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ARTHROPOD SAMPLING IN AUSTRALIAN SUBTROPICAL RAIN FORESTS—HOW ACCURATE ARE SOME OF THE MORE COMMON TECHNIQUES?

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ABSTRACT. As part of long-term research on the canopy of subtropical rain forest in southeast Queensland, we have compared three common techniques of insect collecting—sweeping, beating and insecticidal spraying. Segments of understory vegetation were sampled using either sweepnets or beating trays in a standard fashion and then, the same sites were misted using pyrethrum. Samples based on sweep netting collected only 10% of the numbers collected by misting, and beating approximately 25%. The proportions of insect orders collected by each method also different significantly, illustrative of the fact that these methods are effective only for certain groups of insects. Misting and beating generated similar proportions of the major taxa whereas sweeping underestimated Collembola and overestimated Diptera.

For non-insect arthropods, both beating and sweeping overestimated the proportions of Araneida and substantially underestimated the Amphipoda. The use of sweeping and beating, therefore, provided very substantial underestimates of the fauna.

INTRODUCTION

The task of quantifying the numbers and kinds of arthropods within forest communities is daunting, not only due to the abundance and cryptic behavior of the organisms themselves, but also because of the lack of standard techniques (Noyes 1989). Two methods, sweeping and beating, have been widely used and much cited. Sweeping, using appropriate nets, has been frequently used in temperate forests (e.g. Whittaker 1952, Janzen & Pond 1975) and in rain forests (e.g. Janzen & Schoener 1968, Elton 1973, 1975; Lowman 1982). Beating the foliage and collecting arthropods from trays held beneath the foliage has also been commonly used (e.g. White 1984, Lowman 1982). Both methods are technically easy to carry out and readily replicated through different forests. They have been used as the basis for many comparative studies. However, because arthropods are often very small and diverse, and also because they tend to display differential trapability with each sampling method, it is difficult to assess the accuracy of each method, especially when measures of abundance and diversity are required.

Sweeping and beating are the widely used methods of daylight sampling of terrestrial arthropods. A third technique—misting and also insecticidal fogging have been recently developed to collect large, taxonomically diverse samples (e.g. Wolda 1979, Southwood *et al.* 1982, Erwin 1982, Erwin & Scott 1980, Stork 1987a, 1987b; Majer & Recher 1988, Kitching 1991, Basset 1991, R.L. Kitching and M.D. Lowman unpublished data). Fogging and misting are technically different by virtue of their methods of application with the former creating smaller droplets. Both fogging and misting usually employ short-lived pyrethroid insecticides dispensed into the foliage using a motorized fogging device. Only free-living animals are knocked down by this technique and some larger animals may escape (but see Majer & Recher 1988). Some groups are less efficiently sampled than others, but overall a larger and reasonably representative sample of the entire free-living arthropod community is obtained.

In 1988 we began a major study of the arthropod fauna of subtropical rain forest canopy in southeast Queensland (see Kitching *et al.* 1993). We have employed a variety of techniques with a view to obtaining comprehensive samples. We observed that the results obtained from varying sampling methods tended to differ, in part due to the selective characteristics of particular methods and, also, due to the operator involved (Ma-

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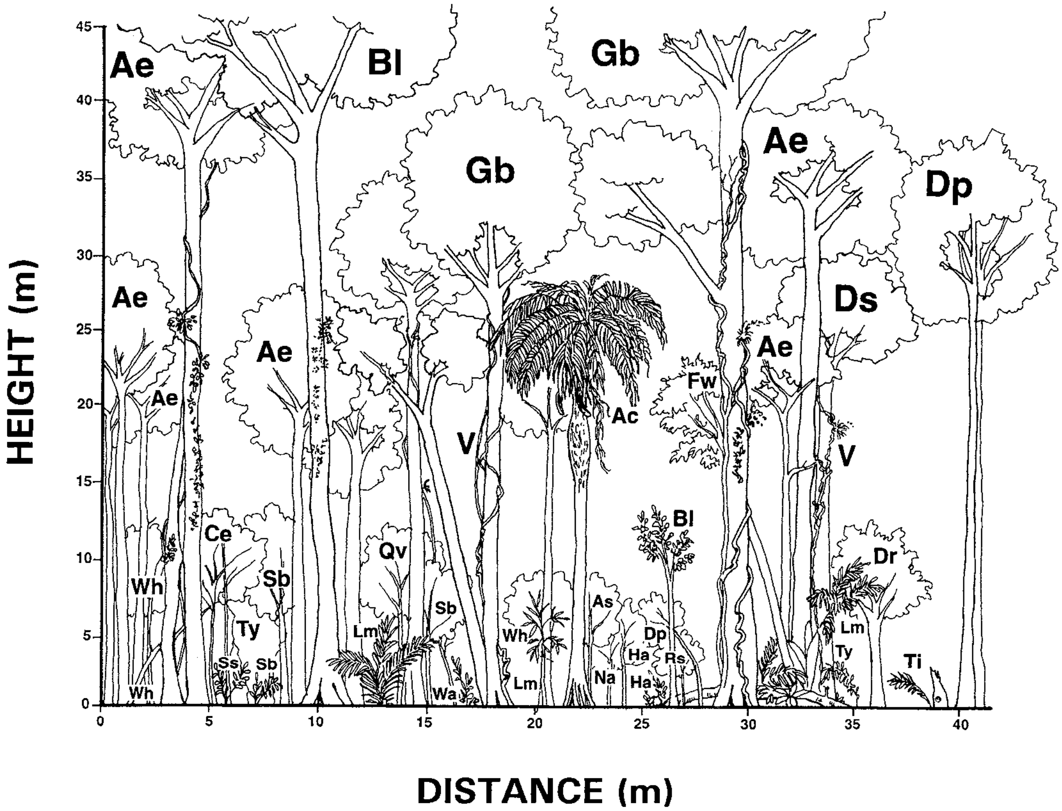

FIGURE 1. Vegetation profile for a representative site which is central to the experimental area. Key: Ae *Acradenia euodiiformis*; Ac *Archontophoenix cunninghamiana*; As *Acmena smithii*; Bl *Baloghia lucida*; Ce *Cryptocarya erythroxylon*; Dp *Diospyros pentamara*; Dr *Dysoxylon rufum*; Ds *Doryphora sassafras*; Fw *Ficus watkinsiana*; Gb *Geoissois benthamii*; Ha *Harpulia alata*; Lm *Linospadix monostachyus*; Na *Neolitsea australiensis*; Pb *Platycerium bifurcatum*; Qv *Quintinia verdonii*; Rs *Rapanea subsessilis*; Sb *Scolopia braunii*; Ss *Sarcopteryx stipata*; Ti *Tasmania insipida*; Ty *Triunia youngiana*; V vines; Wa *Wilkiea australoqueenslandica*; Wh *Wilkiea huegliana*.

jer & Recher 1988, M.D. Lowman & K. McGuiness unpublished data).

This paper reports a field trial in which we compare the numbers and proportions of different major taxa of arthropods captured using sweeping and beating methods, and then quantify the degree of underestimation involved in these non-destructive techniques in comparison with misting.

METHODS

Study Area

Sampling was conducted in the summer (December–January) of 1988–1989. The site is located on the borders of Lamington National Park adjacent to O'Reilly's Guesthouse in the Green Mountains, Queensland, Australia (28°S, 153° 10'E). The vegetation of the area is described by McDonald and Whiteman (1979). Eight segments of forest, each 5 × 5 m, were selected for sampling along the "Wishing Tree Track." Each selected area was representative of well developed subtropical forest with distinct layers of vegetation and a well developed understory. A vegetation profile was constructed for a location central to the sampling sites and representative of the area (FIGURE 1). At each site, understory was separated from the mid-canopy by at least 10 m. This last characteristic assured that the insects captured in the lower vegetation could be ascribed confidently to that vegetation component and minimized inclusion of vagrants from the upper layers.

Within each site, 10 m^3 foliage of the low level vegetation were sampled by sweeping and a separate 10 m^3 by beating. For sweeping, nets of 45 cm diameter and 1 mm mesh were used and the contents of 10 full sweeps of the net collectively comprised one sample. This was equivalent to a standardized 10 m^3 sample, as first described in the literature by Janzen and Schoener (1968) and used by Lowman (1982) in rain forest similar to those studied here. For beating, a 1 m^2 tray was laid beneath a section of the understory canopy that was then shaken for 10 seconds. All arthropods falling onto the tray were removed, and this process was repeated 10 times to approximate the foliage area of the sweep sampling of 10 m^3. This technique has previously been described by Lowman (1982).

Replicates of beating and sweeping at all eight sites were collected by different workers between 1100h and 1300h in an attempt to minimize inter-individual sampling bias (M. Lowman & K. McGuiness unpublished data). Immediately following sweeping and beating, the same vegetation was misted. Misting was preferred over fogging because the application was easily controlled, in contrast to fogging where the cloud of insecticide drifts upwards. Ten m^3 of the vegetation were sprayed thoroughly using a backpack sprayer with hand held nozzle. Arthropods falling from the vegetation were collected in five 0.5 m^2 collecting funnels suspended beneath the sprayed foliage. A concentrate of pyrethrin 2EL (2%) with the synergist piperonyl butoxide (8%) was diluted in water at the rate of 139 ml per liter. The branches were thoroughly shaken after the misting and samples collected from the funnels after 10 minutes.

For all three sampling methods, the arthropods were preserved in 80% ethanol and returned to the laboratory where they were sorted according to order with the aid of a stereo-microscope.

Analysis

Data collected from each site by each sampling method were pooled (i.e. the December 1988 and January 1989 replicates) to give totals, means and standard errors for each method, and compared using t-tests (Snedecor & Cochran 1980). Following arcsine square root transformation, one way analyses of variance were performed to compare sampling methods for the major taxa: Collembola, Diptera, Coleoptera, Psocoptera, Hymenoptera, Isopoda, Araneida, and Acarina. Because of problems of non-independence in the data sets, comparison of the results from sweeping were made with those from misting after beating, and beating was compared with misting after sweeping. As a precursor to these analyses, it was shown that no significant differences existed between the two sets of misting results with respect to each taxa analyzed.

Results

TABLE 1 summarizes the results obtained for beating, misting after beating, sweeping, and misting after sweeping. Beating produced 39.0 $\pm$ 5.65 individuals per m^3, and sweeping 52.1 $\pm$ 11.89 individuals per m^3 whereas fogging the same sites produced an additional 142.3 $\pm$ 14.76 and 378.1 $\pm$ 81.9 individuals per m^3 respectively. From all techniques collectively, we found an average of 305.8 individual arthropods per m^3 of understory vegetation.

The number of major taxa represented in these samples were 8.63 $\pm$ 0.63 (6.50 insects and 2.12 non-insects) for sweeping, and 11.88 $\pm$ 0.60 (8.40 insects, 3.40 non-insects) for misting (TABLE 2). Qualitatively, the different methods of sampling produced very different results. The top five ranked taxa in descending order of abundance for sweeping were: Diptera, Araneida, Collembola, Psocoptera, and Coleoptera. For beating this ranking was Collembola, Araneida, Coleoptera, Diptera, and Psocoptera. Both misting after beating and misting after sweeping gave broadly similar results in this regard, with the rankings for the former as follows: Collembola, Diptera, Psocoptera, Coleoptera, and Araneida. The list for misting after sweeping was identical except for the transposition of Coleoptera and Psocoptera in the list.

TABLE 3 presents the results of the analyses of variance carried out to identify which taxa gave rise to the qualitative differences apparent in TABLE 2. Among the insect orders, analyses of proportions of Psocoptera and Hymenoptera showed no significant differences. A similar non-significant result was obtained for the Isopoda and Acarina among the non-insects. The results in TABLE 3 show that the samples obtained by beating are hardly different from those obtained by misting (except for a slight over-representation of Coleoptera in the beating samples). Samples obtained by sweeping, however, underestimate the proportions of Collembola and overestimate the Diptera at a high level of significance. The fact that the numerically dominant Collembola show significantly different proportions, as indicated, will in turn affect the proportions of Diptera so, in that sense, the analyses of the two orders are not independent one from the other. However, when the proportions of Diptera in the samples of insects minus Collembola are computed, the sweeping samples are again shown to have an over-representation of Diptera (a mean of 48% Diptera in the sweeping samples compared with 16% for misting after sweeping, 12% for misting after beating, and 11% for beating), thus lending credence to the patterns indicated by the analyses of variance.

TABLE 1. Results of sampling by beating, sweeping and misting in rain forest vegetation.

	Beating			Misting after beating			Sweeping			Misting after sweeping		
Order	Total	Mean	Standard error	Total	Mean	Standard error	Total	Mean	Standard error	Total	Mean	Standard error
COLLEMBOLA	113	14.13	3.56	631	78.88	14.51	72	9.00	3.59	1,461	182.63	39.03
BLATTODEA	1	0.13	0.13	1	0.13	0.13	1	0.13	0.13	5	0.63	0.50
ORTHOPTERA	6	0.75	0.53	15	1.88	1.08	0	0.00	0.00	43	5.38	1.93
PSOCOPTERA	21	2.63	0.73	91	11.38	4.20	40	5.00	1.90	206	25.75	12.74
HOMOPTERA	7	0.88	0.30	26	3.25	0.84	11	1.38	0.26	32	4.00	1.12
HETEROPTERA	3	0.38	0.18	11	1.38	0.38	7	0.88	0.30	42	0.25	2.48
THYSANOPTERA	0	0.00	0.00	2	0.25	0.25	1	0.13	0.13	32	27.38	2.21
NEUROPTERA	0	0.00	0.00	0	0.00	0.00	4	0.50	0.27	2	0.25	0.25
COLEOPTERA	40	5.00	1.00	72	9.00	2.04	30	3.75	1.39	219	27.38	7.18
STREPSIPTERA	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00	2	0.25	0.25
DIPTERA	25	3.13	0.74	111	13.88	1.93	110	13.75	4.34	409	51.13	10.72
LEPIDOPTERA	7	0.88	0.44	6	0.75	0.49	10	1.25	0.67	21	2.63	0.86
HYMENOPTERA	22	2.75	0.56	49	6.13	1.33	16	2.00	0.71	178	22.25	5.13
Sub-total Insects	245	30.63	4.49	1,015	126.88	13.13	302	37.75	9.65	2,652	331.50	69.85
ISOPODA	12	1.50	0.76	24	3.00	1.49	26	3.25	1.88	102	12.75	5.22
AMPHIPODA	0	0.00	0.00	17	2.13	1.42	1	0.13	0.13	65	8.13	5.34
MYRIAPODA	1	0.13	0.13	2	0.25	0.25	0	0.00	0.00	4	0.50	0.50
PSEUDOSCORPIONES	1	0.13	0.13	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
OPILIONES	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00	2	0.25	0.25
ARANEIDA	48	6.00	1.60	52	6.50	1.28	84	10.50	2.21	111	13.88	3.82
ACARINA	5	0.63	0.26	28	3.50	1.25	4	0.50	0.19	89	11.13	3.61
Sub-total Non-Insects	67	8.38	1.74	123	15.38	2.54	115	14.38	3.05	373	46.63	12.96
GRAND TOTAL	312	39.00	5.65	1,138	142.25	14.76	417	52.13	11.89	3,025	378.13	81.90

TABLE 2. Comparisons of key sample statistic between various sampling methods.

Taxon	Comparison Method 1 vs Method 2	Method 1 Mean ± S.E.	Method 2 Mean ± S.E.	F	Probability
Insects					
Collembola	M/S vs F/B	0.54 ± 0.047	0.60 ± 0.061	0.627	n.s.
	M/S vs B	0.54 ± 0.047	0.43 ± 0.064	2.044	n.s.
	M/B vs S	0.60 ± 0.061	0.19 ± 0.065	16.18	***
	B vs S	0.43 ± 0.064	0.19 ± 0.065	6.54	*
Diptera	M/S vs F/B	0.16 ± 0.015	0.12 ± 0.023	3.174	n.s.
	M/S vs B	0.16 ± 0.015	0.11 ± 0.026	3.873	n.s.
	M/B vs S	0.12 ± 0.023	0.41 ± 0.068	18.048	***
	B vs S	0.11 ± 0.026	0.41 ± 0.068	17.964	***
Coleoptera	M/S vs F/B	0.09 ± 0.015	0.08 ± 0.018	0.52	n.s.
	M/S vs B	0.09 ± 0.015	0.19 ± 0.026	7.714	*
	M/B vs S	0.08 ± 0.018	0.10 ± 0.025	0.007	n.s.
	B vs S	0.19 ± 0.026	0.10 ± 0.025	4.219	n.s.
Araneida	M/S vs F/B	0.30 ± 0.051	0.44 ± 0.051	3.5	n.s.
	M/S vs B	0.30 ± 0.051	0.71 ± 0.091	12.6	**
	M/B vs S	0.44 ± 0.051	0.76 ± 0.085	10.21	**
	B vs S	0.71 ± 0.091	0.76 ± 0.085	0.047	n.s.

Key: M/B—Misting after beating, M/S—Misting after sweeping, B—Beating, S—Sweeping. n.s.—not significant, * $0.5 > P > 0.01$, ** $0.01 > P > 0.001$, *** $P < 0.001$.

Within non-insect groups, both beating and sweeping significantly overestimated the proportions of spiders in the samples. In addition, Amphipods—although representing over an eighth of the organisms in both misting samples—were hardly represented at all within either the beating or sweeping samples (one individual caught by sweeping!).

Among the numerically less well represented taxa, both sweeping and beating were relatively efficient in collecting lepidopterous larvae and adults—an order which misting or fogging do not sample efficiently.

DISCUSSION

The task of accurately assessing the numbers and kinds of invertebrates at any level in a rain forest canopy is very difficult. All sampling methods used for the arthropod assemblage within a community produce a biased sample. Fogging probably produces the most comprehensive samples of the free-living arthropods, although some large or cryptic insects may escape the pyrethroid knockdown. Others, like lepidopterous larvae and spiders (which were less abundant in knockdowns) may be affected by the insecticide but remain in the canopy suspended by silk threads. Our results also suggest that forest amphipods are particularly sensitive to spraying techniques although their normally cryptozoic habit leads to virtual absence in samples obtained by other means. Only one collection technique in the literature claims to have nearly 100% accuracy. Basset's (1991) restricted area misting method uses carbon dioxide knockdown within large plastic bags over segments of the foliage of trees. This technique, however, demands complete access to the segment of canopy to be sampled and, although producing an excellent sample, remains a specialized technique of limited applicability.

In numerical terms, our results show, not surprisingly, that spraying produces much more comprehensive samples than either beating or sweeping with concomitant larger representation of major taxa. Although it might be assumed that a larger sample is in some sense 'better,' this must be viewed in light of the subsequent sorting effort required—always the limiting factor in the case of insecticidal spraying. Also, important is the representation of the taxa in arthropod samples. Our analyses of the more common taxa show that beating produced a qualitative profile of the insect major taxa very similar to that produced by misting. Sweeping, in contrast, produced a very different, (presumably unrepresentative) sample. Surprisingly, this was due in large part to two taxa: Collembola and Diptera. Sweeping was not very successful in estimating Collembola, possibly because many of these are very small, fast and cryptozoic, thereby minimizing encounters with the net.

If the limited techniques of beating or sweeping are employed, or if these methods were employed in earlier literature, then it is possible to apply a correction factor, based on insecticidal spraying results, to calculate a more accurate es-

TABLE 3. Results of one-way analyses of variances for proportions of selected orders in samples. (Similar analyses for Psocoptera, Hymenoptera, Isoptera and Acarina produced no significant results.)

Arthropod samples	Mean	Standard error	df	t-value	Significance
Total organisms in sweeps	52.13	11.89	7	0.997	n.s.
Total organisms in beats	39.00	5.65	7		
Total organisms in sweeps	52.13	11.89	7	−3.942	***
Total organisms in misting after sweeping	378.38	81.89	7		
Total organisms in beats	39.00	5.65	7	−6.482	***
Total organisms in misting after beats	143.25	15.06	7		
Total organisms in misting plus sweeps	430.50	90.76	7	2.677	**
Total organisms in misting plus beats	182.25	18.99	7		
Total major taxa in sweeps	8.60	0.75	7	0.001	n.s.
Total major taxa in beats	8.63	0.63	7		
Total major taxa in sweeps	8.60	0.75	7	−4.031	***
Total major taxa in misting after sweeps	13.38	0.91	7		
Total major taxa in beats	8.63	0.63	7	−2.28	*
Total major taxa in misting after beats	10.50	0.54	7		
Total major taxa in misting after sweeps	13.38	0.91	7	−2.735	*
Total major taxa in misting after beats	10.50	0.54	7		
Hymenoptera in sweeps	2.00	0.71	7	0.832	n.s.
Hymenoptera in beats	2.75	0.56	7		
Hymenoptera in misting after sweeps	24.25	5.39	7	2.739	*
Hymenoptera in misting after beats	8.88	1.56	7		

timate of total arthropods. In our study, these corrections would be ×4.6 and ×8.3 respectively. This does not, however, correct for disproportionate representation of taxa, and also does not correct for the larger arthropods that may not be harvested by spraying.

In comparing the three techniques, factors other than absolute efficiency may also be important. Both sweeping and beating are non-destructive and easy to carry out. Conversely, misting and fogging require mechanized dispensers and are noisy and invasive, even when very short-lived insecticides are used. Each method, accordingly, has its advantages and disadvantages in studies of arthropod assemblages. We suggest, however, that for the most comprehensive and representative samples, insecticide spraying is more comprehensive than the other two techniques.

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