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Bird's nest ferns: islands of biodiversity in the rainforest canopy

Tom M. Fayle
M. D. Farnon Ellwood
Edgar C. Turner
Jake L. Snaddon
Kalsum Mohd Yusah
William A. Foster

Insect Ecology Group,
University Museum of Zoology,
Cambridge, CB2 3EJ.

Figure 1. Bird's nest ferns grow throughout the rainforest canopy at Danum Valley. They are found at heights of up to 60 m, and can weigh as much as 200 kg.

As you walk through the towering Malaysian rainforest you are bound to notice the epiphytes that festoon the trunks and branches of nearly every tree. Predominant among these plants are the ferns, with perhaps the most abundant being the bird's nest fern (*Asplenium nidus* complex). These are litter basket epiphytes, with a rosette of simple fronds which efficiently intercepts and retains falling leaf litter, giving them a nest-like appearance. The litter then decomposes providing the fern with a source of nutrients. On this diet the ferns can grow to be huge, up to 200 kg wet weight (Ellwood & Foster 2004, Fig 1). If you cut open a bird's nest fern you discover a world of ants, termites, cockroaches, centipedes and many other arthropods, sheltering in the cool, humid interior of the fern, away from the hot, dry conditions of the canopy. Our group has been studying the diverse invertebrate fauna of these epiphytes for over ten years at the Royal Society run Danum Valley Field Centre in Sabah, Malaysia (Fig 2). Initially work focussed on the importance of the fern as a previously under-sampled habitat for invertebrate biodiversity. Further work has used the ferns as microcosms to investigate questions relating to ecosystem function and species assembly rules. At the landscape scale we have investigated the importance of bird's nest ferns as reservoirs of biodiversity in logged forest and oil palm plantation.

Bird's nest ferns 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). They are found at all heights in the canopy, from ground level to the tops of emergent trees. Up to 15 m in the canopy, ferns are found at densities of 90, 53 and 117 ferns per hectare in primary forest, logged forest and oil palm plantation respectively (Turner 2005). In primary forest, where surveys over the whole height of the canopy have been made, ferns are

Figure 2. Danum Valley Field Centre in Sabah Malaysia is located on the edge of Danum Valley Conservation Area, an area of primary lowland rainforest. The centre is jointly run by the Royal Society and Yayasan Sabah.

found at densities of 180 per hectare (Fayle, in prep). In addition to being convenient, discrete units for studying invertebrates, the ferns can be moved around the canopy without any apparent adverse effect on their survival, making them ideal for experimental studies (Ellwood 2002). The *Asplenium nidus* complex of ferns has very few morphological characters on which to base species recognition, and molecular evidence suggests that a number of cryptic species may co-occur at a single location (Yatabe *et al*. 2001). Molecular and morphological investigations into the taxonomy of the ferns at Danum Valley are ongoing.

In order to assess the importance of the ferns as a habitat for animals in the canopy, we compared the biomass of arthropods within these large and abundant epiphytes with that found from fogging tree crowns. It was discovered that the ferns may support up to half of the estimated biomass in the crowns of emergent trees (Ellwood & Foster 2004). Using data from Dial *et al.* (2006), who fogged over the whole height of the canopy, we find that the proportion of animal biomass of the canopy as a whole which is held in the ferns is somewhat lower, although still 14% of the total. The majority of invertebrates in the ferns are either ants, or as one would expect in an aerial compost heap, termites, millipedes and cockroaches (Ellwood *et al.* 2002; Ellwood & Foster 2004). Indeed the arthropod community of bird's nest ferns is more similar to that of the leaf litter from the forest floor than that found in the rest of the canopy (Ellwood 2002; Turner 2005). The canopy is a relatively difficult habitat to survey and as a result some of the animals found in the ferns are new to science. For example, Disney & Ellwood (2001) describe a new genus of scuttle fly (Phoridae) inhabiting ferns in the high canopy.

In addition to describing the ferns' invertebrate fauna and their role in supporting canopy biodiversity, the group has also used the ferns as microcosms for studying more general ecological questions. As ferns are small contained habitats which act as a discrete arena for species interactions they are an ideal natural microcosm (Srivastava *et al.* 2004). One line of investigation has been the role of biodiversity in the maintenance of ecosystem function. Do we need the full complement of species that usually exists in a habitat for ecosystem function to be unimpaired? The ferns, as isolated sites of decomposition in the canopy, are ideal microcosms with which to investigate this question in relation to decomposition. A range of different leaf types fall into each fern and this diversity can be manipulated and its effect both on insect diversity and on the rate of litter decomposition can be assessed. We found that when the leaves are in monocultures the rate of decomposition does not differ between different species of leaf. However, when the leaves are added in mixtures some species decompose more slowly than they do in monoculture (Snaddon, in prep). This may be the result of a "choosing effect" whereby more palatable leaves are favoured by decomposers when in a mixture. The responses and functions of the decomposers themselves are still under investigation. Such processes may have effects beyond the immediate vicinity of the fern. For example, the concentration of nutrients in stemflow water increases on passing through a fern, which may alter the structure of the trunk-dwelling plant and animal community below (Turner *et al.* in press).

The ferns can also be used as a microcosm to investigate species assembly rules. Approximately three quarters of the individuals in any one fern are ants, and multiple species being able to coexist in a single fern (Ellwood *et al.* 2002; Turner 2005, Fig 3). Due to their colonial nature it is possible to determine whether or not an ant species is living in a fern by noting the presence of brood and reproductive individuals. We have found that the assembly of ant species in the ferns is partially determined by the physical environment. Larger ferns, with lower surface area to volume ratios, should be better at buffering microclimate than smaller ones. This is reflected by the fact that large ferns contain the same assemblage of ants regardless of height, but small ferns contain different assemblages at different heights. Presumably the hot, dry environment of a small fern in the high canopy is only a suitable habitat for a certain set of species. Biotic factors also play a role in the assembly of ant species in the ferns. Larger ferns contain more colonies of ants and also different species of ant. Smaller ferns are more likely to contain ruderal genera such as *Paratrechina*, while larger (and therefore presumably older) ferns are more likely to contain larger bodied genera such as *Pachycondyla*, suggesting the presence of a competition-colonisation trade-off. Colonies from the same species never co-occur and colonies from the same genus co-occur less frequently than one would expect (Fayle, in prep). This may be due to aggressive interactions between colonies that are similar taxonomically and similar in terms of their niches. We are also investigating the assembly rules governing another important group in the ferns; the decomposers. There is a succession of species that inhabit the ferns over long time periods, but the composition of any one fern is drawn at random from the pool of species present in ferns of that age (Ellwood, in prep).

The ferns may also be important in determining the structure of the ant community of the whole of the rainforest canopy. Two or more dominant ant species may occur in the same habitat, but exclude each other on a local basis, forming what is known as an ant mosaic. Ant mosaics can be of great importance, as the identity of the dominant species determines the nature of the rest of the ant community. Such mosaics have been described from cocoa farms (Room 1971) and various other agricultural systems, but their prevalence in natural systems remains contentious. Floren & Linsenmair (2000), failed to find an ant mosaic in the rainforest understorey, but it is not known if a mosaic exists at higher levels in the canopy. One of the main factors regulating ant populations is nest site availability (Kaspari 2000). As ferns provide an important nest site for ants in the canopy it is likely

Figure 3. Two ants of vastly differing sizes survey one another. At least 35 species of ant inhabit the ferns, with up to 12 species inhabiting any one fern. Body size may play an important role in the way that ant communities are structured.

that they are of great importance in determining the existence and nature of the ant mosaic. We are in the process of investigating this experimentally.

Southeast Asia has the highest relative rate of deforestation of any tropical region, the majority of which results from logging and conversion of forest to oil palm plantation (Sodhi *et al.* 2004). Arthropods from the area are also relatively poorly known (Chung *et al.* 2000). Given that the ferns are important in structuring invertebrate communities in natural rainforest, and that they persist in degraded habitats (Fig 4), they may play an important role ameliorating the effects of habitat change. Our work has shown that arthropod abundance and biomass decrease in the canopy and leaf litter in transition from forest to oil palm plantation. A similar pattern is seen if one considers individual ferns – the biomass and numbers of arthropods also decrease. However, while there are fewer arthropods per fern in oil palm plantations, the density and average size of ferns is actually greater than in the other habitat types, meaning that the total fern arthropod abundance and biomass remains unchanged. Ferns are also able to buffer the effects of habitat conversion on arthropod community composition. Although the relative abundances of arthropod orders in the leaf litter and canopy are altered by habitat change, those in the fern remain unchanged (Turner 2005), possibly as a result of the ferns' ability to buffer microclimate (Turner & Foster 2006). In this way the ferns act as reservoirs of biodiversity in degraded habitats.

These previously under-sampled epiphytes harbour a large proportion of rainforest canopy biodiversity by virtue of their enormous size and high abundance. Using these isolated, highly diverse habitats we are investigating general ecological questions relating to biodiversity ecosystem function and species assembly rules. With increasing levels of human impact on the natural world the diversity contained within these epiphytes may provide an important buffer against such changes. We are now continuing our research into these fascinating islands of biodiversity in the rainforest canopy.

Acknowledgements

We would like to thank the Natural Environment Research Council and the Natural History Museum, London for funding during these projects. The Danum Valley Field Centre staff, RSSEARP research assistants and senior scientist Glen Reynolds have all made field work at Danum a pleasure. The Danum Valley Management Committee, Yayasan Sabah, the Economic Planning Unit Putrajaya and the Economic Planning Unit Sabah have been most helpful in allowing research to be carried out in Danum. All work has been carried out as part of the Royal Society South East Asia Rainforest Research Programme. Our local collaborators Arthur Chung and Chey Vun Khen have been of great assistance in the course of this research. We are grateful to Paul Eggleton of the Natural History Museum for his help in the role as the CASE supervisor for two of us (JLS & TMF).

Figure 4. Bird's nest ferns are highly abundant in oil palm plantations, where they provide an important reservoir of arthropod biodiversity.

References

Chung, A. Y. C., Eggleton, P., Speight, M. R., Hammond, P. M. & Chey, V. K. -(2000). The diversity of beetle assemblages in different habitat types in Sabah, Malaysia. *Bulletin of Entomological Research* **90**: 475-496.

Dial, R., Ellwood, M. D. F., Turner, E. C. & Foster, W. A. (2006). Arthropod Abundance, Canopy Structure, and Microclimate in a Bornean Lowland Tropical Rain Forest. *Biotropica*: 643-652.

Disney, R. H. L. & Ellwood, M. D. F.- (2001). An intriguing new genus of scuttle fly (Diptera: Phoridae) from Borneo. *Fragmenta Faunistica* **44**: 319-328.

Ellwood, M. D. F. (2002). The ecology and diversity of the animal communities of a rainforest canopy epiphyte. PhD. University of Cambridge, Cambridge.

Ellwood, M. D. F. & Foster, W. A. (2004). Doubling the estimate of invertebrate biomass in a rainforest canopy. *Nature* **429**: 549-551.

Ellwood, M. D. F. Jones, D. T. & Foster, W. A. (2002). Canopy Ferns in Lowland Dipterocarp Forest Support a Prolific Abundance of Ants, Termites and Other Invertebrates. *Biotropica* **34**: 575-583.

Floren, A. & Linsenmair, E. (2000). Do ant mosaics exist in pristine lowland rain forests? *Oecologia* **123**: 129-137.

Holttum, R. E. (1976). Asplenium Linn., sect. Thamnopteris Presl. *Gardens' Bulletin, Singapore* **27**: 143-154.

Kaspari, M. (2000). A primer on ant ecology. *in* D. Agosti, J. D. Majer, L. E. Alonso, and T. R. Schultz, editors. Ants, standard methods for measuring and monitoring biodiversity. Smithsonian Institution Press, Washington and London.

Room, P. M. (1971) The Relative Distributions of Ant Species in Ghana's Cocoa Farms. *The Journal of Animal Ecology* **40**: 735-751.

Sodhi, N. S., Koh, L. P., Brook, B. W. and Ng., P. K. L. (2004). Southeast Asian biodiversity: an impending disaster. *Trends in Ecology & Evolution* **19**: 654-660.

Srivastava, D. S., Kolasa, J., Bengtsson, J., Gonzalez, A., Lawler, S. P., Miller, T. E., Munguia, P., Romanuk, T., Schneider, D. C. & Trzcinski, M. K. (2004). Are natural microcosms useful model systems for ecology? *Trends in Ecology & Evolution* **19**: 379-384.

Turner, E. C. (2005). The ecology of the Bird's Nest Fern (*Asplenium* spp.) in unlogged and managed habitats in Sabah, Malaysia. PhD. University of Cambridge, Cambridge.

Turner, E. C. & Foster, W.A. (2006). Assessing the Influence of Bird's Nest Ferns (*Asplenium* spp.) on the Local Microclimate across a Range of Habitat Disturbances in Sabah, Malaysia. *Selbyana* **27**: 195-200.

Turner, E. C.,Snaddon, J.L., Johnson, H.R. & Foster, W.A. *in press*. The impact of bird's nest ferns on stemflow nutrient concentration in a primary rain forest, Sabah, Malaysia. *Journal of Tropical Ecology*.

Yatabe, Y., Masuyama, S., Darnaedi, D. & Murakami, N. (2001). Molecular systematics of the *Asplenium nidus* complex from Mt. Halimun National Park, Indonesia: evidence for reproductive isolation among three sympatric *rbcL* sequence types. *American Journal of Botany* **88**: 1517-1522.