Tree trunk invertebrates in Australian forests: conserving unknown species and complex processes

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ABSTRACT

An ecological survey of tree trunk invertebrates in northern New South Wales was used as a model to demonstrate both the scale of arthropod diversity and the limits of our knowledge. Sticky traps were an effective way of systematically sampling trunk-utilising invertebrates, particularly Diptera, and over 103,000 arthropods in 215 families were caught. This paper discusses sticky-trap methodology, the taxonomic impediment in studying invertebrates beneath family level, seasonal differences in composition and abundance, and rarity. The category "tourist" in arboreal arthropod trophic guilds is regarded as highly misleading, as such taxa are usually local, but simply have their major trophic interaction as larvae. Approximately 75% of the invertebrates caught were soil detritivores during their larval stage. Because invertebrates are so diverse, and our knowledge of their ecological functioning is sketchy, conservation of forest invertebrates depends on maintaining overall forest integrity. Establishing biotic integrity indices that reflect essential ecosystem functioning, such as soil detritivore activity, may provide a useful tool for monitoring forest health.

Key words: tree trunk arthropods, sticky traps, Australian eucalypt forests, arthropod trophic guilds, rare taxa, soil detritivores, invertebrate conservation, Diptera.

Introduction

Terrestrial invertebrates are both abundant and speciose, a fact so often noted in the biological literature as to have become a truism. But what does such diversity mean in reality? In particular, how do we study and gather information about it? Further, how should forest invertebrates be conserved? Should we approach the problem in the same manner as we might to conserve arboreal mammals; do we identify and monitor endangered species and their requirements, or are totally different methods required?

Invertebrates perform many essential roles in ecosystem functioning, and are the "little things that run the world" (Wilson 1987). For example, they are important in the processes of pollination, nutrient cycling, breakdown of organic matter, phytophagy, predation, parasitism, and participate in numerous mutualistic relationships with plants and other animals. A number of studies, such as that of Moldenke *et al.* (2000) on the role of arthropods in recycling soil nutrients (especially the observation that soil is largely composed of arthropod faeces), and that of Williams and Adam (1994, 1999) on the pollination of rainforest trees, provide interesting glimpses into our limited knowledge of this functional complexity.

Taxonomically these invertebrates are also poorly known; Andre *et al.* (2002) estimate that 90% of soil fauna is currently undescribed. Since we know so little, a broad and inclusive approach to invertebrate biodiversity conservation must be adopted, one which will encompass taxa that are both known and unknown. Indeed, the actual taxonomic and life history details of the organisms which perform essential ecosystem services will probably only ever be known in outline.

We approach the topic of conserving invertebrate forest fauna from two different angles in this chapter. First, we provide some results of an ecological survey of tree trunk invertebrates in northern New South Wales as background information. This study is comprehensive enough to reflect both the scale of invertebrate diversity and the limits of our knowledge. We use this survey as a model of forest invertebrate faunas generally, and the following topics are considered: i) taxonomic richness and taxonomic impediments; ii) seasonality; iii) abundance and rarity and iv) functional groups and trophic guilds.

In the second part of the chapter we address some broader aspects of the conservation of Australia's forest invertebrate fauna. Although the sheer diversity and unquantifiability of invertebrates logically dictates a different approach to conservation than that taken for vertebrate fauna, the invertebrate conservation literature still shows an overwhelming focus on the preservation of individual species. Many invertebrate workers have adopted the methods and approaches used in conserving vertebrates and some plants. They focus on species autecology, threatening processes, establishment of reserves, monitoring, legislation, and even captive breeding and reintroduction of species (see general review in New 1995). Frequently targeted terrestrial groups include Lepidoptera (especially butterflies), dragonflies, beetles, orthopteroids, and some snails.

Most of these taxa have relatively large individuals, are well documented taxonomically, are readily observed, or are the specific focus of individual researchers. One cannot deny the cultural appeal of some invertebrates,

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particularly butterflies, and ideally such endangered invertebrates serve as umbrellas to promote habitat preservation or modify inappropriate land use. But in general, the species approach does not address the overall problem of invertebrate conservation, especially the vital roles of invertebrates in ecosystem functioning. In addition, most rare or restricted species (including the rarest of all, the ones we have not encountered) will survive or become extinct with or without our knowledge. The entire scope of invertebrate interactions, which we can only know in outline, is well beyond our current knowledge, and thus our ability to manage in any specific manner. Consequently, in the second part of this chapter, we propose the development of an index of ecosystem 'health' using trunk invertebrates to assess important underlying ecosystem processes.

I. Investigating forest invertebrates and what we might find: a study of tree trunk fauna

Invertebrates utilise the surface of tree trunks in many different ways: i) phytophagy: sucking sap, scouring bark surfaces, chewing bark, association with kino (many Homoptera, thrips, psocids, beetles, lepidoptera larvae); ii) scavenging (mites and ants); iii) predation (cursorial Diptera, wasps, spiders, ants); iv) as a substrate for mating assemblies or leks (many Diptera); v) concealment and protection from predators, especially under bark (nocturnal insects); vi) as a source of hosts for parasitoids (Diptera and Hymenoptera); vii) as a host for subcortical and boring insects (beetles, termites); viii) as a perch or resting place for both habitual and transient fauna; ix) as a pathway to the canopy or nest (ants and termites); x) as the source of specialised microhabitats, such as moist tree holes and epiphytic plants.

Observations and collections from eucalypts just above ground level indicate that bark texture, bole size and aspect may affect the composition of trunk invertebrate faunas. Bark texture, for example affects fly species utilising trunks as lekking arenas, with most lekking taking place on smooth-barked *Eucalyptus* and *Angophora* (Bickel 1986). Bark type also determines the feeding, concealment and predation strategies adopted by epifauna (e.g. Nicolai 1993).

The surface invertebrate fauna of tree trunks has received only superficial study, especially in comparison with rainforest canopies. Apart from casual observation, there have been few studies of invertebrates on tree trunks. Of these, most employed hand collection or aspiration of arthropods off trunks (e.g. Nicolai 1993). In other cases, traps were designed to capture cursorial arthropods moving up and down tree trunks (e.g. Moeed and Meads 1983). A few studies have used a combination of such traps with intercept traps to sample trunk invertebrates (e.g. Majer *et al.* 2002).

Sampling invertebrates for ecological study (as opposed to taxonomic sampling) requires a trapping method that allows replicated and reasonably large samples of the relevant fauna to be collected. Whatever method is used, however, will be biased in some manner depending on the nature of the trap. *Passive* traps (e.g. sticky traps) intercept only moving fauna, *attractive* traps (e.g. yellow pan traps) draw in individuals of certain species by an attractant such as light or pheromones, and *extractive* traps (e.g. Tüllgren funnels) force organisms that avoid the stimulus used (e.g. heat) out of a medium such as soil. Not all associated organisms will be captured; and a specific trap type will sample only a certain component of the fauna.

This study focused primarily on aerial fauna utilising trunks, and sticky traps (clear plastic sheets coated with glue) are ideal for capturing such small invertebrates. Sticky traps are often used to monitor agricultural pests in fields, and by vertebrate ecologists to estimate potential food resources available to birds and small mammals. There have been few studies using sticky traps in large ecological surveys, but a notable exception was an early study by Brues (1933), which documented the modern trunk fauna in Massachusetts for comparison with early Tertiary Baltic amber fauna. One drawback with sticky traps is the frequent poor condition of specimens, and this led the authors of the Biological Survey of Canada handbook (1994) to state, "We do not recommend the general use of sticky traps in biodiversity studies". However, this can be countered by the fact that sticky traps are much easier and cheaper to use than other aerial traps (e.g. Malaise traps), can provide much replication, and therefore a strong basis for statistical analysis. As well, even damaged specimens can be useful for taxonomic study if numerous.

Study Area and Background

The tree trunk invertebrate survey was part of a study on the ecological effects of cattle grazing and associated burning in the eucalypt forests of northern New South Wales (Tasker 2002). Cattle grazing on these poor forest pastures is often accompanied by frequent burning by graziers to promote a flush of new vegetative growth. The impact of these activities on forest ecosystems is rather poorly known, but there is mounting evidence that a regime of frequent, low intensity fires significantly affects forest structure and floristics, and in turn faunal diversity.

The study areas were located on two adjacent plateaux, or sub-regions, at an elevation of 800-1100 m, on the Northern Tablelands of New South Wales (see Fig. 1 in Tasker and Dickman 2004). These comprised the Carrai Plateau in the north, which drains into the Macleay River, and the 'Werrikimbe plateau' to the south, an extension of the tablelands east of Walcha, and part of the Hastings River drainage system. The vegetation of the sites was wet sclerophyll eucalypt forest (see Tasker and Dickman 2004 for details). Twelve sites were established for permanent sampling and were used to test the hypothesis that faunal abundance, diversity, and community composition are affected by a regime of cattle grazing and burning.

Six of the sites had been subjected to cattle grazing and associated burning at roughly 2-5 year intervals over the past century. These *grazed/burnt* sites had a structurally simplified understorey, were dominated by grasses and small herbs, and lacked a mid-storey shrub layer. The other six sites had not been grazed, and had been burnt only infrequently by wildfire. These *ungrazed* sites had a structurally complex multi-layered shrub understorey.

A set of three grazed/burnt and three ungrazed sites were located in both the Carrai and Werrikimbe sub-regions. Replicated flora and faunal surveys and monitoring were undertaken at each of the twelve sites. The faunal surveys comprised small mammal trapping and radio tracking (Tasker and Dickman 2004; Tasker 2002), ground invertebrate pitfall trapping (currently unanalysed) and a tree trunk sticky trap survey (reported here, plus Tasker 2002, Tasker and Bickel, unpublished).

In summary, this trunk sticky trap survey was undertaken to document : i) composition and abundance of tree trunk invertebrate fauna, with minimum identification to family; ii) seasonal variation in composition and abundance; and iii) the impact of grazing and frequent burning, and the consequent vegetation changes, on faunal composition.

Trapping Methods

Sticky traps were placed on the trunks of six trees at each of the 12 sites in spring 1997, summer 1998, and autumn 1998, and at the six Werrikimbe Plateau sites only in winter 1998. Each sticky trap consisted of a clear polyethylene plastic sheet 1 m wide by 0.20 m high (total area = 0.2m^2). Each sheet was stapled to a tree 1.2 metres above the ground (Fig. 1), and painted with Tanglefoot® insect trap coating diluted with mineral turpentine (a solvent which soon evaporated) for easier application. Only mature trees of greater than 1 m circumference at breast height were used, comprising a mixture of smooth and rough-barked *Eucalyptus* species at each site. All traps were placed on the western side of the trunks, to avoid possible confounding effects from differences in aspect, and associated variables such as insolation.

All sites within a sub-region (Carrai or Werrikimbe) were trapped concurrently but, apart from spring 1997, it was not logistically possible to trap both sub-regions concurrently. However, the longest time between trapping the sub-regions was two weeks (summer 1998). After seven days, the traps were detached from the trunks, carefully rolled up and frozen pending further processing. The insects were removed by submerging the traps in a tray of De-Solv-it® orange oil solvent. The specimens were then transferred into 80% ethanol, sorted and identified.

Trap Results

More than 103,000 arthropod specimens in 215 families were obtained from the sticky traps. The biases of the sticky traps were evident (Table 1). Almost 84% of the total catch was Diptera, followed by Hymenoptera at 8.5 %. Clearly these traps favoured small flying insects, as illustrated in Fig. 1. Most specimens drift, fly or jump onto the trap, often with the intent of using the trunk as a resting place. Cursorial taxa, such as small ants, were often captured at the trap edge, but large ants and beetles were observed escaping the sticky margin by pulling themselves free. The sticky traps caught a strikingly different component of the trunk fauna than did the "up and down" traps of both Moeed and Meads (1983) and Majer *et al.* (2002). The principal difference was the overwhelming abundance of Diptera captured while landing directly on the sticky traps, while few such flies were enticed into the funnels of "up and down" traps. At the family level (Table 2), the overall dominance of the Diptera was again evident in the ranking for all seasons combined.

There was no significant difference in the overall abundance of arthropods between grazed/burnt and ungrazed forest in either sub-region, in spring, summer or autumn, although there were large seasonal differences in abundance, with much higher numbers recorded in summer. When the numerically dominant Diptera were excluded, there were significantly more invertebrates in grazed/burnt sites in spring and autumn, in both sub-regions. There was also no significant difference in the number or diversity of invertebrate orders or families between the grazed/burnt and ungrazed treatments, although there were significant differences in the composition of families in all seasons.

That the overall abundance of invertebrates did not differ between grazed/burnt and ungrazed sites may be explained by the moderate nature of grazing and

Table 1. Total count and ranking of orders in the Carrai-Werrikimbe sticky trap study.

Order	Sum of Count	% of Total
Diptera	86 908	83.97
Hymenoptera	8 768	8.47
Coleoptera	2 594	2.51
Homoptera	2 593	2.51
Araneida	1 280	1.24
Collembola	425	0.41
Lepidoptera	245	0.24
Acarina	128	0.12
Isoptera	111	0.11
Heteroptera	103	0.10
Blattodea	94	0.09
Thysanoptera	85	0.08
Neuroptera	59	0.06
Psocoptera	30	0.03
Orthoptera	28	0.03
Phasmatodea	16	0.02
Pseudoscorpionida	11	0.01
Insecta Undet	11	0.01
Geophilomorpha	9	0.01
Plecoptera	2	0.00
Diplura	1	0.00
Dermaptera	1	0.00
Odonata	1	0.00
Amphipoda	1	0.00
TOTAL	**103 504**	**100**

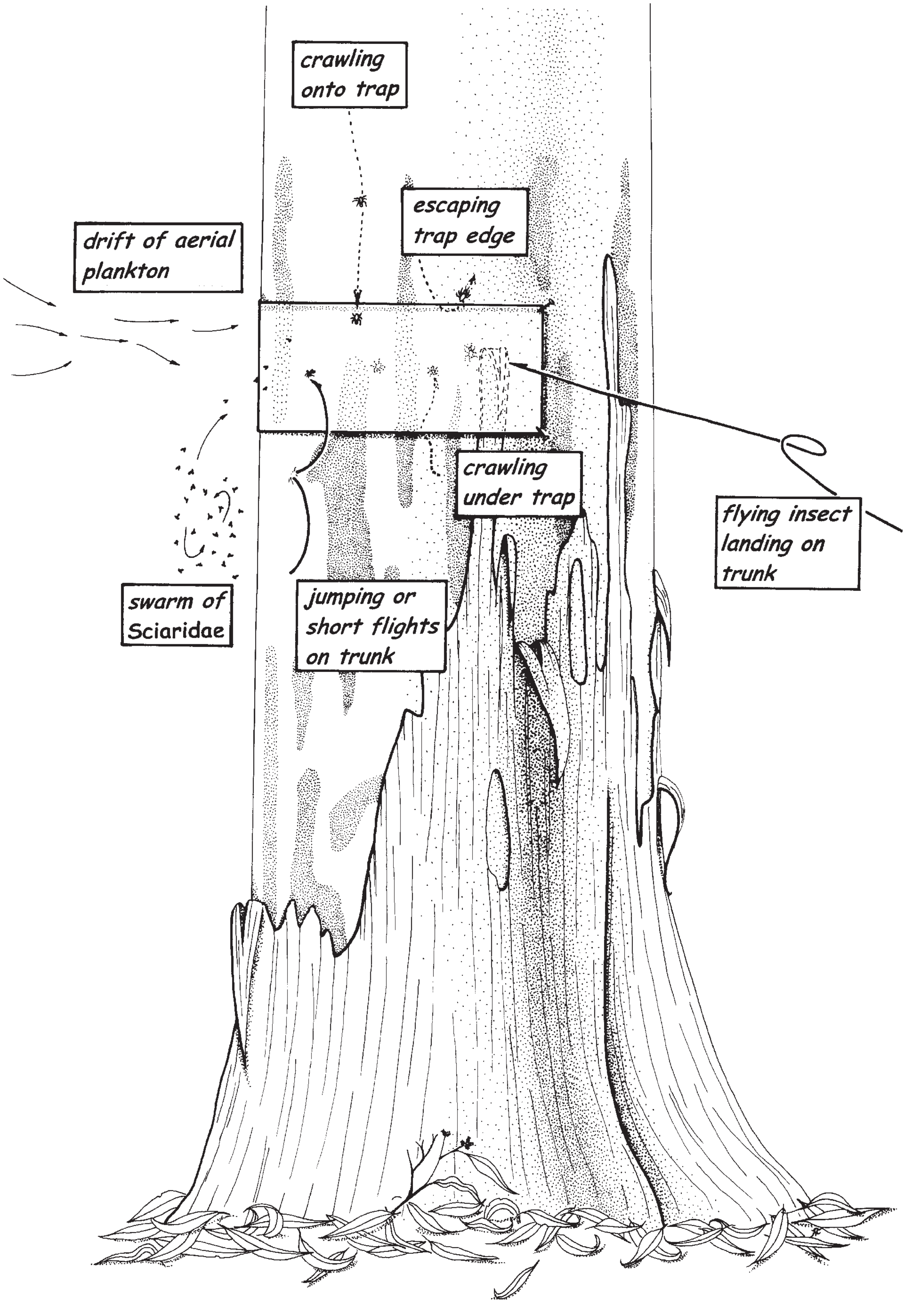

Figure 1. Tree trunk with sticky trap, showing invertebrate interactions.

Table 2. Total count and ranking of families and other taxonomic groupings in the Carrai-Werrikimbe sticky trap study.

Order	Family/ Taxon	Count	% of Total
Diptera	Sciaridae	48 958	47.31
Diptera	Phoridae	14 851	14.35
Diptera	Dolichopodidae	5 494	5.31
Diptera	Mycetophilidae	3 395	3.28
Diptera	Ceratopogonidae	2 583	2.50
Diptera	Chironomidae	2 429	2.35
Diptera	Chloropidae	2 063	1.99
Hymenoptera	Ceraphronidae	1 520	1.47
Diptera	Scatopsidae	1 451	1.40
Diptera	Tachinidae	1 348	1.30
Araneida	Undetermined	1 280	1.24
Diptera	Empididae	1 232	1.19
Homoptera	Cicadellidae	1 170	1.13
Hymenoptera	Pteromalidae	1 110	1.07
Diptera	Cecidomyidae	1 064	1.03
Hymenoptera	Scelionidae	882	0.85
Hymenoptera	Platygasteridae	806	0.78
Homoptera	Homoptera nymphs	791	0.76
Hymenoptera	Braconidae	688	0.66
Hymenoptera	Formicidae	654	0.63
Diptera	Muscidae	594	0.57
Hymenoptera	Bethylidae	482	0.47
Hymenoptera	Diapriidae	449	0.43
Collembola	Undetermined	425	0.41
Coleoptera	Undetermined	392	0.38
Hymenoptera	Encyrtidae	335	0.32
Hymenoptera	Megaspilidae	303	0.29
Hymenoptera	Ichneumonidae	294	0.28
Diptera	Psychodidae	274	0.26
Diptera	Clusiidae	268	0.26
Coleoptera	Elateridae	267	0.26
Homoptera	Derbidae	236	0.23
Hymenoptera	Eulophidae	227	0.22
Diptera	Milichiidae	216	0.21
Coleoptera	Throscidae	205	0.20
Lepidoptera	Undetermined	202	0.20
Coleoptera	Staphylinidae	187	0.18
Hymenoptera	Undetermined	175	0.17
Hymenoptera	Mutillidae	157	0.15
Coleoptera	Phalacridae	149	0.14
Hymenoptera	Sphecidae	132	0.13
Homoptera	Achilidae	131	0.13
Acarina	Undetermined	128	0.12
Coleoptera	Chrysomelidae	115	0.11
Coleoptera	Coccinellidae	112	0.11
Hymenoptera	Undetermined	112	0.11
Isoptera	Termitidae - alates	111	0.11
Diptera	Tipulidae	108	0.10
Homoptera	Psyllidae	107	0.10
Coleoptera	Cavognathidae	105	0.10
Hymenoptera	Mymaridae	104	0.10
Coleoptera	Scydmaenidae	100	0.10
Diptera	Lauxaniidae	95	0.09
Blattodea	Undetermined	94	0.09
Coleoptera	Anthicidae	88	0.09
Coleoptera	Pselaphidae	87	0.08
Coleoptera	Corylophidae	86	0.08
Thysanoptera	Undetermined	85	0.08
Coleoptera	Lathridiidae	84	0.08
Hymenoptera	Formicidae - Alate	84	0.08
Hymenoptera	Trichogrammatidae	79	0.08
Coleoptera	Mordellidae	78	0.08
Diptera	Asilidae	73	0.07
Coleoptera	Melyridae	70	0.07
Hymenoptera	Aphelinidae	59	0.06
Neuroptera	Hemerobiidae	53	0.05
Coleoptera	Scraptiidae	50	0.05
Heteroptera	Undetermined	49	0.05
Diptera	Drosophilidae	48	0.05
Homoptera	Ricaniidae	48	0.05
Diptera	Micropezidae	47	0.05
Coleoptera	Carabidae	45	0.04
Lepidoptera	Lepidoptera larvae	42	0.04
Coleoptera	Cantharidae	41	0.04
Coleoptera	Coleoptera larvae	40	0.04
Coleoptera	Eucnemidae	39	0.04
Diptera	Axiniidae	38	0.04
Coleoptera	Curculionidae	36	0.03
Diptera	Psilidae	31	0.03
Orthoptera	Orthoptera nymphs	28	0.03
Diptera	Pipunculidae	27	0.03
Coleoptera	Salpingidae	26	0.03
Diptera	Ephydridae	26	0.03
Homoptera	Coccoidea	26	0.03
Heteroptera	Lygaeidae	24	0.02
Psocoptera	Undetermined	24	0.02
Diptera	Undetermined	21	0.02
Diptera	Bibionidae	20	0.02
Homoptera	Aphrophoridae	20	0.02
Coleoptera	Mycteridae	19	0.02
Diptera	Platystomatidae	18	0.02
Diptera	Aulacigastridae	17	0.02
Coleoptera	Anobiidae	16	0.02
Coleoptera	Cleridae	16	0.02

Order	Family/ Taxon	Count	% of Total
Homoptera	Eurymelidae	16	0.02
Phasmatodea	Phasmatidae nymphs	16	0.02
Homoptera	Flatidae	15	0.01
Hymenoptera	Apoidea	15	0.01
Coleoptera	Bostrichidae	14	0.01
Coleoptera	Leiodidae	14	0.01
Diptera	Hippoboscidae	14	0.01
Diptera	Calliphoridae	13	0.01
Hymenoptera	Pompilidae	13	0.01
Hymenoptera	Torymidae	13	0.01
Diptera	Stratiomyidae	12	0.01
Diptera	Teratomyzidae	12	0.01
Coleoptera	Colydiidae	11	0.01
Heteroptera	Miridae	11	0.01
Hymenoptera	Eucoilidae	11	0.01
Hymenoptera	Eupelmidae	11	0.01
Pseudoscorpionida	Undetermined	11	0.01
Coleoptera	Aderidae	10	0.01
Coleoptera	Endomychidae	10	0.01
Diptera	Fergusoninidae	10	0.01
Hymenoptera	Chrysididae	10	0.01
Coleoptera	Scirtidae	9	0.01
Coleoptera	Tenebrionidae	9	0.01
Geophilomorpha	Undetermined	9	0.01
Homoptera	Issidae	8	0.01
Coleoptera	Scarabaeidae	7	0.01
Diptera	Periscelididae	7	0.01
Homoptera	Cercopidae	7	0.01
Hymenoptera	Evaniidae	7	0.01
Coleoptera	Lycidae	6	0.01
Coleoptera	Nitidulidae	6	0.01
Coleoptera	Oedemeridae	6	0.01
Diptera	Heleomyzidae	6	0.01
Diptera	Sphaeroceridae	6	0.01
Heteroptera	Aradidae	6	0.01
Homoptera	Cixiidae	6	0.01
Hymenoptera	Eurytomidae	6	0.01
Coleoptera	Bruchidae	5	0.00
Coleoptera	Erotylidae	5	0.00
Diptera	Pyrgotidae	5	0.00
Diptera	Rhagionidae	5	0.00
Diptera	Tephritidae	5	0.00
Hymenoptera	Proctotrupidae	5	0.00
Neuroptera	Coniopterygidae	5	0.00
Coleoptera	Dermestidae	4	0.00
Coleoptera	Melandryidae	4	0.00
Coleoptera	Pyrochroidae	4	0.00
Diptera	Acroceridae	4	0.00
Diptera	Therevidae	4	0.00
Heteroptera	Anthocoridae	4	0.00
Homoptera	Eurybrachyidae	4	0.00
Hymenoptera	Chalcidae	4	0.00
Hymenoptera	Pergidae larvae	4	0.00
Diptera	Anisopodidae	3	0.00
Diptera	Ironomyiidae	3	0.00
Diptera	Syrphidae	3	0.00
Homoptera	Delphacidae	3	0.00
Hymenoptera	Agaonidae	3	0.00
Hymenoptera	Dryinidae	3	0.00
Coleoptera	Attelabidae	2	0.00
Coleoptera	Clambidae	2	0.00
Coleoptera	Cucujoidea	2	0.00
Coleoptera	Lymexylidae	2	0.00
Coleoptera	Sphindidae	2	0.00
Diptera	Dixidae	2	0.00
Heteroptera	Reduviidae	2	0.00
Heteroptera	Thaumastocoridae	2	0.00
Homoptera	Meenoplidae	2	0.00
Hymenoptera	Embolemidae	2	0.00
Plecoptera	Undetermined	2	0.00
Psocoptera	Psocidae	2	0.00
Amphipoda	Talictridae	1	0.00
Coleoptera	Brentidae	1	0.00
Coleoptera	Buprestidae	1	0.00
Coleoptera	Cerambycidae	1	0.00
Coleoptera	Chrysomelidae larvae	1	0.00
Coleoptera	Cucujidae	1	0.00
Coleoptera	Cupedidae	1	0.00
Coleoptera	Ptinidae	1	0.00
Dermaptera	Undetermined	1	0.00
Diplura	Campodeidae	1	0.00
Diptera	Chamaemyiidae	1	0.00
Diptera	Culicidae	1	0.00
Diptera	Platypezidae	1	0.00
Diptera	Scenopinidae	1	0.00
Diptera	Sepsidae	1	0.00
Heteroptera	Cydnidae	1	0.00
Heteroptera	Enicocephalidae	1	0.00
Heteroptera	Pentatomidae	1	0.00
Heteroptera	Schizopteridae	1	0.00
Heteroptera	Tingidae	1	0.00
Homoptera	Aphididae	1	0.00
Homoptera	Machaerotidae	1	0.00
Homoptera	Membracidae	1	0.00
Hymenoptera	Colletidae	1	0.00

Order	Family/ Taxon	Count	% of Total
Hymenoptera	Gasteruptiidae	1	0.00
Hymenoptera	Megalyridae	1	0.00
Hymenoptera	Orussidae	1	0.00
Hymenoptera	Pergidae	1	0.00
Hymenoptera	Perilampidae	1	0.00
Hymenoptera	Signiforidae	1	0.00
Hymenoptera	Tiphiidae	1	0.00
Hymenoptera	Xiphydriidae	1	0.00
Lepidoptera	Nymphalidae	1	0.00
Neuroptera	Mantispidae	1	0.00
Odonata	Aeschnidae	1	0.00
Psocoptera	Amphipsocidae	1	0.00
Psocoptera	Caeciliusidae	1	0.00
Psocoptera	Elipsocidae	1	0.00
Psocoptera	Lepidopsocidae	1	0.00
TOTAL		**103 493**	**100**

burning disturbances at these particular sites. Although the physical structure of the understorey had been much simplified at the grazed sites, there was a well-developed and diverse ground-cover and small shrub layer present. Overall, the sporadic grazing and moderately frequent associated burning appear to have had a relatively minor impact on the overall trunk associated arthropod fauna. Full results, including statistical analyses, can be found in Tasker (2002) and Tasker and Bickel (in prep.).

Taxonomic impediments and orphan taxa

For terrestrial invertebrates, family is the essential minimum taxonomic level for obtaining meaningful life-history and ecological information, especially since insect family groupings are often associated with a specific adaptive radiation and/or feeding strategy. The problem of the "taxonomic impediment", or the difficulty of identifying specimens - sometimes even to family - is often a reason for not using invertebrates in ecological work, or for using only a coarse ordinal level sorting.

In well-studied taxa, species can often be identified with reasonable effort, and any undescribed species assigned at least to an appropriate genus. Only a small percentage of arthropod species, usually those of medical, economic, or cultural interest, have been examined beyond a gross morphological level. The literature for the majority of species comprises only original taxonomic descriptions, and most species are unlikely to be examined further.

An even larger problem though is that of "orphan taxa", groups that have been totally neglected or are without current taxonomists (Janzen and Hallwachs 1994). In many arthropod groups, a taxonomic "impediment" exists at the level of genus, which means specimens cannot be identified much beyond family level. Quite simply, appropriate keys do not exist, old descriptions are unusable, and there are insufficient specialist taxonomists in the world. This problem is not confined to rarely encountered taxa. Some of the most abundant families cannot be identified much beyond family level.

This is certainly the case with the Sciaridae (Diptera), the most abundant family in this sticky trap survey, comprising 48 % of all specimens and the dominant taxon at most sites from all seasons. Sciarids, or dark-winged fungus gnats (Fig. 2), are small, fragile flies that are often seen hovering in mating swarms near tree trunks, hence their abundance in the traps. The larvae feed variously on detritus, rotten wood, fungi, and decaying plant tissue, while the short-lived adults take only nectar or other liquids. In the Australian fauna, some 65 species have been described, mostly by Frederick Skuse between 1888-1890, who placed them in the then vaguely defined type-genus, *Sciara*. There has been little work since and there are no keys to the Australian fauna. By comparison, some 728 species are described for the Palaearctic region, keys are available, and there are several active workers, who estimate the Palaearctic fauna to be nearer 1,100 species (Menzel and Mohrig 1997), not including complexes of cryptic species (i.e. closely related species that are difficult to distinguish). The Sciaridae is an orphan taxon in Australia (as well most of the world), unidentifiable below the level of family. A similar "orphan taxon" status applies to the Phoridae (Diptera), the second most abundant family in the survey, and comprising 14.5% of all specimens.

Within families, published lists of described species are often an artefact of taxonomic effort – not all taxa have been treated equally. Because of the problems associated with species identification, many workers divide their specimens into "morphospecies", informal taxa based on readily recognisable characters. While some morphospecies may indeed correspond to true biological species, the degree of correspondence greatly reflects the skill and experience of the worker. Using morphospecies also does not allow comparison of data between studies or the accumulation of information on particular taxa.

Seasonality

It is well known that season strongly affects invertebrate abundance and activity levels. The insects collected on the sticky traps were predominantly winged adults and, since most undergo complete metamorphosis (egg-larva-pupa-adult), their immature stages are both hidden in a different habitat and usually unidentifiable.

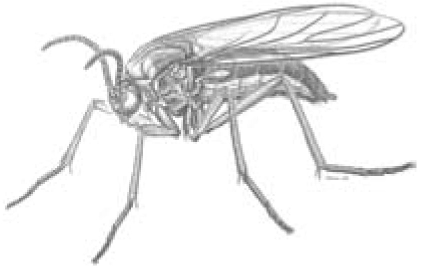

Figure 2. Family Sciaridae, general appearance of female *Sciara* (Manual of Nearctic Diptera, vol 1. Research Branch, Agriculture Canada, Ottawa.).

Such species therefore escape detection over much of the year and cannot be assessed, unlike populations of many vertebrates and vascular plants. Table 3 shows the seasonal abundance and rank of the top families comprising 90% of the fauna in Werrikimbe sub-region. The two most abundant families, Sciaridae and Phoridae, maintain first and second place respectively, throughout the entire year. However, the fourth and fifth-placed families, Chironomidae and Dolichopodidae, show strong seasonality in opposing fashion, with the Chironomidae almost absent (2 specimens) in spring but third in abundance in winter, and the Dolichopodidae are third in spring and almost absent in winter (1 specimen).

Specific life-history events are often seasonal and this was reflected in the traps. For example, all termites (Termitidae, Isoptera) were collected in the January sample, reflecting the synchronous emergence of winged alates, recorded at 8 of the 12 sites. The sticky traps caught only alate termites, because the wingless castes are sub-surface dwellers which thereby escape capture on the trunk surface.

This study shows that sampling in different seasons will give different results, and that to gain a clearer picture of all taxa present at a site – and to detect any differences between control and impacted sites – sampling should be carried out not only at the time of peak invertebrate activity.

Abundance and rarity

The occurrence of families was often highly patchy among the sites, suggesting local microhabitat variation and perhaps the natural patchiness of the organisms themselves. For example, during the January sampling period, the catches of Ceratopogonidae (Diptera) varied among the six trees at one Werrikimbe site to the extent of 20, 21, 29, 32, 499 and 750. In the Sciaridae (Diptera), ten traps yielded more than 1,000 specimens each, and the number on all 252 traps in the study ranged from 4 - 1,800. Similarly, in the Phoridae (Diptera) the number of specimens on all traps ranged from 2 - 613.

Another natural feature of large intact communities – and not necessarily part of any threatening process of human origin – is the rarity of many invertebrates. Although this survey concentrated on family level identification, the distribution of abundances at the family level shows that rarity can be considered at higher taxonomic levels than species. Of the 206 families identified (Table 2), some 38 or 21 % are represented by single individuals which, by definition, are also single species.

Some species are acknowledged to be common, and are regularly found in numbers over a wide geographical area. By contrast, rarity is a more difficult concept to define. Many species are by their very nature "rare", not in a sense that threatens their survival, but that they are infrequently encountered. Such rarity may reflect collecting difficulty, restricted activity period, seasonal vagaries, historical factors, and/or metapopulation dynamics. A species' rarity may also vary considerably through its range (see Murray *et al.* 1999). For insects generally, the fact that identification is based on the winged adult stage means that many species are not seen and cannot be assessed for most of the year. In this sense, holometabolous insects, whose immature stages are both hidden and unidentifiable, may escape detection much of the time.

While some rare species are local endemics, others have wider ranges but with patchy distributions or small

Table 3. The seasonal abundances and guild assignment of families comprising 90% of the trunk invertebrate fauna in Werrikimbe sub-region only.

Overall Rank	Order	Family	Functional Group	Total Abundance	Proportion of total	Spring	Summer	Autumn	Winter
1	Diptera	Sciaridae	detritivore	31 569	49.32	3 109	23 551	1 895	3 014
2	Diptera	Phoridae	detritivore	9 686	15.13	2 978	3 398	1 400	1 910
3	Diptera	Ceratopogonidae	detritivore	2 334	3.65	255	1 965	21	93
4	Diptera	Chironomidae	detritivore	2 148	3.36	2	85	161	1 900
5	Diptera	Dolichopodidae	predator	2 080	3.25	1 714	329	36	1
6	Diptera	Mycetophilidae	fungivore	1 958	3.06	173	316	65	1 404
7	Diptera	Scatopsidae	detritivore	1 366	2.13	84	1 282	0	0
8	Diptera	Chloropidae	various	1 276	1.99	903	264	33	76
9	Hymenoptera	Ceraphronidae	parasitoid	906	1.42	456	371	51	28
10	Diptera	Empididae	predator	829	1.30	542	247	31	9
11	Diptera	Cecidomyidae	various	808	1.26	479	241	66	22
13	Hymenoptera	Pteromalidae	parasitoid	718	1.12	214	447	52	5
14	Homoptera	Cicadellidae	sap-sucker	587	0.92	414	96	52	25
15	Hymenoptera	Platygasteridae	parasitoid	488	0.76	255	219	13	1
16	Hymenoptera	Scelionidae	parasitoid	474	0.74	196	246	20	12
18	Hymenoptera	Formicidae	ants	382	0.60	207	126	26	23
19	Hymenoptera	Braconidae	parasitoid	335	0.52	181	102	46	6

populations. Only long-term trapping will yield such rare and usually undescribed species. This is similar to classical studies of Lepidoptera collected by light traps, where the "veil-line" is continually pushed back to yield additional rare species (Williams 1964). Large samples from complex habitats often contain an abundance of rare species, as defined by singletons. For example, Morse *et al.* (1988) found that as many as 58% of species collected by canopy fogging in Borneo were represented only by single individuals. Novotný and Basset (2000), in a study of herbivorous insects in New Guinea, found in a sample of 27, 000 individuals comprising 606 leaf chewing species collected off *Ficus* and species of Euphorbiaceae, that 180, or 30% were represented by single individuals. They concluded,

> "Rare species are an important part of rainforest communities of insect herbivores. This conclusion is supported even by large samples containing only feeding individuals. Therefore, rare species cannot be excluded from community studies as an artifact or a group of marginal significance. Rather, they should be targeted as an interesting biological phenomenon, albeit one difficult to study."

Functional groups and "tourists"

To discuss functional groups with respect to trunk fauna, we must first review the guild concept based on arboreal canopy arthropods, notably that derived from the initial work by Moran and Southwood (1982). Much of their discussion is also directly applicable to trunk faunas.

Most guild classifications of insects are based on the major feeding stage, the period of greatest trophic interaction with the environment. In most Hemimetabola (insects with incomplete metamorphosis, egg-larva-adult) such as sap-sucking Hemiptera, and in some Holometabola (with complete metamorphosis, egg-larva-pupa-adult) such as leaf feeding beetles (Chrysomelidae), both larvae and adults have similar feeding habits and are associated with the same host. However, in most Holometabola, the larval stages are for feeding and growth only, and usually occupy a totally different microhabitat to the adult. Adults are engaged in mating and dispersal, often taking only nectar and water as nutrition, and thereby having a negligible effect as consumers on the trophic structure. In other words, the real impact is in the larval stage.

Arthropod taxa associated with tree canopies have been classified into ecological guilds (Moran and Southwood 1982, with modifications by Stork 1987). For example, Stork (1987) assigns arthropod families to the following guilds: phytophages (chewers), phytophages (suckers), epiphyte grazers, scavengers, dead wood and fungal feeders, predators, parasitoids, ants, "tourists", and "not known". This classification has a serious anomaly, that of "tourist." Although most of Stork's guilds reflect a specific trophic interaction with the habitat, the term "tourist" implies an accidental intrusion into the study area, i.e. that of a taxon which somehow does not belong there and should not be included in the final analysis. It does not imply the guild is not known, since that is a specific category.

What taxa are included in the "tourist" guild? They are almost all Diptera families, some of which are quite common in canopy catches, such as Phoridae, Drosophilidae, and Chloropidae. The tourist guild is totally inadequate to describe the interactions of Diptera with the canopy. Further, it is anomalous in that it describes a vague "place of origin" while all other guild categories refer to trophic interaction.

Why were so many dipteran families almost *en block* classified as tourists? The exceptions will provide clues to the rule. For example, long-legged flies (Dolichopodidae) are common in canopy catches, but were classified as predators, since they are known to be predacious as both larvae and adults. And yet they do not greatly differ in their overall use of trees as structural habitat from common canopy "tourists" such as the Chloropidae and Phoridae. All these families have their larvae in various substrates, mostly terrestrial or aquatic, and the adults are vagile, apparently not necessarily having strong fidelity to any given tree. In general, many dipteran larvae are classified as "detritivores" and are found in decaying vegetation, fungi and leaf litter. Their actual trophic role may be uncertain, since although they are ingesting detritus, they actually are digesting the yeasts, fungal hyphae and bacterial films on the detritus. Also, many families may not be readily classified, and some comprise a range of larval nutrition: fungivory, gall makers, plant feeders (again they may be feeding on bacteria and yeasts within a plant wound), saprophages and scavengers. Overall, detritivores are more or less equivalent to the category "scavengers, dead wood and fungal feeders" of Moran and Southwood (1982). It is perhaps the unclear nutritional status of some families that led them to be classed as "tourists".

Therefore, with the elimination of the "tourist" concept for routine categorisation of many Diptera families, and the designation of "detritivore" as a more expanded category of trophic interaction, a guild structure of sticky trap catches can be characterised (modified from Moran and Southwood 1982). Of the top 17 families which comprise 90% of all invertebrates caught in the study (see Table 3 for details and Werrikimbe totals), the following guilds are assigned: detritivores - 73.6% (5 families), predators- 4.6% (2 families), parasitoids - 4.6 % (5 families), various – 3.3% (2 families), fungivores – 3.0% (1 family), sap-suckers – 0.9% (1 family), and ants, 0.6% (1 family). The relative abundances are shown in Fig. 3.

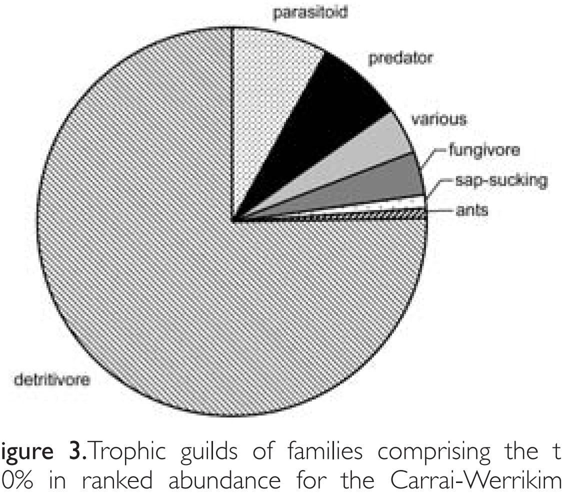

Figure 3. Trophic guilds of families comprising the top 90% in ranked abundance for the Carrai-Werrikimbe sticky trap study.

In summary, approximately 74 % of the sticky trap catch comprised the winged adult stage of larval dipteran detritivores. Most would have originated from the surrounding forest soil and leaf litter. Diptera larvae are an important component of the soil arthropod fauna (see Petersen and Luxton 1982; Moldenke *et al.* 2000). However, few sources in the literature identify soil Diptera larvae much beyond ordinal level, and there is little information on their relative abundances (see André *et al.* 2002, for a critical assessment of soil ecology methodology). However, the following information is summarised from A. Moldenke, *pers. comm*. He confirmed that Sciaridae in Oregon coniferous forests occur in "*vast* numbers in spider webs or any sort of aerial trap." The larvae are basically detritivores which feed preferentially on old "seasoned" coniferous litter and can crush old needles readily.

II. Conservation of forest invertebrates and ecosystem health

The taxonomic and life history details of the organisms which perform essential ecosystem services will probably only ever be known in outline. Therefore, when we talk about conservation of invertebrate forest fauna in the broad sense, what do we actually mean? In one sense, we hope that conservation enables ecosystems to continue functioning in a manner that ensures broad homeostasis, or "ecosystem health".

The term "ecosystem health" is used in the applied ecological literature as a general approach to ecosystem condition. The concept was originally developed for freshwater ecosystems by Karr (1981), who regarded an ecosystem as healthy when "its inherent potential is realised, its condition is stable, its capacity for self-repair when perturbed is preserved, and when minimal external support for management is needed". With respect to the included biota, it is an ecosystem with a "balanced, integrative, adaptive community of organisms having a species composition, diversity and functional organisation comparable to that of natural habitats of the region" (Karr and Dudley 1981).

What then is a healthy forest regarding its invertebrate community and ecosystem functioning, and further, how might we measure it? Biological indicator species or assemblages of species might provide some indication of ecosystem health. Karr (1981, 1991), for example, devised an Index of Biotic Integrity (IBI), a multi-parameter measurement based on fish community attributes which is widely used in North America. Majer and Beeston (1996, and see Majer 2000) developed a "biodiversity integrity index" using the composition of ant communities as indicators of environmental impacts in different Western Australian vegetation types. Similar indices perhaps could be devised for forest communities, based on sampled invertebrate assemblages such as in this study. For example, the relative dominance of certain detritivore families (such as Sciaridae) on trunk sticky traps might be used to indicate "health", especially as a reflection of processes in underlying soil communities.

Such an index of ecosystem health is likely to be particularly useful for assessing the degree and ramification of various types of habitat modification. Invertebrate conservation must be viewed in relation to the landscape matrix, rather than just the limited percentage of land set aside as national parks and nature reserves. Most land is utilised by humans, either extensively or intensively, for forestry, extractive industries, grazing, cropping, habitation, or pavement. Some conservationists often ignore these lands and prefer to concentrate on "natural" or minimally altered habitats. But Recher (2002), in a controversial opinion piece, criticised the conservation movement for focusing almost entirely on forested areas with scenic and recreational values, while virtually ignoring the much greater environmental degradation which continues outside reserves. He stressed the importance of maintaining the ecological health of the "matrix" of land surrounding the reserves. Ultimately, what happens in this matrix will affect life everywhere, including the reserves.

Even small parcels of highly modified land can be important refuges and reservoirs for invertebrates, particularly in highly impacted coastal plains where often these are all that remains. For example, the tiny remaining patches of lowland riverine rainforest along the Manning River, NSW, harbour a rich insect fauna with many endemic species, even though they were previously infested with exotic weeds (Williams 1993; Williams and Adam 1999). Weed removal has allowed spectacular regeneration of these sites, demonstrating their resilience.

There is no simple approach to broad landscape management to ensure that ecosystems (and their essential component invertebrate communities) are not degraded or irreparably damaged. However, we consider that an understanding of how functional groups of invertebrates - such as decomposers - respond to different disturbances will be the way forward to managing and conserving the broad sweep of invertebrate diversity and the relative health of ecosystems. It is the complex of functional relationships, both known and unknown, that must be conserved to ensure the maintenance of healthy forests.

Conclusion

Through the study of one habitat, the surface of tree trunks, this paper has demonstrated some general attributes of forest invertebrates, including taxonomic richness, their importance in ecosystem functioning, the natural rarity of many taxa, and the potential resilience of faunas. More importantly, we show that this is known only in outline - entire faunas and processes exist for which we have only fragmentary glimpses. A means of monitoring overall forest health is needed, perhaps by establishing biotic integrity indices based on critical ecosystem functioning. For example, an index based on detritivore diversity and/or abundance on trunk sticky traps might indicate processes in underlying soil communities and be useful for monitoring the health of highly modified environments. Such understanding will become increasingly important as human modification and clearing of forests is now taking place at an unprecedented rate.

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