# Comparison of arthropod species richness in Eastern and Western Australian canopies: a contribution to the species number debate

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# COMPARISON OF ARTHROPOD SPECIES RICHNESS IN EASTERN AND WESTERN AUSTRALIAN CANOPIES A CONTRIBUTION TO THE SPECIES NUMBER DEBATE

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Apart from forest pest species, our knowledge of *Eucalyptus* canopy arthropods is rudimentary This has contributed to a lack of appreciation of the differences in arthropod abundances, biomass and richness on different species of eucalypts and in different forests throughout Australia A three year chemical knockdown study has been carried out in one western Australian forest, where jarrah *Eucalyptus marginata* and marri *E calophylla* were sampled and one eastern Australian forest, where narrow-leaved ironbark *E. crebra* and grey box *E. moluccana* were sampled The arthropods from one year of sampling have been sorted to morphospecies. This paper documents the range of species found and compares arthropod species richness within orders and families and between the two forest types. Hymenoptera, Coleoptera, Diptera and Araneae were the richest in species Nine hundred and seventy-seven species in 173 families were found in the eastern Australian forest, while 691 species in 176 families were found in the western Australian forest Only 53% of families were common to both forests, but almost half the families recorded were represented by fewer than five species. Reasons for these patterns are briefly discussed and arthropod species richness in eucalypt communities is contrasted to that in other temperate and tropical forests The implications of forest and land management practices for the conservation of arthropod richness are presented. □*Invertebrates, insects, arthropods, forest, Eucalyptus, diversity.*

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Erwin's (1982) seminal paper on rainforest canopy invertebrates, which included the global estimate of 30 million arthropods, resulted in a steady flow of papers on canopy arthropods Some supported Erwin's estimate and some regarded his figure as an overestimate (May, 1988; Stork 1988; Gaston, 1991) To recapitulate, Erwin (1982) identified beetles from the canopy of one species of Panamanian tree. Then, using an estimate of the proportion of beetle species which were specific to individual tree species, the number of tropical tree species worldwide and the proportion of the total arthropod fauna represented by beetles, he extrapolated to provide an estimate of total arboreal arthropod species richness of 20 million. On the assumption that arthropod richness is twice as high in the canopy as on the ground, Erwin (1982) went on to estimate a global arthropod richness of 30 million species.

The assumptions on which Erwin based his estimates are subject to question. For instance, the degree of host specificity that Erwin assumed may not be correct (Gaston, 1991) and the proportion of key taxa in a sample may vary from community to community (e g., Abbott et al., 1992; Kitching et al., 1993), thus leading to problems in extrapolating from a single sample to provide global figures. Arthropod species richness in the canopy may not exceed that of the demonstrably rich soil and litter fauna and they may not be totally separate faunas (see, e.g., Adis, 1988, Hammond, 1990) A further problem with this debate is that most estimates are based upon samples taken in the rainforests, the implicit assumption is that most of the world's biological diversity occurs in the tropics. Clearly, if the conflict of opinion about global arthropod richness is to be sensibly resolved, we need reliable data on arthropod richness from temperate areas as well.

Australian *Eucalyptus* forests represent a vegetation type for which few data on arthropod richness exist. Eucalypt communities are of particular interest in relation to rainforests because they are evergreen and seasonal extremes in temperature are not as great as in temperate forests of the northern hemisphere. Thus, in terms of these features, they are intermediate between rainforests and temperate deciduous forests, which have had arthropod richness documented by a series of detailed investigations (e.g. Southwood et al., 1982a, 1982b; Erwin, 1983a, 1983b; Adis et al., 1984; Hijii, 1984; Stork, 1991). Im-

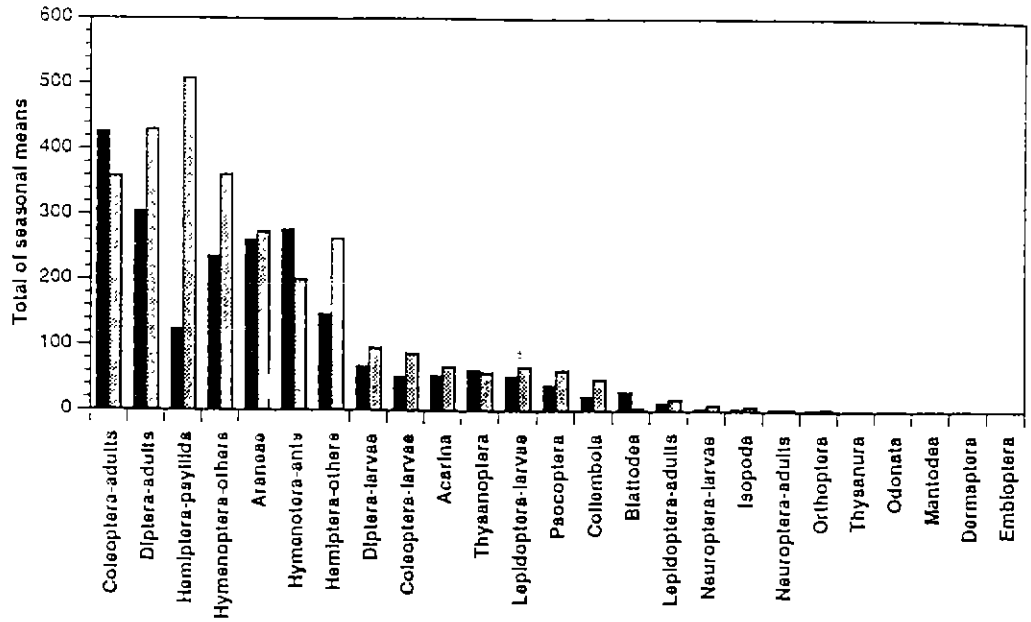


Fig. 1. Numbers of individuals in different arthropod orders on grey box (*E. moluccana*, black) and narrow-leaved ironbark (*E. crebra*, stippled) Values are mean arthropods per tree (n = 10 trees) summed over the four seasons (Table 1)

portantly, eucalypt forests are dominated by a single genus, *Eucalyptus*, which in most habitats is represented by only a few species. Therefore, studies of eucalypt communities not only provide an opportunity to test predictions of global species richness but can be used to investigate various assumptions about the distribution of insect species between habitats and their degree of host specificity. The evergreenness of eucalypts, coupled with moderate seasonal changes in temperature and rainfall also allows an assessment of the contribution to species richness arising from temporal changes in community composition as distinct from spatial and habitat variation.

In 1985, we initiated studies in eucalypt forests on the relationship between arboreal invertebrate communities, foliage nutrient levels and tree species selection by foraging birds (Majer & Recher, 1988, Majer et al., 1990, 1992, in prep.; Recher et al., 1991, 1993, Recher & Majer, in press). Arboreal invertebrates were sampled seasonally on each of two species of eucalypts in a marri-jarrah forest in western Australia and a box-ironbark forest in eastern Australia. A subset of the samples has now been sorted to morphospecies. Here, we present a preliminary analysis of the species richness of the arboreal invertebrate faunas in eucalypt forests. The numbers of species in the two forest types sampled are compared to the numbers reported for other forest communities. Subsequent papers will analyse the similarity of species composition between the eastern and western faunas, the extent of tree species specificity within each forest type, the variation in faunal composition within a tree species and the extent to which seasonal changes in community composition contribute to overall patterns of species richness.

## METHODS

Sampling was done seasonally from February 1987 through January 1988 at Scheyville, New South Wales (33°53'S, 150°51'E), where we sampled invertebrates on co-dominant narrow-leaved ironbark (*Eucalyptus crebra* F.Muell.) and grey box (*E. moluccana* Roxb.) and from April 1987 through November 1989 at Karragullen, Western Australia (32°04'S, 116°07'E) on co-dominant marri (*E. calophylla* R.Br.ex Lindley) and jarrah (*E. marginata* Donn. ex Smith). During each season, samples were taken from the canopy (>7 m) and subcanopy (<7 m).

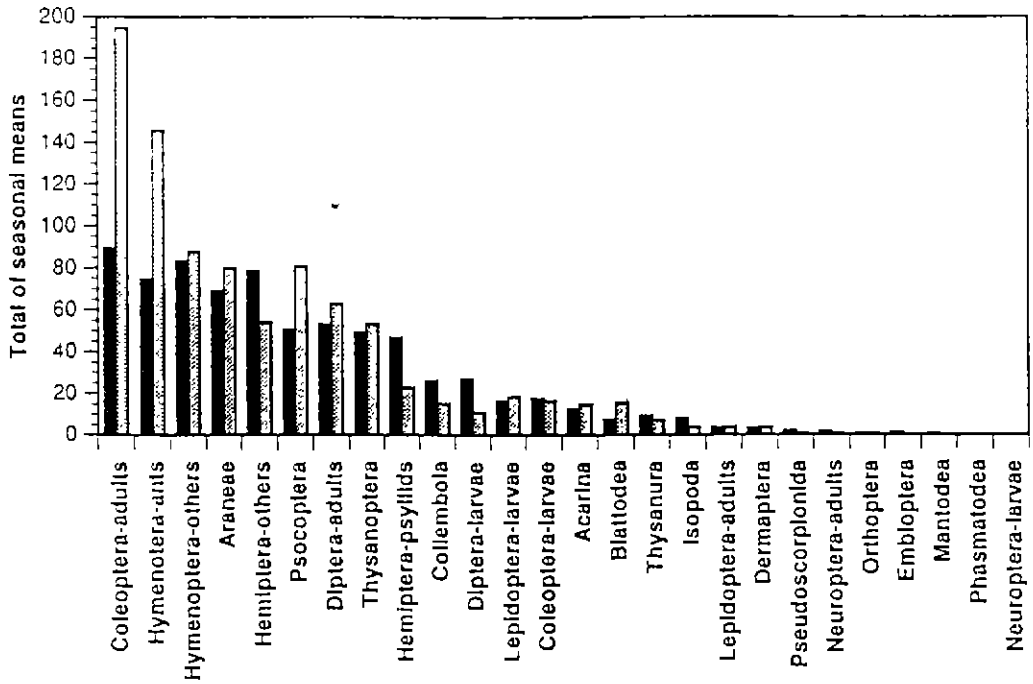


Fig. 2. Numbers of individuals in different arthropod orders on jarrah (*E. marginata*, black) and marri (*E. calophylla*, suppled). Values are mean arthropods per tree (n = 10 trees) summed over the four seasons (Table 1.).

Because we were specifically interested in foliage-associated arthropods, we avoided sampling trees which were flowering.

Branch clipping and chemical knockdowns were used to sample invertebrates but only the data from material obtained by chemical knockdown are presented here Details of the procedures used and the habitats sampled are presented in Majer & Recher (1988) and Majer et al. (1990, 1992). Briefly, in each season we selected 10 trees of each species and stratum for sampling. No tree was sampled more than once. Within each tree, we suspended ten 0.5 $m^2$, funnel-shaped nets using a cherry-picker. Nets were positioned so as not to overlap and to sample all parts of the tree canopy. After a period of equilibrium (usually overnight), the trees were sprayed with a fast-acting pyrethrin insecticide synergised with piperonyl butoxide. Spraying was done only under calm conditions during early morning. Invertebrates collected by the nets were stored in 70% ethanol until sorted.

Limited time has allowed material only from the upper canopy samples and for the samples taken from April 1987 through January 1988 to be sorted to species (i.e. once for each season from autumn through summer in both States). The invertebrates were sorted initially to ordinal level; resulting data were described in papers quoted above. Subsequently, except for the endopterygote larvae, the arthropods from each of the four seasons and four tree species were sorted to species. All animals were assigned to families and were labelled with code numbers for each species. Because of the taxonomic complexity of dealing with many juvenile spiders and of the extremely high richness of Hymenoptera, we sorted these two groups for the first two seasons only. In addition, because of the uncertainty in deciding whether individuals from eastern and western Australia were the same species, we used a separate numbering system for the material from the two areas. The putative species representatives are currently being sent to taxonomists in order to obtain generic and, where possible, specific names.

## RESULTS

Ordinal profiles derived from the numbers of arthropods collected in each taxon are presented for each tree species and for the two forests sampled (Figs. 1, 2). The current status of data-coding prevents segregation of arthropod species by tree species, so the number of species in each

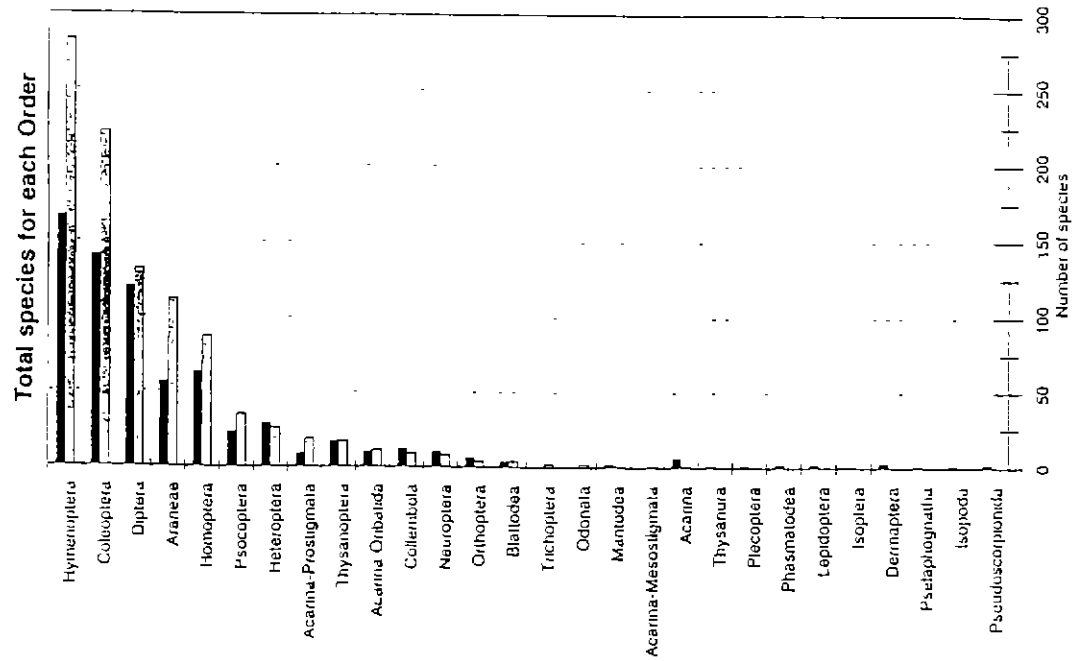


Fig. 3 Total number of species within each arthropod order sampled on 80 eastern Australian trees (*E. moluccana* and *E. crebra*, stippled) and 80 Western Australian trees (*E. marginata* and *E. calophylla*), black).

taxon can be compared between eastern and western Australia only

A total of 67,400 individual arthropods were obtained from the 160 upper canopy trees sampled. Arthropods sampled numbered 50,900 in the eastern forest, but only 16,500 in the west. They were more abundant on narrow-leaved ironbark and grey box than on jarrah and marri in all seasons sampled (Table 1). Narrow-leaved ironbark supported consistently more arthropods than grey box and, apart from spring, their abundance was higher on marri than on jarrah. The most pronounced differences were in the many more psyllids, other Hemiptera, Diptera and Hymenoptera (excluding ants) on narrow-leaved ironbark and ants and adult Coleoptera on grey box (Fig. 1). Marri had many more adult Coleoptera, ants and Psocoptera than jarrah, while psyllids and other Hemiptera were more abundant on jarrah (Fig. 2).

### Ordinal Profiles

Overall, arthropods from 23 orders of insects (Heteroptera and Homoptera counted as one order), arachnids and crustaceans were collected, with 20 sampled in western Australia and 17 in eastern Australia (Figs. 1, 2).

Hymenoptera, Hemiptera, Coleoptera, Diptera and Araneae were the most abundant orders of arthropods in both forests (Figs 1, 2). These were followed by Psocoptera, Thysanoptera, Collembola, Lepidoptera and Acarina in that order in western Australia, and by Acarina, Thysanoptera, Lepidoptera, Psocoptera and Collembola in eastern Australia.

While there was some consistency in the ranked abundance of orders between eastern and western Australia, their relative abundance on different species of eucalypts was more variable. In Western Australia, Hymenoptera, Hemiptera, Coleoptera, Diptera, Araneae and Psocoptera in that order were the most abundant arthropods on jarrah, while Hymenoptera, Coleoptera, Psocoptera, Araneae, Hemiptera and Diptera were most abundant on marri In eastern Australia, Hemiptera, Hymenoptera, Diptera, Coleoptera, Araneae and Lepidoptera in that order were most abundant on narrow-leaved ironbark. On grey box, Hymenoptera, Coleoptera, Diptera, Hemiptera, Araneae and Lepidoptera were most abundant.

### Species Profiles

A total of 691 species of arthropod were identified from western Australia and 977 from east-

| Tree Species | Season | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Autumn 1987 | | Winter 1987 | | Spring 1987 | | Summer 1[illegible] | |
| | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| Grey box | 411 40 | 48 68 | 416 10 | 38 20 | 605 50 | [illegible] | 742 00 | 116 26 |
| Narrow-leaved ironbark | 760 10 | 131 21 | 490 30 | 42.57 | 844 50 | [illegible] | 823 50 | 154 39 |
| Jarrah | 242 20 | 17 93 | 180 20 | 35 54 | 206 60 | [illegible] | 125 60 | 14 64 |
| Marri | 252 70 | 27 82 | 241 10 | 58 14 | 184 80 | 22 74 | 216 30 | 42 74 |

Table 1 Mean values (and standard deviation) of total number of arthropod individuals sampled per tree (n = 10)

ern Australia Some species would undoubtedly be 'tourists' which have temporarily alighted or been carried onto the trees (e g the lycosid spider) Although the two reference collections have not yet been homologised, our knowledge of the material and early determinations from specialists indicate little overlap between the two faunas The total number of arthropod species can conservatively be estimated to exceed 1500 species, of which some 1300 are insects.

A total of 229 families were encountered, of which 176 were represented in western Australia and 173 in eastern Australia (Table 2). Thus, although there are about 40% more species on eastern than on western Australian trees, the numbers of families in the two forests are relatively similar There is a 53% overlap in the families sampled in the two forests, suggesting a high level of biological richness at family level Forty-seven families represented in the eastern samples were absent in the west, while 56 families were sampled solely in the western Australian forest. Of the families which were confined to one particular forest, only four contained five or more species. Of the 229 families, 95 were represented by fewer than three species.

The total species within each order (Fig. 3) are ranked by the average of the amalgamated eastern and western Australian counts. The most diverse groups in both forests were the Hymenoptera (a total of 450 species), the Coleoptera (363) and Diptera (252), in that order Araneae (168) and Homoptera (150) were the next richest taxa. The richness of species in Hymenoptera and Araneae is based on samples from two seasons and we estimate that their species richness would be 50% greater had the full set of samples been sorted This does not alter the position of the Hymenoptera as the most species-rich taxon but could mean that the Araneae are the third most species-rich group. The numbers of species within each of the orders in the two forests were strongly correlated ($r=0.98$, $df=26$, $p<0.001$). There were significant correlations between the number of individuals and of species within the various taxa ($r=0.92$, $df=18$, $p< 0.001$ for western Australia; $r=0.91$, $df=13$, $p< 0.001$ for eastern Australia)

Of the richest five orders, all were represented by more species in eastern Australia than in the west The differences in species numbers were greatest among the Hymenoptera, with 283 species in eastern Australia and 167 in the west, the Coleoptera with 222 species versus 141; the Araneae with 112 species versus 56, and the Homoptera with 87 species versus 63 The Psocoptera with 35 species versus 23 was also substantially richer in the eastern than the western forest. Numbers of species in the less rich taxa exhibited broadly similar trends, with the only taxa having more species in western than eastern Australia being the Collembola Heteroptera, Neuroptera and Orthoptera. The remaining taxa were represented by relatively few species, so the differences could well be an artifact of sampling Thus, although generally more arthropod species were sampled in the eastern than the western forest, the inconsistent trends in the less speciose taxa meant that richness within order values between the two forests were not significantly different (paired t-test)

## DISCUSSION

The arthropods discussed here were sampled by chemical knockdown from 40 trees of each of two species in western and each of two species in eastern Australia The work of Abbott et al. (1992), also performed in jarrah-marri forest, indicates that chemical knockdown samples only a part of the canopy fauna The nets were hung near the extremities of branches of non-flowering trees, so animals collected were largely those associated with the foliage. The only exception to this amongst the most abundant elements of the fauna was the Psocoptera, which tend to be associated with the bark. Within eastern and western Australia respectively, these animals were most common on narrow-leaved ironbark and marri and, of the pairs of tree species in each

| | WA | NSW |
|---|---|---|
| CRUSTACEA | | |
| Isopoda | 1 | |
| ARACHNIDA | | |
| Pseudoscorpionida | | |
| Chernetidae | 2 | |
| Araneae | | |
| Araneidae | 14 | 32 |
| Clubionidae | 4 | 6 |
| Corinnidae | | 2 |
| Ctenidae | | 1 |
| Desidae | | 5 |
| Gnaphosidae | 2 | 2 |
| Hahniidae | | 1 |
| Herstu[illegible] | 1 | 1 |
| Hetero[illegible] | 2 | 2 |
| Linyph[illegible] | 1 | 1 |
| Lycosidae | 1 | |
| Microphotcommatidae | 1 | |
| Oxyopidae | | 2 |
| Pararchaeidae | 1 | |
| Philodromidae | | 1 |
| Salticidae | 9 | 19 |
| Segestriidae | 1 | |
| Tetragnathidae | | 2 |
| Theridiidae | 9 | 14 |
| Thomisidae | 5 | 7 |
| indet | 5 | 14 |
| Acarina-Mesostigmata | | |
| Phytoseiidae | | 1 |
| Acarina-Oribatida | | |
| Ceratozetoidea | 2 | |
| Cymbaeremaeidae | 1 | |
| ?Cymbaeremaeoidea | | 4 |
| Oribatulidae | | 1 |
| Oribatuloidea | 1 | 5 |
| Plaeremaeidae | 1 | |
| Plateremaeidae | 4 | |
| indet | 1 | 1 |
| Acarina-Prostigmata | | |
| Anystidae | 2 | 5 |
| ?Anystidae | | 1 |
| Bdellidae | 2 | 2 |
| Erythraeoidea | 3 | 8 |
| ?Erythraeoidea | 1 | |
| Oribatuloidea | | 1 |

| | WA | NSW |
|---|---|---|
| Trombidioidea | | 3 |
| Acarina indet | 6 | 1 |
| DIPLOPODA | | |
| Pselaphognatha | 1 | |
| COLLEMBOLA | | |
| Brachystomellidae | 1 | 1 |
| Dicyrtomidae | 1 | 1 |
| Entomobryidae | 4 | 3 |
| Hypogastruridae | | 2 |
| Isotomidae | 2 | |
| Neanuridae | 1 | |
| Sminthuridae | 3 | 2 |
| INSECTA | | |
| Thysanura | | |
| Lepismatidae | 1 | |
| Odonata | | |
| Coenagrionidae | | 1 |
| Lestidae | | 1 |
| Plecoptera | | |
| Gripopterygidae | 1 | |
| Orthoptera | | |
| Gryllacrididae | 2 | 2 |
| Gryllidae | 2 | |
| Tettigoniidae | 2 | 2 |
| Blattodea | | |
| Blattellidae | 4 | 3 |
| Blattidae | | 1 |
| Isoptera | | |
| Rhinotermitidae | 1 | |
| Dermaptera | | |
| Pygidicranidae | 3 | |
| Phasmatodea | | |
| Phasmatidae | 2 | |
| Mantodea | | |
| Amorphoscelidae | 1 | |
| Mantidae | 1 | |
| Psocoptera | | |
| Caeciliidae | | 2 |
| Ectopsocidae | 2 | 3 |
| Elipsocidae | 2 | 1 |
| Lepidopsocidae | 1 | 1 |
| Myopsocidae | 1 | 1 |
| Peripsocidae | 2 | 1 |
| Philotarsidae | 7 | 7 |
| Pseudocaeciliidae | 1 | 5 |

Table 2. Numbers of species found within various arthropod families sampled from trees in a western and an eastern Australian forest.

Table 2 continued

| | WA | NSW |
|---|---|---|
| Psocidae | 3 | 4 |
| indet | 4 | 10 |
| Homoptera | | |
| Achilidae | | 2 |
| Aleyrodidae | 2 | 1 |
| Aphididae | 5 | 3 |
| Aphrophoridae | 1 | |
| Cercopidae | 2 | |
| Cicadellidae | 17 | 34 |
| Cicadidae | | 2 |
| Cixiidae | 2 | 1 |
| Coccoidea | 2 | |
| Eurybrachyidae | 2 | 1 |
| Eurymelidae | 4 | 2 |
| Flatidae | 2 | 3 |
| Machaerotidae | 4 | 3 |
| Membracidae | 2 | 1 |
| Psyllidae | 16 | 36 |
| Heteroptera | | |
| Alydidae | 2 | |
| Anthocoridae | 3 | 3 |
| Ceratocombidae | 2 | 1 |
| Lygaeidae | 2 | 3 |
| Miridae | 7 | 15 |
| Pentatomidae | 6 | 3 |
| Reduviidae | 3 | 1 |
| Thaumastocoridae | 2 | |
| Tingidae | 2 | |
| Thysanoptera | | |
| Aelothripidae | 3 | 4 |
| Phlaeothripidae | 6 | 10 |
| Thripidae | 8 | 3 |
| Neuroptera | | |
| Chrysopidae | 2 | 1 |
| Coniopterygidae | 3 | 3 |
| Hemerobiidae | 2 | 1 |
| Mantispidae | 2 | 3 |
| Myrmeleontidae | 1 | |
| Lepidoptera | | |
| Yponomeutidae | 1 | |
| indet. | 1 | |
| Trichoptera | | |
| Leptoceridae | | 2 |
| Diptera | | |
| Agromyzidae | | 1 |

| | WA | NSW |
|---|---|---|
| Anisopodidae | 1 | 1 |
| Anthomyzidae | | 1 |
| Asilidae | | 1 |
| Aulacigastridae | | 1 |
| Bombyliidae | 1 | |
| Calliphoridae | 1 | 1 |
| Cecidomyiidae | 4 | 10 |
| Ceratopogonidae | 9 | 9 |
| Chamaemyiidae | 2 | 1 |
| Chironomidae | 11 | 7 |
| Chloropidae | 15 | 24 |
| Chyromyidae | | 1 |
| Cryptochaetidae | | 2 |
| Dolichopodidae | 3 | 4 |
| Drosophilidae | 5 | 4 |
| Empididae | 17 | 9 |
| Ephydridae | 3 | 1 |
| Fergusoninidae | 1 | 2 |
| Heleomyzidae | 1 | |
| Lauxaniidae | 3 | 7 |
| Longchaeidae | | 1 |
| Milichiidae | 2 | 2 |
| Muscidae | 3 | 7 |
| Mycetophilidae | 6 | 4 |
| Phoridae | 3 | 8 |
| Pipunculidae | 1 | |
| Platystomatidae | 1 | |
| Pseudopomyzidae | 1 | |
| Psychodidae | 1 | 1 |
| Scatopsidae | 1 | 1 |
| Sciaridae | 6 | 5 |
| Sepsidae | 1 | 3 |
| Simulidae | 2 | |
| Stratiomyidae | 3 | |
| Syrphidae | 2 | 1 |
| Tabanidae | 1 | 1 |
| Tachinidae | 2 | 5 |
| Therevidae | 2 | 1 |
| Tipulidae | 1 | 2 |
| indet | 7 | |
| Coleoptera | | |
| Aderidae | 1 | 1 |
| Alleculidae | 3 | 3 |
| Anobiidae | 3 | 9 |
| Anthicidae | 2 | |
| Anthribidae | | 1 |
| Attelabidae | 2 | 8 |

Table 2. continued

| | WA | NSW |
|---|---|---|
| Belidae | 1 | 3 |
| Bostrichidae | | 1 |
| Buprestidae | 3 | 3 |
| Cantharidae | 2 | 10 |
| Carabidae | 5 | 9 |
| Cerambycidae | | 5 |
| Chrysomelidae | 12 | 30 |
| Cisidae | 1 | 1 |
| Cleridae | 5 | 6 |
| Coccinellidae | 9 | 18 |
| Colydiidae | | 2 |
| Corylophidae | 2 | 3 |
| Cryptophagidae | 2 | 2 |
| Cucujidae | 1 | |
| Curculionidae | 37 | 43 |
| Dascillidae | 2 | |
| Dermestidae | 2 | 5 |
| Dryopidae | | 1 |
| Elateridae | | 5 |
| Endomychidae | 1 | |
| Endomychidae ? | | 1 |
| Histeridae | 2 | 1 |
| Hydraenidae | | 1 |
| Laemophloeidae | 3 | |
| Lagriidae | | 1 |
| Lathridiidae | 3 | 2 |
| Leiodidae | 1 | |
| Melandryidae | 1 | 2 |
| Melyridae | | 5 |
| Mordellidae | | 2 |
| Mycetophagidae | | 1 |
| Nitidulidae | 2 | 2 |
| Oedemeridae | 1 | |
| Phalacridae | | 1 |
| Phloeostichidae | | 1 |
| Pselaphidae | 2 | |
| Ptiliidae | 1 | 1 |
| Pythidae | | 1 |
| Salpingidae | 3 | 2 |
| Scarabaeidae | 7 | 6 |
| Scraptiidae | 2 | 1 |
| Scydmaenidae | 1 | |

| | WA | NSW |
|---|---|---|
| Silvanidae | 1 | 2 |
| Spercheidae | | 1 |
| Staphylinidae | 4 | 9 |
| Tenebrionidae | 7 | 7 |
| Throscidae | 1 | |
| Trogossitidae | | 1 |
| Zopheridae | 1 | |
| indet | 4 | |
| Hymenoptera | | |
| Anthocoridae | 1 | |
| Aphelinidae | 9 | 9 |
| Apidae | 3 | |
| Bethylidae | 7 | 4 |
| Braconidae | 14 | 31 |
| Ceraphronidae | 4 | 1 |
| Chalcidae | 2 | |
| Chalcidae | | 1 |
| Colletidae | 1 | |
| Diapriidae | | 1 |
| Dryinidae | | 1 |
| Elasmidae | | 1 |
| Encyrtidae | 16 | 60 |
| Eulophidae | 32 | 43 |
| Eupelmidae | 5 | 4 |
| Eurytomidae | 3 | 3 |
| Figitidae | 1 | |
| Formicidae | 22 | 33 |
| Ichneumonidae | | 4 |
| Megaspilidae | 1 | |
| Mymaridae | 2 | 13 |
| Pergidae | 1 | 5 |
| Platygasteridae | 6 | 18 |
| Pompilidae | 1 | |
| Pteromalidae | 18 | 26 |
| Scelionidae | 3 | 10 |
| Sphecidae | 4 | 3 |
| Thysanidae | 1 | |
| Tiphiidae | 1 | |
| Torymidae | 5 | 4 |
| Trichogrammatidae | | 2 |
| Vespidae | | 1 |
| indet | 4 | 5 |
| Total families | 176 | 173 |
| Total species | 691 | 977 |

area, these are the ones which retain a thick bark layer on their branches.

As well as species associated with bark (J Monaghan, pers. comm.), flowers, fruits and the wood of trees, there is also that component of the biota associated with other tree species, with the shrubs and with the soil and litter layer. These parts of the ecosystem also support a rich arthropod fauna in these two areas of Australia. For instance, Postle et al. (1991) sampled the soil and litter arthropods in jarrah-marri forest at Dwellingup, some 50 km south of Karragullen and found 290 animal species in nine small sample plots. Thus, the total arthropod species richness for our two sample sites is a conservative estimate; the actual total would be considerably higher than the figure we obtained.

The high correlation between the ordinal and species profiles indicates that the former provides some reflection of the species richness of a sample or a site. Indeed, our finding that species richness is far higher in the eastern than the western forest had already been alluded to by the substantially higher abundance of arthropods in the eastern than the western site (Majer et al., 1990, in prep.; Recher et al., 1991). The reason for this difference between forests has not yet been conclusively found. However, Majer et al. (1992) found substantially higher levels of foliar nitrogen and phosphorus in the eastern than in the western Australian trees and, by referring to other trends in foliar nutrients between tree species and within tree canopies, suggested that the abundance of arthropods might be a response to nutrient levels If this is the case, the differences may well apply to eastern and western Australia as a whole.

Reasons for the high richness of arthropods in these two forests is not here discussed. The degree of host plant specificity (Fox & Morrow, 1981) and also the geographical range of the host plant (Strong, 1979) could be contributory factors but the data have not yet been processed to the extent required to investigate this aspect of eucalypt-associated invertebrates. This paper aims only to introduce a planned series of papers on arthropod community structure in *Eucalyptus* forest canopies. However, one immediately evident component of richness is the, as yet unanalysed, seasonal variation in community composition. This component of richness has generally been overlooked by canopy workers, most of whom base their richness counts on a single season of sampling. It was evident from our samples that each season which we sorted always yielded a considerable number of additional species and that this seasonal turnover was a major factor contributing to the high species richness in our samples. We believe that this is an important component of diversity which needs to be considered in future studies and that it is important enough to be considered as a separate component of diversity. We refer to this new component as sigma ($\sigma$) diversity

Using current estimates of between 108,000 and 145,000 species of Australian insects (Taylor, 1983; Nielsen & West, in press), our samples represent some 0.9-1.2% of the total Australian insect fauna. We sampled only four of the 600 or so Australian eucalypt species, sampled only the canopy and sampled only from two extremely localised sites. We thus feel that it is unlikely that we have sampled as great a percentage as this of the Australian insect fauna. This leaves us with no other conclusion than that the number of Australian insect species has been grossly underestimated

Our figures for arthropod species richness are intermediate between the high values for the canopy of tropical forests ( Erwin, 1982, 1983b; Stork, 1987; Basset & Arthington, 1992) and the much lower values for deciduous temperate forests (Southwood et al., 1982a, 1982b). Most contributions to the debate on global arthropod species richness are based on data obtained from the tropics. Limited consideration is given to data from temperate forests. Our data support the statement that Australia is one of the 12 megadiverse countries that together account for 75% of the total biodiversity of the planet (McNeely et al., 1992) and concur with Platnick's (1991) statement that more attention should be given to the temperate regions when estimating global biodiversity. If this were done, it is likely that current estimates of arthropod species richness would be elevated to even higher levels.

The richness of the canopy arthropod fauna from only two sites and four species of eucalypts confirms the need to include a consideration of invertebrates when planning and managing conservation reserves The 1500 or so species which we sampled represent only part of the invertebrate species richness of the forests where we worked.

There were no *a priori* reasons for expecting either site to have a rich canopy invertebrate fauna. Neither forest has a floristically diverse or complex structured canopy. Five species of eucalypt occur on the Scheyville site and four at Karragullen but the two eucalypts sampled on

each area dominate the canopy (>90% of foliage) and understorey vegetation Both forests have a long history of disturbance (e.g., logging, changed fire regimes and, in the case of Scheyville, grazing) and occur on relatively poor soils. Scheyville retains a diverse, albeit depleted avifauna (>70 breeding bird species) (H.F Recher, unpublished data) and prior to European settlement would have had a rich mammal fauna (Recher & Hutchings, 1993). Jarrah forest, of the type represented at Karragullen, has a relatively poor avifauna (about 45 breeding bird species) (H.F.Recher, unpublished data), a feature which is typical of dry, open eucalypt forests.

The Karragullen site is part of a Western Australian State Forest which is managed by the government for timber and firewood production and, as such, is relatively secure from development. As one of the largest remaining fragments of an originally extensive woodland on the Cumberland Plain, Scheyville has been proposed for nature reserve status since the late 1960's. It is also Crown Land (i.e. government owned) but only a small part has been reserved and the remainder has been proposed for development as a housing estate. Failure to reserve the entire area is in part a failure to appreciate the biological richness and in part a consequence of a paradigm that emphasises large, predominantly natural or wild areas with little economic value for nature conservation. Such attitudes do not consider the possibility that invertebrate communities may persist relatively intact or at least retain high species richness, regardless of a history of disturbance and habitat fragmentation. The diversity of the flora and the number of vertebrate species may also not be good predictors of invertebrate species richness. This is particularly so if historical changes to the flora and vertebrate fauna are not considered.

The richness and abundance of canopy arthropods at Scheyville and Karragullen are compelling arguments for the use of broader criteria when planning and managing conservation reserves. Areas such as Scheyville that represent the only remaining fragments of formerly extensive habitats, may retain most of the original fauna, although much of the vertebrate fauna may have become extinct. As such, these areas have considerable conservation value regardless of their size and the lack of wilderness values. The management of more extensive habitats, such as that at Karragullen, needs to consider how management practices, for example prescription burning, affect the whole fauna rather than just the vertebrate fauna.

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## PHOTOGRAPHIC IDENTIFICATION OF STREAM MACRO-FAUNA: A MINIMALLY DESTRUCTIVE SAMPLING TECHNIQUE.

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Sampling of streams typically involves the removal and preservation of fauna for subsequent identification and enumeration in the laboratory (e g. Storey et al., 1990). Such methods, however, might not be appropriate in studies of temporal changes in small stream communities because they alter the composition of the communities under investigation Observed differences in subsequent samples may therefore reflect changes precipitated by earlier sampling activity as well as natural alterations in community structure.

The following method has been developed to identify and enumerate stream macro-fauna from photographs, permitting animals to be released alive after photography. A search of the literature did not reveal any references to this method of sampling stream macro-fauna.

Live specimens are picked from associated debris by hand, placed in a white perspex tray (measuring 14 5 × 10cm with clear perspex sides 2cm high), covered with water and photographed. The base of the tray has been roughened to reduce reflections and a small scale bar glued to one side to permit measurement of animals. An SLR camera fitted with 50mm lens and 12mm extension ring is loaded with ISO 50/188 transparency film. This lens combination produces an image magnification of × 0 25 at which the specimen tray fills the field of view A small cross in the centre of the tray permits rapid alignment and focusing Illumination is by two electronic flash guns (Guide Number 15m @ ISO 100) mounted on small tripods, one at approximately 20cm from either end of the tray and aimed at its centre One flash is synchronised to the camera's shutter via its coaxial socket by a synchronising cable, while the second is automatically discharged by a built-in photovoltaic slave cell when the first is fired Exposure is calculated with an electronic flash meter An aperture half a stop larger than indicated is used to compensate for the light- reducing effect of the extension ring.

Photographic transparencies of the samples are later projected onto sheets of white paper for identification and enumeration of the fauna. At times, to aid identification, it is necessary to view some transparencies under a dissecting microscope with sub-stage illumination

Photographic sampling is being used to study temporal changes in the macro-fauna of pools in small rainforest streams Photographs of animals from several habitats at twelve sites in two streams are taken monthly Examples of species that have not previously been encountered, or that are difficult to identify, are preserved for later comparison with voucher specimens. Thus sampling is not totally without effect on the community, but it is considerably less destructive than it would be if all animals were killed.

Taxonomic resolution obtainable from photographed samples is often not as high as can be achieved from conventional preserved samples This obstacle is considerably reduced when the fauna studied is well known and a reference collection of preserved specimens is available for comparison with photographed specimens In the present study, for example, 64 of the 78 taxa recorded (82%) can be identified to species from photographs and most of the remainder can be identified to genus or family However, the photographic sampling method is not suitable for samples where the animals are not readily separated from associated debris

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