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SPATIAL VARIATION OF INVERTEBRATE ABUNDANCE WITHIN THE CANOPIES OF TWO AUSTRALIAN EUCALYPT FORESTS

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Abstract. We compared branch-clipping and pyrethrin-knockdown methods for estimating relative abundances of arboreal invertebrate taxa in two Australian eucalypt forests, one at Karragullen in Western Australia, the other at Scheyville in New South Wales. Branch clipping was designed to sample sessile invertebrates and galls. The pyrethrin method sampled mainly mobile invertebrates and those associated with bark and branches. Invertebrates were sampled in subcanopy (1–7 m) and the canopy (7.1–20 m) layers. Both methods indicated higher levels of invertebrates at Scheyville than at Karragullen. Adjusted for exceptionally abundant taxa, both techniques showed invertebrates to be more abundant in the upper canopy of all tree species and, within a particular forest, most abundant on marri (*Eucalyptus calophylla*) and narrow-leaved ironbark (*E. crebra*). Differences between tree species were more pronounced with branch-clipping than with pyrethrin data; however, branch-clipping data were insufficient for computing variances. Pyrethrin data showed that within-tree variation was generally greater than that between trees. Variances were generally greater for invertebrates from the subcanopy. In both forests, tree species with the highest invertebrate abundance had the highest variances in counts of invertebrates. Each method has its limitations. We recommend using both together to measure relative abundances of invertebrates in forest ecosystems.

Key Words: Invertebrates; insects; invertebrate sampling; relative abundance; arboreal.

INTRODUCTION

Understanding processes that govern the dynamics of bird communities requires information on the abundance and variability of food resources. For many reasons well known to avian ecologists, estimates of the absolute abundances of invertebrates available to birds are seldom available. However, indices of invertebrate abundance can be used to interpret seasonal patterns of avian abundance (e.g., Bell and Ford, this volume; Recher et al., 1983), year-to-year variation in numbers (e.g., Bell and Ford, this volume), and the timing of reproductive activities (e.g., Nix 1976, Recher et al. 1983). In these instances, avifauna respond to large changes in the abundance of invertebrate prey. Indices of invertebrate abundance are less useful for interpreting differences in population densities and community composition between habitats or differences between species in the use of particular substrates. Understanding the reasons why birds select particular substrates, and explaining small differences in species abundance or community composition, require precise measures of the abundances of individual prey items on specific substrates.

Before such measurements can be obtained, we need sampling procedures with predictable levels of variance. Two inherent sources of error confound all invertebrate sampling procedures: variation in the application of the procedure itself, and spatial and temporal variation in the distribution and abundance of the invertebrates being studied. Sources of error due to temporal variations in invertebrate numbers can be controlled by taking samples on consecutive days, sampling at the same time of day, and restricting samples to specific weather conditions (i.e., temperature, cloud cover, wind speed, incidence of rain). Assuming that sampling procedures can be standardized, the major sources of error in invertebrate samples result from variation in spatial patterns of distribution and abundance of invertebrates and also the substrates on which they occur.

Our objectives in this study were (1) to examine the patchiness of invertebrate abundance within and between tree species in forests at two localities, and (2) to compare two different methods for measuring the relative abundances of various invertebrate taxa in tree canopies.

METHODS

STUDY SITES

Sampling was done during February 1987 at Scheyville, New South Wales (56°05′S, 150°51′E), where we sampled invertebrates on narrow-leaved ironbark (*Eucalyptus crebra*) and grey box (*E. mollucana*); and during April 1987 at Karragullen, Western Australia (32°04′S, 116°07′E), where we sampled jarrah (*E. marginata*) and marri (*E. calophylla*). The forest at Scheyville was dominated by narrow-leaved ironbark (51% of trees, 42% of tree foliage) and grey box (40% of trees, 51% of tree foliage) with smaller numbers of forest red gum (*E. tereticornis*) (7% of trees) and thin-leaved stringybark (*E. eugenoides*) (<1% of trees). Canopy cover was 40–45%, with the canopy averaging 15–18 m in height. Individual trees emerged above the canopy to 25 m (Recher and Gebski, this volume). The understory consisted of eucalypt saplings; grasses and forbs

comprised the ground cover. At Karragullen, jarrah (92% of trees and foliage) dominated the forest; marri comprised only 8% of all trees. Canopy cover was 60%, and mean canopy height was 15–18 m, with individual trees to 30 m. Karragullen had a more diverse understory than the forest at Scheyville, with a dense subcanopy of eucalypt saplings, sheoak (*Allocasuarina fraserana*), and banksia (*Banksia grandis*). The site had a rich ground vegetation.

Climate at the Karragullen site is Mediterranean—cool, wet winters and hot, dry summers. Mean annual rainfall is 1241 mm with most rain falling between May and October. At Scheyville, although spring (August–October) tends to be drier than other seasons, rain falls fairly evenly throughout the year. Mean annual rainfall is 874 mm, summers are warm and winters are cool with occasional frosts.

Invertebrate Sampling Procedures

Two methods were used to sample invertebrates: branch clipping and chemical (pyrethrin) knockdown. The efficiency of these methods for sampling canopy arthropods is reviewed by Cooper and Whitmore (this volume). Majer and Recher (1988) described both methods and compared their effectiveness and costs (in time) for sampling invertebrate communities in eucalypt forests. In brief, branch clipping sampled sessile foliage invertebrates, which could be expressed as sample weight or numbers/leaf area. Pyrethrin knockdowns sampled mobile invertebrates on leaves and bark, with abundances expressed per unit area of canopy.

For each procedure 10 trees of each species were sampled at each of two height ranges—the subcanopy layer (1–7 m) and the canopy (7.1–20 m). Flowering trees were avoided. Mature trees (>15 m in height) were selected for sampling canopy vegetation. These were reached with a trailer unit with an extendable arm and bucket capable of lifting two people to a height of 13 m. Ten samples were taken from each tree. We sometimes had difficulty taking 10 samples from saplings; in such cases we sampled from a monospecific cluster of trees. A ladder was used to place nets in the subcanopy.

Pyrethrin-knockdown samples

Cotton, funnel-shaped nets with a surface area of 0.5 m^2 were used to collect pyrethrin samples. Each net was fitted with a sleeve that held a 100-ml plastic tube. Nets were held about 60–70 cm below the vegetation. A swivel-and-line arrangement allowed movement in the wind but kept nets from slipping vertically. Within a given tree (or cluster of saplings), nets were suspended at different heights according to the distribution of suitable branches for attachment, so that no nets overlapped. As nearly as possible, net positions were selected to equalize the amount of foliage (determined by visual inspection) in the column directly above the nets. The height of each net was recorded. Nets were positioned the afternoon prior to spraying, to allow disturbed invertebrates to return, although we detected no case (e.g., insects flying away) of disturbance during this process.

The morning (07:00–10:00) of the following day, the canopy to a height of 7 m above each net was sprayed with 0.2% synthetic pyrethrin pesticide, synergized with piperonyl butoxide, using a motorized-knapsack mistblower. Two liters of diluted (10:1) pesticide were used per tree, and trees were left for 30 min to allow silk-attached invertebrates to drop into nets. The canopy was then shaken to dislodge remaining invertebrates, and specimens were brushed into the collecting tubes and preserved with 70% ethanol.

We sampled five trees (50 nets) each morning for 10 days (10 high and 10 low trees of each of two species = 400 nets) to sample each height range at each site. The canopy was sampled first, then the subcanopy layer. Spraying was done only when it was dry and calm. In the event of poor weather, nets were left in place and we sprayed on the first suitable morning (usually the next day).

Branch clipping

At the same time that nets were hung, 10 small branches (<10 mm in diameter) were clipped from the outer foliage of each tree. Samples weighed from 25 to 125 g and contained at least 40 leaves. Branches with numerous seed capsules were avoided. Samples were inserted into a plastic bag prior to clipping; bags were sealed and frozen until processed. We never saw invertebrates leaving samples before bagging. In the laboratory, bags were weighed and samples vigorously shaken prior to removal. Invertebrates dislodged by shaking were identified and counted. Forty leaves were taken randomly from each sample and inspected on both surfaces for sessile invertebrates and those in webs or cocoons; these were identified and counted. Each 40-leaf sample was weighed to the nearest 0.1 g. Mean leaf area of each tree species at each height range at each site was estimated from the mean of a randomly selected subsample of 150–200 leaves, using a Li-Cor® portable area meter.

Data Summary and Analysis

Pyrethrin samples

The objective of the analysis was to compare mean levels of each taxon in each stratum and tree species, with an assessment of the relative variability of taxon counts attributable to "between-tree" and "within-tree" (between-net) variation. The experimental design involved selection of a random sample of 10 trees (experimental units) from each stratum and subsample of 10 nets/tree. Means and variances of the numbers of each invertebrate taxon in each stratum of each tree, and on all 10 trees of a given species and stratum, were computed using the SPSS computer package. Three independent comparisons were made for each individual taxon: (1) between strata for each tree species; (2) between jarrah and marri for each stratum; and (3) between grey box and narrow-leaved ironbark for each stratum. Analyses were restricted to common invertebrate taxa—those occurring in >80% of samples.

To compare between strata for each tree species, we denoted by Y_{ijk} the observed value of each taxon (invertebrate count per net) for the k^{th} net from the j^{th} tree in the i^{th} stratum and assumed the following nested design model for Y_{ijk}:

$$Y_{ijk} = m + S_i + t_{ij} + n_{ijk}$$

where i = 1 (lower) or 2 (upper) for comparisons (1); j = 1, 2, . . . 10 (trees); and k = 1, 2, . . . 10 (nets).

TABLE 1. MEANS AND STANDARD DEVIATIONS OF THE NUMBERS OF INVERTEBRATES SAMPLED PER TREE BY THE PYRETHRIN METHOD FOR BOTH CANOPIES AND SUBCANOPIES OF JARRAH (*Eucalyptus marginata*) AND MARRI (*E. calophylla*) IN WESTERN AUSTRALIA. THE NUMBER OF INVERTEBRATES PER TREE WAS BASED ON 10 0.5-m^2 NETS WITHIN EACH TREE

		Jarrah				Marri			
		Canopy		Subcanopy		Canopy		Subcanopy	
	Taxon	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
Arachnida	Pseudoscorpionida	1.8	4.7	0.0	0.0	0.3	0.7	0.0	0.0
	Acarina	7.5	5.1	11.9	9.9	7.7	5.7	10.2	13.9
	Araneae	26.1	10.5	26.1	13.4	31.7	10.7	18.7	9.4
Crustacea	Isopoda	1.0	3.2	0.3	0.5	0.1	0.3	0.4	0.7
Collembola		3.0	3.3	32.4	37.1	1.2	1.0	109.6	94.6
Insecta	Thysanura	4.3	5.6	1.3	1.6	5.2	11.3	0.8	1.2
	Odonata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Blattodea	4.9	5.0	0.8	0.6	7.6	9.4	1.2	1.0
	Mantodea	0.6	1.6	0.1	0.3	0.2	0.4	0.0	0.0
	Dermaptera	1.1	0.9	1.5	2.6	2.8	2.6	0.2	0.4
	Orthoptera	0.0	0.0	0.2	0.4	0.1	0.3	0.2	0.4
	Phasmatodea	0.0	0.0	0.1	0.3	0.1	0.3	0.1	0.3
	Embioptera	0.5	0.9	0.3	0.7	0.0	0.0	0.3	0.7
	Psocoptera	13.3	10.2	3.7	2.2	14.7	8.5	8.4	8.8
	Hemiptera (psyllids)	8.0	6.7	4.5	4.4	4.1	2.3	4.9	4.8
	(others)	16.1	8.3	5.5	6.0	15.5	4.8	10.2	11.5
	Thysanoptera	5.1	2.3	3.5	3.7	16.1	9.6	4.6	5.5
	Neuroptera (adults)	0.2	0.4	0.1	0.3	0.1	0.3	0.0	0.0
	(larvae)	0.0	0.0	0.1	0.3	0.0	0.0	0.0	0.0
	Coleoptera (adults)	40.4	10.3	18.2	10.8	48.0	28.5	20.5	15.5
	(larvae)	2.1	0.7	1.7	1.5	4.7	4.2	1.5	1.8
	Diptera (adults)	12.0	6.9	11.0	6.9	13.9	7.7	12.1	6.4
	(larvae)	3.2	2.0	6.1	3.7	0.4	0.8	1.3	1.5
	Lepidoptera (adults)	0.7	1.0	1.4	1.6	1.4	2.6	0.5	0.9
	(larvae)	1.4	1.2	1.7	3.7	3.2	4.8	1.3	1.2
	Hymenoptera (ants)	44.7	40.5	6.2	7.9	25.3	28.4	4.8	5.1
	(others)	44.3	16.7	20.4	11.3	48.6	21.8	20.4	10.9
Totals (excluding ants)		197.6	50.9	152.9	72.7	227.7	72.3	227.4	125.5

Algebraically, the model states that the observed invertebrate count Y_{ijk} was equal to the overall mean (m), plus the deviation (S_i) of the i^{th} stratum mean (m + S_i) from the overall mean, plus a random deviation (t_{ij}) representing global variation between trees, plus an independent random deviation (n_{ijk}) representing local (within-tree) variation between nets. Additionally, t_{ij} and n_{ijk} were assumed to be independently distributed with zero means and variances σ^2_t and σ^2_n, respectively. Thus the model implies that the Y_{ijk} (invertebrate counts per net) were distributed about a mean of m + S_i with total variance $\sigma^2_{tot} = \sigma^2_t + \sigma^2_n$. The analysis of variance (ANOVA) for this model gave estimates of m + S_i as the stratum means, with assessment of the statistical significance of the difference between stratum means, along with estimates of the components of variance σ^2_t and σ^2_n that show relative variability "between-trees" and "within-trees," respectively.

A similar nested-design model was used for Y_{ijk} to compare between trees in each stratum:

$$Y_{ijk} = m + T_i + t_{ij} + n_{ijk}$$

where i = 1 (jarrah) or 2 (marri) for comparison (2), or i = 1 (grey box) or 2 (narrow-leaved ironbark) for comparison (3), and T_i = deviation of the i^{th} species mean from the overall mean m. The t_{ij} and n_{ijk} have the same interpretation as in comparison (1).

Branch-clipping samples

Because counts of invertebrates were so low in the branch-clipping samples, we could not analyze the data statistically. Instead we computed the number of invertebrates/g of sample (bag contents) and the number/cm^2 of leaf area for each tree species and stratum. In the latter case, numbers were halved to allow for invertebrates on upper and lower leaf surfaces.

RESULTS

TOTAL INVERTEBRATES IN PYRETHRIN SAMPLES

Twenty-seven taxa were sampled at both sites, but counts of invertebrates were generally much higher at Scheyville than at Karragullen (Tables 1 and 2). The most abundant taxa on trees at Karragullen were Araneae (spiders), Psocoptera (booklice), Hemiptera (sucking bugs other than psyllids), Coleoptera (adult beetles), Diptera (adult flies), and Hymenoptera (ants). At Scheyville, the most abundant taxa were Acarina

TABLE 2. MEANS AND STANDARD DEVIATIONS OF THE NUMBERS OF INVERTEBRATES SAMPLED PER TREE BY THE PYRETHRIN METHOD FOR BOTH CANOPIES AND SUBCANOPIES OF GREY BOX (*Eucalyptus mollucana*) AND NARROW-LEAVED IRONBARK (*E. crebra*) IN NEW SOUTH WALES. THE NUMBER OF INVERTEBRATES PER TREE WAS BASED ON 10 0.5-M² NETS WITHIN EACH TREE

		Grey box				Narrow-leaved ironbark			
		Canopy		Subcanopy		Canopy		Subcanopy	
	Taxon	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
Arachnida	Pseudoscorpionida	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Acarina	24.6	26.1	23.0	16.1	18.0	14.9	31.0	16.9
	Araneae	65.8	29.6	68.8	30.0	70.7	39.4	119.7	36.8
Crustacea	Isopoda	0.0	0.0	0.0	0.0	0.1	0.3	0.0	0.0
Collembola		0.2	0.6	1.5	2.4	0.0	0.0	1.1	1.3
Insecta	Thysanura	0.2	0.6	0.0	0.0	0.2	0.4	0.1	0.3
	Odonata	0.0	0.0	0.3	0.5	0.1	0.3	0.2	0.4
	Blattodea	10.5	6.5	17.4	11.6	0.3	0.5	1.3	1.7
	Mantodea	0.0	0.0	0.0	0.0	0.2	0.4	0.3	1.0
	Dermaptera	0.1	0.3	0.0	0.0	0.0	0.0	0.0	0.0
	Orthoptera	0.4	0.5	1.6	1.6	0.4	0.7	1.5	1.7
	Phasmatodea	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Embioptera	0.3	0.7	0.0	0.0	0.1	0.3	0.1	0.3
	Psocoptera	0.8	1.9	3.4	2.3	1.3	1.6	4.3	6.9
	Hemiptera (psyllids)	164.6	111.4	67.8	37.0	637.0	587.7	306.0	295.2
	(others)	56.1	32.4	40.3	8.0	37.9	28.0	29.7	11.6
	Thysanoptera	13.7	11.8	16.1	11.2	25.1	22.0	26.5	31.4
	Neuroptera (adults)	1.6	1.3	1.6	2.6	3.3	2.9	3.4	4.3
	(larvae)	2.6	4.3	1.9	3.3	0.8	1.9	1.3	2.3
	Coleoptera (adults)	83.2	27.4	77.8	40.5	70.2	20.0	94.5	39.2
	(larvae)	13.7	11.9	14.3	10.8	8.9	6.2	17.7	13.8
	Diptera (adults)	23.3	11.5	15.8	6.8	25.2	22.9	26.4	15.7
	(larvae)	26.9	17.3	15.5	12.5	18.8	18.8	12.2	9.5
	Lepidoptera (adults)	7.3	4.9	5.7	4.1	2.1	1.5	5.1	5.5
	(larvae)	8.0	4.6	7.4	4.8	9.5	5.7	5.5	2.5
	Hymenoptera (ants)	168.1	176.8	105.8	98.7	218.6	253.8	206.8	136.3
	(others)	81.4	48.3	51.2	33.2	117.4	88.7	61.8	43.6
Totals (excluding ants)		585.3	173.5	431.4	151.7	1047.6	730.7	749.7	441.8

(mites), Araneae, Blattodea (cockroaches), Hemiptera (psyllids and other families), Coleoptera (adults and larvae), Diptera (adults and larvae), and Hymenoptera (ants and wasps).

The invertebrate count was higher on marri than on jarrah (excluding ants), regardless of stratum (Table 1) and higher on narrow-leaved ironbark than on grey box (Table 2). Counts were higher in the upper than the lower strata of jarrah, grey box, and narrow-leaved ironbark. This was also the case for marri, if the high count of Collembola (springtails) for the lower stratum was taken into account (Table 1).

STATISTICAL ANALYSIS OF PYRETHRIN DATA

Influence of tree species and stratum

Mean counts of invertebrates differed significantly between tree species and strata [$P < 0.05$, F statistics from ANOVA of comparisons (1), (2), and (3)]. More taxa were more abundant on either the upper or lower stratum of marri than on the corresponding stratum of jarrah. However, only counts of insect larvae were significantly different, with more larvae found on the lower stratum of the jarrah than of marri [$P < 0.05$, F statistics from ANOVA of comparison (2)].

At Scheyville, spiders were significantly more abundant on narrow-leaved ironbark (lower stratum), as were psyllids (both strata) and total invertebrates (lower stratum). Other sucking bugs were significantly more abundant on the lower stratum of grey box than of narrow-leaved ironbark [$P < 0.05$, F statistics from ANOVA of comparison (3)].

Many taxa were significantly more abundant in samples from upper than lower strata (e.g., spiders on marri; booklice on jarrah, other sucking bugs on jarrah; psyllids on grey box; beetles, ants, and other hymenopterans on jarrah and marri). Only two taxa had significantly higher

counts on lower foliage—spiders on narrow-leaved ironbark and booklice on grey box [$P < 0.05$, F statistics from ANOVA of comparison (3)].

Variability within and between trees

Values pooled across tree species for a particular forest showed that variability within trees (σ^2_n) was generally greater than that between trees (σ^2_t). The average percentage contribution of within-tree variance (σ^2_n) to total variance (σ^2_n) was 80% (range 65–96%) at Karragullen and 66% (range 35–100%) at Scheyville. Little difference was evident in within-tree variability for the tree species in a particular forest (percentage contribution averaged 80% and 77% for jarrah and marri, respectively). Again the lower within-tree variability at Scheyville was evident (percentage contribution 66% and 67% for grey box and narrow-leaved ironbark, respectively).

The coefficient of variation ($CV = \sigma^2_{tot}/\bar{X}$) of each tree species and stratum revealed some interesting trends. At Karragullen, the CV was greatest for each invertebrate group on the lower stratum of the tree (mean = 1.09 and 1.65 for upper and lower strata, respectively). It was also greatest on the lower stratum for six of the nine groups tested at Scheyville (mean = 1.24 and 1.40 for upper and lower strata, respectively).

Mean CV on marri (1.36) was slightly higher than on jarrah (1.18), with six of the nine common invertebrate groups exhibiting the highest CV on marri. At Scheyville, invertebrates generally had a higher CV on narrow-leaved ironbark (1.59) than on grey box (1.05), with seven of the invertebrate groups having the highest CV on narrow-leaved ironbark. Thus, in both forests the trees with the highest invertebrate abundance also had the greatest variability in counts of invertebrates. Note that CVs in the two forests were similar. Thus, invertebrates in the two forests generally exhibited the same degree of patchiness, although individual taxa exhibited differences between forests.

Total Invertebrates in Branch-clipping Samples

This method detected only 12 taxa at Karragullen and 17 at Scheyville, compared with the 27 taxa obtained in the pyrethrin samples at both locations. The most abundant invertebrates in branch-clipping samples at Karragullen were spiders, psyllids, other sucking bugs, adult beetles and ants. At Scheyville, the most abundant were spiders, psyllids, other sucking bugs, adult beetles, moth larvae, and ants (Tables 3 and 4).

As with the pyrethrin samples, many more invertebrates were detected per cm^2 of foliage at Scheyville than at Karragullen (Tables 3 and 4). This was also true on a per g basis, except for grey box. The trends between tree species and strata at Scheyville were similar for both the branch-clipping and pyrethrin samples. However, in this case, the numbers of invertebrates per g of foliage were between 5 and 10 times greater on narrow-leaved ironbark than on grey box, depending on which stratum was considered. This compares with a differential of only 1.7–1.8 times for the pyrethrin method (Table 2). Similarly, the differential in number of invertebrates per cm^2 of foliage was also more pronounced by the leaf-clipping method, with about five times the number being observed on narrow-leaved ironbark than on grey box foliage.

Invertebrates were more abundant per g and per cm^2 of leaf area in the upper than the lower stratum of grey box and per cm^2 in the upper than the lower stratum of ironbark (Tables 3 and 4).

The data from tree species at Karragullen did not give the same trends as observed by the pyrethrin procedure. More individuals from branch clipping were found on the upper than the lower stratum by a factor of 3.5–5.0, using the leaf-area measure. Similarly, 1.7 times more invertebrates on a per g basis were on the upper than the lower stratum of jarrah. Slightly fewer invertebrates were on the upper than the lower stratum of marri, and this seemed to be associated with the high count of spiders on the lower stratum.

The between-tree species trends for branch clips were most at variance with results obtained from pyrethrin samples. No differences were observed between the lower stratum of marri and jarrah on a per g basis. Twice as many invertebrates were observed on the upper stratum of jarrah than on marri. This differential was exaggerated with the leaf-area measure, with 7–10 times more invertebrates observed on jarrah than marri, depending on stratum. This compares with 1.1–1.4 times more invertebrates on marri than on jarrah by the pyrethrin method.

DISCUSSION

The two methods produced similar results: both yielded more invertebrates in Scheyville than in Karragullen. We do not know whether this was due to a real difference in invertebrate abundance or to different seasonal patterns of abundance between the forests, although preliminary analyses suggest that invertebrates were more abundant in all seasons at Scheyville. At Scheyville, both techniques indicated similar differences in invertebrate abundance between tree species. However, the excess of invertebrates on narrow-leaved ironbark vs. grey box was exaggerated by

TABLE 3. MEANS AND STANDARD DEVIATIONS OF NUMBERS OF INVERTEBRATES SAMPLED BY BRANCH-CLIPPING METHOD FOR BOTH CANOPIES AND SUBCANOPIES OF JARRAH (*Eucalyptus marginata*) AND MARRI (*E. calophylla*) IN WESTERN AUSTRALIA. THE NUMBER OF INVERTEBRATES PER BAG WAS BASED ON 10 CLIPS OF 40 LEAVES EACH TAKEN FROM EACH TREE

Taxon or measure		Jarrah								Marri							
		Subcanopy sample (N = 6)				Canopy sample (N = 6)				Subcanopy sample (N = 6)				Canopy sample (N = 6)			
		Bag		40-leaf		Bag		40-leaf		Bag		40-leaf		Bag		40-leaf	
		$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
Arachnida	Araneae	2.3	1.0	0.2	0.4	2.8	1.6			3.2	1.2			2.0	0.9		
Collembola		0.2	0.4														
Insecta	Blattodea													0.2	0.4		
	Dermaptera													0.2	0.4		
	Hemiptera (psyllids)	1.0	1.3	1.5	1.8	1.2	0.8	2.8	3.1	0.7	0.8	0.7	1.6	0.5	0.8	5.3	10.2
	(others)	0.2	0.4	5.5	3.9	0.3	0.5	28.2	14.2			1.7	2.3			2.5	2.5
	Coleoptera (adults)	0.2	0.4			3.2	3.4			0.8	1.2			1.0	0.9		
	(larvae)							0.5	0.6								
	Diptera (adults)									0.2	0.4						
	Lepidoptera (larvae)			0.2	0.4	0.2	0.4	0.2	0.4							0.8	1.2
	Hymenoptera (ants)	0.5	1.2			2.5	3.8			0.5	0.8			0.3	0.8		
	(others)	0.8	0.5			0.7	0.8			0.2	0.4			0.2	0.4		
	Unidentified			6.3	6.3			26.0	36.5							1.7	3.3
Mean biomass (g/40 leaves)		50.0	10.0			69.0	18.7			58.9	7.8			61.3	14.5		
Mean leaf surface (cm^2)				17.8				15.1				21.4				27.4	
Number of bags without invertebrates (40 leaves)		6.7	1.0			4.2	1.2			5.8	1.0			6.7	2.3		
Number of leaves without invertebrates				37.7	1.4			36.1	1.5			27.1	7.8			32.5	2.4
Number of invertebrates/1000 g of sample		9.1				15.7				9.3				7.0			
Number of invertebrates/100,000 cm^2 of leaf surface				96.2				469.4				13.4				47.0	

TABLE 4. MEANS AND STANDARD DEVIATIONS OF NUMBERS OF INVERTEBRATES SAMPLED BY BRANCH-CLIPPING METHOD FOR BOTH CANOPIES AND SUBCANOPIES OF GREY BOX (*Eucalyptus molluscana*) AND NARROW-LEAVED IRONBARK (*E. crebra*) IN NEW SOUTH WALES. THE NUMBER OF INVERTEBRATES PER BAG WAS BASED ON 10 CLIPS OF 40 LEAVES EACH TAKEN FROM EACH TREE

		Grey box								Narrow-leaved ironbark							
		Subcanopy sample (N = 10)				Canopy sample (N = 10)				Subcanopy sample (N = 10)				Canopy sample (N = 10)			
		Bag		40-leaf		Bag		40-leaf		Bag		40-leaf		Bag		40-leaf	
Taxon or measure		$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
Arachnida	Acarina					0.1	0.3					0.1	0.3			0.2	0.6
	Araneae	4.2	2.6	0.7	0.7	4.3	4.9	0.8	2.2	5.8	3.6	0.8	0.8	4.5	3.9	0.3	0.6
Insecta	Blattodea			0.1	0.3	0.1	0.3										
	Mantodea	0.2	0.4														
	Orthoptera	0.2	0.4														
	Hemiptera (psyllids)	1.2	2.0	10.3	11.0	2.7	2.7	17.9	23.7	2.2	3.0	16.8	16.7	4.2	3.1	25.0	16.3
	(others)	0.5	1.3	0.1	0.3	2.0	2.1	0.1	0.3	1.3	2.1	0.4	1.0	0.9	1.4	1.3	3.1
	Thysanoptera			0.2	0.6			0.6	0.7			0.1	0.3			0.2	0.4
	Neuroptera (larvae)					0.1	0.3										
	Coleoptera (adults)	0.5	1.1	0.1	0.4	1.4	1.4	0.4	0.9	0.7	0.3	0.1	0.3	1.7	0.9	0.3	0.6
	(larvae)			0.3	0.7	0.1	0.3	0.2	0.6	0.1	0.3	0.2	0.4	0.1	0.3		
	Diptera (adults)					0.1	0.3							0.4	0.9		
	(larvae)					0.1	0.3	0.5	1.2					0.1	0.3		
	Lepidoptera (adults)	0.1	0.3			0.2	0.4										
	(larvae)	0.6	0.7	2.4	1.1	0.6	1.0	2.4	2.5	0.4	0.5	1.9	2.6	0.3	0.4	1.4	1.5
	Hymenoptera (ants)	2.0	1.5	1.2	1.0	1.5	3.1	0.1	0.3	3.3	3.1			3.1	3.7		
	(others)					0.2	0.4			0.1	0.3			0.4	0.9	0.2	0.4
	Unidentified			0.1	0.3	0.6	1.8	0.3	1.0			0.1	0.3			0.1	0.3
Mean biomass (g/40 leaves)		111.2	29.3	—	—	126.3	3.5	—	—	26.7	9.7	—	—	50.9	22.7	—	—
Mean leaf surface (cm^2)		—	—	17.2	10.0	—	—	17.0	7.7	—	—	5.0	2.3	—	—	3.5	2.0
Number of bags without invertebrates (40 leaves)		2.7	2.1	—	—	2.3	1.9	—	—	1.6	1.6	—	—	0.7	1.1	—	—
Number of leaves without invertebrates		—	—	37.6	2.4	—	—	36.6	3.5	—	—	37.8	2.0	—	—	37.3	2.4
Number of invertebrates/1000 g of sample		13.0	—	—	—	22.0	—	—	—	138.0	—	—	—	107.0	—	—	—
Number of invertebrates/100,000 cm^2 of leaf surface		—	—	194.0	—	—	—	369.9	—	—	—	1102.5	—	—	—	1850.0	—

branch clipping. The two techniques at first seemed to produce conflicting trends between tree species at Karragullen. Although more invertebrates were obtained from pyrethrin samples of marri than of jarrah, the reverse was true of branch clipping. This reversal was exaggerated when comparing the number of invertebrates per cm^2 of leaf area. However, Table 3 shows that the preponderance of invertebrates on jarrah was tied up with numbers of sucking bugs (excluding psyllids) and certain other small, unidentified invertebrates. The trend between tree species is reversed if these categories are deleted.

Branch clipping produced fewer invertebrates from a narrower range of taxa than the pyrethrin method (cf. Majer and Recher 1988). However, branch clipping gave a good representation of sessile invertebrates such as web-spinning and leaf-rolling spiders, moth larvae, psyllids, and certain other families of sucking bugs that remain attached to leaves. Suitability of this technique for sampling sessile invertebrates has also been pointed out by Cooper and Whitmore (this volume). Some of these invertebrates were obtained only by branch clipping. However, the clipping method was less efficient at obtaining rare or mobile invertebrates.

We conclude that branch clipping was more susceptible to "noise" caused by the abundance of one or a few types of invertebrates, perhaps because some of the most abundant sessile invertebrates are colonial (e.g., psyllids) and their distribution may be patchy. Because it samples sessile fauna less effectively, the pyrethrin method is less vulnerable to this problem. Pyrethrin sampling gives larger samples of a wider range of invertebrates. Variations in the distribution of individual taxa may therefore cancel out, producing a "more uniform" sample. However, the pyrethrin technique did have limitations, because some invertebrates flew away at the time of spraying and some remained attached to trees. In addition, wind may have blown dying organisms away from collection nets. This problem may be mitigated by keeping the drop distance from 0.5–1.0 m.

The greater variance in numbers of invertebrates within trees than between trees was due in part to differences in the volume of foliage above each net, despite our efforts to standardize canopy volumes. Differences in the amount of foliage sampled may be relatively high for nets hung within the same tree or cluster of saplings, but this effect tends to even out between trees. A way to compensate for this would be to use more, smaller nets but that would increase maintenance time.

Sampling of two tree species at a site required three persons for two weeks. The clipping and pyrethrin methods could be done concurrently. At Scheyville, the laboratory phase took one person two weeks to sort the clip samples and four weeks to sort the pyrethrin samples. Because of the smaller samples, lab work at Karragullen required one and three weeks, respectively. Field time did not change appreciably when branch clipping was omitted, although the time needed to process samples decreased markedly.

Because both techniques underestimate the true abundance of canopy invertebrates, we recommend using them together and interpreting results with an understanding of each method's limitations.

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