et al., 2012), remnant secondary forests may harbour considerable amounts of species diversity. More studies are needed (Chazdon et al., 2009), but it has been suggested that secondary forests may have a role to play in the long-term rescue of many threatened forest species (Wright & Muller-Landau, 2006).

## 1.3. Oil palm agriculture

Palm oil is the most economical and sustainable source of food and biofuel in the world market (Fitzherbert et al., 2008; Lam et al., 2009). The oil palm (*Elaeis guineensis*; Figure 1.3) is a plant originating from West Africa. The oil is extracted from its fruits and impurities, colours and odours are removed before it can be used for consumption (RSPO, 2006). Oil palm plantations cover over 13 million hectares, primarily in Southeast Asia, where they have directly or indirectly replaced a considerable area of tropical rainforest (Millennium Ecosystem Assessment, 2005; Danielson et al., 2009). Between 1990 and 2005, over 1.04 million hectares of Malaysia's remaining forests were converted to oil palm plantations, accounting for 94% of the deforestation throughout the entire nation (FAO 2005). Improving yields and converting degraded land into plantations may suffice to meet the ever-increasing demand for palm oil without further deforestation until 2020 (Wicke et al., 2011; Fitzherbert et al., 2008). However, by 2050, an additional 12 million hectares of palms would be required (Corley,

*Figure 1.3. Oil palm plantation just outside the Lower Kinabatangan Wildlife Sanctuary (photograph by author)*

2009; OECD-FAO 2012) and this puts considerable pressure on the remaining forests (Wicke et al., 2011). If the demand for biofuel continues to rise, an even larger expansion of oil palm plantations will be needed (Corley, 2009).

For biodiversity, oil palm plantations seem to be a poor substitute for native tropical forests (figure 1.4; Fitzherbert et al., 2008; Danielsen et al., 2009). Danielsen et al. (2009) suggested that palm plantations support few species of conservation importance, and affect biodiversity in adjacent habitats through fragmentation, edge effects and pollution. As a consequence, the conversion of primary or secondary forests into oil palm plantations will cause significant biodiversity losses (Koh & Wilcove, 2008).

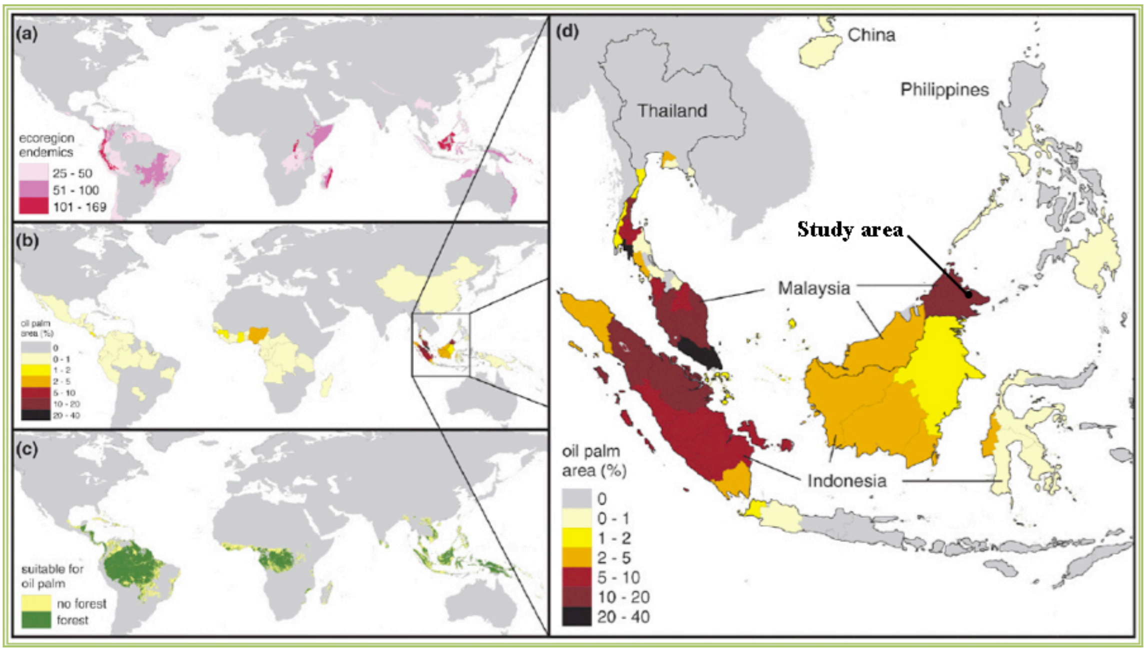


*Figure 1.4. Global distribution of oil palm and potential conflicts with biodiversity: (a) areas of high terrestrial vertebrate endemism; (b) global distribution of oil palm cultivation; (c) agriculturally suitable areas for oil palm with and without forest; (d) oil palm-harvested area in Southeast Asia. Study area indicated in NE-Borneo (Fitzherbert et al., 2008)*

A recent meta-analysis on the subject revealed that trees, lianas, epiphytic orchids and indigenous palms are mostly absent from oil palm plantations, and that total vertebrate species richness of oil palm plantations was less than half that of natural forest (Danielsen et al., 2009). The majority of individual plants and animals in oil palm plantations belonged to a small number of generalist species of low conservation concern (Danielsen et al., 2009). The encroachment and unregulated expansion of plantations are also considered major threats to mammals like rhinos, tigers, elephants and orang-utans as they are a target for poaching and illegal logging activities and can disrupt mammalian movement (Sodhi et al., 2010). For birds, overall species richness in forests declined by 43% following conversion to oil palm and abundance declined by 18% following conversion (Senior et al., 2012). The number of ant species in oil palm plantations is only 64% of that of primary forests, and plantations contain a larger percentage of non-native ant species (Fayle et al., 2010; Senior et al., 2012). Arthropod abundance and biomass in general was lower in oil palm plantations compared with primary forest (Turner & Foster, 2009). For beetles, Senior et al. (2012) report a 52% decline in species richness and a 54% decline in abundance following conversion. Several studies on amphibians have also reported lower species diversities in palm plantations compared to primary forests (Gillespie et al., 2012; Scriven, 2011), but I will return to this in section 1.5 and 1.6.

Several ways of mitigating biodiversity loss in oil palm plantations have been proposed, including agro forestry (Bhagwat & Willis, 2008), reducing field sizes, creating a patchwork of differently aged plantations, increasing connectivity, mitigating disturbances (Luskin & Potts, 2011), optimizing yields and reducing input (Basiron, 2007).

## 1.4. Bird’s nest ferns (*Asplenium nidus* complex)

Epiphytic plants are a dominant component of the rain forest canopy biota. They represent a significant proportion of canopy plant biomass and diversity, play a key role in nutrient cycling, and support highly abundant and diverse animal communities (Fayle et al., 2009). Epiphytes are plant species that germinate and grow exclusively, or at least primarily, on other plants, but do not parasitize their hosts (Zotz 2013). Thus epiphytes need their host plant only as a substrate to attach to (Fedrowitz, 2008). Worldwide, 27614 species of vascular epiphytes are recognized, representing 913 genera in 73 families, or approximately 9% of extant vascular plant diversity (Zotz, 2013). Predominant among these plants are the ferns (Fayle et al., 2005), with Polypodiaceae as an important family, which alone accounts for around 50% of all epiphytic fern species (Zotz, 2013). One of the genera with the largest numbers of species is the paraphyletic *Asplenium* L. s.s. (Fayle et al., 2005; Zotz, 2013).

Bird’s nest ferns (*Asplenium nidus* complex; Figure 1.5) are found from the east coast of Africa through India and Southeast Asia to Japan, northern Australia and many islands in the western Pacific (Holttum, 1976). The plants have a large basket-shaped rosette that accumulates leaf litter (Elwood et al., 2002; Fayle et al., 2005) and also intercepts water, which is stored in sponge-like root mass (Fayle et al., 2009; Freiberg & Turton, 2007; Zhang et al., 2010). The ferns use the nutrients resulting from the decomposition of the litter (Nadkarni, 1984; Fayle et al., 2005; Fayle et al., 2009). In the forests of Sabah, two sympatric fern species coexist: *Asplenium nidus* and *Asplenium phyllitidis*. The two species are morphologically very similar, and almost impossible to tell apart if reproductive structures are not present; however, their ecologies differ markedly (Fayle et al., 2011). *Asplenium nidus* is able to survive at all heights up to the top of the canopy (60m) and is associated with emergent trees and more open areas, while *A. phyllitidis* is never found above 30m high. Larger *A. phyllitidis* live higher up in the canopy, while the size of *A. nidus* is limited only by the diameter of its substrate plant (Fayle et al., 2011). *Asplenium nidus* seems adapted to withstand the hot dry conditions in the upper canopy and in gaps (Fayle et al., 2009). Because of that, the epiphyte is also present in oil palm plantations, where similar microclimatic conditions prevail (Fayle et al., 2011). Several recent studies in and around Danum Valley (Lahad Datu district of Sabah) found lower epiphyte abundance in secondary forests than in oil palm plantations, with on average respectively 48 and 114 ferns/ha present (Foster et al., 2011; Turner & Foster, 2009; Turner & Foster, 2006; Turner, 2005). *Aspelnium nidus* has an aggregated spatial distribution at multiple spatial scales. At larger scales, a preference for swampy areas is the driving force for this clumped distribution. At a more local scale, the limited dispersal capacity of their wind-dispersed spores most likely explains the occurrence of clusters of individuals (Zhang et al., 2010).

*Figure 1.5. Bird's nest ferns (Asplenium nidus) growing on branches in secondary forest in the Lower Kinabatangan Wildlife Sanctuary (photograph by author)*

By virtue of their large size and high abundance, epiphytes harbour a substantial proportion of rainforest canopy biodiversity (Fayle et al., 2005). Because they buffer temperature variation and reduce evaporative water loss, they provide an important refuge for animals ranging from arthropods to bats (Fayle et al., 2010; Freiberg & Turton, 2010; Turner & Foster, 2006;

Hodgkison et al., 2003). In primary forest plots in Danum Valley, for instance, Elwood and co-workers (2002; 2004) found an average of 41000, 8000 and 670 invertebrates in large, intermediate and small epiphytic ferns, respectively. The largest ferns weighed around 200 kg and contained half of the total host tree's invertebrate biomass Termites and ants represented at least 90 % of the abundance in these ferns. In several taxa, species have specialised in living in epiphytes (e.g. oribatid mites on Okinawa Island, Karasawi & Hijii, 2006). A meta-analysis revealed that epiphytes higher up in the canopy often support more insects than those closer to the ground (Basset, 2001).

Because *Asplenium nidus* is abundantly present in secondary forests and also occurs in oil palm plantations, it has been suggested that the ferns may act as reservoirs of biodiversity (Fayle et al., 2005; Turner & Foster, 2009). However, little is known on how well the epiphytes survive outside the forest, and whether epiphytes in plantations have the characteristics that make their conspecifics in more natural habitats so suitable as biodiversity asylums. Factors that may thwart the local survival of epiphyte populations include limited dispersal capacities due to weak air currents (Zhang et al., 2010), and high mortality due to unfavourable microclimatic conditions (Fayle et al., 2009). Drought is probably the most important abiotic mortality factor controlling population of *A. nidus* (more than wind, air temperature, relative humidity or sunlight, Freiberg & Turton, 2007; Fayle et al., 2009). Four weeks of dry weather suffice to kill the roots of *A. nidus*, causing ferns attached on vertical stems to fall to the ground. If drought persists longer than eight weeks, even adult plants sitting in more protected branch forks will succumb (Freiberg & Turton, 2007). Under the current models of global climate change, the geographic range of *A. nidus* is expected to decline, and locally the species likely will be become more restricted to wetter habitats and understorey (Freiberg & Turton, 2007; Zhang et al., 2010).

## **1.5. Amphibians**

Amphibians are a group of vertebrates containing over 6300 known species worldwide (AmphibiaWeb, 2013), including the Anura (frogs and toads), Caudata (newts and salamanders) and Gymnophiona (caecilians). Most species are ectothermic and lay eggs (IUCN, 2012). The majority of species have biphasic life histories and undergo an ontogenetic shift from aquatic to terrestrial habitats (Becker et al., 2010). Almost all are dependent on moist conditions, and many require freshwater habitats in which to breed (AmphibiaWeb, 2013). The greatest species diversity occurs in tropical forests (AmphibiaWeb, 2013; IUCN, 2012).

Amphibians are convenient indicators of environmental quality, because their highly permeable skins make them sensitive to environmental toxins or changes in patterns of temperature or rainfall (IUCN, 2012; Alford and Richards, 1999). Because of this sensitivity, amphibian species are more threatened and are declining more rapidly than either birds or mammals (Stuart et al., 2004). Around 32% of the world's extant amphibian species are known to be threatened or already extinct, 43% are not threatened, and for 25% of the species, there is too little information to determine their status. At least 42% of all amphibian species are declining, indicating that the number of threatened species can be expected to rise in the future (IUCN, 2012). The causes for amphibian population declines are complex and may differ among species, populations and life stages within a population (Blaustein et al., 2011). Although habitat loss and alteration clearly pose the greatest threats to amphibians (Alford & Richards. 1999; Blaustein et al., 2011; IUCN, 2012), a newly recognized fungal disease called chytridiomycosis is seriously affecting an increasing number of species (Skerratt et al., 2007). Also, global climate change is thought to be a major threat to amphibians (AmphibiaWeb, 2013) as well as pollutions and introduction of exotic species (Kueh & Maryati, 2008). Unidentified processes threaten 48% of rapidly declining species and are driving species to extinction at perturbing rates (Stuart et al., 2004). Many amphibian species occur as metapopulations, so the dynamics of local populations may be poor indicators of their status. Studies integrating research within local populations with investigations at the metapopulation level are most likely to discover the causes of amphibian declines (Alford & Richards, 1999).

In Borneo, the largest island of Asia, about 155 named species/subspecies of anurans, together with several caecilian species, have been reported (Matsui, 2006). Six of the eight families of anurans can be found in Sabah, a Malaysian part in the north of Borneo (Haas & Das, 2012). A total of 109 species, with 18 species of true toads (Bufonidae), 11 of true frogs I (Dicroglossidae), 14 of litter frogs (Megophryidae), 14 of narrow-mouthed frogs (Microhylidae), 20 of true frogs II (Ranidae) and 32 of tree and flying frogs (Rhacophoridae), are currently known to occur in the region. The degree of endemism is approximately 17% (Kueh & Maryati, 2008; AmphibiaWeb, 2013). Because of the exploration of new localities and the identification of cryptic species through examination of morphological variations, the use of acoustic records and the use of biochemical methods, it seems likely that more species will be found in the near future (Matsui, 2006). Sadly, many frog populations in Sabah are threatened by several of the factors mentioned above, although luckily the fungal disease chytridiomycosis has not yet been detected in this area (Kueh & Maryati, 2008).

Three protected areas in Sabah (Tabin Wildlife Reserve, Crocker Range Park and Maliau Basin Conservation Area) still hold substantial areas of primary forest. These remnants are home to several species of Rhacophoridae (Figure 1.6), primary forest specialists that depend heavily on pristine ecosystems for both survival and reproduction. Species such as the grass frog (*Fejervarya limnocharis*), green paddy frog (*Hylarana erythraea*), and four-lined tree frog (*Polypedates leucomystax*) are more typically associated with man-made habitats, such as oil palm plantations (Figure 1.7; Inger et al., 2005; Kueh & Maryati, 2005; Sheridan, 2008). Gillespie et al. (2012) and Scriven (2011) have studied amphibian diversity in the area where I also did my research. Gillespie et al. (2012) reported 31 frog species belonging to five families (Bufonidae, Dicroglossidae, Microhylidae, Ranidae, Rhacophoridae) from around the Lower Kinabatangan River. In addition, they found single specimens of three probably undescribed species. Thirteen species were restricted to forested habitats and two species were restricted to non-forest habitats. Scriven (2011) found 27 species, belonging to the same 5 families, 17 of which were typical forest species and nine were endemic to Borneo. Five species were considered 'disturbance' species. Both studies mention that oil palm plantations have low conservation value for amphibians, but that secondary forests retained a large proportion of amphibian species known from lowland primary rainforests.

*Figure 1.6. Polypedates macrotis, a common forest species (photograph by author)*

*Figure 1.7. Hylarana erythraea, a typical commensal of man (photograph by author)*

## 1.6. Arboreal frogs

In the tropics, over 75% of all tetrapod vertebrate species are fully or partly arboreal (Kays & Allison, 2001). Many tropical canopy animals are difficult to study and have therefore received much less scientific attention than their temperate or terrestrial counterparts, although they often serve as umbrella or flagship species in conservation programs. Most studies on tropical arboreal species have focused on primates or birds. Arboreal reptiles and amphibians have caught much less scientific attention (Kays & Allison, 2001).

Many arboreal frogs, like many other tree-dwelling vertebrates, exhibit distinctive adaptations that allow them to live in the canopy. Several species have evolved a way of gliding or controlled falling that they use to travel from branch to branch or from tree to tree. This particular mode of locomotion is associated with a flattening of the body, the presence of lateral skin flaps, flattened or lengthened tails and webbed fingers and toes webbing, morphological changes that increase effective aerodynamic surface area and improve lift and drag performance of the body as a whole (Emmons & Gentry, 1983; Dudley et al., 2007). Rhacophorid frogs (Rhacophoridae) for example are almost exclusively arboreal (Haas & Das, 2012). They have independently converged on gliding morphologies and behaviour, with at least five species in the genus *Rhacophorus* documented to be aerially proficient (Boulenger, 1912; Emerson & Koehl, 1990; Inger, 1966; Liem, 1970; McCay, 2001: cited in Dudley et al., 2007). Another adaptation to life in the canopy is that many tree frogs possess large disc-like digital pads, which facilitate adhesion (Pertel et al., 2010; Smith et al., 2006). The relationship between morphology, size and adhesion is of particular interest for tree frogs, because evolution of adhesive ability has facilitated niche expansion into arboreal habitats (Smith et al., 2006). Gillespie et al. (2012) found that 15 out of 31 species encountered along the Kinabatangan River were arboreal and that dry forest transects had three times as many arboreal species compared to plantations.

## 1.7. Project aims and hypotheses

The effects of the replacement of tropical forest by oil palm plantations on amphibian diversity have not been studied well (Gillespie et al., 2012). I chose to look at the effect on anurans because they are sensitive to environmental changes, play an important role in tropical ecosystems and have a high conservation value due to their fast worldwide decline. The current study focuses on arboreal frogs in bird's nest ferns, which are common in this area.

The general question in this master thesis is whether epiphytic bird's nest ferns, fulfil their putative role as biodiversity reservoirs in fragmented secondary forests, oil palm plantations and edge habitats along the Lower Kinabatangan River in East Sabah, Malaysia. In particular, the following research questions are tackled:

(1) What is the relative abundance of bird's nest ferns in plantation plots, compared to secondary forest plots and edge plots?

(2) Do bird's nest ferns in plantation, forest and edge plots differ in characteristics that may affect their suitability as refuges for arboreal frogs?

(3) Can the presence/absence of frogs in epiphytes be predicted on the basis of epiphyte characteristics?

(4) Does frog abundance and species diversity differ between plots of different types?

(5) Which arboreal frog species survive in plantation plots and edge plots, and which species are confined to forests?

# 2. Materials and methods

## 2.1. Location

The study area is situated along the Lower Kinabatangan River floodplain in east Sabah, Malaysia (N5° 28’ – N5° 21’; E117° 56’ – E118° 09’; Figure 2.1). Most of the area is low and flat, poorly drained and periodically flooded, but some low mudstone hills and several karstified limestone outcrops do occur (Azmi, 1998). Floodings happen mostly during the wet season between November and March when the west monsoon prevails (Scott, 1989). The region is characterized by a warm, wet and humid tropical climate. Mean monthly temperatures vary from 21 to 34°C and mean annual precipitation is between 2500 and 3500mm (Malaysian Meteorological Services Department, cited in Ancrenaz et al., 2004). The natural habitats in this area include evergreen freshwater swamp forests (permanently waterlogged swamps or frequently flooded), (*Nipa* palm) mangroves, low stature forests and grasslands in backswamp areas (Ancrenaz et al., 2004).

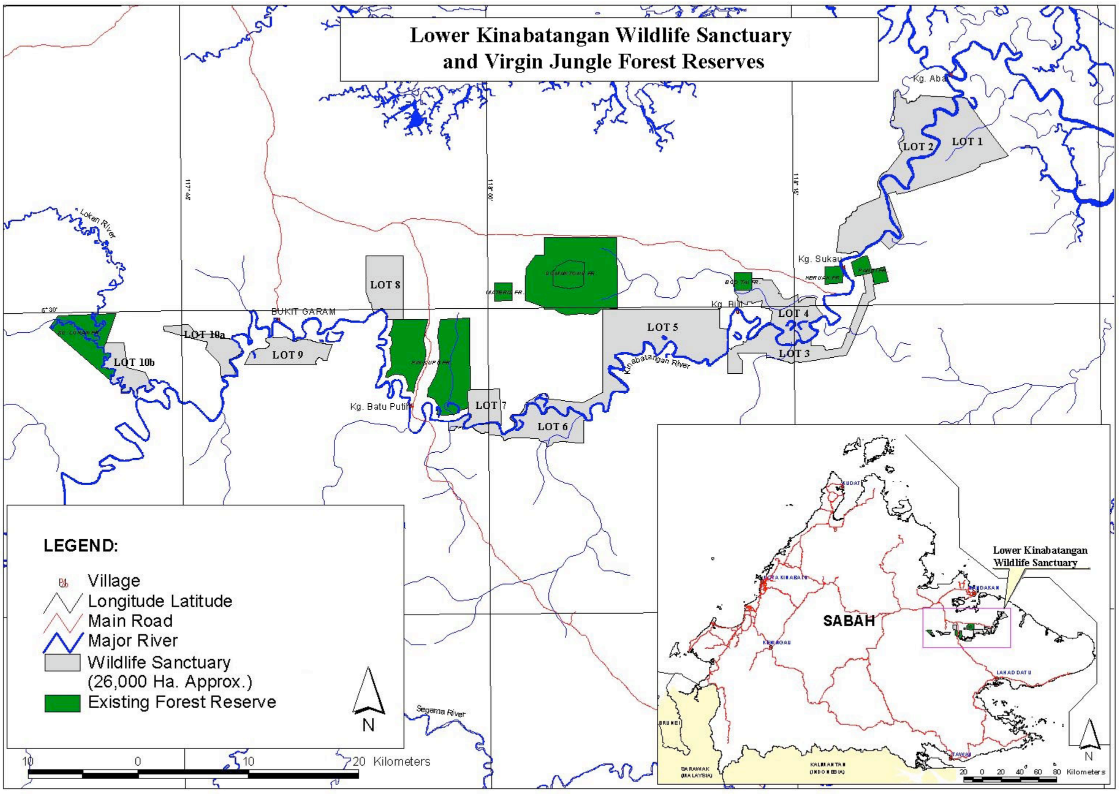


*Figure 2.1. Map of the Lower Kinabatangan River Floodplain with the 10 forest lots of the Lower Kinabatangan Wildlife Sanctuary and Virgin Jungle Forest Reserves. Inside map shows the location of the study region in Sabah, Malaysian Borneo. © DGFC*

Almost the entire area was intensively logged between 1960 and 1995, officially as well as illegally. Much of the original forested areas were cleared for oil palm plantations (Azmi, 1998). Secondary forest persists as fragmented remnants along the Lower Kinabatangan

River. These fragments together with protected primary forest blocks (the so-called ‘Virgin Jungle Reserves’) form the Lower Kinabatangan Wildlife Sanctuary, gazetted in 2005 by the State Government of Sabah (Gillespie et al., 2012). The forest lots function to increase connectivity between the remaining coastal mangrove swamps and the dry forests upriver (Goossens et al., 2005). Twenty-four small villages, agricultural lands and many oil palm plantations of various ages are situated between the forest patches (Gillespie et al., 2012). The study was carried out between July 16 and October 25 of 2012. During this period, I enjoyed the hospitality of the Danau Girang Field Centre, a research centre situated in lot 6 of the Sanctuary (http://www.cardiff.ac.uk/biosi/facilities/danaugirangfieldcentre/index.html; N5° 24’ 49.4” E118° 02’ 14.9”)

## 2.2. Transect and epiphyte selection

In a recent study of amphibian biodiversity along the Kinabatangan River, Scriven (2011) selected 75 transects of different lengths in four habitat types. For the current study, I used a random subsample of these transects with a fixed length. Each transect had a surface area of 0.625 ha (125m by 50m). Eleven of these transects were situated in secondary forest plots, five were in the forests’ edges, five in plantation’s edges and eleven were within plantations (Figure 2.2). Edge transects were located within 25m of the forest-oil palm plantation boundary.

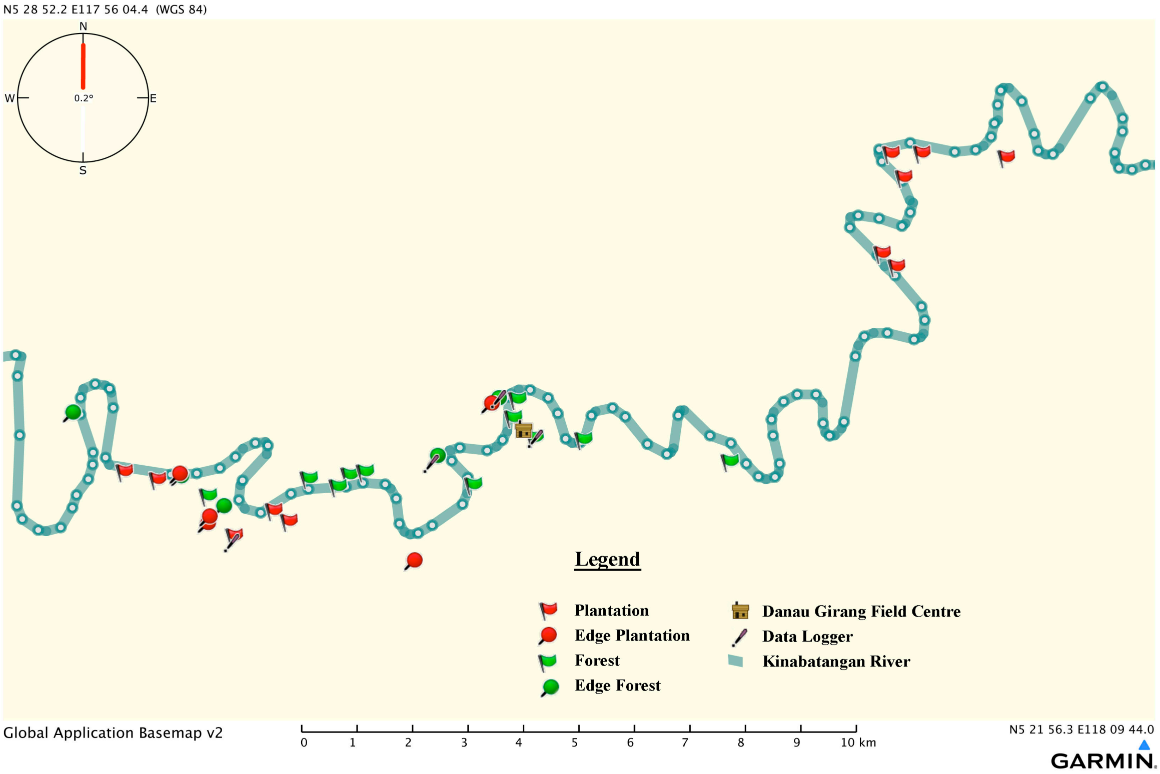


*Figure 2.2. Location of transects and data loggers in the study area. Transects are located along the Kinabatangan River. (Map made with Garmin Basecamp version 2.1.2)*

At the unset of the study, I explored the transects to verify the presence of bird's nest ferns (*Asplenium nidus* complex), sometimes using a binocular (type: Kite petrel). Bird's nest ferns were not found in young oil palm plantations, so these were ignored in the rest of the study. The plants proved also difficult to find in forest edges. In those transects where epiphytes were present, all small, medium and large individuals (with a rosette diameter of respectively < 0.3m, 0.3 < 0.6m and > 0.6m) within twenty-five meters on each site of the transect were counted. An educated guess determined the size of the epiphytes. The length of each transect was measured using a range-finder (type: toolcraft LDM 70). The start and end point was marked with a piece of ribbon and located with a gps (Garmin GPSmap 60CSx). Along each transect, five epiphytes were chosen randomly by throwing a die (yielding a number x) and sampling the x-th epiphyte encountered. If the epiphyte was unreachable for technical reasons (e.g. lack of an anchor point) or for safety reasons (e.g. presence of dead branches), I sampled the nearest-by plant. The tree holding the epiphyte was photographed with a Canon Powershot A800 and also the location was marked with a gps.

Sampling a transect took two or three days, depending on the climatic conditions. On the first day, starting around 7 AM, I installed the pilot lines and climbing rope where necessary. If the epiphyte was located below 8 meters in the tree, I used a ladder to sample it. A first ascend and sampling took place during daylight. Because the majority of Asian tree frogs are nocturnal, the second and third ascend began after dusk (approximately 6:30 PM) on the same and the following day. I used H7 LED lenser© headtorches (170 lumens, 3 watt CREE) for illumination when sampling at night. Hence, every epiphyte was checked for frogs thrice, once in the daytime and twice at night.

## 2.3. Environmental temperature

To be able to compare daily temperature profiles among habitat types, one data logger (HOBO® Temp) was placed in each plot type (Figure 2.2). The BoxCar software was used to program the unset, end and interval time (15 minutes) of sampling for temperature measurements. The loggers were placed in a waterproof box that was attached to the north site of a tree, approximately at one meter height. At the end of the stay, the loggers were collected and data was downloaded and stored in a txt-file.

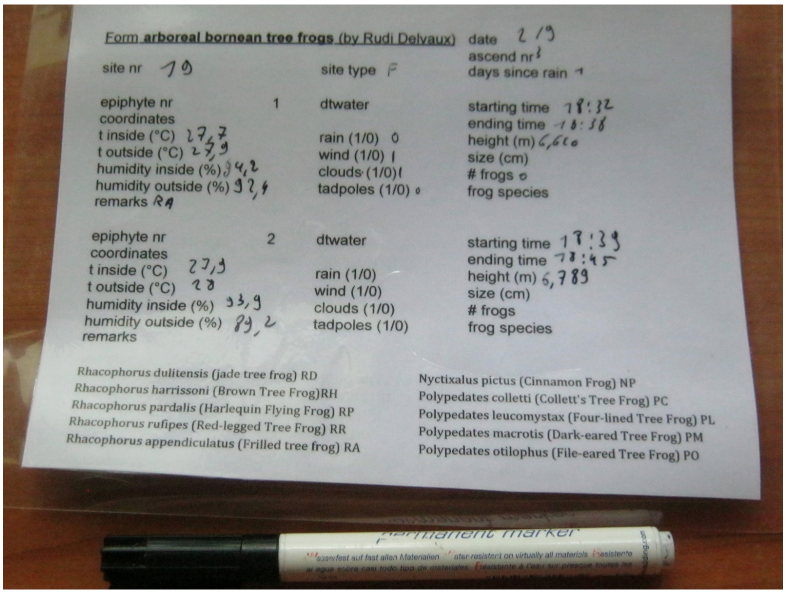
## 2.4. Getting to the plots

Not all study plots were readily accessible. Most often, I used a small, motorised boat to travel up- or downstream the Kinabatangan River. Which plot could be visited on a given day, typically depended on the water level. Some plots were only accessible through tributaries, which fill only when the water level is high. The remaining distance has to be done on foot. The choice of study plots was also dependent on the availability of one of the two guides, Baharudin Resake (Budin) and Samsir Laimin. Only Budin was well trained for climbing trees so when he wasn't available, Samsir accompanied me to the plantations, where only a ladder was needed for sampling.

## 2.5. Notes taken before climbing

Because of the wet conditions in the field, the use of a laminated form with all the necessary variables written on it proved very practical (Figure 2.3). Before ascending a tree carrying an epiphyte, I took the following notes:

(1) date and site nr (=transect number), site type ('forest'=F, 'edge forest'=EF, 'plantation'=P and 'edge plantation'= EP);
(2) epiphyte (1-5) and ascend number (1-3);
(3) time of day at the start of the ascend;
(4) the epiphyte's geographical position (gps coordinates);
(5) weather conditions: the number of preceding days without rain; occurrence of rainfall, wind or clouds.



Form arboreal bornean tree frogs (by Rudi Delvaux)

| | | |
|---|---|---|
| | | date 2/9 |
| | | ascend nr 3 |
| site nr 19 | site type F | days since rain 1 |
| epiphyte nr 1 | dtwater | starting time 18:32 |
| coordinates | | ending time 18:38 |
| t inside (°C) 27,7 | rain (1/0) 0 | height (m) 6,660 |
| t outside (°C) 27,9 | wind (1/0) 1 | size (cm) |
| humidity inside (%) 94,2 | clouds (1/0) 1 | # frogs 0 |
| humidity outside (%) 92,4 | tadpoles (1/0) 0 | frog species |
| remarks RA | | |
| epiphyte nr 2 | dtwater | starting time 18:39 |
| coordinates | | ending time 18:45 |
| t inside (°C) 27,9 | rain (1/0) | height (m) 6,789 |
| t outside (°C) 28 | wind (1/0) | size (cm) |
| humidity inside (%) 93,9 | clouds (1/0) | # frogs |
| humidity outside (%) 89,2 | tadpoles (1/0) | frog species |
| remarks | | |

| | |
|---|---|
| Rhacophorus dulitensis (jade tree frog) RD | Nyctixalus pictus (Cinnamon Frog) NP |
| Rhacophorus harrissoni (Brown Tree Frog)RH | Polypedates colletti (Collett's Tree Frog) PC |
| Rhacophorus pardalis (Harlequin Flying Frog) RP | Polypedates leucomystax (Four-lined Tree Frog) PL |
| Rhacophorus rufipes (Red-legged Tree Frog) RR | Polypedates macrotis (Dark-eared Tree Frog) PM |
| Rhacophorus appendiculatus (Frilled tree frog) RA | Polypedates otilophus (File-eared Tree Frog) PO |

*Figure 2.3. Form with all the necessary notes and variables*

## 2.6. Ascending a tree

Epiphytes can be found at different heights in a tree. In oil palm plantations, epiphytes usually did not occur higher than 6 meters above ground and could be sampled by climbing a ladder. In the forest, epiphytes were often found much higher up the tree. If they were situated above

8 meters, climbing material was needed for ascending. In what follows I give a detailed technical description of the tree climbing technique I used, namely the Single Rope Technique (SRT). More specifically I used the R.A.D. system (Rapid Ascend and Descend, Jepson et al., 2006; Sharpe et al., 2010), combined with an extra safety line (Figure 2.4). It is advisable to go through the different techniques of tree climbing beforehand, because the use is dependent on personal preferences. Also, knowledge of appropriate knots is necessary in case of emergency or unexpected moves (Sommerville, 2010). Following Houle et al. (2004), the following steps were taken in consideration while planning and executing the study. The first step consisted in selecting the equipment needed. Because the work had to be done in difficult accessible forest, the weight of the gear was an important factor. Beside a semi static climbing rope with a length of 100m, nylon lines, pilot ropes, a bigshot, arborist harness, helmet, grigri, hand ascender with foot strop, small pulley and several karabiners were needed (Photographs in appendix 1 Figure 6.1). All the equipment was stored and carried in a big waterproof backpack (Ortlieb). The second step was to select trees to climb into (see above). Installing the climbing rope requires a number of actions. First a ’bigshot’ is used to project the throw-line over an anchor point, at least a few meters above the epiphyte. The anchor point has to be solid enough, but it proved not always easy to appreciate that from below.  Knowledge of the tree species can be handy. Secondly, a pilot rope is attached to the throw-line in order to pull the small nylon rope in the tree. Finally, the double used climbing rope can be pulled over the anchor point using the pilot rope. The third step is to secure one end of the climbing rope to the base of the same or another solid tree and to climb the other end. A grigri, hand ascender with foot strop, pulley and karabiners are used to ascend the rope. The second rope is a security line, attached with a mechanical ascender and sling to the harness. All ascenders employ a toothed cam allowing the ascender to slide freely in one direction on a rope, but to grip tightly when pulled in the opposite direction. All the gear must be double-checked to make certain that it is properly set and works fine before starting the climb. Hanging from the rope with two persons can test the strength of the anchor point. The fourth step is to prepare for an immediate descent, should an emergency arise. Attacks of bees or other animals are always possible, but also sudden sickness, rain and storm can occur. A second person on ground level, also capable of climbing, should be present in case the climber needs help. The fifth step is obviously collecting the data when the epiphyte is reached (see

*figure 2.4. R.A.D. system and safety line © Budin*

section 2.7). The final step is to descend the tree via rappelling. In this study, because each epiphyte had to be sampled thrice, a pilot rope was left in the tree to facilitate subsequent ascends. I would not recommend leaving a climbing rope unattended for a long time in the tree, because animals like rodents or termites can chew on it.

## 2.7. Notes taken in the tree

To avoid disturbing any frogs present in the epiphytes, all trees were climbed making a minimum of noise and movements. During the climb all the necessary tools like multimeter (Amprobe TH1), measuring tape, range finder (toolcraft LDM 70), compact camera (Canon powershot A800), with fish-eye lens attached (Jackar) were safely stored in a photo jacket (Photographs of tools in Appendix 2 Figure 6.2). Once I reached an epiphyte, I first looked for frogs, photographed any present and identified the species. Identification was aided by the list of arboreal frogs found in this area in the recent paper by Gillespie et al. (2012). Whenever identification was difficult or when I assumed a new species was found, frogs were caught by hand and taken to the lab at the field centre for further investigation. I also searched for tadpoles. After identification, frogs were released at the same place. I then measured the temperature (°C) and humidity (%) within the epiphyte (inserting the sensor into the litter) and at 2 meters distance using a multimeter.  I measured the diameter of the rosette between the bottom of the leaves using measuring tape and the height from the ground by holding the rangefinder upside down at the at the same level of the top of the leaf litter. During the first ascend (i.e., in daylight conditions), minimum three hemispherical photographs of the canopy were taken by holding the compact camera, equipped with a fish-eye lens, upward about one meter above the rosette of the epiphyte. Canopy cover (%) was estimated from the hemispherical photographs using the software program CAN-EYE version 4.1 (appendix 3, Duveilier et al., 2009).

After the descend, the distance to the nearest water source was estimated and the end time was noted.

## 2.8. Data use and statistics

Coordinates (WGS 84) of the start and end points of the explored transects and all the sampled epiphytes were marked with a gps and downloaded with the software ‘Garmin BaseCamp version 2.1.2’. Each plot type was indicated with a different symbol. The software allows measuring distances, which I used for the shortest distance between each epiphyte and the Kinabatangan River. The starting points of each transect were used to indicate their location on a map.

I used the software package 'R version 2.10.1' for all statistical analyses. Normality was checked with the Shapiro-Wilk test (W>0.9). When variables deviated from normality, traditional transformations where applied. If these did not improve normality, non-parametric tests were used. Differences in environmental temperature, epiphyte numbers and characteristics, numbers of frogs per epiphyte or per transect among plot types were assessed by ANOVAs or Kruskal-Wallis tests. I used a generalized linear model (GLM) to investigate the simultaneous effects of weather conditions on the likeliness of finding at least one frog in an epiphyte. I used principal component analysis to summarize overall variation in the characteristics of epiphytes used by the different frog species. The average scores on the new important axes were investigated among frog species.

# 3. Results

Overall, the study went quite well. Exploring transects, finding epiphytes and ascending trees caused no major problems. Elephants proved a matter of concern. Once we had to pass a herd of elephants in order to reach our motorized boat. On some days, the presence of elephants precluded us from going out at all. Despite the limited size of the study plots, getting lost also proved easy. One night, having forgotten the gps, my guide and I walked disoriented through the forest for over an hour. More than once, heavy rain or wind forced us to return to base before any sampling could be done, or even prevented us from going out at all.

I explored a total of 32 transects in ‘plantation’ (P), ‘forest’ (F), ‘edge plantation’ (EP) and ‘edge forest’ (EF) plot types. Many of the transects that had been sampled by Scriven (2011) and were situated in the ‘edge’ habitats did not have epiphytes (bird’s nest ferns, *Asplenium nidus* complex), so only five transects were sampled in those plot types in comparison with the eleven transects in plot types F and P.

## 3.1. Environmental temperature

I checked the data loggers once a month, and on two occasions, elephants had displaced loggers. Elephants are curious and like to play with strange objects. In the week after 12 October three out of four data loggers were collected. One was missing, probably also due to elephant behaviour. So unfortunately, temperature data for the plot type EF is missing. Data for the three other plot types were successfully downloaded and used for looking at differences in temperature between the different plot types. Mean daily temperature varied between 24.38 °C (SD=0.69 °C) and 31.56 °C (SD=3.07 °C).

Mean temperature among plot types differed highly significantly (two-way ANOVA, $F_{2,21093}=5767.25$, $P<0.001$). The differences in temperature among the plots were most striking during the day (Figure 3.10). Thus there was an interaction among the two factors plot type and time of day (two-way ANOVA, $F_{46,21093}= 62.39$, $P<0.001$). Especially in plot type EP, temperature reached much higher values during the day than in the two other plot types. Differences between the P and F plots were small. There was a difference in mean temperature among time of the day (two-way ANOVA, $F_{23,21093}= 1719.84$, $P<0.001$).

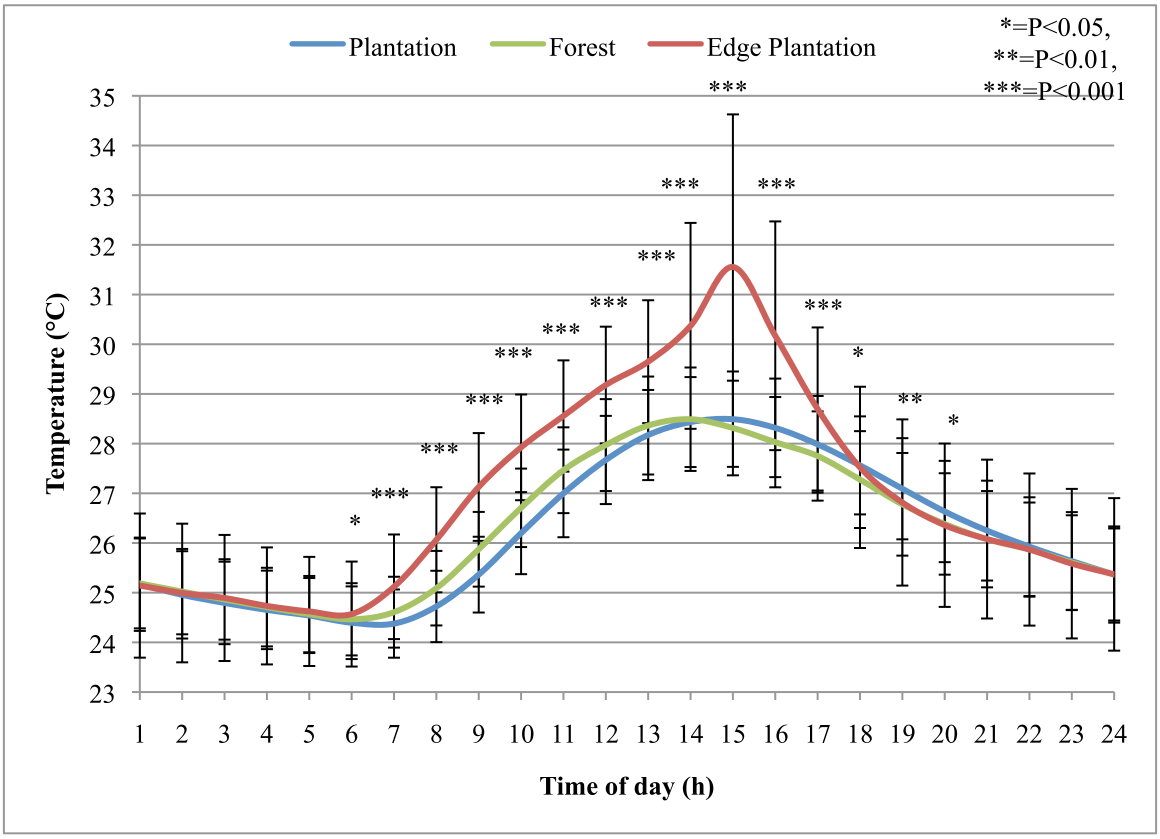


*Figure 3.10. Mean hourly temperature (and SD) for plot types Forest, Plantation and Edge plantation. Day temperature in edge plantation differs with the two other plot types. Significant differences between the plot types for every hour are indicated with *=P<0.05, **=P<0.01 and ***=P<0.001(one-way ANOVAs).*

## 3.2. Epiphyte numbers per transect

Epiphyte numbers found per transect were not normally distributed (Shapiro-Wilk test: number of small epiphytes: W=0.83, P<0.001; medium: W=0.69, P<0.0001; large: W=0.76, P<0.0001; total: W=0.81, P<0.0001). $\text{Log}_{10}$-transformation improved normality for the numbers of small (W=0.93, P=0.04) and medium epiphytes (W=0.98, P=0.92), and the total number of epiphytes (W=0.95, P=0.10). I examined the differences among plot types in these variables with ANOVA. Transformation did not improve the normality of the number of large epiphytes. Therefore I used a Kruskal-Wallis ANOVA to test for differences among plot types in that variable.

The mean number of epiphytes per transect differed among plot types for small, medium and all epiphytes (ANOVAs, Table 3.1). The number of large epiphytes did not differ significantly among plot types (Kruskal-Wallis ANOVA, Table 3.1). According to a Tukey post-hoc test, small epiphytes were more abundant in the plot types F and EF than in the P and EP plots. Similar results were found for medium-sized epiphytes and for the total number of epiphytes (Figure 3.1).

*Table 3.1. Differences in the mean number of different sized epiphytes found per transect in the four types of plots studied. Tests were performed with ANOVA or Kruskal-Wallis ANOVA. Except for the large epiphytes, differences in the mean number of epiphytes between the plot types were significant. (*=tests performed on $log_{10}$ transformed variables, P-values of less than 0.05 are in bold type)*

| Epiphyte size class | Test statistic and degrees of freedom | Result | P-value |
|---|---|---|---|
| Small | $F_{3,28}$ (*) | 9.65 | **0.00015** |
| Medium | $F_{3,28}$ (*) | 7.38 | **0.0086** |
| Large | $\chi 2_{3,28}$ | 2.3 | 0.51 |
| All | $F_{3,28}$ (*) | 8.66 | **0.00032** |

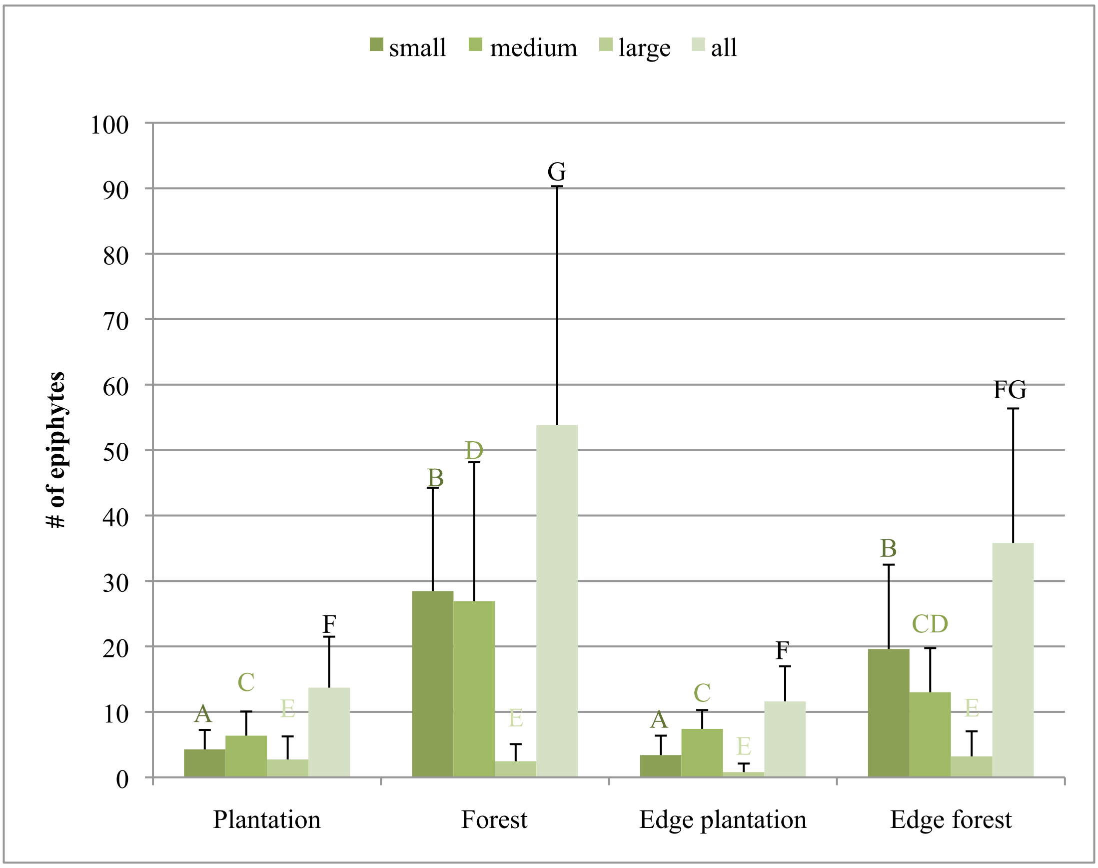


*Figure 3.1. Mean number (with SD) of different sized epiphytes for each plot type. More epiphytes were found in plot type F and EF, mainly due to the large numbers of small and medium epiphytes found there. Plot types that do not differ significantly according to a Tukey post-hoc test or Kruskalmc test share the same letters, indicated above the bars.*

Proportionally there’s a significant difference among the plot types for small epiphytes, but not for medium and large epiphytes (Table 3.2, Figure 3.2). A pair-wise comparison for small sized epiphytes did not reveal any differences.

*Table 3.2. Differences in the proportional number of different sized epiphytes found per transect in the four types of plots studied. Tests were performed with ANOVA. Except for the small epiphytes, differences in the mean number of epiphytes between the plot types were not significant. (*=tests performed on sqrt-transformed variables, P-values of less than 0.05 are in bold type)*

| Epiphyte size class | Test statistic and degrees of freedom | Result | P-value |
|---|---|---|---|
| Small | $F_{3,28}$ | 3.25 | **0.037** |
| Medium | $F_{3,28}$ | 2.61 | 0.071 |
| Large | $F_{3,28}$ (*) | 1.09 | 0.36 |

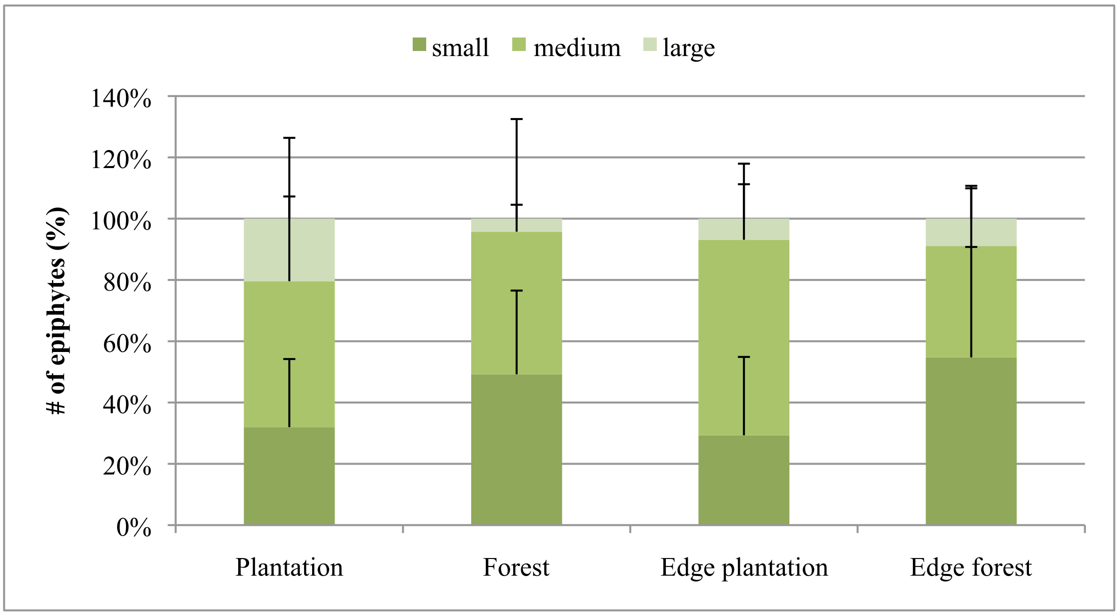


*Figure 3.2. Proportional number (with SD) of epiphytes for each plot type. Mean number of small and medium epiphytes differed among plot types.*

## 3.3. Epiphyte characteristics

With 32 transects, five epiphytes per transect and three visits per epiphyte, I should have obtained 480 data points on temperature, humidity and the presence/absence of frogs in total. However, on five occasions the discovery of bee's nests in the epiphyte during the second or third climb precluded further data collection. Although care was taken to minimize disturbance, frogs were observed leaping out of the fern.

Most of the variables considered were normally distributed (W>0,9). Height above ground (W=0,84), distance to the nearest water source (W=0,88) and distance to the Kinabatangan River (W=0,83) were normally distributed after $\log_{10}$-transformation. Temperature measured outside the epiphytes was not normally distributed (W=0,56) and various transformations did not improve normality. Therefore I used univariate ANOVA's (followed by Tukey post-hoc analyses) to test for differences among plot types in most variables, but a Kruskal-Wallis ANOVA (followed by a Kruskalmc-test) for temperature outside.

I found significant among-plot type differences in all variables except canopy cover (Table 3.3). Epiphytes in F and EF plots were on average situated much higher up in the tree than in P and EP plots (Table 3.3, Figure 3.3). The differences in temperature, although statistically significant, were very small (Table 3.3, Figure 3.4). There was no significant difference between the in- and outside temperature (Figure 3.4, paired t-test, plot type P: $t_{110}$= -0.43, P=0.66; plot type F: $t_{110}$= -1.13, P=0.26; plot type EP: $t_{80}$= -0.51, P=0.61; plot type EF: $t_{80}$= -0.54, P=0.59). Humidity was on average somewhat higher in the F and EF plots than in P and EP plots (Table 3.3, Figure 3.5). Except for EP, humidity inside the epiphytes was significantly higher than outside (Figure 3.5, paired t-test, plot type P: $t_{110}$= 2.61, P=0.01; plot type F: $t_{110}$= 3.97, P=0.0001; plot type EP: $t_{80}$= 1.37, P=0.18; plot type EF: $t_{80}$= 3.49, P=0.001). The mean diameter of the rosette of the epiphyte, measured at the bottom of the leaves, was significantly larger in F plots than in P plots (Table 3.3, Figure 3.6). Mean canopy cover was slightly higher in the F and EF plots, but the differences were not statistically significant (Table 3.3, Figure 3.7). The average distance to the nearest water source is much smaller in P plots than in the other plot types (Table 3.3, Figure 3.8). The mean distance to the Kinabatangan River is much higher for EP plots than for other plots (Table 3.3, Figure 3.9).

*Table 3.3. Differences in epiphyte characteristics among the four types of plots. Tests are univariate ANOVA's or a Kruskal-Wallis ANOVA for looking at differences among plot types. Only canopy cover didn't differ significantly between the plot types. (*=Tests performed on $log_{10}$ transformed variables, P-values of less than 0.05 are in bold type)*

| Characteristic | Test statistic and degrees of freedom | Result | P-value |
|---|---|---|---|
| Height above ground (m) | $F_{3,156}$ (*) | 141.57 | **<0.0001** |
| Temperature inside (°C) | $F_{3,156}$ | 2.87 | **0.038** |
| Temperature outside (°C) | $\chi2_{3,156}$ | 9.62 | **0.022** |
| Humidity inside (%) | $F_{3,156}$ | 7.1 | **<0.0001** |
| Humidity outside (%) | $F_{3,156}$ | 3.67 | **0.014** |
| Diameter (m) | $F_{3,156}$ | 5.13 | **0.0021** |
| Canopy cover (%) | $F_{3,156}$ | 2.08 | 0.11 |
| Distance to water source (m) | $F_{3,156}$ (*) | 10.2 | **<0.0001** |
| Distance to Kinabatangan River (m) | $F_{3,156}$ (*) | 12.84 | **<0.0001** |

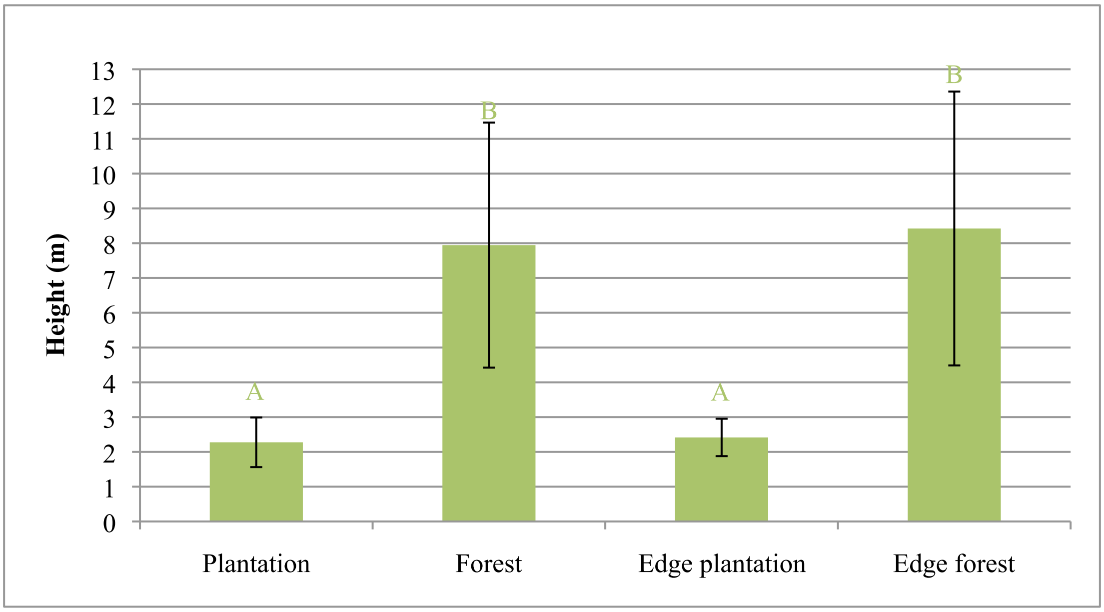


*Figure 3.3. Mean epiphyte height above the ground (with SD) for the different plot types. Epiphytes in F en EF are situated much higher in the tree than the other plot types. Plot types that do not differ significantly according to a Tukey post-hoc test share the same letters.*

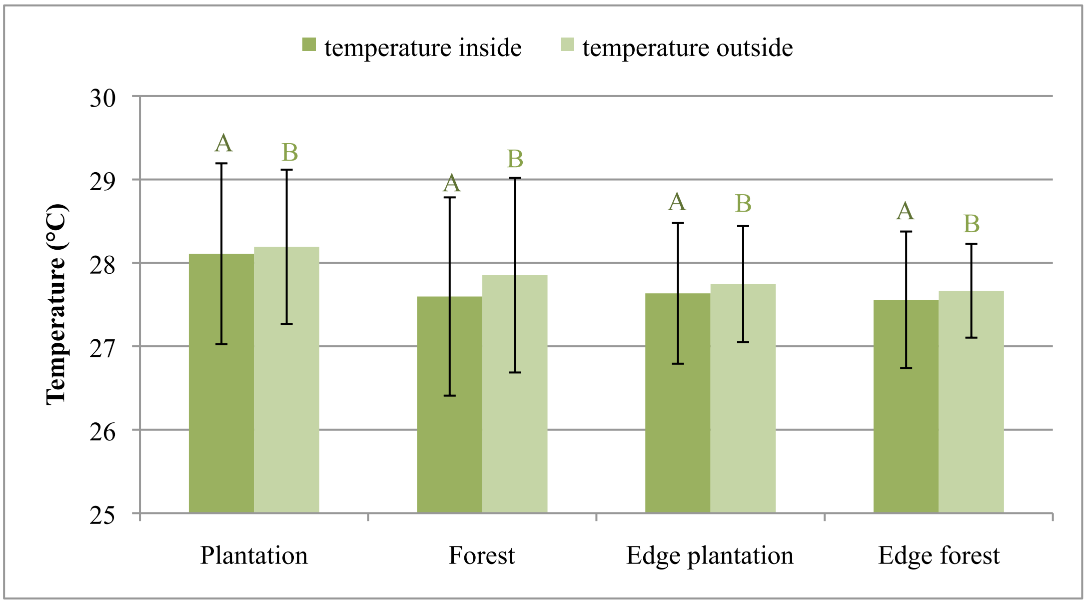


*Figure 3.4. Mean temperature in- and outside the epiphytes (with SD) for the different plot types. Temperature is slightly higher in P than in the other plots. In each plot temperature outside was slightly higher than inside but not significant. Plot types that do not differ significantly according to a Tukey post-hoc test or Kruskalmc test share the same letters.*

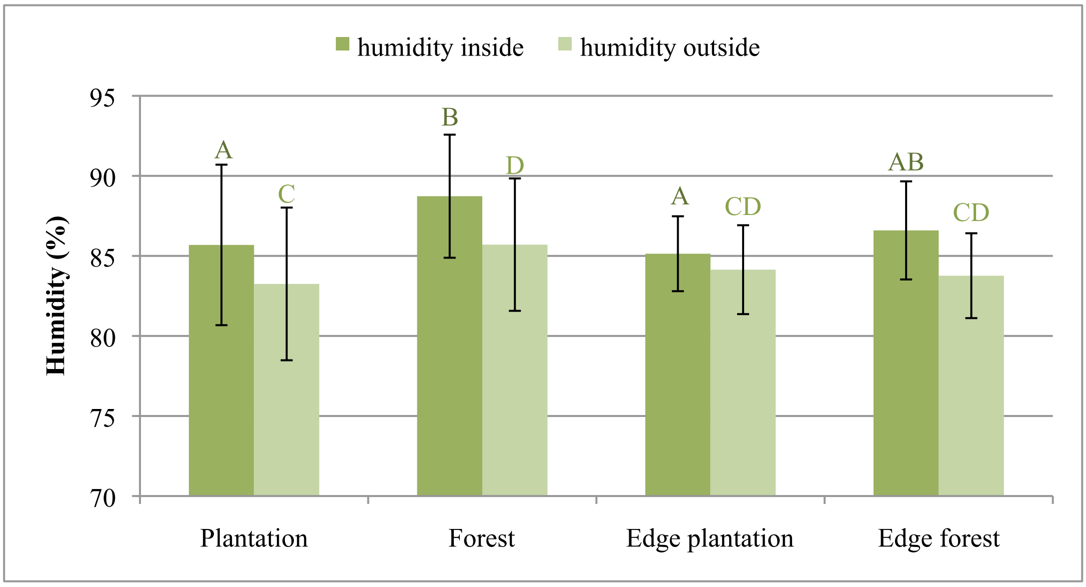


*Figure 3.5. Mean humidity in- and outside the epiphyte (with SD) for the different plot types. Humidity inside for plot type F differs significantly with P and EP. A significant difference in humidity outside occurs between plot types P and F. In each plot type humidity inside was significantly higher than outside, except for EP. Plot types that do not differ significantly according to a Tukey post-hoc test share the same letters.*

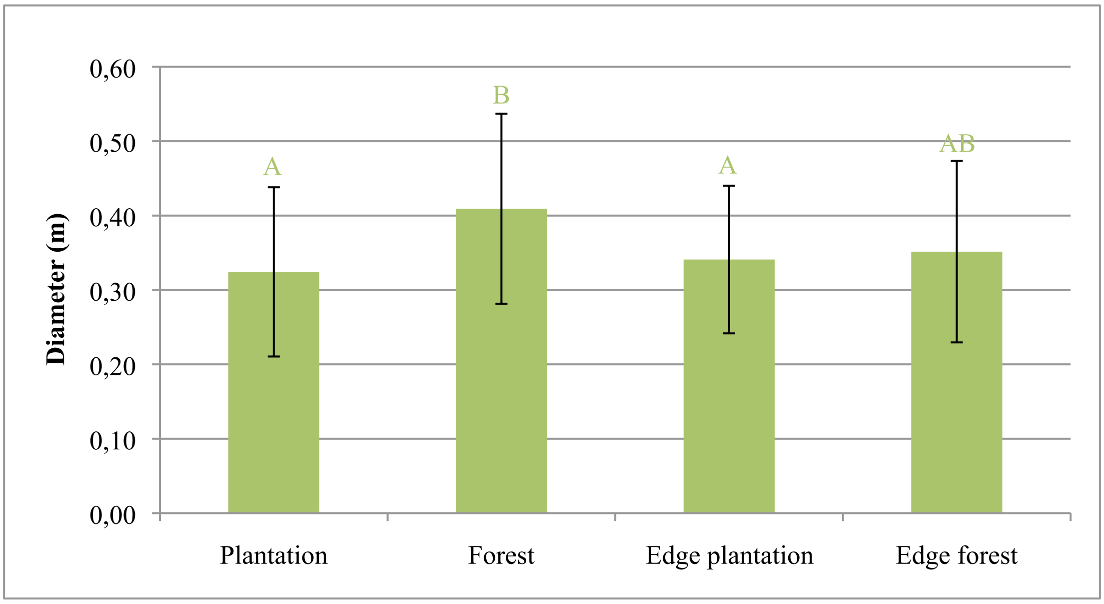


*Figure 3.6. Mean diameter (with SD) of the rosette of the epiphyte for the different plot types. The mean diameter of epiphytes in plot type F are significantly larger than in plot type P and EP. Plot types that do not differ significantly according to a Tukey post-hoc test share the same letters.*

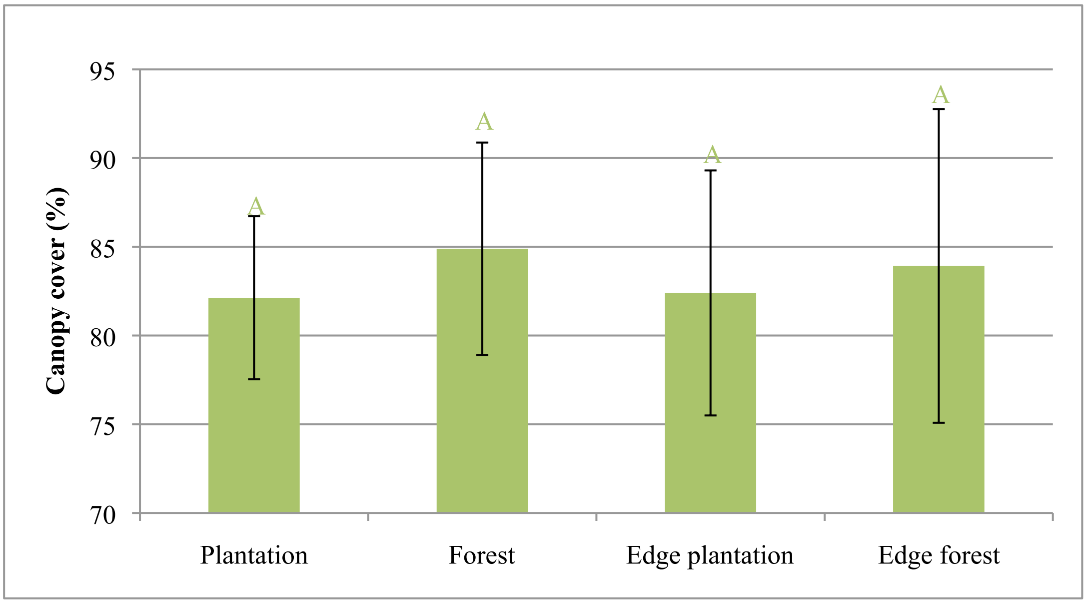


*Figure 3.7. Mean canopy cover (with SD) above the epiphyte for the different plot types. Although canopy cover looks denser in F and EF, differences are not significant. Plot types that do not differ significantly according to a Tukey post-hoc test share the same letters.*

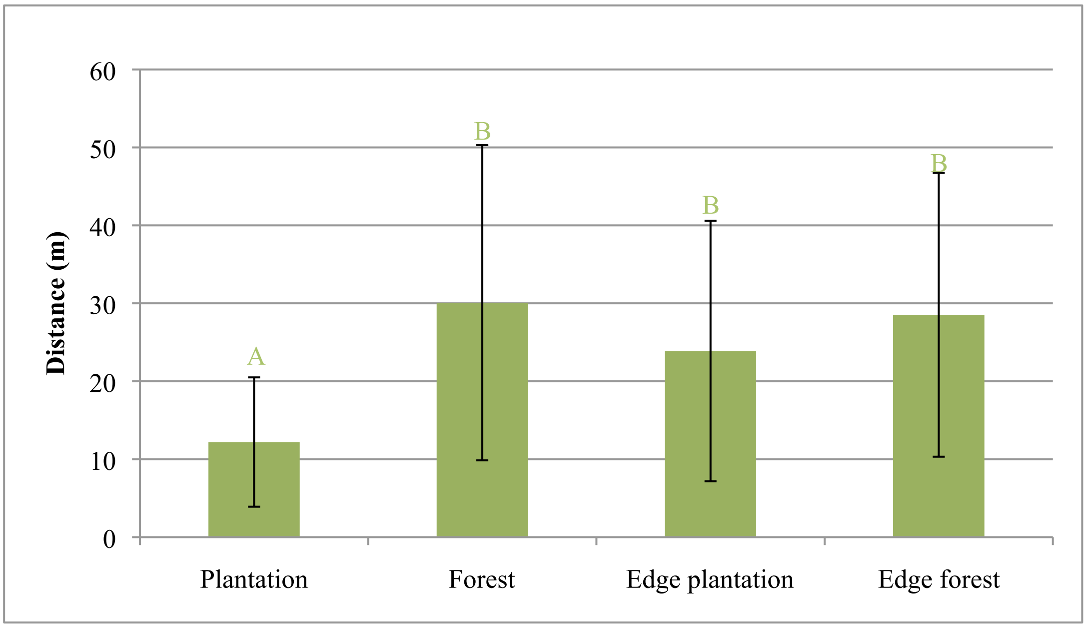


*Figure 3.8. Mean distance to nearest water source from the epiphyte for the different plot types. In plot type P water sources were found much closer to the epiphyte than in the other plot types. Plot types that do not differ significantly according to a Tukey post-hoc test share the same letters.*

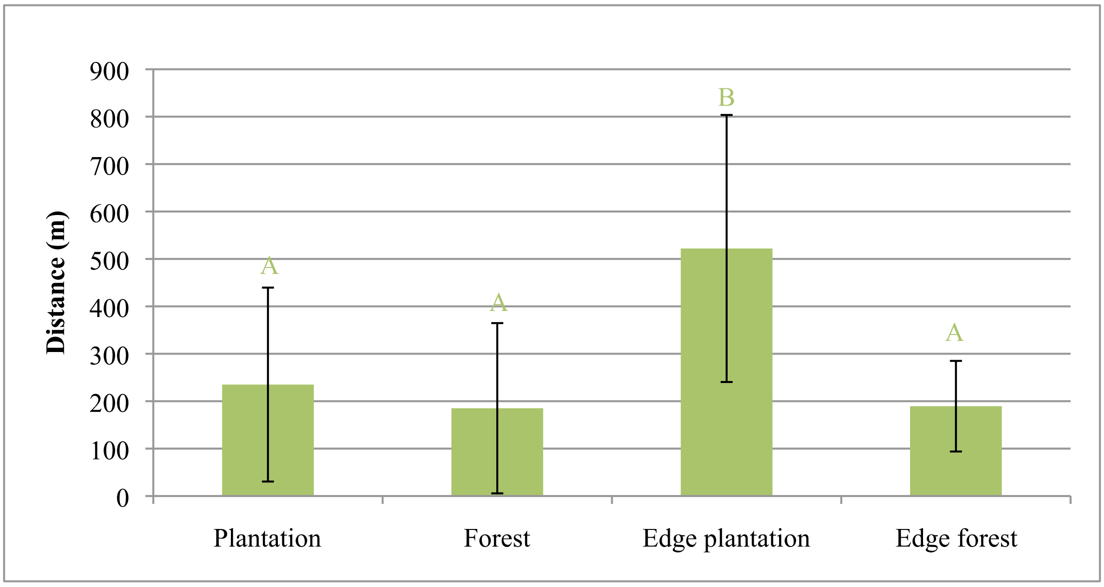


*Figure 3.9. Mean distance to the Kinabatangan River from the epiphyte for the different plot types. Epiphytes in plot type EP are situated further away from the Kinabatangan River than the ones in other plots. Plot types that do not differ significantly according to a Tukey post-hoc test share the same letters.*

## 3.4. Frogs

During the whole of my stay in the study area, I came across 19 species of frogs, eight arboreal and eleven terrestrial (appendix 4). Of these, 5 arboreal species were observed during the sampling of epiphytes and thus are part of subsequent analyses.

### 3.4.1. Presence/absence of frogs in epiphytes

In the 160 epiphytes sampled, a total of 80 individual frogs were found: 57 in plots of type P, 13 in F plots, 6 in EP and 4 in EF. Most of the frogs were found in the plot type P, followed by F, EP and EF (Table 3.4). I found four and two frogs together in one epiphyte respectively two and eleven times, mainly in plot type P.

*Table 3.4. Presence/absence of frogs in the epiphytes sampled in the four different plot types and all the plots. In total 80 frogs were found, most of them in plot type P. Most epiphytes were checked three times. In F and EF respectively 2 and 3 epiphytes were sampled less than thrice because of presence of bee's nests, discovered before the second or third ascent.*

| Presence/absence of frogs in the four different plot types | | | | | |
|---|---|---|---|---|---|
| | Plantation | Forest | Edge Plantation | Edge Forest | All plots |
| Frogs | 57 | 13 | 6 | 4 | 80 |
| No frogs | 124 | 150 | 70 | 68 | 417 |
| # of epiphytes sampled | 165 | 163 | 75 | 72 | 475 |

I investigated whether the presence/absence of frogs found in epiphytes in the four plot types differed as a function of time of day, rainfall, wind speed, cloud cover and days since it has rained (Table 3.5). More frogs were found in the night than during the day (Kruskal-Wallis $\chi^2$=26.74, df=1, P<0.001). Frogs were more likely to be found in rainy (Fisher's Exact Test for Count Data, P=0.015) and cloudy conditions (Kruskal-Wallis $\chi^2$=12.87, df=1, P=0.0003). The number of days since it had rained contributed significantly to the presence of frogs in the epiphytes (Kruskal-Wallis $\chi^2$=42.32, df=10, P<0.001). For example, when there was rain not more than two days before sampling, 22% (61/271) of the epiphytes contained frogs, but when it was longer ago, less than 2% (2/115) of the epiphytes had frogs present. Wind speed had no effect on the presence of frogs in epiphytes (Kruskal-Wallis $\chi^2$=0.52, df=1, P=0.47).

*Table 3.5. Effect of time of day, previous rain and present weather conditions during sampling on the presence/absence of frogs in the epiphytes*

| | Time of day | | Rainfall | | Wind speed | | Cloud cover | | Days since rain | |
|---|---|---|---|---|---|---|---|---|---|---|
| Epiphytes | Day | Night | Dry | Rain | Low | High | Open | Clouded | dsr>2 | dsr<2 |
| Without frogs | 157 | 260 | 400 | 17 | 309 | 108 | 138 | 279 | 115 | 271 |
| With frogs | 3 | 60 | 56 | 7 | 44 | 19 | 7 | 56 | 2 | 61 |

To investigate the simultaneous effects of plot type, time of day, present weather conditions (rainfall and cloudiness) and number of days when it has rained previously on the likeliness of finding at least one frog, I used a generalized linear model (GLM). Only plot type ($\chi^2$=29.20, P<0.001), time of day ($\chi^2$=36.47, P<0.001) and days since it has rained ($\chi^2$=10.62, P=0.001) contributed significantly to the final model. In plot type P the number of inspected epiphytes with at least one frog is much higher than in the other plot types. (parameter estimates ± SE relative to P: EF -1.77 ± 0.54, EP -1.53 ± 0.88, F -1.35 ± 0.80). More frogs were found during the night (parameter estimate ± SE relative to daytime: 2.48 ± 0.61) and when days since rain were less than two days (parameter estimate ± SE relative to more than 2 days without rain: 1.90 ± 0.74).

### 3.4.2. Comparison of characteristics of epiphytes with and without frogs.

Here, I explore whether epiphyte characteristics influenced the presence or absence of frogs by using univariate t-tests. Frogs were more likely to be found in epiphytes with lower temperature and higher humidity outside and when the epiphytes were found lower above ground. Humidity inside the epiphyte, diameter, canopy cover and distance to a water source and Kinabatangan River did not differ between epiphytes that contained frogs and those that did not (Table 3.6).

*Table 3.6. Comparison of characteristics of epiphytes with and without frogs. Mean values (X) standard deviations (SD) and results of univariate t-tests. (P-values of less than 0.05 are in bold type)*

| | With frogs (N=45) | | Without frogs (N=115) | | T-test | |
|---|---|---|---|---|---|---|
| Characteristic | X | SD | X | SD | $t_{160}$ | P |
| Height above ground (m) | 4.13 | 3.52 | 5.63 | 3.97 | 2.33 | **0.022** |
| Temperature inside (°C) | 27.45 | 1.01 | 27.90 | 1.07 | 2.47 | **0.015** |
| Temperature outside (°C) | 27.63 | 0.92 | 28.24 | 2.34 | 2.35 | **0.020** |
| Humidity inside (%) | 87.67 | 3.93 | 86.43 | 4.28 | -1.75 | 0.083 |
| Humidity outside (%) | 85.50 | 4.02 | 83.84 | 4.03 | -2.35 | **0.021** |
| Diameter (m) | 0.34 | 0.12 | 0.37 | 0.12 | 1.32 | 0.192 |
| Canopy cover (%) | 82.71 | 5.82 | 83.64 | 6.48 | 0.88 | 0.380 |
| Distance to water source (m) | 25.16 | 26.97 | 29.59 | 30.60 | 0.90 | 0.371 |
| Distance to Kina river (m) | 258.93 | 237.79 | 254.24 | 225.82 | -0.11 | 0.910 |

### 3.4.3. Comparative occurrence of frog species

*Hylarana raniceps* was by far the most abundant species with sixty-seven individuals, followed by five of *Polypedates leucomystax*, four of *Rhacophorus appendiculatus*, three of *Metaphrynella sundana* and one *Polypedates macrotis* (Table 3.7). An individual of *Rhacophorus appendiculatus* was found in an epiphyte at 16.2m height, while an individual of *Hylarana raniceps* was present as low as 1.2m.

*Table 3.7. Frog species abundance in the different plot types and in all the plots. Hylarana raniceps was the most abundant frog species overall and was present in all the plot types. Typical forest species were only present in plot type F and Polypedates leucomystax only in plot types P and EP. Rhacophorus appendiculatus was mostly found in plot type EF.*

| Frog species | Plantation | Forest | Edge plantation | Edge forest | all plots |
|---|---|---|---|---|---|
| *Hylarana raniceps* | 53 | 8 | 5 | 1 | 67 |
| *Metaphrynella sundana* | 0 | 3 | 0 | 0 | 3 |
| *Polypedates leucomystax* | 4 | 0 | 1 | 0 | 5 |
| *Polypedates macrotis* | 0 | 1 | 0 | 0 | 1 |
| *Rhacophorus appendiculatus* | 0 | 1 | 0 | 3 | 4 |

In plots of type P, 53 individuals of *Hylarana raniceps* and four of *Polypedates leucomystax* were found in all the sampled epiphytes. The same species were also found in plots of type EP, with respectively five and one individual. In plots of type F, eight individuals of *Hylarana raniceps,* three of *Metaphrynella sundana*, and one of *Polypedates macrotis* and *Rhacophorus appendiculatus* were present. Three individuals of the last species and one of *Hylarana raniceps* were also present in plot type EF. Clearly, although frog numbers were highest in plot type P, species diversity is higher in plot type F. *Hylarana raniceps* is the only species present in all plot types (Figure 3.10).

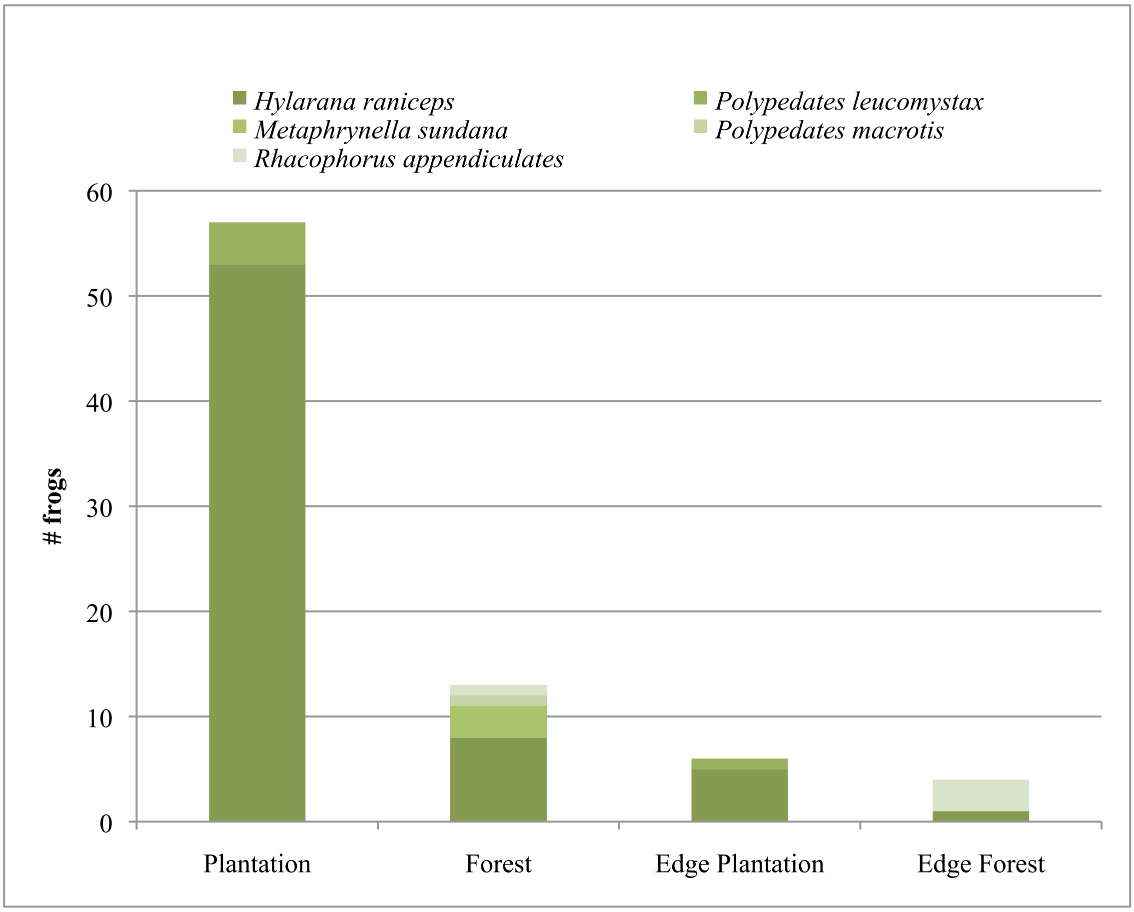


*Figure 3.10. Absolute number of the five frog species found in epiphytes for each plot type. Species abundance is highest in plot type P, but species diversity is higher in plot type F. Hylarana raniceps is present in all the plot types.*

A principal component analysis was used to summarize overall variation in the characteristics of epiphytes used by the different frog species. The first three composite axes explained 32% (PC1), 17% (PC2) and 12% (PC3) of the total variation (Figure 3.11). PC1 was positively correlated with the humidity outside (factor loading = 0.524), humidity inside (0.507) and negatively correlated with temperature inside (-0.492) and temperature outside (-0.385). PC2 was positively correlated with height above ground (0.667) and PC3 with canopy cover (-0.620) and diameter of the epiphyte's rosette (0.609). The average scores on the first and second axes differed significantly among species (ANOVA, PC1: $F_{5,154}=3.60$, $P=0.004$, PC2: $F_{5,154}=5.59$, $P<0.001$, Figure 3.12). The scores on the third axis did not differ (ANOVA, PC3: $F_{5,154}=0.99$, $P=0.43$). With this result a closer look to the first and second axes in the presence of frog species is interesting (Figure 3.12).

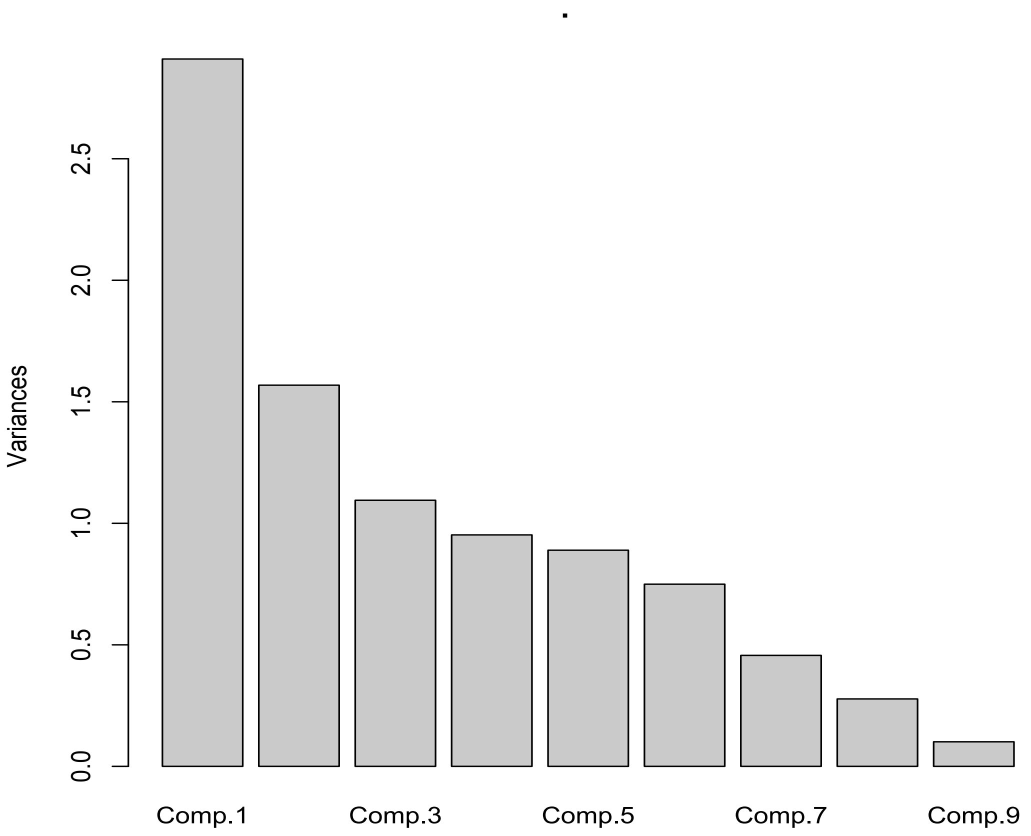


*Figure 3.11. Screeplot for the new component axes. PC 1 is correlated with temperature and humidity, PC 2 with height above the ground and PC 3 with canopy cover and diameter.*

*Polypedates leucomystax* was found on moderate height above ground. *Hylarana raniceps* and *Rhacophorus appendiculatus* were found in epiphytes where temperature and humidity was average, but *Rhacophorus appendiculatus* was found in epiphytes higher from the ground and therefore found more in plot type EF than the other plot types. *Hylarana raniceps* was present in all the different plot types at the lower elevations. The last two species *Metaphrynella sundana* and *Polypedates macrotis* were seen in epiphytes which were high in the tree and where temperature was lower and humidity higher than average. Those epiphytes were found in the plot types F and EF.

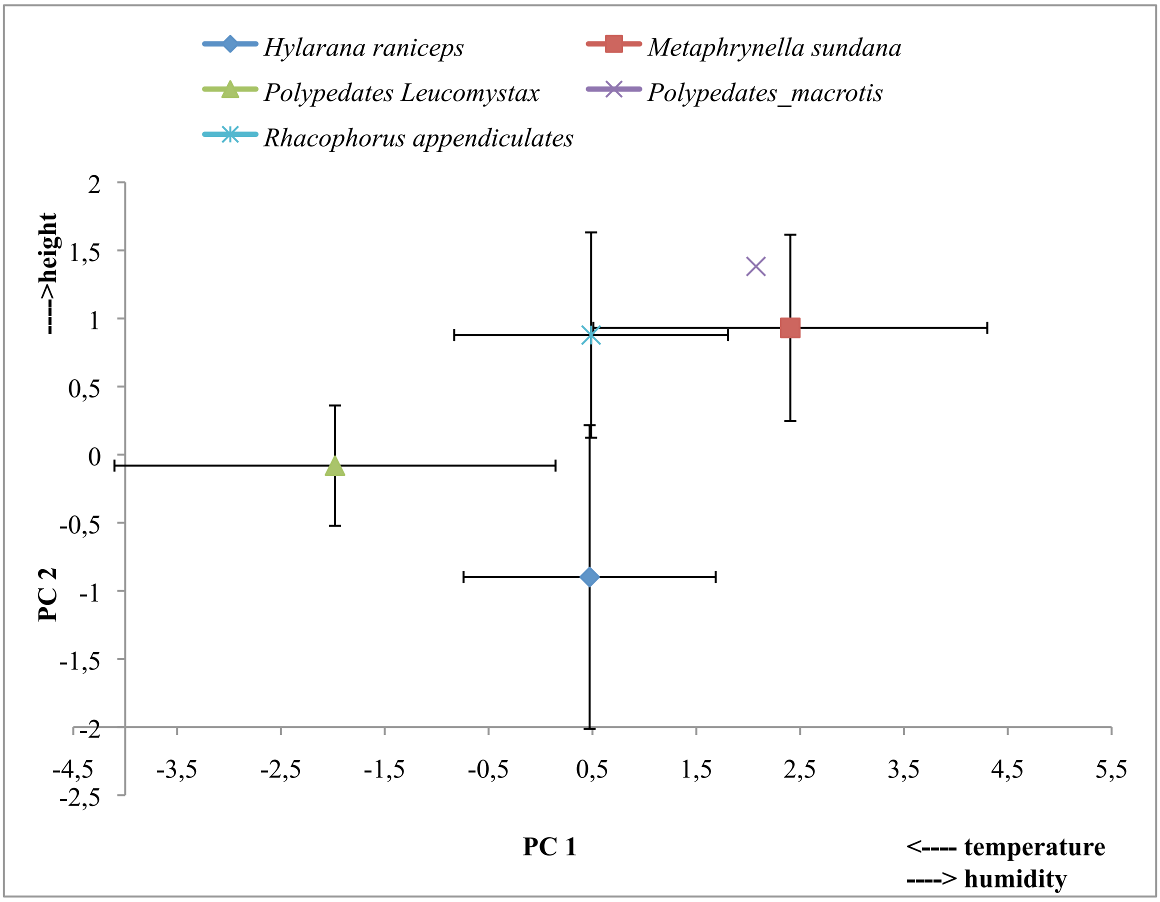


*Figure 3.12. Mean scores (and SD) on the first and second principal component axes for the five frog species found in the epiphytes. PC1 is correlated with temperature and humidity; PC2 is correlated with the height of the epiphyte. Polypedates leucomystax was found in epiphytes where temperature was higher and humidity lower than average while for Metaphrynella sundana and Polypedates macrotis it was the opposite. Hylarana raniceps and Rhacophorus appendiculatus were found in epiphytes with average temperature and humidity, but the last one occurred at higher elevations.*

## 3.5. Estimating the number of frogs per transect

Although I sampled five epiphytes in every transect, the number of epiphytes actually present along a transect clearly differed among plot types (see Table 3.1). To obtain a crude estimate of the relative abundance of frogs per transect and per plot type, I combined information on epiphyte numbers and occupancy. There was no difference in the prediction to find frogs in transects among the plot types (univariate ANOVA, $F_{3.28}$=1.44, P=0.25, Figure 3.13).

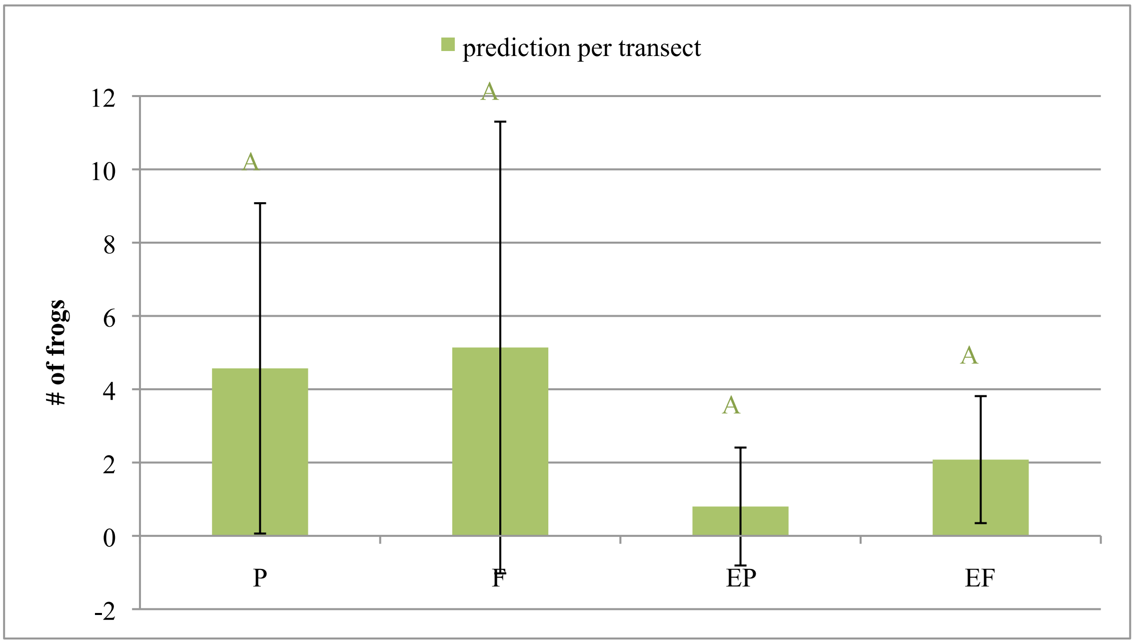


*Figure 3.13. Estimating the mean number (with SD) of frogs per transect in different plot types. Although in plot type P and F the prediction to find frogs in transects looks higher than in the other two plots, the differences are not significant. Plot types that do not differ significantly according to a Tukey post-hoc test share the same letters.*

# 4. Discussion

Before I started this research, the evidence that arboreal frogs were using bird's nest ferns in the forests of Sabah as refuges was scant. The idea occurred when I visited the area in previous years, and found several frogs in epiphytes while exploring the forest. A subsequent search of the literature revealed that only a few studies had been done on amphibians in epiphytes worldwide. Brown and Alcala (1961) searched for amphibians and reptiles in three different tropical forest habitats, paying special attention to bird's nest ferns. They found two arboreal *Cornufer* frog species (Ranidae) in the leaf axils of ferns at heights between 1 and 10 m above the ground. Romero et al. (2010) investigated if the tree frog *Scinax hayii*, which uses the tank epiphytic bromeliad *Vriesea bituminosa* as a diurnal shelter, contributes to host plant nutrition using isotopes (15N) and physiological methods. As far as I know, however, no study has looked at frog diversity and abundance in epiphytes in a systematic way.

In contrast, studies on invertebrate communities in epiphytes are common. For instance, Karasawi and Hijii (2006) looked at the abundance of litter-associated microarthropods and the number of species of oribatid mites in bird's nest ferns. Fayle et al. (2010) compared the diversity of ants in bird's nest ferns between rainforest and oil palm plantations. Because these two and several earlier studies (Basset, 2001; Ellwood & Foster, 2002; Ellwood & Foster, 2004; Turner & Foster, 2009) revealed that epiphytes contain high numbers of invertebrate species that are readily eaten by frogs (Stebbins & Cohen, 1995), I gathered that the plants would make up ideal microhabitats for these amphibians. .

After 10 weeks of climbing trees, I conclude the following.

(1) More epiphytes can be found in plots of type F and EF than P and EP, which is the opposite what I hypothesized, but seemingly the distribution is more widespread in plot types P and EP than in F and EF;

(2) (a) Local temperature conditions in and near the sampled epiphytes were similar in all plot types, but humidity was lower in plot types P and EP than in F;

(b) Relative humidity was higher in- than outside the epiphyte as hypothesized, but there was no difference between in- and outside temperature;

(3) More frogs were found in plot type P, during the night and when days since rain were less than two days (frog characteristics), and in epiphytes with lower temperature, higher humidity outside and lower above ground;

(4) Surprisingly, frog abundance was highest in plot type P. However, diversity was highest in plot type F. Frog abundance and diversity was low in both edge plots;

(5) *Hylarana raniceps* and *Polypedates leucomystax* survived in plantation plots and *Rhacophorus appendiculatus* in edge plots; *Metaphrynella sundana* and *Polypedates macrotis* are confined to forests.

In what follows I will discuss these results in greater detail. I will also reflect upon a number of methodological issues that may help future studies of this kind.

## 4.1. Ascending a tree

Organising the work around the Danau Girang Field Centre was a crucial part of the project. Especially climbing in order to reach the epiphytes was important. Although I chose the 'Single Rope Technique' (Houle et al., 2004; Jepson J., 2006; Sharpe & Cody, 2010), still twenty-five kilograms of equipment had to be carried through the forest. Preferable a double ladder was used in the forests or plantations. This is an easier and faster method and the chance to disturb the animals in the epiphyte is less than climbing with ropes. A major problem in both ascending methods is that the approach of the epiphyte is from below, so you don't know if there are frogs present until you are at the same level of the epiphyte or heard one calling before arriving. A second problem occurred when sampling was not possible due to weather conditions unsafe for climbing. The sampling was delayed until weather conditions ameliorated or to the next day, with some bias in data as a consequence. A third problem was that not every randomly chosen epiphyte was possible to reach, which augmented also some kind of bias in the data. At last you had to be prepared for an immediate descend if necessary. I had to descend more than once because of the attack of bees. When down it's no use to run away, but better to make quickly a small fire with leaves. The smoke will scare away the bees. Nevertheless I was bitten several times in the face and arms. At night it helped to dim your head torch and wait until the bees were gone. Ants could also be a problem, but only when you touched the leaves where they are present.

## 4.2. Environmental temperature

As mentioned before, the data logger placed in plot type EF was lost, probably taken by playing elephants. Although it was safely stored in a plastic box and well attached to a tree, it was attractive to several animals. Maybe it was better to hide the box, or choose a more camouflaged one instead of a blue one.

At Sukau, a small town at 30 km distance from the study site (downstream the Kinabatangan River), the mean monthly temperature from July to October was between 22 °C and 33 °C (Malaysian Meteorological Services Department, cited in Ancrenaz et al., 2004). The temperatures recorded with the data loggers in this study (24.4 °C - 31.6 °C) fall within this range, indicating that thermal conditions during the study were typical for the time of year.

The diurnal variation in temperature was highest in the plot of type EP. This result may be due to the fact that the data logger was placed in a new plantation, with relatively small palm trees and a canopy that was not yet completely closed. Indeed, Luskin and Potts (2011) showed that the diurnal temperature in new plantations is, 100m or 1km from the forest edge, respectively 2.97 °C or 4.03 °C above that in the forests.

I found no difference in environmental temperatures between the plot types F and P. This is in contrast with data reported by Luskin and Potts (2011), who found that even in old plantations, temperatures were above those typical of forests. I must note however, that my conclusions are based on a very limited sample size (one logger per plot type). The exact position of the data loggers on the tree may have influenced the outcome.

The differences in temperature among the plot types can have implications for epiphytes as well as frog species. It’s striking that less epiphytes were found in plot type EP where higher diurnal temperature prevailed. In addition, when epiphytes were present, frog species richness was low. This suggests that temperature could have an effect on both epiphytes and frogs. Global warming can even increase this unfavourable condition for epiphytes (Fayle et al., 2009) and frogs (Alford & Richards, 1999; Sheridan et al., 2012). Skerratt et al. (2007) even suggest that chytridiomycosis outbreaks are facilitated in warmer years that are due to global warming by higher minimum and lower maximum temperatures, which may be optimal for the disease, but could not prove this hypothesis.

## 4.3. Epiphyte numbers per transect

I am not entirely confident that the epiphyte numbers reported here are representative for the whole of the plots. Epiphytes are known to have a clumped distribution (Zhang et al., 2010; Fedrowitz, 2008) and this makes the extrapolation of counts from transects of limited length somewhat cumbersome. This should be kept in mind when reading the next paragraph.

I estimated an average of 21 epiphytes/ha in plot type P and 85 epiphytes/ha in plot type F The fact that I found many more epiphytes in forest plots than in plantation plots is in sharp contrast with findings reported by earlier studies (table 4.1) This discrepancy might be an artefact induced by the way I selected my transects. Only those transects (established by Scriven (2011)) with epiphytes present were sampled, which was especially the case in the edge plots. Given the typically aggregated distribution of the ferns, this has most likely caused a bias in the numbers estimated. I also had the impression (but no data to back this up) that the epiphytes in plots of type P were more uniformly distributed than in F-plots. If true, this would lead to an overestimation of relative epiphyte density in P-plots. The (putatively) more widespread distribution in plot type P may be due to the dispersal of spores by wind, which can blow easier between the trees in this plot type than in plot type F. Turner (2005), Turner & Forest (2009) and Luskin & Potts (2011) concluded that more epiphytes were found in older plantations. I had the impression observing this as well.

*Table 4.1. Number of epiphytes per hectare found in plantations and forests. These studies suggest that more epiphytes are found in plantations than in forests.*

| Study | Location | Plantation | Forest |
|---|---|---|---|
| Turner & Foster (2006) | Danum Valley, Sabah | 117 | 44 |
| Foster et al. (2011) | Danum Valley, Sabah | 112 | 44 |
| Turner & Foster (2009) | Danum Valley, Sabah | 112 | 51 |
| Karasawa & Hijii (2006) | Okinawa Island, Japan | NA | 13 |

More small and medium epiphytes were present in plot types F and EF than in the other plot types. Turner & Foster (2009) reported similar results: ferns in oil palm plantations being on average larger than those in forests. Possibly, climatic conditions in plot types F and EF are more suitable for the development of young epiphytes. Or perhaps the ample availability of supporting structures facilitates anchoring in F-plots (Fayle et al., 2009). Another possibility is that drought, which is the main cause of mortality in epiphytes (Freiberg and Turton, 2007) has destroyed a disproportionate number of epiphytes in P and EP plots. An unusually severe period of drought persisted for 85 consecutive days in the area in 1998 (Ancrenaz et al., 2004). Epiphytes on palm trees must attach to the vertical stem and tend to fall off as their roots die off (Freiberg and Turton, 2007). I witnessed this during my research: after a relatively minor spell of drought (10 consecutive days without rain), I encountered several small epiphytes that had fallen off trees, especially from palms in plots of type P.

### 4.4. Epiphyte characteristics

Nine epiphyte characteristics were investigated and most of them differed significantly among the plot types. Surprisingly, and in conflict with studies by Oldekop et al. (2012), Scriven (2011), Fairhurst & McLaughlin (2009) and Ficetola et al. (2007), mean canopy cover did not differ among plot types. A possible explanation for this disparate result is that earlier studies report canopy covers for random places within plots, while I measured canopy cover immediately above the epiphytes. This would suggest that bird's nest ferns tend to grow in light conditions that are not representative for the whole of their environment, and which may be independent of habitat type.

Epiphytes grew higher up in the trees in plot types F and EF than in P and EP. This was already obvious while I was doing the study. Mature palm trees in plantations reach a maximum height of 11-12m (Bernard et al., 2009), while canopy height in secondary forests is on average 24.8m (Okuda et al., 2003). Epiphytes had therefore the possibility to grow higher above ground in plot types F and EF than in the other plot types. This can have implications for the different frog species. Some frogs prefer lower elevations as perching places or are not capable to climb high in the tree and use therefore epiphytes on a lower level. Good climbers can benefit from higher occurring epiphytes.

Epiphytes grew on average closer to water sources in plots of type P than in the other plot types. In oil palm plantations, straight ditches are dug along the palm trees to drain water from adjacent forests (Basiron, 2007; Greenpeace, 2007; personal observation). During my stay, the ditches were dry most of the time, but that was also the case in other plot types because of the rather overall dry conditions at that time. Water filled ditches are a good breeding place for several frog species, so when dried up, these ditches were of no use.

Epiphytes sampled in plot type EP were further away from the Kinabatangan River than epiphytes in the other plot types. This may be due to the fact that the majority of transects for plot type EP were situated in one plantation, which happened to be separated from the river by a forest fragment.

Although the total number of small and medium epiphytes counted in plot types F and EF were higher in comparison with those in plot types P and EP, sampled epiphytes were on average larger in plot types P and EP than in F and EF plots. Epiphytes growing on palm trees often proved smaller than judged from the ground, because their rosettes were semicircular, rather than circular. This was a consequence of having to attach to the vertical stem of the palm tree. Epiphytes in plot types F and EF were more frequently attached to horizontal substrates, so rosettes could form more or less a circle. Maybe it is advisable to measure the circumference of the rosette instead of the diameter.

Foster et al. (2011), Luskin & Potts (2011), Brühl & Eltz (2010) and Fayle et al. (2010) have suggested differences in ambient temperature and humidity between forests and plantations. I did find a statistically significant variation in temperature among the plot types considered, but the actual difference was small (and post hoc comparisons failed to identify any pair-wise differences). This is in line with my finding that the overall environmental temperatures (as measured by the data loggers) were also similar for plot types P and F. Therefore oil palm plantations can be suitable for epiphytes and frogs concerning microclimatic conditions, but only on condition that the plantations are fully grown.

Humidity measured near to but outside the epiphytes also differed among plot types. In particular, humidity was higher in plot type F than in P. This result is in line with findings by Luskin and Potts (2011). Global climate change models suggest that tropical Asia will experience in seasonal areas more severe and prolonged dry seasons (Zhang et al., 2010). Epiphytes can resist drought between four and eight weeks (Freiberg & Turton, 2007) and can provide shelter for arboreal frogs. Zhang et al. (2010) expected that the range of *Asplenium nidus* outside the core-aseasonal centre of Southeast Asia will decline, and where they occur they will be restricted to the wetter habitats and understorey to a greater extent. Therefore this fern can be useful as an indicator species for climate change (Zhang et al., 2010).

I found no differences in mean temperature between in- and outside the epiphyte, but significant higher mean relative humidity in- than outside. Freiberg and Turton (2007) reported differences in microclimatic conditions inside and outside epiphytes, but during rainy periods. Both the temperature and the humidity were higher inside than outside the plants. In dry periods no differences were found. Turner and Foster (2006) found no difference in inside and outside temperatures for epiphytes growing in the forest, but for epiphytes living in plantations, temperature was higher outside than inside. The same authors found no difference in relative humidity in- and outside the epiphyte, regardless of whether the plants grew in forests or plantations. For knowing if bird’s nest ferns can buffer temperature and humidity, variation in temperature and humidity has to be measured during the day (Turner & Foster, 2006). Buffering might require a minimum of rain. During sustained periods of drought, epiphytes may fall dry and evaporation will be too low to permit efficient buffering (Freiberg & Turton, 2007). Because frogs are sensitive to environmental changes, they can take advantage of the epiphytes as long as they can buffer efficiently the surrounding microclimate.

## 4.5. Frogs

A major uncertainty at the onset of the study was whether I would be able to find frogs. Not only was the use of epiphytes by frogs poorly documented, but circumstances also forced me to go and look for them in suboptimal conditions. I got to Sabah at the end of the dry season, and the study started during a relatively long period without rain. Consequently, as the first weeks passed without a single frog found, I was left wondering whether this was due to the weather, or whether I was looking in the wrong places. Luckily, the frogs started to appear soon after the first downpour. A decision in principle, I have never attempted to take apart epiphytes to look for inactive frogs hidden within them, so I cannot ascertain whether the animals are using the plants to overcome periods of drought. This seems an important question, which could be tackled by detailed behavioural observations on individual frogs.

Below, I discuss my findings on which factors affect the presence/absence of frogs in epiphytes, and look at frog abundance and diversity in the different plot types.

### 4.5.1. Presence/absence of frogs in epiphytes

Surprisingly, and in contrast with studies by Scriven (2011) and Gillespie et al. (2012), the majority of frogs was found in plot type P. A possible reason for this divergence is that the studies mentioned did not focus on arboreal species in epiphytes, but instead sampled the whole anuran community. The high number of frogs per epiphyte in type P plots could have two (and somewhat conflicting) explanations. Perhaps plantations are suitable habitat for frogs, but only for a limited number of species (Scriven, 2011; Gillespie et al., 2012); or frogs in P-plots use epiphytes so frequently because plantations, in comparison with forest plots, offer few other perching places (Wanger et al., 2010). Results from studies on other taxa are equivocal. Turner and Foster (2009) found that epiphytic ferns in oil palm plantations contained fewer arthropods than those in the forest, but Fayle et al. (2010) failed to find any difference in the abundance of ants. In addition, the comparison is dubious, because while invertebrates live mainly in the leaf litter inside the epiphytes, frogs are mostly observed sitting on the leaves. The effect of habitat on the microclimatic conditions may differ between the sheltered centre and the more exposed edge of the epiphytes.

I saw more frogs at night than during the day. This is likely because during daytime, the frogs are inactive and stay put deep in the epiphyte (Gillespie et al., 2012).

The effects of three characteristics on frog presence suggest that humidity is an important determinant (see also Bickford et al. 2010). More frogs were found when it had rained, although sampling was restricted by the severity of rainfall. Cloud cover and fewer days without rainfall prior to sampling increased frog presence (Bala et al., 2007). The positive effect of humid conditions on the number of frogs observed were not restricted to epiphytes. It also increased the number of frogs observed in other places along the transects (although I have made no systematic notes on this). Cloud cover and rainfall were no longer significant when we looked at the simultaneous effects of all the frog characteristics on the likeliness of finding at least one frog. Probably higher humidity was in particular determined by the days without rainfall prior to sampling.

Wind did not significantly affect the presence/absence of frogs. It should be noted that wind speed was relatively low and varied little throughout the study period (or at least, during sampling). Wind conditions can affect activity of frogs through their effect on water loss (Wygoda, 1988), but the range of wind speeds observed during this study was probably too small to notice any such effects.

### 4.5.2. Comparison of characteristics of epiphytes with and without frogs.

Overall, the likeliness of finding a frog in a particular epiphyte was dependent on the epiphyte's location (height above the ground), its temperature and its relative humidity. More frogs were found in epiphytes that grew relatively close to the ground, because a majority of frogs was found in plot type P where epiphytes occurred much lower than in plot type F. More frogs were found when temperature was lower and ambient relative humidity higher than average, probably due to the constraining demands of thermoregulation and water balance (Sinsch, 1990; Thomas et al., 2004; Pounds & Puschenendorf, 2004). Prior I analysed that temperature was higher and humidity lower in plot type P than in plot type F, yet the majority of frogs was present in plot type P. Twice as many samples were done in plot type P than in F plots when it has rained that day. Maybe this explained the higher frog abundance in plot type P. For example in a transect in plot type P, 7 frogs were found just after a downpour.

Canopy cover did not differ already among the plot types, as a result also not for the presence/absence of frogs. Larger epiphytes did not contain frogs more often than smaller epiphytes. This may seem unexpected, because larger epiphytes, could provide more place and food sources for the frogs (Wanger et al., 2010). Probably the rather small frogs used the epiphytes mainly as a perching place and not as a foraging site source because many forest anuran species have a fairly narrow diet breadth that consists of just a few types of invertebrate taxa (Inger & Stuebing, 2005). Scriven (2011) found that presence and absence of streams and the distance to the Kinabatangan River were the most influential determinants of anuran community composition in plot type F. My results do not corroborate this finding. This could be due to the fact that most water sources had dried up in the period preceding sampling.

### 4.5.3. Comparative occurrence of frog species

During this study I found 19 species of frogs, 11 terrestrial and 8 arboreal inclusive 5 in epiphytes. Because the aim was to look only into epiphytes, arboreal species were of interest (Table 4.1). On the basis of the number of frogs found previously (Scriven, 2011; Gillespie et al., 2012), I indicated what species to expect.

*Table 4.1. Arboreal frog species (with threat status (IUCN, 2012)) encountered by Gillespie et al. (2012) and Scriven (2011). Expected (Exp) and observed (Obs) frog species in epiphytes are indicated with* x. *(*=unidentified species only found once by Gillespie et al. (2012) and **=species only found once by Scriven (2011)).*

| Frog family | Frog species | Threat status | Population trend | Exp | Obs |
|---|---|---|---|---|---|
| Microhylidae | *Kaloula baleata* | LC | stable | | |
| | *Metaphrynella sundana* | LC | decreasing | | x |
| Ranidae | *Hylarana raniceps* | LC | stable | x | x |
| Rhacophoridae | *Nyctixalus pictus* | NT | decreasing | | |
| | *Philautus* sp. nov. *1*(*) | | | | |
| | *Philautus* sp. nov. *2*(*) | | | | |
| | *Polypedates colletti* | LC | decreasing | x | |
| | *Polypedates leucomystax* | LC | stable | x | x |
| | *Polypedates macrotis* | LC | unknown | x | x |
| | *Polypedates otilophus* | LC | decreasing | | |
| | *Rhacophorus appendiculatus* | LC | decreasing | x | x |
| | *Rhacophorus dulitensis* | NT | decreasing | x | |
| | *Rhacophorus harrissoni* | NT | decreasing | | |
| | *Rhacophorus pardalis* | LC | decreasing | x | |
| | *Rhacophorus rufipes* (**) | NT | unknown | | |
| | *Chiromantis* sp. nov. (*) | | | | |

*Hylarana raniceps* is known to occur in a broad range of habitats; its usual perching site is in shrubs and small trees (Inger & Stuebing, 2005). This may explain the high abundance in the plantations. Also the presence of ponds, intermittent streams, or quiet side pools of streams in plot type P for local explosive reproduction may increase the abundance of this species (Haas & Das, 2012; AmphibiaWeb, 2013). *Polypedates leucomystax* prefers anthropogenic habitats (Kueh, 2005; Furlong et al., 2005; Inger et al. 2005) and is even considered to depend on them (Kueh & Maryata, 2005). The species is tolerant for variation in environmental conditions (AmphibiaWeb, 2013). Gillespie et al. (2012) proved this by finding strong affinities of *Polypedates leucomystax* with plantations. Just as *Hylarana raniceps*, this species has a conservation status of least concern and the population trend is stable (IUCN, 2012).

The other three frog species encountered had also a conservation status of least concern, but their population trends were decreasing or unknown (IUCN, 2012). They were not present in plot types P and EP. *Rhacophorus appendiculatus* is a very common ecologically adaptable lowland species and can be found abundantly in plot type F and EF (Haas & Das, 2012) as well as in some occasions in plantations (Gillespie et al., 2012; Scriven, 2011). Indeed, three out of four individuals were found in plot type EF, even though I sampled less epiphytes there than in plot type F. Surprisingly, one individual was found sixteen meters high above ground, while Inger & Stuebing (2005) and Furlong et al. (2005) suggested that this species perches between one and three metres above ground on twigs and leaves. *Metaphrynella sundana* is a common stocky-looking frog in primary and secondary rainforest and males call from tree holes or other suitable phytothelmes (Haas & Das, 2012; Kueh & Maryata, 2008; Inger & Stuebing, 2005). Three individuals were found only in plot type F and higher than expected at approximately six and eleven meters above ground. These frogs are good climbers thanks to their expanded toe pads (Haas & Das, 2012). At last one individual of *Polypedates macrotis* was found in plot type F, the plot type suggested by Haas & Das (2012). Furlong et al. (2005) encountered *Polypedates macrotis* in trees approximately 1 to 1.5m from the ground, while I found this individual much higher.

I expected to find *Polypedates colletti*, *Rhacophorus dulitensis* and *Rhacophorus pardalis* in plot types F and EF because they are all common arboreal frogs in this area (Haas & Das, 2012). Especially the last two species had to be found because they live mostly at higher elevations in the canopy (Haas & Das, 2012). *Polypedates colletti* was not seen during the research period and *Rhacophorus dulitensis* was encountered only once around a pool and a few times high in a tree. On the contrary, *Rhacophorus pardalis* was encountered frequently, both at high and low elevations. This species was mainly observed sitting on small branches but not on leaves, which may explain the absence in epiphytes.

### 4.6. Epiphytes as perching sites for arboreal frogs

28 % of the sampled epiphytes contained at least one frog, with 56 % of the frogs found in plot type P. This suggests that epiphytes found in plot type P could provide a stable microclimate and a refuge for frogs from the harsh microclimatic conditions (Turner & Foster 2009). Unfortunately the frog species found in plot type P are species with low conservation value (IUCN, 2012). Probably typical forest species are not found in plot type P, because of unsuitable environmental conditions or the lack of suitable food supplies (Gillespie et al., 2012; Stebbins &Cohen, 1995). In plot type F, epiphytes are less important as perching sites, because more suitable substrates were present for frogs. Nevertheless epiphytes can facilitate frog survival during periods of less regular rainfall or heat waves.

### 4.7. Future directions

First of all this was a preliminary study with rather limited data. Moreover the study was done only at the end of the dry season, which less chance finding frogs. At least such a study has to be done during one year or spread over more years, so all seasons, mainly influenced by the monsoon, are covered. Due to logistical constraints the study was also limited to one specific area. More research need to be done in this area as well as in other areas in Southeast Asia with additional habitats like for example primary forests, peat swamps and montane forests.

It would be advisable to search for alternative methods for sampling more epiphytes in an easier way and with fewer disturbances. Maybe investigating the use of small multicopters with FPV (First Person View) or the combination of data loggers and camera traps could be interesting.

To mitigate biodiversity loss in plantations, conservation management plans can be implemented. Plantations are not a good habitat for several frog species. Although fully-grown plantations can harbour a lot of epiphytes, forest frog species were not found. Therefore oil palm plantations should be managed as agro forestry systems, like growing oil palm in mixed-tree orchards rather than monoculture plantations and enhancing buffers and corridors connecting distant forest reserves (Bhagwat & Willis, 2010). This management can be of interest especially for *Rhacophorus appendiculatus*, because they can adapt quite well and are already found in EF plots. Another management plan is creating a patchwork of different aged plantations, which may enhance frog abundance but probably not in diversity (Luskin & Potts, 2011). In this way sudden environmental changes on a large area can be avoided. Decreasing the use of herbicides and fertilisers can have a positive effect on species richness, but is difficult to impose to plantation owners.

Secondary forests might be pivotal for the conservation of biodiversity in tropical areas (Ficetola et al., 2007; Barlow et al., 2007). The conservation value of a secondary forest is expected to increase over time (Chazdon et al., 2009) so a long term management plan is essential. Because many primary rainforest has already been lost, remnant secondary forest can help in mitigating biodiversity loss and may have a role to play in the long-term rescue of many threatened forest species (Wright & Muller-Landau, 2006). For amphibians for example remnant secondary forests may harbour considerable amounts of species diversity (Gillespie et al., 2012). Along the Kinabatangan River, it would be advisable to make corridors and buffer zones between the fragmented secondary forests. This implies removal of stretches of plantations and planting native tree species. The already existing corridors proves helpful for many species (personal observation). Another management plan could be controlling tourism along the Kinabatangan River to reduce stress and disturbance for the animals in the already small patches of secondary forest.

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# 6. Appendix

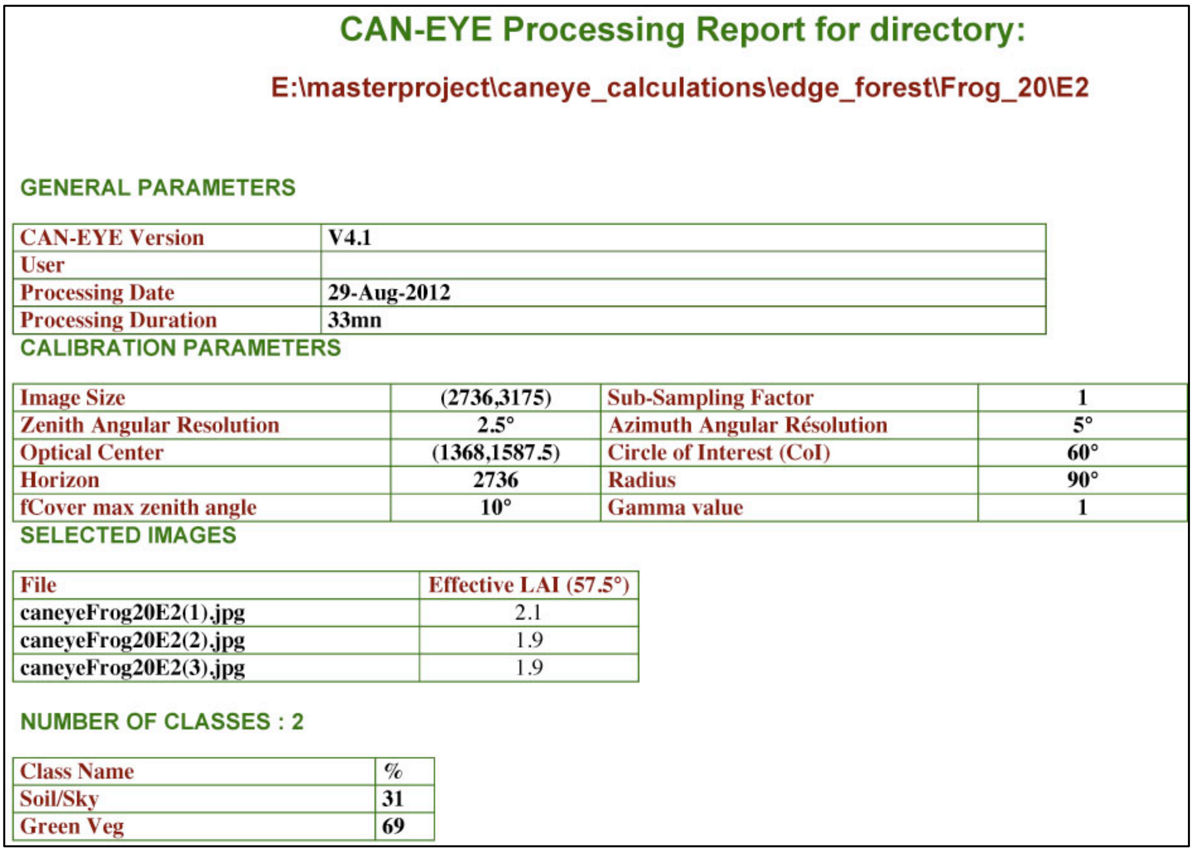
## Appendix 1: Climbing equipment and ladder

*Figure 6.1. On the left climbing equipment ((a) semistatic climbing rope (100m) in ortlieb waterproof backpack, (b) nylon lines, (c) pilot ropes, (d) a bigshot, (e) arborist harness, (f) helmet, (g) grigri and sling, (h) hand ascender with foot strop and small pulley, (i) slings, (j) extra rope and several karabiners) and on the right (k) and aluminum ladder*

## Appendix 2: Tools

*Figure 6.2. Tools for all the necessary measurements: (a) multimeter (Amprobe TH1), (b) range finder (toolcraft LDM 70), (c) gps (Garmin GPSmap 60CSx), (d) dies, (e) measuring tape, (f) compact camera (canon powershot A800) and (g) fish-eye lens (Jackar)*

## Appendix 3: Output CAN-EYE for canopy cover



CAN-EYE Processing Report for directory:

E:\masterproject\caneye_calculations\edge_forest\Frog_20\E2

GENERAL PARAMETERS

| | |
|---|---|
| CAN-EYE Version | V4.1 |
| User | |
| Processing Date | 29-Aug-2012 |
| Processing Duration | 33mn |

CALIBRATION PARAMETERS

| | | | |
|---|---|---|---|
| Image Size | (2736,3175) | Sub-Sampling Factor | 1 |
| Zenith Angular Resolution | 2.5° | Azimuth Angular Résolution | 5° |
| Optical Center | (1368,1587.5) | Circle of Interest (CoI) | 60° |
| Horizon | 2736 | Radius | 90° |
| fCover max zenith angle | 10° | Gamma value | 1 |

SELECTED IMAGES

| File | Effective LAI (57.5°) |
|---|---|
| caneyeFrog20E2(1).jpg | 2.1 |
| caneyeFrog20E2(2).jpg | 1.9 |
| caneyeFrog20E2(3).jpg | 1.9 |

NUMBER OF CLASSES : 2

| Class Name | % |
|---|---|
| Soil/Sky | 31 |
| Green Veg | 69 |

*Figure 6.3. Part of output of CAN-EYE software. Canopy cover is 69% for epiphyte 2 on transect 20 in edge forest.*

## Appendix 4: Anuran photographs

All photographs of anurans taken by author