

The rich invertebrate community in tropical epiphytes: a survey of the microhabitat of the Elephant Ear Fern (*Platyserium elephantotis*)

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Abstract

This study presents a survey of the microhabitat of the epiphytic fern *Platyserium elephantotis*. A total of 18 samples (individual plants) were randomly taken from several different host tree species in Kibale National Park, Uganda. Epiphytes were sampled according to three different height categories: low, medium, and high. Epiphytes were taken apart and all macroinvertebrates on and within the suspended soil of the epiphyte were collected and assigned morphospecies. Results show that the microhabitat is highly diverse and very variable between individual plants. Most common taxa were ants (five ant nests encountered), spiders, beetles, millipedes, and isopods, and included a large number of larval and pupal stages. No significant relationship was found between diversity and weight or height of the epiphytes. We estimate that this fern species is host to about 362 macroinvertebrate morphospecies.

INTRODUCTION

In tropical rainforests the vegetation is composed of several structural layers. Higher plants furnish complex, multi-layered, spatially and temporally diverse habitats that support species-rich assemblages of organisms (Forster *et al.*, 2004). As part of the forest vegetation there is also a wide range of plant forms that reach up into the canopy vicariously; they either climb and then scramble in the tree canopy (vines and lianas) or grow as epiphytes (Begon *et al.*, 2006).

Epiphytes are an important component of world tropical forest biodiversity yet remain less understood. They represent a significant part of the forest plants biodiversity, accounting for 12% to 16% of the species at moist forest sites, and for about 25% in wet forests (Forster *et al.*, 2004). They play important roles in nutrient dynamics, primary production and indirectly in secondary production (Coxson & Nadkarni, 1995). These plants benefit by using their hosts for aerial support but gain their resources from the atmosphere and are thus able to grow in the canopy by using forks in trees to establish roots, thus bypassing the problem of growing from far below on the ground (Pullin, 2002). They establish a relationship of commensalism with the tree (Huggett, 1998). However Begon *et al.* (2006) suggest that there is an increase in the likelihood that overweight branches will break during high winds, a detriment for the host tree.

The floristic composition and abundance of epiphytes in the forests are influenced by moisture availability, light intensity, altitude, bark characteristics and position within the host (Wolf, 1994).

Few tree trunks are perfectly vertical, and the upper side of an angled trunk or branch receives more moisture than and has a very different morphology and epiphyte flora from the lower side. In the upper canopy, light intensities and fluctuations of ambient temperatures and moisture levels are more extreme than in the more sheltered lower canopy (Forster *et al.*, 2004) which influences epiphyte occurrence.

The diversity of epiphytes provides for a corresponding diversity of resources for herbivores and so on up on the food chain (Begon *et al.*, 2006). These diverse micro-/mesohabitats contribute significantly to ecosystem processes in the canopy and support rich, diverse, and distinctive invertebrate communities (Leather, 2005). As observed by Markussen *et al.* (2005), inside the cushions of epiphytes many different groups of invertebrates pass their life cycles. In fact, in the tropics, epiphytes are known to house a high density and species richness of arthropods (Nadkarni & Longino, 1990; Richardson, 1999; Ellwood & Foster, 2004; Karasawa & Hijii, 2006).

Despite this knowledge, until recently most of the attention on the insects in tropical forest canopies focused on the trees themselves. Ellwood & Foster (2004), however, showed that forest epiphytes contain large numbers of insects. They studied the abundance of insects and other invertebrates in the Bird's Nest Fern *Asplenium nidus* growing on dipterocarp rainforest in Borneo and found that the biomass of invertebrates in these ferns was as great as that found on the trees, doubling the estimate of invertebrate biomass in the canopy. They also found that the ferns contained different proportions of the various invertebrate taxa present. One important feature of these ferns that allows the support of great biomass and diversity is the presence of large amounts of suspended soil and plant material (Speight *et al.*, 2008).

Platyserium elephantotis Schweinf. (Polypodiaceae, Pteridophyta), commonly known as the Elephant Ear Fern, is a widespread epiphyte occurring in lowland and submontane habitats in eastern Africa (Doody *et al.*, 2001). The species is dependent on a forest habitat but can occur outside of primary forests. The plant has dimorphic fronds: sterile shield-like fronds clasping support and fertile pendulous fronds bearing sporangia (Mabberley, 1987). The sterile fronds accumulate humus within which roots ramify. The plant usually grows in clusters of several plants in branch forks or other suitable anchoring points in trees. This fern has been scarcely studied and – to our knowledge – no previous work has been done on its microhabitat.

In this study we aim to explore the macroinvertebrate communities associated with the epiphyte fern *Platyserium elephantotis*, in a pristine patch of a mid-altitude moist tropical forest, in Kibale National Park (KNP), Uganda. The specific objectives of this research are (i) to survey the

biodiversity and species richness, as well as organisms' density within these ferns; (ii) to compare macroinvertebrate communities from ferns at different heights and of different weights and (iii) identify patterns of macroinvertebrate assemblages according to the mentioned variables.

MATERIALS AND METHODS

Epiphyte collection

Sampling was conducted during four days in July, 2012, in a patch of pristine forest in KNP (0°33'N; 30°21'E), near Makerere University Biological Field Station (MUBFS), Uganda. KNP includes a medium altitude (1,110–1,590 m above sea level), transitional, moist forest interposed between a dry forest and a typical rain-forest in the Albertine region (Mucunguzi, 2007). The sampling design consisted of choosing 18 random host trees where the epiphytes were present. The ferns were removed from the trees by pulling and using a machete. All samples consisted of single plants which were taken from a cluster. Higher epiphytes (above 8 m) were collected by a climber. The plants were placed in a bucket straightaway to prevent any organisms escaping and lowered with a line (hoist). Bucketed epiphytes were transferred to a plastic bag by tipping the bucket contents into the plastic bag, and then sealing it, after checking the bucket for any remaining organisms.

For each collected specimen, data was recorded on the (a) height in the tree, (b) host tree species, (c) coordinates, (d) exposure (direction of the fern), and (e) direction and exposure of the slope. Specimens were selected according to three different height categories: low (0-2 m), medium (8-11 m), and high (17-22 m). Low height category epiphytes were only encountered and collected in and around the main field station and lower camp of KNP. For epiphytes that were detected in tree species other than those from which the samples are from, a list of tree species was made.

Macroinvertebrate collection and identification

The epiphytes were placed on white sorting trays and taken apart. We collected the entire fauna of the 18 ferns of a range of sizes from 31.8-49.5 cm (biggest non-fertile leaf length) and 390-1,750 g (fresh weight: habitat samples should be of a known weight or volume so that the density of animals can be standardised to habitat unit, e.g. biomass of fern) and heights from 1.7-22 m. Macroinvertebrates on the outer surfaces of epiphytes as well as those on the surface and within the suspended soil of the epiphyte were collected using forceps. The organisms collected were fixed in either a formalin solution or ethyl acetate. All invertebrates were then stored in a formalin solution for later identification.

The organisms of all samples were surveyed with a dissection microscope and sorted into morphospecies and identified to the order, or to the family, when possible. To keep a record of the morphospecies, we made a drawing of each one, with a small description of its main features. Total number of morphospecies and total number of individuals per morphospecies, as well as total number of organisms per sample were recorded. When an ants' nest was encountered, an estimate number of total ants in the sample was made and several representative individuals were collected. Additional findings within the samples were also annotated.

Statistical analysis

For each sample we calculated a series of diversity indices, Shannon H', Margalef, Evenness and Dominance using the PAST software package v2.15 (Hammer *et al.*, 2001). The total number of morphospecies and individuals within each taxonomic order was also assessed, as well as the mean density of organisms (number individuals/g of epiphyte) inhabiting the epiphytes. To compare macroinvertebrate communities and identify diversity patterns we performed a MANOVA, testing for differences in diversity (using four indices as dependent variables) between height categories, and adding the covariate of fern weight to the analysis, as implemented in Minitab v14 (Minitab Inc, 2003). To estimate the total number of morphospecies inhabiting the microhabitat of the Elephant Ear Fern we fitted a rarefaction curve to our dataset, based on the cumulative new species per sample, using the model: $S = \frac{a * N_0}{b - N_0}$.

RESULTS

A total of 3,813 invertebrate animals were collected and identified to order (or family) level from the 18 ferns. The invertebrate communities within the ferns were made up of a diverse range of taxa. The ferns contained a total of 16 orders, and 126 morphospecies. Most morphospecies belonged to the Hymenoptera (16%, all but one morphospecies were ants), the Coleoptera (beetles, 23%), and the Araneae (spiders, 22%), followed by the Lepidoptera (only the caterpillar stage of butterflies or moths, 8%), Blattodea (cockroaches, 8%), and Hemiptera ('true bugs', 8%) orders (Figure 1A). Most abundant in number were the ants (Figure 1B, 90%); in addition to those simply present on or within the epiphyte five ant nests were encountered (sample 9, 11, 13, 14, and 17). Of the remaining taxa, those with the highest number of individuals were Isopoda (isopods, 27%), Julida (an order of millipedes, 22%), Coleoptera (beetles, 11%), Araneae (spiders, 11%), Blattodea (cockroaches, 7%), and Lepidoptera (butterflies and moths, 7%).

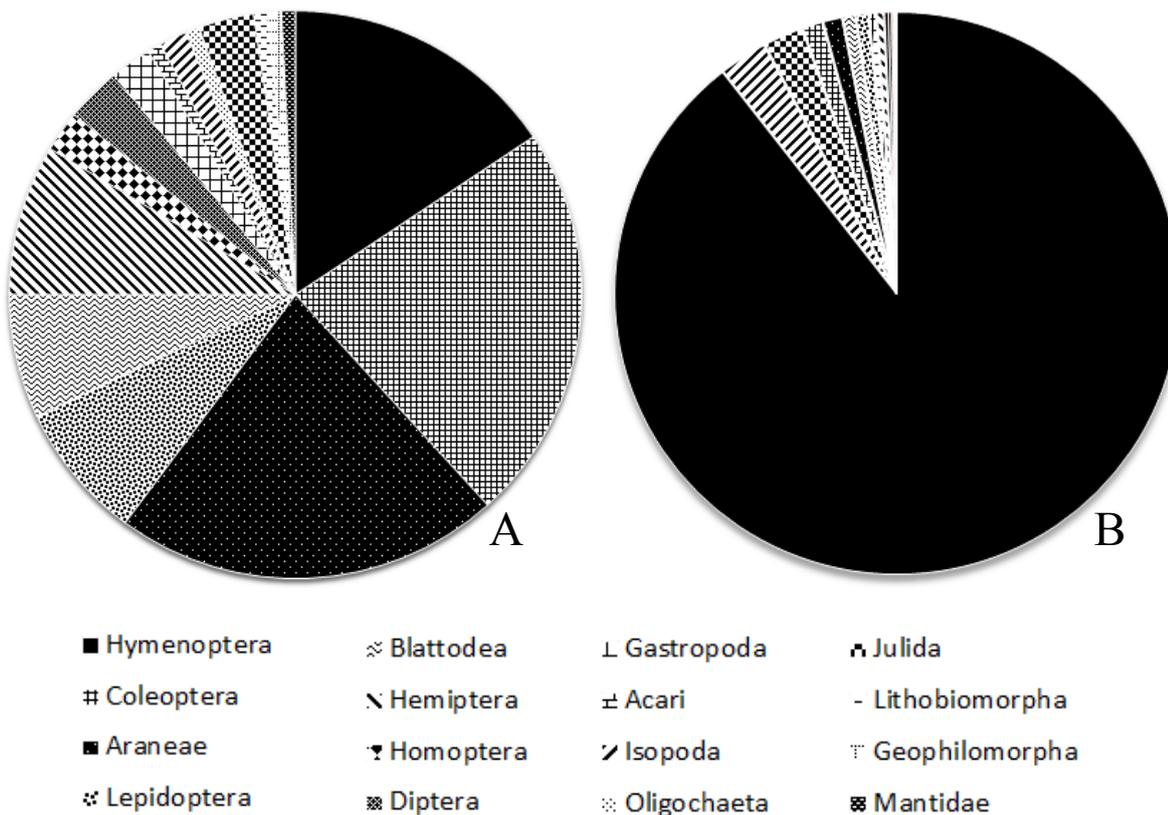


Figure 1. Pie charts illustrating the relative number of invertebrates collected: (A) relative number of morphospecies per taxon, (B) relative number of individuals per taxon.

Table 1. Overview of samples and diversity indices. Height categories: L (low, up to 2 m), M (medium, 8-11 m), H (high, 17-22 m).

Sample	Height category	Weight (g)	Morpho-species nr	total N	Shannon H'	Margalef	Evenness	Dominance
1	L	620	13	35	1.925	3.628	0.4895	0.233
2	L	500	10	64	1.129	2.164	0.3092	0.4805
3	L	1,415	6	53	0.5299	1.259	0.2831	0.7892
4	M	900	15	24	2.415	4.405	0.7463	0.1285
5	M	1,500	12	24	2.184	3.461	0.7404	0.1493
6	M	900	3	9	0.6837	0.9102	0.6604	0.6296
7	H	1,600	13	44	2.083	3.19	0.6176	0.1725
8	H	900	5	14	1.215	1.516	0.6743	0.3878
9	H	1,750	5	1,004	0.7205	0.5787	0.4111	0.496
10	M	800	5	1,504	0.02211	0.5468	0.2045	0.9947
11	M	1300	12	213	0.3733	2.052	0.121	0.882
12	H	720	16	322	0.4244	2.598	0.09554	0.8684
13	M	1,400	11	138	1.367	2.03	0.3565	0.3466
14	M	640	16	242	0.8232	2.733	0.1424	0.6896
15	M	390	5	9	1.332	1.864	0.9473	0.28
16	H	750	9	27	1.761	2.427	0.6467	0.2483
17	M	1,510	14	44	2.064	3.456	0.5629	0.1942
18	H	900	9	49	0.9087	2.056	0.2757	0.6401

The ferns showed great variation in weight, number of morphospecies and number of individuals (Table 1). Though the lengths of longest non-fertile leaf were of a similar order of magnitude (31.8-49.5 cm), the weight varied greatly (390-1,750 g) and not necessarily according to leaf size. The variance in number of individuals was negatively affected by the presence of ant nests. The number of morphospecies varied from 3-16 per epiphyte and at first sight no relation to either height or weight appeared to exist.

The results of the MANOVA testing for differences in diversities according to height categories, with weight added as a covariate, showed no relation between morphospecies diversity and the variables tested (weight: Wilks' $\lambda = 0.613$, $F = 1.740$, $P > 0.05$, Figure 2; height: Wilks' $\lambda = 0.744$, $F = 0.439$, $P > 0.05$) so we could not reject the null hypothesis of no difference according to the predictor variables.

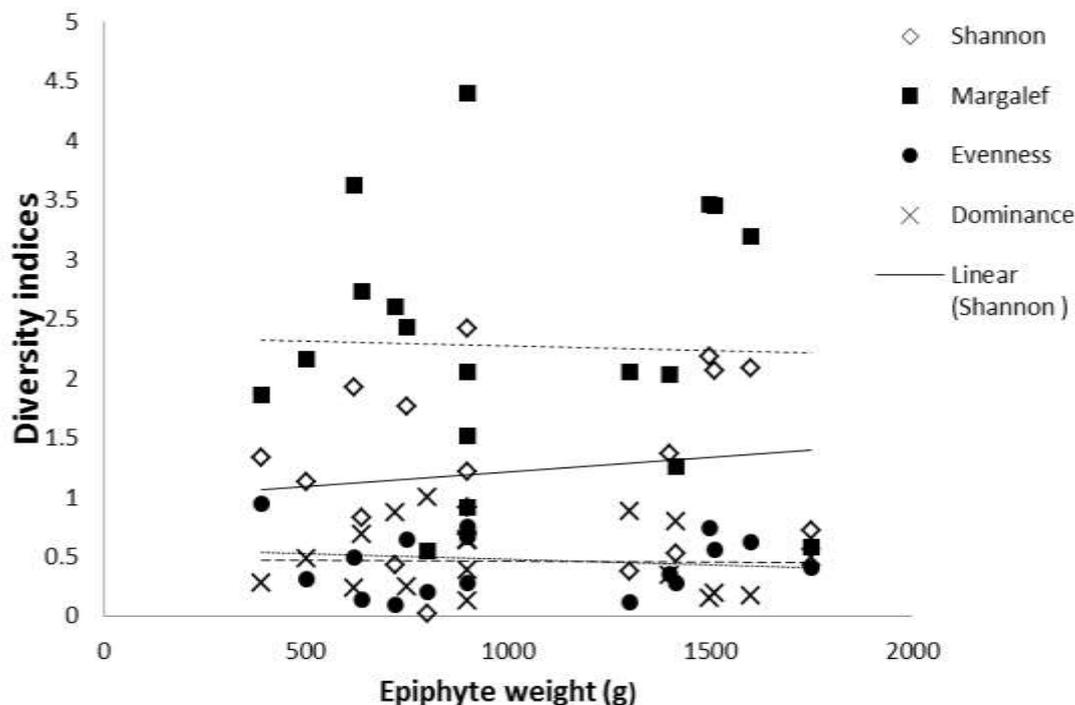


Figure 2. Linear regression using weight as an independent variable and diversity indices as dependent variables. No statistical significance was found for these regressions.

The results of the rarefaction curve (Figure 3) allowed us to estimate the total number of morphospecies inhabiting this species of fern, and the predicted value by the model was 362 morphospecies. This estimate represents the asymptote in the model, where the number of morphospecies found does not increase any longer with new samples.

We also estimated the density of organisms as an average of 0.22 individuals/g epiphyte.

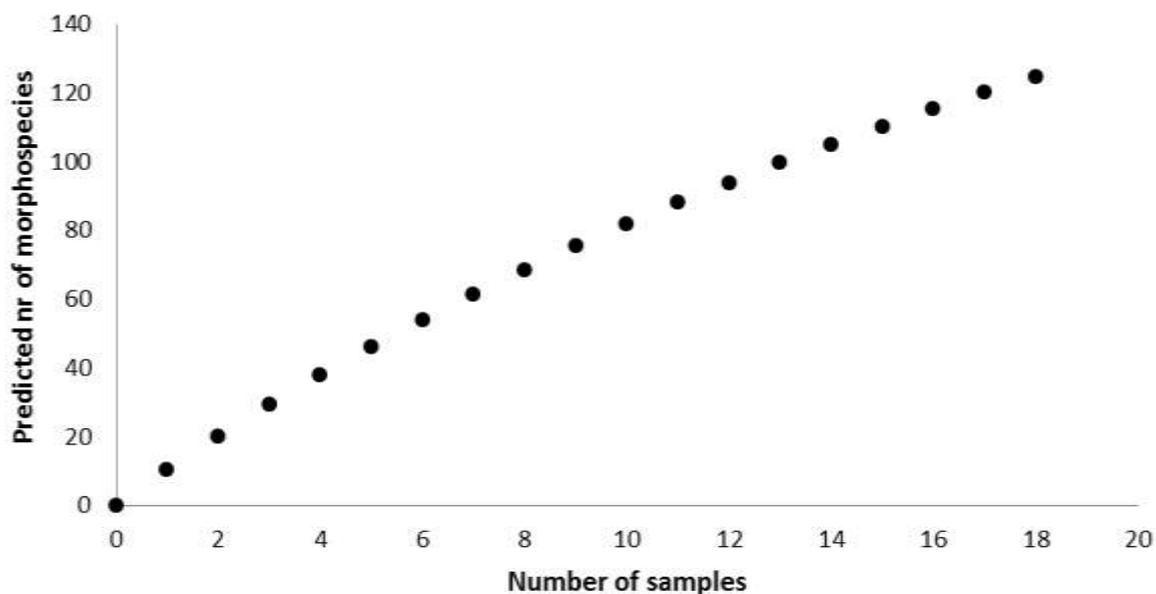


Figure 3. Rarefaction curve for the predicted number of morphospecies as the number of samples increases.

Additional observations

About half of the beetles found were in their larval stage and were of many different families. Many caterpillars and butterfly or moth cocoons were found (28), as well as a great number of empty fly cocoons (for example about 300 in sample 14). Additionally many predators were present, including a large variety of spider morphospecies (these were rarely found on multiple epiphytes), assassin bugs (Reduviidae) and a praying mantis (Mantidae). Overall the differences between the microhabitats of the epiphytes were very large. A good illustration is sample 13, which had an exceptional number of millipedes (72) and isopods (50), in addition to 8 other morphospecies. In contrast, sample 6 had only 3 morphospecies and 9 individuals in total, whereas sample 10 contained about 1,500 ants (nest) amongst others.

Table 2. Overview of host tree species of *Platyserium elephantotis* encountered during this study. Indicated are the host tree species of samples (S)

Host tree species sampled	Additional host tree species encountered
<i>Bridelia micrantha</i> (S2)*	<i>Albizia grandibracteata</i>
<i>Celtis durandii</i> (S8, S10, S11, S15, S16)	<i>Balanites aegyptiaca</i>
<i>Dombeya mukole</i> (S14, S17)	<i>Celtis africana</i>
<i>Erythrina abyssinica</i> (S1)*	<i>Cordia abyssinica</i>
<i>Ficus exasperata</i> (S6, S13)	<i>Diospyros abyssinica</i>
<i>Funtumia latifolia</i> (S18)	<i>Polyscias fulva</i>
<i>Markhamia platycalyx</i> (S7, S9)	<i>Sapium ellipticum</i>
<i>Olea welwitschii</i> (S12)	
<i>Persea americana</i> (S3)*	
<i>Prunus africana</i> (S4, S5)	

* These tree species were on the grounds of the main field station and lower camp in KNP.

Table 2 reports all host tree species from which the epiphytes were collected as well as other tree species where the epiphyte were observed, but not collected in this study. *Platycterium elephantotis* was present on 17 tree species.

DISCUSSION

Our results show that the communities in *Platycterium elephantotis* are highly diverse and very variable between individual plants. Epiphytic communities provide a classic example of niche differentiation. They comprise diverse and complex environments which allow the support of a very wide range of macroinvertebrates. We estimate that this fern species is host to about 362 macroinvertebrate morphospecies. The most common taxa present in our samples were ants (five ant nests encountered), spiders, beetles, millipedes, and isopods, and included a large number of larval and pupal stages.

Studies on canopy insects have also shown very diverse communities, where some insects are tourists (*sensu* Moran & Southwood, 1982), others are habitat generalists that move between forest strata, whilst some are specialists well adapted to the particular niches available in trees – e.g. leaves, bark crevices, epiphyte surfaces, and suspended soils (Leather, 2005). In fact, Novotny & Basset (2000), after reviewing studies of host specificity in tropical insect herbivores, concluded that few species are restricted to a single host plant and most are able to feed on whole plant genera. Although a particular type of organism is often characteristic of a particular ecological situation, it will almost inevitably be only part of a diverse community of species. Most communities also contain a variety of different species that are all constructed in a fairly similar way and all living (at least superficially) a fairly similar life (Begon *et al.*, 2006).

One interesting observation made during this research was that the *Platycterium elephantotis* epiphyte appears to function as a nursery to many invertebrates, given the high numbers of caterpillars, cocoons, pupas and eggs found within the samples. Resh *et al.* (2003) also found a diversity of insects ovopositing in epiphytes. He observed that the majority of species that ovoposit in the ground can in fact ovoposit in rotting logs, epiphytes and, most likely, the soil in trees caused by the presence of epiphytes, which makes this microhabitat very important in the life histories of many species.

When testing for differences in diversity with height and weight of the epiphyte, no significant relationship was found. Nor did we find a significant relationship between number of organisms in a sample and the sample weight. Nevertheless, Ellwood & Forster (2004) found in their study of invertebrate communities inhabiting bird's nest ferns, a striking relationship between fern size and

the biomass of invertebrates within the ferns: smaller ferns contained just a few grams of animal biomass, but this increased exponentially in ferns with more than 30 leaves. They suggest that because the larger ferns contained disproportionately more animal biomass, these ferns probably make a greater contribution to the canopy biomass as a whole.

Their research also suggests that there is almost as much invertebrate biomass in a single fern as in the whole of the rest of the tree crown on which it is growing, because the crowns – unlike the ferns – are not designed to capture and retain plant and animal matter. By retaining matter, the biomass of all of the epiphytes in montane tropical forests is equivalent to approximately 30% of the foliar biomass (Nadkarni, 1984), and the mineral capital contained in the epiphytes constitutes up to 70% of what is held in the foliage of these forests. Thus, epiphytes swell the labile mineral capital of the above ground portion, expanding the nutrient storage capacity of the ecosystem. Because of the rapid decomposition and heavy leaching pressures characteristic of tropical rainforests, pools of re-utilisable nutrients do not lie in the soil (as in many non-rainforest ecosystems), but in components of the standing vegetation itself (Vanderpoorten & Goffinet, 2009) making the epiphytes one of the richest microhabitats within the forest, suitable of sustaining a large quantity of living organisms.

The lack of relationship between community diversity and fern size or height of the host tree may suggest that the diversity is actually related to the fern itself as a microhabitat. It is the environmental conditions inherent to the fern presence (such as the presence of soil, and high humidity) that make this habitat suitable for specific types of macroinvertebrate diversity. For example: ferns with much soil are very suitable for millipedes, centipedes and isopods, which are not likely to be present in ferns with little or no soil content.

During epiphyte collection, we made a record of the many different host tree species of *Platyserium elephantotis*, including sub-canopy, canopy and emergent tree species (Table 2). Our tree species list is consistent with the findings of Desalegn & Lekelefac (2005). Another observation is that the epiphytes were only abundant in locations where there was much light: during preliminary walks through the forest it became obvious that the *P. elephantotis* epiphytes were almost solely found along the main paths or on high branches of emergent trees. Virtually none were observed in previously logged areas of the forest (recovering forests logged 14 and 25 years ago), which is likely attributable to the higher density and lack of high trees in these forests. In fact in many tropical forests epiphytes have been found to be particularly sensitive to human disturbance and thus are useful indicators of ecological change (Turner *et al.*, 1994). Kibale National Park has a history of human disturbance through logging at different intensities and having the relatively unharvested forest plots (Mucunguzi, 2007), and the presence and distribution of epiphytes likely

reflects that history. It also appears that – when light is abundant – the epiphytes can grow on a wide variety of locations including heights of less than 2 m (low category epiphytes) and non-native host tree species (avocado tree, sample 3) as long as there is a suitable location (branch forks or other suitable anchoring points).

This study contributed to the understanding of the epiphyte fauna and helped to confirm that there are a number of insect groups that make a significant contribution to the canopy community but live within epiphytes and suspended soils, and that are rarely represented in more general canopy samples (Leather, 2005) – actually they have been a neglected component in rainforest ecosystems. This research shows that the inclusion of one species of epiphyte can have a significant impact in the diversity measures of macroinvertebrate communities as well as invertebrate numbers in trees. Although epiphytes are known to be important to the structure and function of rainforest canopies, there have been no detailed studies of how the animals living within epiphytes might contribute to the canopy ecosystem. So there is a need for further research in the area of ecological roles of epiphytes in the tropical forest canopies as they might have a more substantial impact on the animal communities in tropical rainforests than was previously imagined. Epiphytes are a challenge to our current understanding of the distribution and functional significance of animals in the world's rainforest canopies.

There will undoubtedly be other, overlooked, concentrations of invertebrates in the canopy, living in a wide range of habitats other than epiphytes. As further studies are made of the animals both in epiphytes and elsewhere in the canopy, the estimates of total invertebrate biomass will increase and the relative importance of epiphytes may need to be revised.

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REFERENCES

- Begon, M., Towsend, C.R., Harper, J.L. (2006) *Ecology – From individuals to Ecosystems*. Blackwell Publishing Ltd, 4th ed, Oxford, UK.
- Coxson, D.S. & Nadkarni, N.M. (1995) Ecological roles of epiphytes in nutrient cycles of forest ecosystems. In M.D. Lowman & N.M. Nadkarni (Eds) *Forest Canopies*. Academic Press. New York, USA.
- Desalegn, C. & Lekelefac, M. (2005) Host preference by *Platyserium elephantotis* Scheinf. (Polypodiaceae): a case study in Kibale National Park, western Uganda. *TBA Field Course Project Reports* 05/1.
- Doody, K.Z., Howell, K.M. & Fanning, E. (2001) *A biodiversity survey*. Technical paper 52. Amani Nature Reserve. Frontier, Tanzania.
- Ellwood, M.D.F. & Foster, W.A. (2004) Doubling the estimate of arthropod biomass in a rainforest canopy. *Nature* **429**:549–551.
- Forster, M., Mueller, G. & Bills, G. (2004) *Biodiversity of Fungi – Inventoring and monitoring methods*.
- Hammer, O., Harper, D.A.T. & Ryan, P.D. (2001) PAST: Paleontological Statistics software package for education and data analysis. *Palaeontologia Electronica* **4**:9.
- Huggett, R.J. (1998) *Fundamentals of Biogeography*. Rutledge Press. London, UK.
- Karasawa, S. & Hijii, N. (2006) Effects of distribution and structural traits of bird's nest ferns (*Asplenium nidus*) on oribatid (Acari: Oribatida) communities in a subtropical Japanese forest. *Journal of Tropical Ecology* **22**:213–222.
- Leather, S. (2005) *Insect Sampling in Forest Ecosystems*. Blackwell Publishing. Swindon, UK.
- Mabberly, D.J. (1987) *The Plant Book: A portable dictionary of the higher plants*. Cambridge University Press. Cambridge, UK.
- Markussen, M., Buse, R., Garrelts, H., Manez-Costa, M.A., Menzel, S. & Marggraf, R. (2005) *Valuation and Conservation of Biodiversity: Interdisciplinary Perspectives on the Convention on Biological Diversity*. Springer. Berlin, Germany.
- Moran, V.C. & Southwood, T.R.E. (1982) The guild composition of arthropod communities in trees. *Journal of Animal Ecology* **51**:289–306.
- Mucunguzi, P. (2007) Diversity and distribution of vascular epiphytes in the forest lower canopy in Kibale National Park, western Uganda. *African Journal of Ecology* **45**:120–125.
- Nadkarni, N.M. (1984) The biomass and nutrient capital of epiphytes in a neotropical cloud forest, Monteverde. *Biotropica* **15**:1–9.
- Nadkarni, N.M. & Longino, J.T. (1990) Arthropods in canopy and ground organic-matter in a neotropical montane forest, Costa-Rica. *Biotropica* **22**:286–289.
- Novotny, V. & Basset, Y. (2000) Rare species in communities of tropical insect herbivores: pondering the mystery of singletons. *Oikos* **89**:564–572.
- Pullin, A.S. (2002) *Conservation biology*. Cambridge University Press. New York, USA.
- Resh, V.H. & Carde, R.T. (2003) *Encyclopedia of Insects*. Academic Press: Elsevier Science. Hong Kong, China.
- Richardson, B.A. (1999) The bromeliad microcosm and the assessment of faunal diversity in a Neotropical forest. *Biotropica* **31**:321–336.

Speight, M.R., Hunter, M.D. & Watt, A.D. (2008) *Ecology of Insects: concepts and applications*. Wiley-Blackwell, 2nd ed. Oxford, UK.

Turner, I.M., Tan, H.T.W., Wee, Y.C., Ibrahim, A.B., Chew, P.T. & Corlett, R.T. (1994) A study of plant species extinction in Singapore: lessons for the conservation of biological diversity. *Conservation Biology* **8**:705-712.

Vanderpoorten, A. & Goffinet, B. (2009) *Introduction to Bryophytes*. Cambridge University Press. New York, USA.

Wolf, J.H.D. (1994) Factors controlling the distributions of vascular and non-vascular epiphytes in the Northern Andes. *Vegetation* **112**:15–28.