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Patterns of abundance and diversity in epiphytic orchids on *Parashorea malaanonan* trees in Danum Valley, Sabah

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Abstract

Research in forest canopies has been restricted by access difficulties for a long time, however in the last 20 years techniques to provide access into tree canopies have been developed, now opening a field of biology to more scientists. This study uses rope techniques for accessing the canopy in a primary rainforest system in Borneo, Malaysia, to study the occurrence and patterns of orchid distribution in *Parashorea malaanonan* dipterocarp trees. Five trees were sampled, a total of 42 orchids from 8 genera were present. Data on branch height, distance from bole, position of the orchid on branch, substrate and associations were recorded and then analysed to find any noteworthy interactions. Significant relationships were found between many of the variables. Branch height was found to correlate with substrate, association, genera, species and position on branch, implying that it is a major contributor to orchid variation. Substrate showed a relationship with both genera and species, and non-uniform distribution across the five trees sampled. Association and position on branch were found to have an inverse relationship, as were genera and tree. However, this study could not establish definitive reasons for the relationships between variables and patterns in orchid diversity and abundance.

Introduction

The upper tree canopy of tropical forest systems is extremely diverse, containing a range of plant communities including vascular and non-vascular epiphytes, hemi-epiphytes, and parasites (Nadkarni 2002; Nadkarni 1994). Erwin (1983) referred to the canopy as the 'last biotic frontier', and despite developments in canopy access techniques that have allowed scientists to reach the upper canopy; this statement remains relevant (Parker & Brown 2000; Barker & Sutton 1997).

Forest canopies are very important biologically, particularly as centres of diversity and acting as the main interface between the atmosphere and the forest, playing a vital role in many ecological processes (Stork *et al.* 2007; Barker & Sutton 1997; Lowman *et al.* 1995; Nadkarni 1994; Ingram & Nadkarni 1993). The forest canopy is considered a structurally complex as well as ecologically critical sub-system of forests (Barker & Pinard 2001; Moffett 2000; Parker 1995).

An epiphyte is considered to be a plant, fungus or microbe that exists non-parasitically, living on any above ground surface and growing either partly or entirely into the air, into suspended soils, or in woody debris (Moffett 2000; Richards 1996). Epiphytes do not extract water and nutrients from the live host; rather nutrients are taken up entirely from suspended soils or other aerial sources, such as mist or rain, airborne dust, dead tissues of the host plant, or falling detritus (Moffett 2000; Whitmore 1998).

Epiphytes exist in many types of ecosystem; however, they are a classic feature of tropical rainforest systems. Of the 25 000 known orchid species, more than 70% are thought to live as epiphytes in tree canopies (Gravendeel *et al.* 2004). Epiphytes contribute to the complexity, structure and function of the canopy, and are an important component in terms of both biomass and species diversity; they represent 10% of all vascular plant species, and clearly prove to be important resources for vast numbers of canopy invertebrates, as well as many vertebrate species (Monteiro *et al.* 2009; Gravendeel *et al.* 2004; Wolf & Flamenco 2003; Ellwood *et al.* 2002; Nadkarni 1984).

Vascular epiphytes are a vital component of tropical biodiversity, however our knowledge of species diversity is limited due to the troubles accessing them (Flores-Palacios & García-Franco 2001). In the past, a combination of ground observations and recording plants from fallen branches or trees was relied upon for gaining this information (Lowman & Wittman 1996). A study by Flores-Palacios & García-Franco (2001) comparing the effectiveness of ground-based observations and climbing the host trees showed that although ground observations may be faster and safer, they often underestimate the species richness of epiphytes present, and also provide less information about vegetation structure and associations.

Although much research has been published on canopy plants, methods of sampling and analyzing their distribution and abundance are fragmented and inconsistent (Nadkarni 2002; Nadkarni & Parker 1994), making it more difficult for accurate comparisons between studies to be carried out. The majority of studies on epiphytes are from Central and South America, leaving a gap in our knowledge of orchids in South-East Asia's rainforests. Much of this published epiphyte research is about

ferns or epiphytes in general, whereas studies on epiphytic orchids are somewhat limited.

Numerous epiphyte species are small or rare, often with short flowering seasons, and many genera are still not well known taxonomically, making identification troublesome; therefore the use of morphospecies can help resolve taxonomic difficulties (Flores-Palacios & García-Franco 2001; Shaw & Bergstrom 1997; Heitz & Wolf 1996). Preferably, long-term sampling would allow for more effective data to be collected (Flores-Palacios & García-Franco 2001), although this is not always possible.

Canopy research is becoming essential for habitat management in forest systems, as well as furthering our understanding of climate change (Lowman & Wittman 1996). As this research becomes more structured and less descriptive, we will begin to better understand the forest canopy and rainforest ecosystems. One of the main factors that has led to an increase in funding for canopy research is the concern about climate change and its effects on tropical rainforests (Nadkarni 2001; Sutton 2001; Nadkarni & Parker 1994), especially on canopies as so little is still known about them (Barker & Sutton 1997; Heatwole & Higgins 1993).

Canopy access has always been difficult, and it is mainly in the last two decades that different techniques for reaching and sampling the forest canopy have allowed scientists to begin to catalogue the diversity within them (Barker 1997). Access to the canopy is still perceived by many researchers as a major obstacle to canopy science (Barker & Pinard 2001; Barker & Sutton 1997; Nadkarni & Parker 1994). Although some methods of access can cause problems due to intrusion affecting organisms under study, rope techniques minimise this effect in comparison to longer term access such as canopy cranes (Barker & Pinard 2001; Sutton 2001; Barker 1997).

Moist tropical rainforests cover 6% to 7% of the planet, mainly occurring about 15°-20° either side of the equator, in areas that receive more than 2000mm of rainfall per year (Stork *et al.* 2007). Rainforests are well known for being incredibly diverse systems, and are said to contain more than half the earth's biodiversity (Stork *et al.* 2007).

The Indo-Malayan rainforest region is the second largest block of tropical rainforest and covers an estimated 2.5×10^6 km² (Whitmore 1998). It encompasses much of Indonesia, and is centred on the Malay Archipelago, although it extends south into Australia and northwards into Burma, Thailand and Indo-China (Whitmore 1998). The largest areas of forest in this region are the Malay Peninsula, Sumatra and Borneo (Richards 1996).

Lowland dipterocarp forest is the most extensive forest type found in Borneo (Newbery *et al.* 1992). At least 180 species of the family *Dipterocarpaceae* are found in Sabah (Marsh & Greer 1992), most of these species occurring within the Danum Valley Conservation Area (DVCA). In Danum Valley the dipterocarp forest is dominated by *Parashorea malaanonan* and *P. tomentella*, along with *Shorea johorensis* and *Rubroshorea* spp. in the upper canopy of the area around the field centre (Marsh & Greer 1992).

The host tree species in this study, *Parashorea malaanonan*, is abundant in the lowlands and low hills of the Philippines and east Sabah, rare in west Sabah, Brunei and west Sarawak and occurs in rainforests up to 1300m (Newman *et al.* 1996). Due to the fact that many trees of the family *Dipterocarpaceae* are commercially valuable, much of the forest area in Sabah has been logged at rates that are among the highest in the tropics (Marsh & Greer 1992).

The aim of this study is to provide an insight into relationships between epiphytic orchids and substrates, associations, positioning and branch height. The study considers orchids on *Parashorea malaanonan* dipterocarp trees in the primary rainforest of the DVCA.

Materials and Methods

STUDY SITE

The study was carried out in the primary rainforest of the DVCA in south-east Sabah, Borneo (004°58'N, 117°48'E) during August 2008. Danum Valley (see Figure 1) is a currently uninhabited conservation area, containing 43 800ha (438km²) of almost entirely lowland evergreen dipterocarp rainforest, with a mean annual rainfall of approximately 2800mm, mean annual temperature of 26.7°C and humidity ranging between 70% and 95%, dependent upon the time of the day (Ellwood *et al.* 2002; Marsh & Greer 1992). Most of the terrain of the DVCA is considered rugged, with moderate elevation. Only 9% of the area lies above the conventional lower limit for montane forest (760m above sea level), another 36% has slopes exceeding 25° despite being of lower elevation (Marsh & Greer 1992).

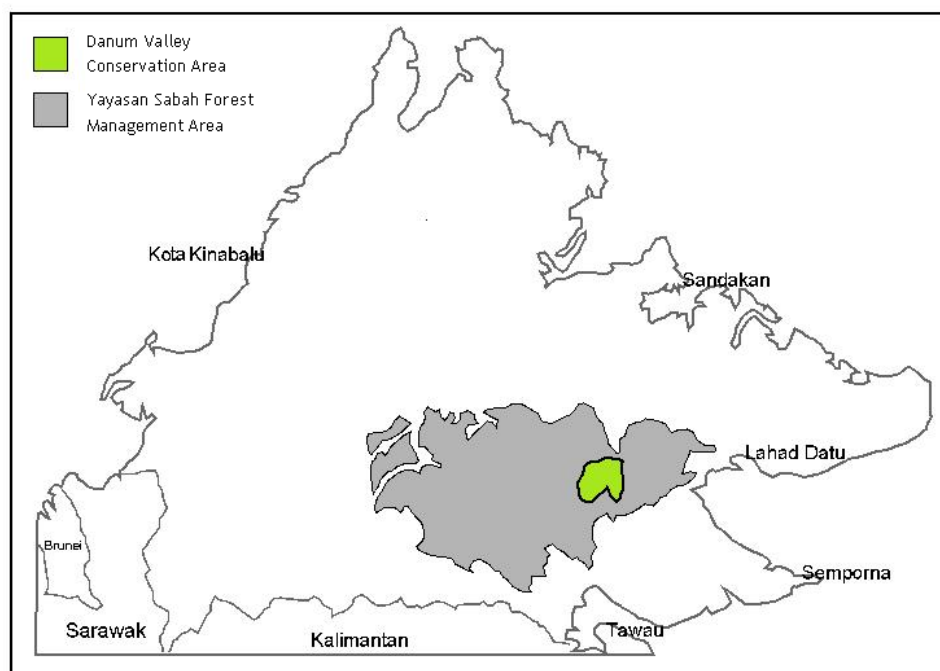


Figure 1: Map showing Danum Valley Conservation Area within Yayasan Sabah Forest Management

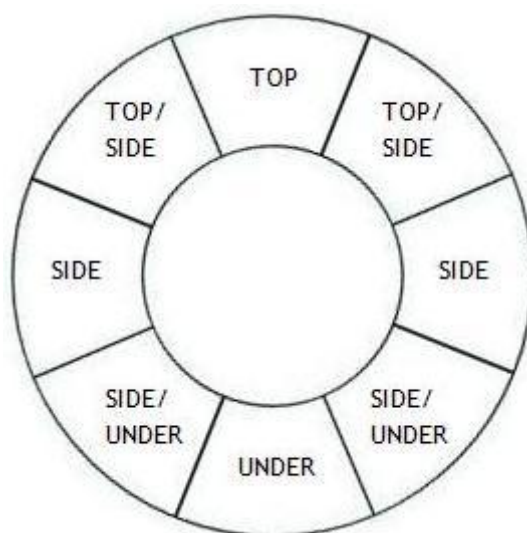
DATA COLLECTION

Five *Parashorea malaanonan* trees were climbed in the rainforest surrounding the field centre in Danum Valley, using the BCAP (Basic Canopy Access Proficiency) rope technique to access the tree canopies. Orchids were sampled on three branches of each tree, except in the case of trees 1 and 4, where orchids were only present on one branch of the tree. Branches were chosen mainly by accessibility, due to the positioning of the ropes in the tree.

Orchids within visible recording distance from the bole were recorded. Each specimen was photographed for later identification and recorded along with the branch height, distance from bole, position of the orchid on branch, the substrate the orchid was found on and any associations with other plants. Branch height and distance from bole were measured in metres, position on branch defined by categories such as top or side (see Diagram 1), substrate recorded as bark, moss or lichen, associations recorded as individual, orchid, angiosperm, fern or fern and orchid.

Information about branch and tree features, along with any relevant photographs, was also noted. Distances were measured using a bamboo stick with markers every 20cm, this measurement was estimated for any orchids recorded beyond reaching distance. The end of a 50m measurement tape was attached to my harness so that once a branch was reached the person on the ground could record the height.

Diagram 1: A cross section of a branch, showing categories used to record orchid position.



IDENTIFICATION

The orchids sampled were identified using the Orchids of Borneo books, volumes 1-4 (Wood 2003; Wood 1997; Chan *et al.* 1994; Vermeulen 1991). Specimens that could not be identified to species were identified to genus, and separated into morphospecies to allow for analysis of the data. Due to the fact that most of the

specimens were not in flower, and only floristic keys for Bornean orchids were available, the identification was done using the line drawings in the books alongside the habitat notes present.

DATA ANALYSIS

Spearman rank-order correlations were calculated on all of the variables to look for any relationships. Linear regression was performed on association versus branch height, and substrate versus branch height. Diversity values for each tree were analysed using a primer matrix. This included the species richness and evenness for each tree as well as the Shannon-Wiener and Simpson's indices of alpha diversity. Statistical analysis was performed using Minitab15 and Primer v6.

Results

Across the five trees sampled, a total of 42 orchids were recorded, from eight different genera. Table 1 shows a summary of the number of species (S) and specimens (N) recorded for each genus present in the survey, *Bulbophyllum* was the genus with both the highest quantity of species and the most orchids found (6 and 24 respectively). The mean height of the branches sampled was 35.0m (N=11, SD=5.76, SE=1.74), with a range of 21.9m.

Table 1: Summary of genus and species observations.

Genera	No. of species (S)	No. of specimens (N)
<i>Bulbophyllum</i>	6	24
<i>Dendrobium</i>	3	5
<i>Dendrochilum</i>	2	4
<i>Laelle</i>	1	1
<i>Luisia</i>	1	1
<i>Porrohachis</i>	1	3
<i>Vanilla</i>	1	3
Unknown	1	1
Total	16	42

TREE CHARACTERISTICS

Tree 1 had no orchids (or other epiphytes) apart from the two recorded, which were found on the lowest branch of the tree. Tree 2 had climbers up the tree, against the trunk. There were mosses and lichens on all branches and trunk. The lowest branch sampled was directly underneath the middle branch sampled. Tree 3 had mosses and lichens all over the tree, but no climbers. Tree 4 had very few mosses in comparison to the other trees climbed; it had a few more lichens but still less than Trees 1, 2, 3 and 5. There was one climber growing very close, but not on the tree (though it may have touched at some point). Tree 5 had a lot of mosses and lichens, as well as many epiphytes above and beyond my reach.

TREE DIVERSITY

Table 2 provides values for the number of species (S), number of specimens (N), species richness (d), species evenness (J'), Shannon's diversity index (H') and Simpson's diversity index (1-Lambda') for each of the five trees surveyed.

Species richness describes the amount of species present in a sample. Tree 3 has the largest number of species and therefore the highest value for species richness. Trees 1, 2 and 4 show similar richness values, whereas Tree 5 is lower due to the occurrence of 14 specimens out of the 16 recorded being from the same species, meaning one species dominates Tree 5. This also explains the low value of species evenness for Tree 5. Species evenness values range from 0 to 1, where 1 represents a community in which all species have equal abundance. Trees 1 to 4 show a high evenness, with Tree 1 having the highest value possible due to the occurrence of only two orchids on the tree, from two species. They are however from the same genus, so this value should be considered in that context.

Shannon's diversity index takes into account the number of species and the species evenness. A higher value signifies higher diversity in the community, it is not often found to exceed 5.0 in biological communities (Krebs 1999). Therefore, Trees 2, 3, and 4 show a higher level of alpha diversity than Trees 1 and 5. Simpson's diversity index is based on the probability of finding two organisms at random that are from different species, the value can range from 0 (low diversity) to 1 (high diversity) (Krebs 1999). Again Trees 2, 3, and 4 show a high level of diversity, whereas Tree 5 has a low diversity. Tree 1 has a diversity index (Simpson's) of 1, for the same reason as the species evenness value being 1 for this tree.

Table 2: Diversity values for each tree.

Tree number	S	N	d	J'	H'(loge)	1-Lambda'
1	2	2	1.443	1	0.6931	1
2	4	8	1.443	0.9056	1.255	0.7857
3	9	10	3.474	0.9849	2.164	0.9778
4	4	6	1.674	0.9591	1.33	0.8667
5	3	16	0.7213	0.4218	0.4634	0.2417

BRANCH HEIGHT AND SUBSTRATE

Spearman rank-order correlation indicates a significant strong positive association between branch height and substrate ($r_s=0.625$, $P<0.001$). This indicates a change from bark to moss to lichen as the branch height increases. Regression analysis yields the values shown in Table 3, and analysis of variance for the regression equation confirms a significant amount of the variation in substrate is explained by the regression line ($F=15.01$, $P<0.001$). Figure 2 shows the regression graph including a line of best-fit, for which the equation is:

$$\text{Substrate Code} = 0.74 + (0.04) \times (\text{Branch Height})$$

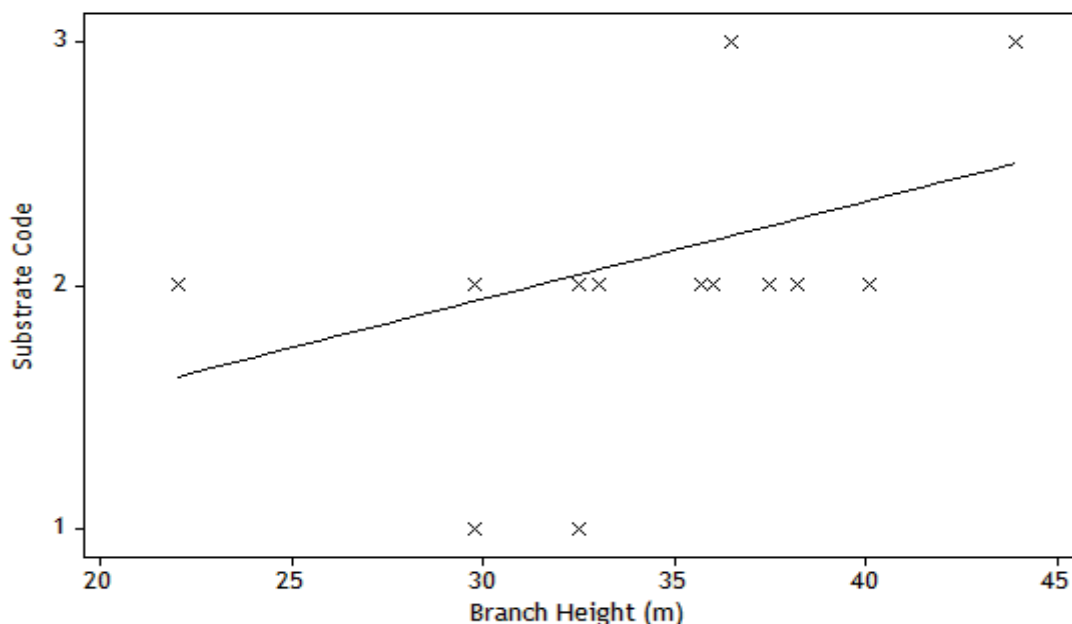


Figure 2: Regression Graph of Branch Height vs. Substrate Code. Key to substrate codes: 1=bark, 2=moss, 3=lichen. $R^2=27.3\%$.

BRANCH HEIGHT AND ASSOCIATION

The correlation between branch height and association found a weak negative correlation ($r_s = -0.290$, $P = 0.062$) with a non-significant P-value which was close to $P = 0.05$, and therefore is an area that may also be suited to further investigation. Regression analysis of association versus branch height gave the values shown in Table 3, the analysis of variance ($F = 16.23$, $P < 0.001$) showed that a significant proportion of the data is explained by the best-fit line, (as seen in Figure 3), for which the equation is:

$$\text{Association Code} = 8.49 - (0.93) \times (\text{Branch Height})$$

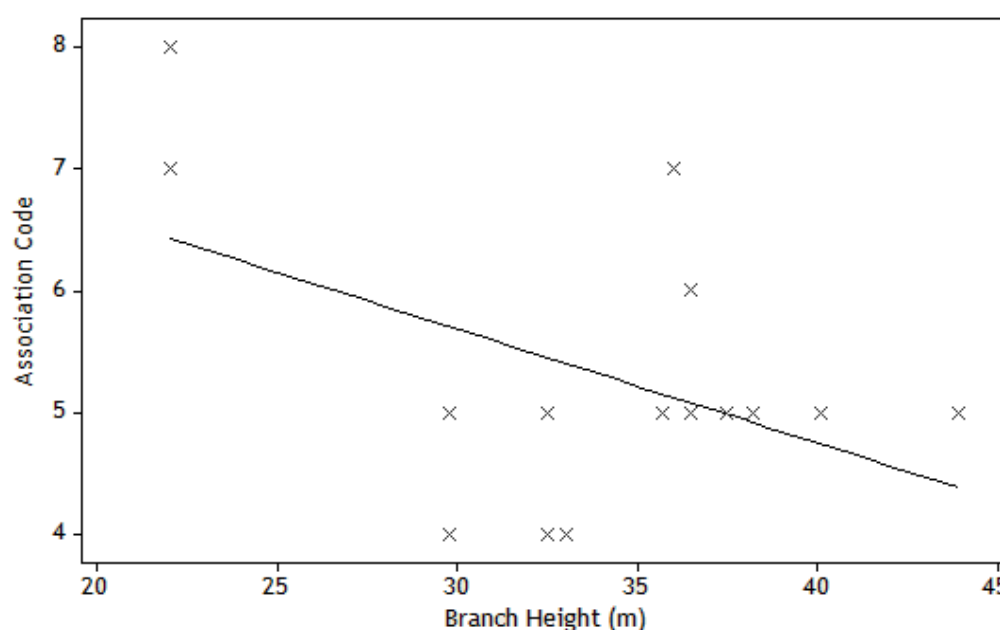


Figure 3: Regression Graph of Branch Height vs. Association Code. Key to association codes: 4=orchid, 5=individual, 6=angiosperm, 7=fern, 8=fern and orchid. $R^2 = 28.9\%$.

Table 3: Regression analysis data.

		Coef	SE Coef	T	P
Substrate	constant	8.48	0.80	10.67	<0.001
	branch height	-0.093	0.023	-4.03	<0.001
Association	constant	0.74	0.36	2.09	<0.001
	branch height	0.040	0.010	3.87	<0.001

GENUS/SPECIES, SUBSTRATE AND ASSOCIATIONS

A significant positive correlation was found between substrate and both species and genus ($r_s=0.496$, $P=0.001$ and $r_s=0.472$, $P<0.005$, respectively). This implies that certain species or genera favour a particular substrate. Most genera (including *Bulbophyllum* and *Dendrobium*), were mainly present on moss substrates whereas *Dendrochilum* and *Porrohachis* occurred more on lichen substrates. Only 3 orchids in total were found on a bark substrate, possibly due to the lack of humus. Table 4 provides the occurrence of each genus for the substrates bark, moss and lichen, as well as associations. Neither species nor genus showed any relationship with association ($r_s=0.0222$, $P=0.158$ and $r_s=0.051$, $P=0.747$, respectively), however this may not be the case in general, due to the small sample size of this survey.

Table 4: Summary of orchids found by genus for substrates and associations.

Genus		Bulbophyllum	Dendrobium	Dendrochilum	Laelle	Luisia	Porrohachis	Vanilla	Unknown
Substrate	bark	2	0	1	0	0	0	0	0
	moss	22	5	0	1	1	0	3	0
	lichen	0	0	3	0	0	3	0	1
Association	individual	17	0	3	0	0	3	3	1
	orchid	4	2	0	0	0	0	0	0
	angiosperm	0	0	1	0	0	0	0	0
	fern	3	1	0	0	1	0	0	0
	fern + orchid	0	2	0	1	0	0	0	0

GENUS/SPECIES AND BRANCH HEIGHT

Both species and genus showed a significant positive correlation with branch height ($r_s=0.479$, $P=0.001$ and $r_s=0.586$, $P<0.001$, respectively). This indicates that orchids show a preference to height of the branch they grow upon, both at the level of genus (Figure 4) and species.

GENERA AND TREE

There is a significant, weak negative correlation between genus and tree number ($r_s=-0.22$, $P<0.001$), meaning that each tree has a tendency to contain certain genera (Figure 5).

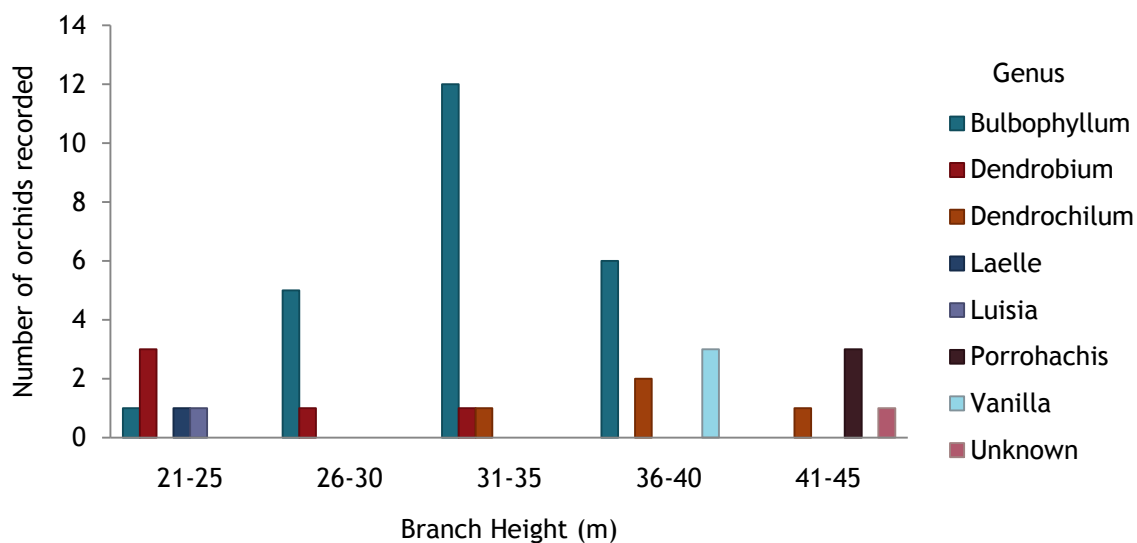


Figure 4: The relationship between genera and branch height. The category of branch heights 21-25 includes all branches between 21.0m and 25.9m, the category 26-30 includes all branches between 26.0m and 30.9m, and so on for the remaining categories.

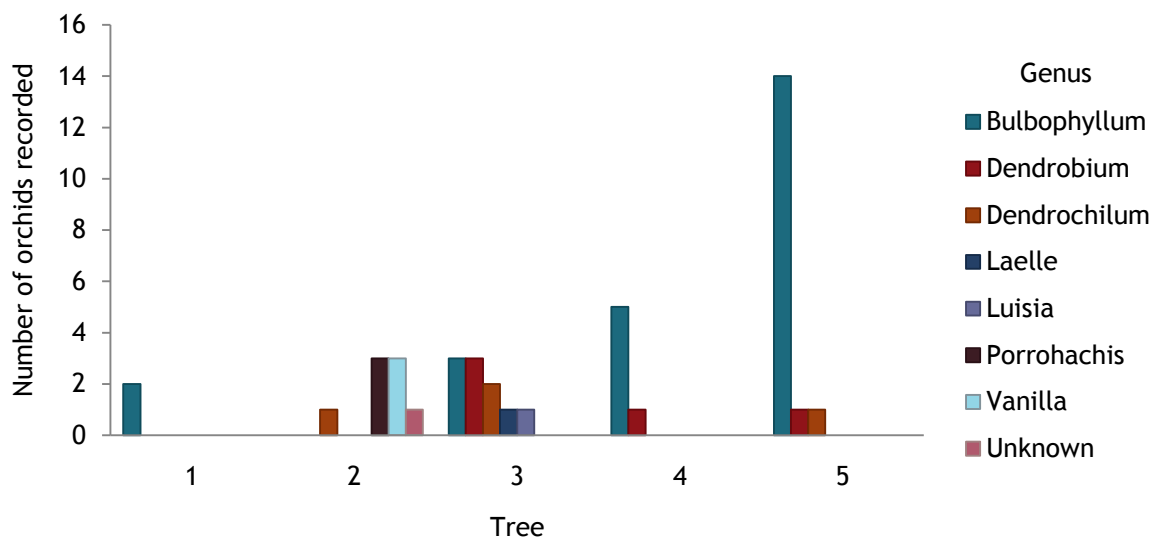


Figure 5: The relationship between genera and tree.

SUBSTRATE AND TREE

A significant negative correlation was found between tree number and substrate ($r_s = -0.443$, $P < 0.005$). This implies that each tree showed a different range of substrates present. Orchids were found on mosses in all five trees, whereas orchids on bark were only found in Trees 4 and 5, and orchids on lichens in Trees 2 and 3 (Figure 6). Tree 4 also had very few mosses and lichens compared to the other trees, which may have had an influence on the orchid species that could colonise the tree.

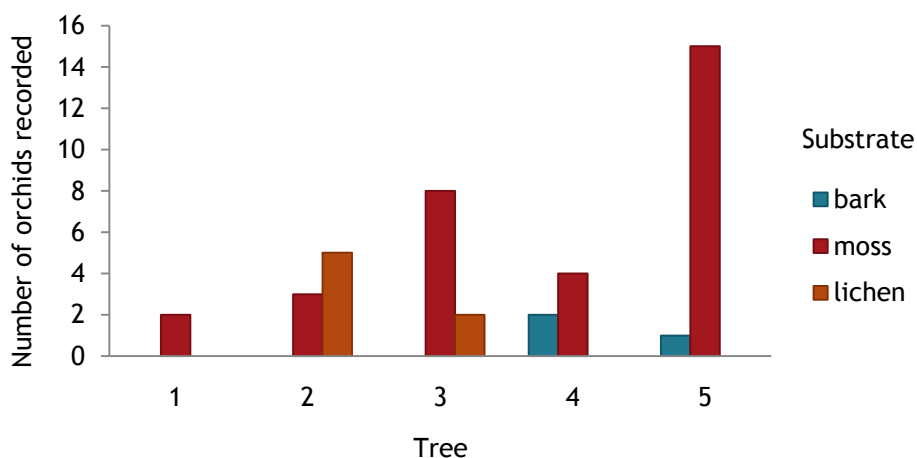


Figure 6: The relationship between tree and substrate.

POSITION ON BRANCH AND ASSOCIATION

The most abundant association across the data set was 'individual', orchids found not growing with other orchids or ferns. 'Side' was the most common orchid position on a branch. Position on branch and association were shown to have a significant negative correlation ($r_s = -0.543$, $P < 0.001$). Figure 7 shows this relationship against orchid abundance, the orchid found with an angiosperm was not included in this graph as there was only one orchid found with this association.

POSITION ON BRANCH AND BRANCH HEIGHT

A significant positive correlation was found between position on branch and branch height ($r_s = 0.345$, $P < 0.05$). Branches with heights from 26 to 40 m contained the most orchids sampled, and also the preference for growing on the side of the branch rather than the top or bottom (Figure 8).

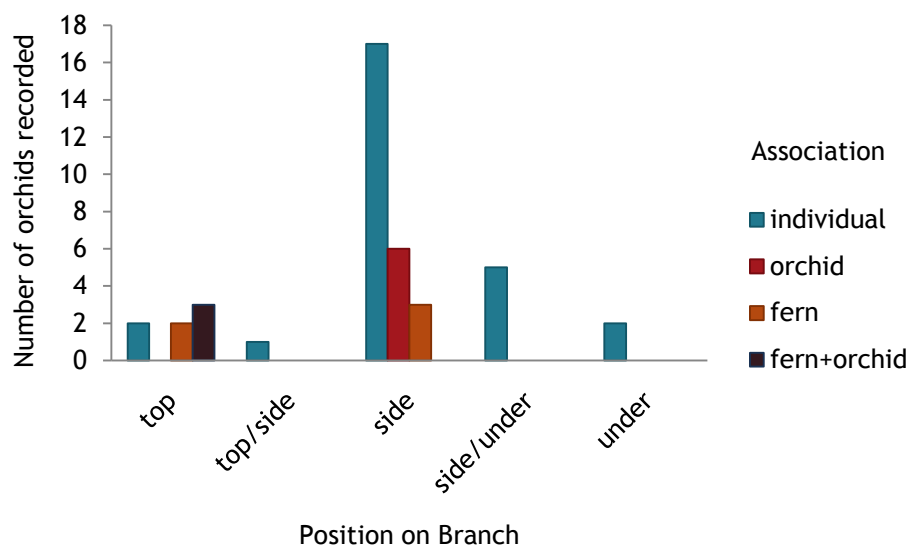


Figure 7: The relationship between position on branch and association.

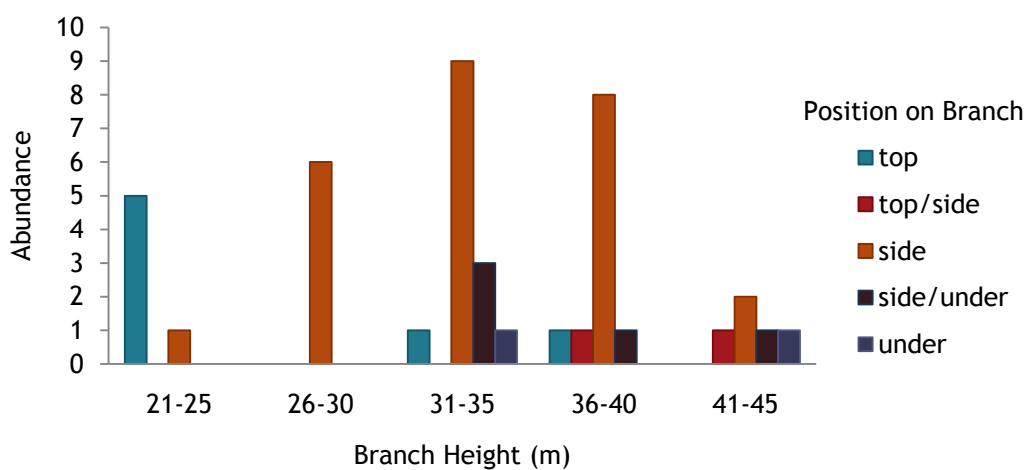


Figure 8: The relationship between position on branch and branch height. See Figure 4 caption for explanation of branch height categories.

Discussion

Orchid diversity and abundance varies considerably between the trees surveyed in this study. There are many variables recorded and plenty that have not even been considered that could contribute to this and the other significant relationships discovered.

TREE ARCHITECTURE

This survey investigates a few aspects relating to tree structure. Branch height has been shown to have relationships with substrate, association, genus, species and position of orchid on branch. There appears to be a link between the occurrence of certain genera or species with the height of the branch. The balance between light requirement and excessive water loss are probably the main reasons for vertical variation such as this (Mucunguzi 2007). This vertical zonation has been found in other studies such as Jarman & Kantvillas (1995), and has been described as separate microhabitats by Gravendeel *et al.* (2004), leading on from Johansson (1974).

Other aspects of branch and tree size may have further implications on orchid diversity. Branch diameter correlates with bark roughness and thick branches tend to have a dense covering of mosses and vascular plants, both ideal substrates for epiphyte growth (Hietz 1997; Hietz & Hietz-Seifert 1995). The inclination angle of branches is a factor that has been shown to contribute to the distribution and abundance of epiphytes (Nieder *et al.* 2001; Lowman and Moffett 1993; Ingram & Nadkarni 1993). Branch size is also an aspect worth considering as large branches provide good platforms for debris accumulation, supplying humus for epiphytes to colonise (Sillett 1999).

Tree height and size are also thought to contribute to epiphyte abundance. Larger trees tend to be older allowing more time for colonization. With the added component of a larger surface area, they maintain more epiphytes (Wolf & Flamenco 2003; Zotz *et al.* 1999). An effective method of presenting epiphyte population data is by mapping positions and size of epiphytes onto a diagram of each tree, with axes to allow for comparison of distances, as shown by Sillett (1999).

Structure of the tree crown, bark characteristics, foliage density, tree health and dispersal limitations of seeds are all factors that may contribute to epiphyte abundance and diversity (Sillett 1999; Hietz 1997). Also relevant are habitat scale factors such as canopy height and mid-storey and under-storey thickness, which vary with climate and altitude (Shaw & Bergstrom 1997).

SUBSTRATES AND ASSOCIATIONS

Lichens and mosses are essential in providing an environment that is suitable for seed germination and seedling growth of orchids (Withner 1974). Heavy humus is important to provide moisture and nutrients to epiphytes, as well as acting as a rooting medium (Benzing 1995). Where high levels of humus build up, they store large quantities of water (Sillett 1999). Epiphytes tend to favour light or heavy humus rather than bark due to these extra resources available (Mucunguzi 2007). This is shown in my results as the majority of specimens are found on moss (32 specimens out of 42 total), a few found on lichen (7 specimens) and only three orchids were found growing directly on the bark. Despite *Parashorea malaanonan* having rough bark with regular fissures (Newman *et al.* 1996), orchids tend to require a more suitable substrate, moss provides this with a source of moisture and nutrients for the orchids.

Nieder *et al.* (2000) found that out of 80 orchids sampled, 50 grew as single plants. Similarly, in this study, 27 out of 42 orchids were categorized as 'individual' under associations. Ferns and flowering plants are considered to be competitors with orchids, hence many orchids grow separately from these flora (Withner 1974).

MYCORRHIZAL INTERACTIONS

Orchids are dependent upon mycorrhizal fungi for germination. However our knowledge on distribution, temporal variation and natural history of these mycorrhizal fungi is seriously lacking (Otero *et al.* 2004). Sometimes mycorrhizal fungi continue to benefit the adult plant, though this relationship is not clearly understood (Bayman *et al.* 2002; Hadley & Williamson 1972).

Mycorrhizal relationships may affect the distribution of orchids. As orchids are dependent upon fungi for at least the beginning of their lifecycle, they cannot spread to areas without the existence of mycorrhizal fungi. Accumulated organic detritus, mosses and other plants may provide a habitat that contains the fungi essential to orchid growth (Hadley & Williamson 1972), another reason for substrate to be an important aspect of epiphytic orchid research.

HOST SPECIFICITY

There is rather contradicting evidence for whether epiphytes prefer one or more host species. Particular host trees may provide a specific range of traits, such as branch sizes and bark characteristics to which epiphytes could show preference (Zotz *et al.* 1999, Hietz & Wolf 1996). Laube & Zotz (2006) found that vascular epiphytes did not show strict species-host specificity, yet they were not randomly distributed. Due to the lack of knowledge about most epiphytes, the reasons behind host preference can only be speculated upon (Laube & Zotz 2006).

Host species may be of importance where uncommon substrates are present such as very rough bark, or thick horizontal branches that tend to accumulate large quantities of detritus (Hietz & Wolf 1996). Both form a substrate likely to be a suitable

habitat for certain orchids. As the information on this topic is varied, it is an area that could be a useful aspect to be considered in orchid diversity studies.

Most studies that investigate host-tree specificity consider whether epiphytes are more likely to exist on a certain species of tree. Another aspect to be considered is whether particular tree species harbour communities or species of epiphytes (Nadkarni 2002).

SAMPLING

One of the main issues with identifying orchids is that where keys exist, they are predominately floristic keys and orchids may only flower for a few weeks every year or two. Carrying out a study over only two weeks, it is apparent that the identification of species is considerably more difficult when nothing is in flower. To develop a more representative data set, sampling should occur over several months, with the same trees climbed repeatedly. This would provide the repetition necessary for more robust statistical tests to be run, and reduce the confusion with identification as most specimens would be recorded in flower at some point during the sampling. In addition, regions with pronounced dry seasons may have some epiphyte species which shed their leaves during dry periods, and repeat sampling would help to avoid neglecting these species (Hietz & Wolf 1996).

Using one host tree for a study allows comparisons between other variables without the possibility of host species affecting the orchid distribution. If time were less of a constraint, two or more host species would provide a more substantial representation of the habitat, assuming tree species chosen are dominant or characteristic of the forest being surveyed. An important consideration when carrying out research in tree canopies is finding trees that not only represent the local population, but also provide a good anchor point for the ropes to be in the right position to allow access to the main branches of the tree.

OTHER AREAS WITH POTENTIAL FOR FUTURE RESEARCH

There are many other variables that could be considered in further studies, including bark pH levels and rainfall. Epiphytes have a tolerance for low pH (Benzing 1995), and so it would provide an interesting study to consider whether pH levels differ with or affect substrates and associations, leading to orchid diversity. Rainfall is also considered a strong predictor for epiphyte diversity (Kreft *et al.* 2004). Species richness was found to increase with increasing precipitation and decrease during the dry months (Kreft *et al.* 2004). Comparisons of orchid diversity between two sites with significantly different rainfall patterns would produce data that could lead to estimations of orchid diversity in particular habitats due to rainfall.

Due to time constraints, this study was conducted solely in primary rainforest, yet the DVCA provides an excellent habitat in which to compare the orchid communities in both primary and logged rainforest. There is easy access to secondary habitats that have a range of time since logging occurred, allowing comparisons to be made between primary and secondary forest, and also considering the colonisation timing

when assessing stands that vary in age. Studies with a comparison between primary and secondary rainforest epiphyte communities, such as Barthlott *et al.* (2001) found a decrease in both species numbers and abundance, attributed to the homogeneity of microclimate and phorophyte structure in the secondary vegetation.

Information about the effects of disturbance such as above will provide more knowledge of the consequences of habitat destruction on epiphytic communities, and as they play a vital role in forest ecosystems, on the forest as a whole. This will help to develop conservation strategies to preserve epiphyte and canopy diversity.

Conclusions

In this paper, the epiphyte diversity and abundance with possible contributing factors, has been investigated. The study created a small but detailed data set, which has provided an outlook of possible relationships and trends of orchid diversity in dipterocarp forest. Establishing the biology between the interactions found would be worthy of further investigations.

Studies such as this can begin to explain the importance of orchids and other vascular epiphytes as a main component of canopy structure within rainforest ecosystems. As changes to tropical forest structure and composition are expected due to climate change, this will extend to changes in forest canopies, including the flora and fauna that exist there (Stork *et al.* 2007), making this a critical time for research based on the biology of rainforest canopies.

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