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SHORT COMMUNICATION

The impact of bird's nest ferns on stemflow nutrient concentration in a primary rain forest, Sabah, Malaysia

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Bird's nest ferns (*Asplenium nidus* complex) (Yatabe & Murakami 2003) are common epiphytes of the Old World tropics and house a high abundance of arthropods (Ellwood & Foster 2004). Through interception and retention of leaf litter (Paoletti *et al.* 1991, Piggott 1996, Richardson 1999), epiphytes interrupt litterfall dynamics (Clark *et al.* 1998, Nadkarni & Matelson 1991) and delay the return of nutrients to the forest floor (Nadkarni 1984). Precipitation percolating through the canopy as throughfall is enriched as nutrients are leached from plant surfaces (Levia & Frost 2006). Water flowing down the trunk of trees as stemflow is further enriched from prolonged contact and accumulated nutrient deposits on the trunk (Levia & Frost 2003, Liu *et al.* 2002). Epiphytes can alter stemflow nutrient concentrations by slowing water percolation and by nutrient uptake and release (Awasthi *et al.* 1995, Strigel *et al.* 1994).

Only a small percentage of the total rainfall in tropical forests is channelled as stemflow compared with throughfall (Burghouts *et al.* 1998, Dezzeo & Chacón 2006, Sinun *et al.* 1992). However, the higher nutrient concentration in stemflow has important localized effects that contribute to the spatial heterogeneity of the forest ecosystem. These effects include altered nutrient availability in the immediate area around the host tree (Crozier & Boerner 1984) and on the trunk for epiphytes (Awasthi *et al.* 1995, Gustafsson & Eriksson 1995), and possible effects on specific bark-dwelling arthropods (Menzel *et al.* 2004, Proctor *et al.* 2002).

We investigated the effect of bird's nest ferns on the total ion conductivity (a surrogate for total ion concentration), the nitrate concentration and the potassium concentration in stemflow during natural rainstorm events. Fieldwork was carried out in the lowland evergreen dipterocarp forest at Danum Valley Field Centre (DVFC), Sabah, Malaysia (4°58′N, 117°42′E, altitude *c.* 170 m asl, for details of site see Marsh & Greer 1992). Data were collected between April and May 2004. Rainfall for April (149.3 mm) and May (371.7 mm) were not markedly different from the respective monthly averages (mean $\pm$ SE) recorded between 1986 and 2004 (April $= 157.9 \pm 26.0$ mm, May $= 248.8 \pm 29.6$ mm). Total rainfall for 2004 (3005.8 mm) was also not markedly different from the annual average (2833.2 ± 103.8 mm) (courtesy DVFC Hydrology project).

Within a radius of 1 km from DVFC suitable ferns of an intermediate size (60–90 cm diameter), on large trees (30–60 cm dbh) and accessible by ladder were recorded (mean height of ferns $= 4.43 \pm 0.284$ m). Out of this subset, we randomly selected 20 ferns from which to make water collections. At each of these sites we fixed water collection gauges on the trunk of the supporting tree, above and directly below the fern, to collect stemflow and at ground level, 1 m from the base of the tree to collect throughfall. Volume collected was recorded for each sample and an Ion Electrode Meter (EDT Instruments Ltd.) was used to measure the conductivity of the water (a proxy for the total ion concentration). A subsample of the water was removed and analysed in the UK using Ion Sensitive Electrodes for nitrate and Flame Emission Spectrophotometry for potassium (MAFF 1986). At each site we recorded canopy openness (using a Spherical Densiometer, Lemon 1956), dbh, maximum diameter of the fern and percentage epiphyte cover on the trunk above the fern.

In addition we investigated whether nutrient release from the ferns was constant through time or released in a pulse. Twelve ferns were selected in a similar way as described previously. After a period of at least 5 d without

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Table 1. Total ion conductivity, nitrate concentration and potassium concentration (mean ± SE) compared between above-fern samples, below-fern samples and throughfall samples. N = 20.

	Above fern	Below fern	Throughfall
Total ion conductivity (μS)	54.0 ± 8.1	73.6 ± 13.2	40 ± 4.0
Nitrate (mg l^{-1})	4.1 ± 0.7	7.6 ± 1.2	4.0 ± 1.0
Potassium (mg l^{-1})	5.8 ± 1.1	6.8 ± 1.2	4.0 ± 0.6

rain, we poured 300 ml of distilled water through the ferns *in situ* and collected the water sequentially in 20-ml samples using a funnel at the base of the fern. The volume used was within the range of that collected in traps below the ferns during natural rainstorm events (range = 10–520 ml). All 20-ml samples were measured for total ion conductivity and the samples representing the highest concentration values for each fern further analysed for nitrate and potassium concentration.

General linear models, with site number as a covariable, were used to assess the difference in ion conductivity and nitrate and potassium concentrations. Stepwise regression analyses were used to assess which factors affected the total ion conductivity, nitrate concentration and potassium concentration (with a P-to-enter value set at 0.05 and a P-to-remove value at 0.10). Total ion concentration and nitrate and potassium concentrations were $\log_{10}$-transformed prior to analyses.

Total ion conductivity was significantly higher in stemflow samples below the fern than in throughfall samples (GLM, $F_{2,38} = 5.53$, $P = 0.008$). Samples from below the fern showed higher total ion conductivity compared with above-fern samples, although this trend was not significant (Table 1). Nitrate concentration was significantly higher in the stemflow samples below the fern than in samples above the fern and in throughfall, which did not significantly differ from each other (GLM, $F_{2,36} = 11.8$, $P < 0.001$) (Table 1). Potassium concentration was significantly higher in samples collected below the fern than in throughfall samples, although the samples from above the fern were not significantly different from either (GLM, $F_{2,38} = 4.26$, $P = 0.021$) (Table 1).

Bird's nest ferns clearly affect nitrate concentrations in stemflow. Nitrate is not easily leached from plant material (Dezzeo & Chacón 2006) but is predominantly released through litter decomposition. Decomposition of the leaf litter stored in bird's nest ferns is therefore likely to be responsible for the enrichment in stemflow. The effect of bird's nest ferns on potassium concentration is less clear. Potassium is more soluble than nitrate and easily leaches from living plant material, so concentrations will increase with prolonged contact with plant surfaces (Tukey 1970). Potassium ion concentration therefore increases both as water flows down the trunk and as it flows through the fern. None of the inputted variables was significant in determining the total ion conductivity in either the stemflow samples above the fern or the throughfall samples. However, volume of water collected was negatively related to the total ion conductivity in the stemflow samples below the fern (stepwise regression, N = 20, $t = -3.77$, $P = 0.001$). The most likely explanation for this result is that there is a finite quantity of soluble ions stored in the ferns and the majority of these are leached out as the water initially percolates through. Therefore stemflow samples below the ferns collected during a short rainstorm have a higher concentration of ions than samples collected during a long rainstorm. No variables were significant in determining the nitrate concentration in any of the samples. No variables were significant in determining the potassium concentration in the stemflow samples below the fern, although dbh showed a significant positive relationship to the potassium concentration in the stemflow above the fern (N = 20, $t = 2.59$, $P = 0.019$). Potassium concentration in throughfall samples was negatively related to fern diameter (N = 20, $t = -3.18$, $P = 0.005$) and canopy openness (N = 20, $t = -2.76$, $P = 0.014$). Potassium release is predominantly as a result of leaching from plant material. A larger dbh will mean a larger tree and therefore more plant material over which rainwater has flowed. Therefore potassium concentration in above-fern stemflow samples will be higher on the trees with a larger dbh. The negative relationship between canopy openness, fern diameter and potassium concentration in throughfall samples has a similar explanation. A more open canopy will result in more rainwater falling straight through and therefore will not be enriched by contact with plant surfaces. Open areas will also be lighter and therefore probably have larger ferns growing in them.

Water samples collected from distilled water that had percolated through the ferns showed a clear pulsed release of nutrients (Figure 1). It is likely that this pattern is due to an initial lag when the fern material is dry and the water simply washes over the material. This is followed by a peak in ion concentration, when the fern material is moist and available ions are quickly washed through.

As the volume of water (mean ± SE) collected below ferns (188.5 ± 41.4 ml) was not lower than the volume of water collected above ferns (158.8 ± 28.3 ml), bird's nest ferns raising the nutrient concentration of stemflow will increase the amount of nutrients available to other epiphytes, algae and fungi on the trunk. This in turn may alter their relative abundance (Gustafsson & Eriksson 1995). Impacts on the trunk flora may alter the trunk fauna, through a change in food resources, and the physical and microclimatic characteristics of the habitat (Majer *et al.* 2003, Menzel *et al.* 2004). The pulsed release of nutrients to the base of trees carrying bird's nest ferns may directly benefit the tree itself and the surrounding

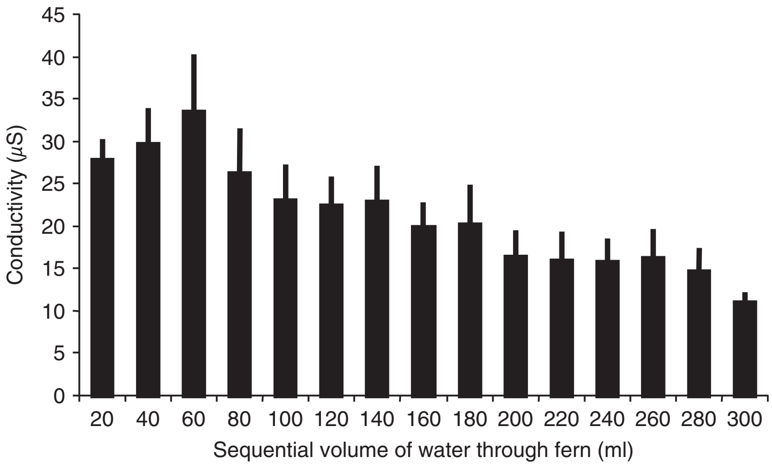

Figure 1. Total ion conductivity against a series of 20-ml water samples that were collected from distilled water percolating through bird's nest ferns. N = 12. Bars represent 1 SE. Samples containing the highest reading for total ion conductivity (mean ± SE) contained 5.47 ± 0.67 mg l^{-1} for nitrate and 7.96 ± 1.24 mg l^{-1} for potassium. Total ion conductivity of the distilled water was 3.14 ± 0.45 mg l^{-1}.

understorey (Crozier & Boerner 1984) by releasing these nutrients at the base of their host tree in manageable bursts after each rainfall.

In the Danum Valley Conservation Area, water percolating through the canopy as stemflow only represents about 2% of the incident rainfall, compared with 81% as throughfall (Sinun *et al.* 1992). Despite this, the localized impacts of stemflow can be marked (Levia & Frost 2003). Bird's nest ferns are abundant at DVFC, with a mean density of 50 ferns ha^{-1} (Ellwood & Foster 2004) so, although these effects may operate on a small scale, their impact can be widespread. Our study provides another example of biological heterogeneity within a tropical forest ecosystem.

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LITERATURE CITED

AWASTHI, O. P., SHARMA, E. & PALNI, L. M. S. 1995. Stemflow: a source of nutrients in some naturally growing epiphytic orchids of the Sikkim Himalaya. *Annals of Botany* 75:5–11.

BURGHOUTS, T. B. A., VAN STRAALEN, N. M. & BRUIJNZEEL, L. A. 1998. Spatial heterogeneity of element and litter turnover in a Bornean rain forest. *Journal of Tropical Ecology* 14:477–505.

CLARK, K. L., NADKARNI, N. M. & GHOLZ, H. L. 1998. Growth, net production, litter decomposition, and net nitrogen accumulation by epiphytic bryophytes in a tropical montane forest. *Biotropica* 30:12–13.

CROZIER, C. R. & BOERNER, R. E. J. 1984. Correlations of understory herb distribution patterns with microhabitats under different tree species in a mixed mesophytic forest. *Oecologia* 62:337–343.

DEZZEO, N. & CHACÓN, N. 2006. Nutrient fluxes in incident rainfall, throughfall, and stemflow in adjacent primary and secondary forests of Gran Sabana, Southern Venezuela. *Forest Ecology and Management* 234:218–226.

ELLWOOD, M. D. F. & FOSTER, W. A. 2004. Doubling the estimate of invertebrate biomass in a rainforest canopy. *Nature* 429:549–551.

GUSTAFSSON, L. & ERIKSSON, I. 1995. Factors of importance for the epiphytic vegetation of aspen *Populus tremula* with special emphasis on bark chemistry and soil chemistry. *Journal of Applied Ecology* 32:412–424.

LEMON, P. E. 1956. A spherical densiometer for estimating forest overstory density. *Forest Science* 2:314–320.

LEVIA, D. F. & FROST, E. E. 2003. A review and evaluation of stemflow literature in the hydrologic and biogeochemical cycles of forested and agricultural ecosystems. *Journal of Hydrology* 274:1–29.

LEVIA, D. F. & FROST, E. E. 2006. Variability of throughfall volume and solute inputs in wooded ecosystems. *Progress in Physical Geography* 30:605–632.

LIU, W., FOX, J. E. D. & XU, Z. 2002. Nutrient fluxes in bulk precipitation, throughfall and stemflow in montane subtropical moist forest on Ailao Mountains in Yunnan, south-west China. *Journal of Tropical Ecology* 18:527–548.

MAFF (MINISTRY OF AGRICULTURE, FISHERIES AND FOOD). 1986. *The analysis of agricultural materials: a manual of the analytical methods* *used by the agriculture development advisory service*. (Third edition). Reference Booklet, No. 427, Her Majesty's Stationery Office, London.

MARSH, C. W. & GREER, A. G. 1992. Forest land-use in Sabah, Malaysia: an introduction to Danum Valley. *Philosophical Transactions of the Royal Society of London, Series B* 335:331–339.

MAJER, J. D., RECHER, H. F., GRAHAM, R. & GUPTA, R. 2003. Trunk invertebrate faunas of western Australian forests and woodlands: influence of tree species and season. *Austral Ecology* 28:629–641.

MENZEL, F., KITCHING, R. L. & BOULTER, S. L. 2004. Host specificity or habitat structure? The epicortical beetle assemblages in an Australian subtropical rainforest. *European Journal of Entomology* 101:251–259.

NADKARNI, N. M. 1984. Epiphyte biomass and nutrient capital of a Neotropical elfin forest. *Biotropica* 16:249–256.

NADKARNI, N. M. & MATELSON, T. J. 1991. Fine litter dynamics within the tree canopy of a tropical cloud forest. *Ecology* 72:2071–2082.

PAOLETTI, M. G., TAYLOR, R. A. J., STINNER, B. R., STINNER, D. H. & BENZING, D. H. 1991. Diversity of soil fauna in the canopy and forest floor of a Venezuelan cloud forest. *Journal of Topical Ecology* 7:373–383.

PIGGOTT, A. G. 1996. *Ferns of Malaysia in colour*. Tropical Press Sdn Bhd, Malaysia. 268 pp.

PROCTOR, H. C., MONTGOMERY, K. M., ROSEN, K. E. & KITCHING, R. L. 2002. Are tree trunks habitats or highways? A comparison of orbatid mite assemblages from hoop-pine bark and litter. *Australian Journal of Entomology* 41:294–299.

RICHARDSON, B. A. 1999. The bromeliad microcosm and the assessment of faunal diversity in a Neotropical forest. *Biotropica* 31:321–336.

STRIGEL, G., RUHIYAT, D., PRAYITNO, D. & SARMINA, S. 1994. Nutrient input by rainfall into secondary forests in East Kalimantan, Indonesia. *Journal of Tropical Ecology* 10:285–288.

SINUN, W., WONG, W. M., DOUGLAS, I. & SPENCER, T. 1992. Throughfall, stemflow, overland flow and throughflow in the Ulu Segama rain forest, Sabah, Malaysia. *Philosophical Transactions of the Royal Society of London, Series B* 325:389–395.

TUKEY, H. B. 1970. The leaching of substances from plants. *Annual Review of Plant Physiology* 21:305–324.

YATABE, Y. & MURAKAMI, N. 2003. Recognition of cryptic species in the *Asplenium nidus* complex using molecular data – a progress report. *Telopea* 10:487–496.