A preliminary survey of the insects collected using mushroom baits in native and exotic New Zealand woodlands

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ABSTRACT

The insects associated with the fruiting bodies of macrofungi are an important component of woodland biodiversity. A preliminary survey of the woodland insects associated with macrofungi was undertaken using commercial mushrooms as a standard bait. Adult insects were collected in different categories of woodland (native mixed forest; native *Nothofagus* forest; exotic conifers; restoration/conservation areas) at 17 sites on the South Island of New Zealand. In total, 2429 specimens were collected, consisting of 1282 Coleoptera, 1022 Diptera and 125 Hymenoptera. Several newly-described genera and species of Diptera were recorded, indicating that the use of unconventional collecting techniques such as bait trapping can be useful in augmenting site-species inventories.

Different orders of insects showed different patterns in terms of their abundance and species richness amongst the different categories of woodland. Coleoptera were more abundant and species-rich in native mixed and *Nothofagus* forests than in plantations of exotic conifers, and were very poorly represented in urban conservation/restoration sites. However, Diptera and Hymenoptera were most abundant and diverse in stands of exotic conifers such as *Pinus radiata* plantations and urban conservation sites. The results indicate that monoculture plantations of exotic tree species can compare favourably to native forests in terms of richness and diversity of insect faunas and, although faunistically poor, urban reserves can also play a valuable role in maintaining indigenous invertebrate biodiversity at a local level.

Some species, such as the agyrtid beetle *Zeanecrophilus prolongatus*, were found primarily in native forest, and the occurrence of such species might be utilized as indicators of site quality in remnant patches of woodland.

KEYWORDS

Conservation, Diptera, forests, fungi, parasitoids.

INTRODUCTION

The insects associated with fruiting bodies of macrofungi are an important component of woodland biodiversity and include specialist fungivores, generalist detritivores and their associated predators and parasitoids (Anderson, 2001; Komonen, 2001). These insect assemblages have been used to investigate a range of ecological phenomena, from the effects of temporal priority and niche partitioning on interspecific interactions, to formulating models of spatial aggregation and community assembly (*e.g.* Hanski, 1989; Shorrocks & Bingley, 1994; Worthern *et al*., 1996; Wertheim *et al*., 2000; Takahashi *et al*., 2005). There are many examples of species surveys and attempts to characterize the insect assemblages associated with macrofungi from the UK, mainland Europe and North America (*e.g.* Worthern *et al*., 1996; Law *et al*., 1997; Wertheim *et al*., 2000; Komonen, 2001). However, insect-macrofungus systems appear not to have been investigated to any great depth in New Zealand, either as a model for examining fundamental ecological theories or as the subject of faunal surveys.

Until recently, 'urban' nature reserves in New Zealand had been assumed to be minor contributors to national insect biodiversity because they represented only small land area compared to that of remaining native forest. However, indigenous forest habitat is still being lost and remaining patches can be highly modified, fragmented and distanced from other forest remnants (Ewers *et al.* 2006; Walker *et al*., 2006). So although generally considered poor in terms of total species richness, it has been suggested that urban reserves and forest remnants could play an increasingly valuable role in the conservation of invertebrate biodiversity at a local level (Watts & Lariviere, 2004; see also Keesing & Wratten, 1998). Similarly, systematic surveys of mature plantations of exotic tree species indicate they can sometimes compare favourably to natural woodlands in terms of richness and diversity of insect faunas, and may have a greater role in maintaining indigenous insect biodiversity than was once thought (Brockerhoff *et al*., 2005, 2008; Pierce, 2005).

Habitat-specific assemblages of insects have been used as indicators of site quality in terms of conservation potential: for example, assemblages of saproxylic Coleoptera have been used in the UK to evaluate and rank the quality of relic woodland sites (Harding & Alexander, 1994; Fowles *et al*., 1999). In Scandinavia, insects found on fungal fruiting bodies have been used to evaluate forest site quality and conservation value, and to measure anthropogenic disturbance and habitat fragmentation (*e.g.* Jonsell & Nordlander, 2002; Selonen *et al*., 2005; Jonsson & Nordlander, 2006). The aim of this investigation was to perform an initial assessment of the Coleoptera, Diptera and parasitoid Hymenoptera associated with macrofungi in different categories of woodland in the South Island by collecting adult insects attracted to a standardized bait consisting of rotted commercial mushrooms. A preliminary list of insect taxa is provided and the abundance and diversity of the assemblages in southern beech (*Nothofagus* spp), native mixed forest, exotic conifer and conservation/restoration sites are compared. The potential of fungus-insect assemblages as bio-indicators of the success of conservation efforts, quality of remnant forest fragments and stands of exotic conifers is discussed.

MATERIALS AND METHODS

Field sites

Field sampling was carried out at 17 sites spanning the South Island of New Zealand, following the route from Christchurch through Lewis Pass to Hokitika, south to Hari Hari and then to Banks Peninsula via Arthur's Pass (Table 1). Although not always straightforward, the sites were classified as: native beech forest, native mixed forest, conservation/restoration sites or exotic conifers. Three of the exotic conifer sites consisted of mature stands of *Pinus radiata*, typically with few understory or ground cover plants and dense carpets of needles. The fourth exotic conifer site was an area of managed *Cupressus macrocarpa* trees on farmland, with no sub-story plants and primarily short grass and bare soil at ground level. The Riccarton Bush and Ashgrove Reserves are remnant patches of mature native mixed broadleaf forest, whereas The King George Reserve and Korimoko site are areas of managed restoration, where recent plantings of native species (*e.g.* totara, mahoe, five finger) had occurred prior to the survey.

All the *Nothofagus* sites were within significant areas of well-established, mature forest. Although one species of beech tended to be dominant at each site (Table 1) there was often other species present (*e.g.* red, silver, black, mountain beech). These sites had well established shrub/ground layer vegetation (*e.g.* bush lawyer, lancewood, lemonwood) with considerable layers of leaf litter and quantities of dead wood.

The mixed forests formed a somewhat disparate group, varying from an area of mixed lowland broadleaf-podocarp forest at Okuti Valley to managed rimu wet forest on the West Coast at Mount Hercules (Table 1). These sites had high floral diversity, both in terms of species richness and structural architecture, and possessed various canopy (*e.g.* totara, rata, rimu) and understorey (*e.g.* ponga, kawakawa, lemonwood, mahoe, fuchsia, lancewood) species. There was usually a deep, rich humus/litter layer, with good quantities of fallen/decomposing wood at various stages of decay.

Sampling

To avoid confounding site differences with seasonal differences, all 17 sites were sampled over the same 10-day period during May/June 1998. Traps consisted of translucent plastic lidded containers (9 cm high, 9 cm in diameter) with nine holes of 0.5 cm diameter in the lid. This diameter of hole allows entry of Diptera, parasitoid wasps and most beetles likely to be associated with decomposing fungi. The only group likely to be excluded are large predatory carabids that could consume the rest of the catch. One whole shop-bought mushroom (*Agaricus* sp; ≈ 15-20g) was placed into each plastic container as bait. To make the mushroom baits more odorous - and thus potentially more attractive to insects - their decay was accelerated by spraying them with water and sealing them in polythene bags for one week before use (see Hodge, 1996). The traps were placed on their sides and gently scraped into the soil surface so that the lowest hole was level with the soil surface/leaf litter. Twenty traps were placed out at each site, approximately 20 cm apart in a rough 5 x 4 grid pattern and left in position for one week. On collection, the traps were shaken to knock insects into the base of the cup and then quickly capped with intact lids. The traps were stored at low temperature (3^{o}C) until their contents could be sorted, usually within 48 hours. Sorting was carried out by emptying the contents into a bowl of water and extracting the animals by flotation. The mushroom was then finely dissected to remove insects that had buried into it.

Adult Diptera, Coleoptera, and Hymenoptera were initially identified to family level (sub-family for Staphylinidae) and separated into 'recognizable taxonomic units' (RTUs). More detailed identification was subsequently performed on the Diptera (I.A., S.H.,

Table 1. Classification, location and brief description of field sites.

Class of woodland	Reserve	Coordinates	Notes
Native mixed forest	Okuti Valley, Little River	43°47'07"S, 172°49'53"E	Mixed broadleaf (totara, kawakawa)
	Kellys Creek, nr Arthur's Pass	42°48'10"S, 171°34'27"E	Mixed broadleaf (rata, kamahi)
	Willberg Reserve, Hari Hari	43°09'04"S, 170°33'56"E	Mixed broadleaf (rimu)
	Mount Hercules, nr Hari Hari	43°09'47"S, 170°28'14"E	Managed wet forest (rimu, kahikatea)
Native beech forest	Duggans Creek, nr Maruia Spr.	42°27'03"S, 172°24'13"E	Silver beech
	Maruia Springs	42°22'44"S, 172°19'58"E	Red beech
	Crate Creek, nr Reefton	42°17'00"S, 171°59'48"E	Mixed beech
	Slab Hut Creek, nr Reefton	42°08'02"S, 171°47'48"E	Red beech
	Halpins Creek, Arthur's Pass	42°58'19"S, 171°34'51"E	Black & mountain Beech
Exotic conifers	Balmoral Forest, Culverden	42°49'53"S, 172°48'07"E	*Pinus radiata*
	Quigleys Road, nr Reefton	42°08'02"S, 171°50'02"E	*Pinus radiata*
	Little River, Banks Peninsula	43°46'34"S, 172°47'03"E	*Pinus radiata*
	'Macrocarpa', Banks Peninsula	43°42'31"S, 172°33'53"E	*Cupressus macrocarpa* copse
Conservation sites	Riccarton Bush, Christchurch	43°31'42"S, 172°35'49"E	Large broadleaf native forest remnant
	Ashgrove, Christchurch	43°34'22"S, 172°35'04"E	Small remnant / park land
	King George V, Christchurch	43°33'45"S, 172°39'44"E	Riverside bush restoration site
	Korimoko, Banks Peninsula	43°45'24"S, 172°52'42"E	Restoration site

S.A.M., H.O.), Hymenoptera (J.B.) and some Coleoptera (J.M.).

Data analysis

For each site the mean numbers of individuals and RTUs per trap were recorded for Diptera, Hymenoptera and Coleoptera. Insects exploiting discrete ephemeral resources tend to exhibit highly aggregated distributions and although different resource patches may contain a similar *number* of species they may not necessarily be the *same* species (*e.g.* Worthen *et al.*, 1996; Takahashi *et al.*, 2005). This phenomenon can result in the average number of species found per patch of resource being considerably lower than the regional species richness as measured over an array of patches. Therefore, a measure of regional species richness was obtained using a bootstrap technique to obtain the average number of species likely to be found in any 10 samples of the 20 available at each site (Species Diversity & Richness Software, Pisces Conservation Ltd., UK).

Comparison of woodland classes for numbers of individuals, RTUs and regional species richness was carried out using one-way analysis of variance, with *a posterior* pairwise comparisons carried out by Tukey tests where valid. The data for numbers of individual insects caught at each site were square-root transformed before analysis to improve the normality of residuals.

RESULTS

Comparison of assemblages in different habitat classes

In total, 2429 specimens were collected, consisting of 1282 Coleoptera, 1022 Diptera and 125 Hymenoptera. The numbers of insects collected, and the measures of local and regional species richness all provided at least moderate statistical evidence ($P < 0.075$) of differences occurring among the different categories of woodland (Table 2). However, these patterns were not consistent over the different insect orders. For Coleoptera, more individuals and RTUs were collected in the native mixed and beech forests than in the conservation sites, with the exotic conifer plantations being somewhat intermediate. However, for Diptera and Hymenoptera the assemblages collected in the exotic plantations were, on average, the most populous and diverse, with the conservation sites also having comparable, and sometimes richer, assemblages than the native forests.

Hymenoptera

The Hymenoptera collected were all parasitic wasps, belonging to six species in four families (Table 3a). The majority (92%) of parasitoids were trapped in plots of exotic conifers and, apart from a single specimen caught in the conifer plantation at Quigleys Road, were all collected from eastern sites. The overall collections were highly dominated by a species belonging to, or near, the genus *Trybliographa* (Figitidae) which constituted 96% of the specimens obtained. Of note is that no hymenopterous parasitoids were collected in any of the 100 traps placed out in beech forests.

All the wasp species except *Idris* are dipteran parasitoids. *Aphaereta aotea* Hughes & Woolcock is a native alysiine braconid with hosts recorded from Lonchaeidae, Muscidae and Sarcophagidae (*e.g.* Bishop, 1998). Species of *Asobara* have been reported from Fanniidae, Calliphoridae and Drosophilidae (Berry, 2007) and *Stylaclista* and *Trichopria* are diapriids and also endoparasitoids of dipterans.

Idris is a member of the scelionid tribe Baeini, all of whose members are exclusively spider egg parasitoids. It is likely that this specimen represents an opportunistic catch, although spiders have been found in similar baited traps, possibly because the decomposing resources provide sites of high prey density (Hodge & Vink, 1999, 2007).

Coleoptera

Nine families and 35 RTUs of Coleoptera were collected (Table 3b). The overall catch rate of 3.8 individuals per trap week was comparable to that recorded by Hodge & Jessop (2005) of 3.3 per trap week in a similar survey using mushroom baits in the UK. All of the families collected contain members associated with fungi or moulds, or are commonly associated with other forms of decomposing organic matter such as carrion, dung, leaf litter and rotting wood.

Staphylinidae was the most numerous beetle family, both in terms of individuals collected and RTUs recorded. This diverse group includes many species that are predators or parasitoids of dipteran larvae and they often exploit prey found in decomposing organic resources including decaying fungi (Anderson, 2001). The Aleocharinae were particularly abundant (345 specimens) and diverse (14 RTUs) and were collected at 13 of the 17 sites. However, this common group was not found in any of the urban conservation sites. Conversely, the Omaliinae was the one group of Coleoptera found in all three of the Christchurch reserves but not found in any of the West Coast mixed forests. A single species of Staphylininae was collected that was very abundant at Okuti Valley but not found at any other sites.

Of the other beetle families, five species of Leiodidae were collected and this family was represented in all the woodland classes except the conservation sites. The Nitidulidae had a predominantly eastern distribution, occurring in the mixed forest at Okuti Valley, all three of the eastern exotic sites and in two of the four conservation sites. No nitidulids were found in the mushroom traps set out in the native beech forests.

The most conspicuous beetle collected was the agyrtid *Zeanecrophilus prolongatus* (Sharp). This species is widespread over the South Island and feeds primarily on carrion, although it also occurs on a range of other decaying substances and has been recorded previously on rotten mushrooms (Newton, 1997). It is a forest-dwelling species and in our survey appeared to be more abundant in the western native forest sites. However, one specimen was found in Okuti Valley on Banks Peninsula suggesting this species is likely to be present where suitable habitat is available.

Another notable finding was a species of Scarabaeidae, *Saphobius* sp, which again appeared to have a western distribution. This species was not found in the mixed woodland at Okuti Valley or the more eastern beech forests at Maruia Springs and Duggans Creek. Neither *Z. prolongatus* or the species of *Saphobius* were found in any of the conservation sites, however both were found at Quigleys Road on the west coast, suggesting exotic pine plantations can support these species if they are proximal to suitable habitat (see also Brockerhoff *at al*., 2005; Berndt *et al*., 2008).

Diptera

Forty-seven Diptera RTUs were collected, belonging to 13 families (Table 3c). All of the families collected are associated with decomposing organic matter, including fungal fruiting bodies (Chandler, 1978). Wertheim *et al*. (2000) reared members of all of these families except the Chironomidae from wild fungi in their survey of mycophagous insects in Holland. The majority of the species collected are known to utilize rotting vegetation as an adult feeding resource or as breeding sites, and no predatory species of Diptera were recorded. The site-species data were somewhat patchy: ten of the RTUs were captured as singletons and eight more were recorded from only one site. Thus it is difficult to derive general patterns in terms of associations of specific groups of Diptera with particular classes of woodland or geographic areas.

The most common species was *Zedura curtisi* (Alexander), a species of Trichoceridae, with 293 individuals recorded, although 290 of these were collected at the Quigleys Road pine plantation. *Zedura* were collected at nine sites in total, including all four conservation sites, where the species recorded was *Z. lobifera* (Alexander). Two trichocerid genera, *Asdura* and *Zedura*, have been reared from native fungi collected at the same sites as those sampled in this survey, although adult *Asdura* were not recovered from the *Agaricus* baits (Andrew & Hodge *pers. obs*.).

Mycetophilidae are commonly associated with fungi but only one adult *Mycetophila* was recovered from the mushroom baits, along with four *Zygomyia* sp, all from beech forest. Sciaridae, in particular the introduced *Lycoriella castanescens* Lengersdorf, are often associated with mushroom spoilage (see Macfarlane & Andrew, 2001) but only 17 sciarids were encountered in this survey, of which a single specimen was *L. castanescens*. The others were either endemic species of *Ctenosciara* or unidentified females (Table 3c).

Psychodidae were represented by at least three distinct species. *Psychoda harrisi* Satchell is an abundant species breeding on a wide range of rotting substrates, animal and vegetable, whereas *P. surcoufi* (Tonnoir) is more confined to plant matter. High numbers of *Psychoda* spp. have been reported in

Table 2. Mean numbers of individuals and RTUs per mushroom baited trap and average RTUs per 10 traps in each class of woodland. [F ratio based on oneway ANOVA; a,b separate categories based on Tukey pairwise comparisons at P < 0.05]

		Mixed	Beech	Exotic	Conservation	$F_{3,13}$	P
Hymenoptera	Individuals per trap	0.05^{a}	0^{a}	1.31^{b}	0.38^{ab}	5.9	< 0.01
	RTUs per trap	0.05	0	0.50	0.25	2.9	= 0.07
	RTUs per 10 traps	0.35^{ab}	0^{a}	1.13^{b}	0.26^{ab}	3.9	< 0.05
Coleoptera	Individuals per trap	6.7^{a}	5.2^{a}	3.0^{ab}	0.6^{b}	8.5	< 0.002
	RTUs per trap	2.2^{a}	2.5^{a}	1.3^{ab}	0.4^{b}	9.7	< 0.001
	RTUs per 10 traps	6.2^{a}	8.0^{a}	5.6^{ab}	1.8^{b}	7.4	< 0.005
Diptera	Individuals per trap	0.9	1.2	8.4*	2.1	3.3	= 0.06
	RTUs per trap	0.4^{a}	0.9^{ab}	2.4^{b}	1.2^{ab}	4.5	< 0.03
	RTUs per 10 traps	3.9^{a}	4.3^{ab}	9.4^{b}	4.8^{ab}	3.7	< 0.04

*** - large variation, and hence lack of statistical significance at P < 0.05 level, was caused by 478 individuals (including 290 *Zedura*) being collected at the Quigleys Road site (See Table 3).**

decaying mushrooms in northern hemisphere studies (*e.g.* Frouz & Makarova, 2001).

Twenty specimens of the chloropid *Gaurax flavoapicalis* (Malloch) were collected in traps at Okuti Valley. Chloropidae are generally considered phytophagous, although Wertheim *et al*. (2000) recorded members of this family emerging from naturally occurring fungi and Chandler (1978) lists three species as having been reared from fungi in the UK. Drosophilids are a much-studied component of fungus-insect systems but no drosophilds were found in any of the native woodland sites. *Drosophila busckii* Coquillett is a cosmopolitan species and often associated with fungal resources, whereas *D. immigrans* Sturtevant is a more ubiquitous, somewhat anthropogenic, generalist feeder (Shorrocks, 1972). *Drosophila immigrans* and *D. neozealandica* Harrison have previously been recorded in Riccarton Bush and King George Reserve in traps baited with ripe banana, indicating some generality in their resource use (Hodge & Vink, 1999; see also Harrison, 1959).

All the genera of Heleomyzidae recorded in this study are considered indigenous or endemic (Harrison, 1959). Although this family was quite diverse and widespread, individual species of heleomyzid were often collected at only one or two sites. For example, *Allophylopsis distincta* Tonnoir & Malloch was restricted to sites on Banks Peninsula and 16 individuals of *Fenwickia hirsuta* Malloch were collected in Ashgrove Reserve but not in the other Christchurch sites. *Allophylopsis scutellata* (Hutton) was the most widespread, being found at sites from the West Coast to Christchurch.

Another diverse family was the Sphaeroceridae, the members of which have a general association with decomposing organic matter (*e.g.* Marshall & Brown, 1984; Buck, 1997). *Opalimosina mirabilis* Collin is a polysaprophagous species sometimes associated with mushrooms and was also reported by Marshall and Brown (1984) in their survey of flies attracted to cultivated mushrooms in Ontario, Canada. *Pullimosina heteroneura* Haliday has been reared from a wide variety of substrates and sometimes reaches nuisance proportions in commercial mushroom houses (Marshall, 1985) so its occurrence in mushroom-baited traps is not surprising. Other common, cosmopolitan species taken in the current study include *Telomerina flavipes* (Meigne) and *Ischiolepta pusilla* (Fallen), neither of which were taken by Marshall and Brown (1984). Indeed, we consider most of the sphaerocerid species taken in the current study to be polysaprophagous species, more often associated with decomposing substrates other than fungi. An exception to this was the newly-described species, *Phthitia emarginata* Marshall (Marshall *et al*., 2009): this species has so far only been recorded from the mushroom-baited traps used in this study and was restricted to conservation sites and exotic conifers towards the east of the South Island (Marshall *et al*., 2009). *Phthitia* is a very common genus in New Zealand and is often abundant where there is moist decaying vegetation. However, the only species of *Phthitia* collected in this survey was *P. emarginata*, suggesting that, on the evidence so far obtained, this species may have specialized habits compared to other members of the genus.

The collections of Phoridae also included several new and/or undescribed species. Only one male phorid was collected, possibly pointing towards the attractiveness of this decaying fungal resource to females as an oviposition site. The most numerous phorid was a small undescribed species of the sub-family Phorinae in the newly-described genus *Minicosta* (Brown & Oliver, 2008), with 85 specimens (all female) recorded over six sites (although 65 of these individuals were recorded from Quigleys Road). *Wharia* is another new genus in the Phorinae, previously collected (by H.O.) in a variety of habitats such as forest, open habitats and wetlands (Brown & Oliver, 2008). A single specimen of another new genus was recorded in the beech forest at Slab Hut Creek, also recorded previously (by H.O.) from mature mixed forests on both North and South Island. The species of *Metopina* collected is again likely to be undescribed. Schmitz (1939) described three species in the genus *Triphleba* in New Zealand. However, he never saw a male and there are doubts they actually belong to the worldwide genus *Triphleba*. We could not confidently attribute the 28 specimens we collected to any of the species Schmitz described.

Of the other species of Phoridae collected, *Beckerina polysticha* Schmitz tends to be associated with native forest and *Megaselia impariseta* Bridarolli is probably the commonest phorid in open pasture in New Zealand (Oliver *pers. obs*.); the three specimens obtained include the only male in the collection. Three further specimens in this genus (and sub-genus) collected from the conifers at Little River and Quigleys Road could not be assigned to species. A single *Aphiura breviceps* Schmitz, a species associated with decomposing organic matter, was collected at Balmoral Plantation. Rather paradoxically, only a single specimen of the mushroom fly *Megaselia halterata* Wood was collected. Similarly, Brown and Marshall (1984) found no *M. halterata* in their traps baited with commercial mushrooms in Canada, although they reared it from wild mushrooms nearby, suggesting it might only be attracted to living mushrooms or compost/soil containing living mycelia (see Scheepmaker *et al*., 1997).

DISCUSSION

Although our results represent collections from a one-off preliminary sampling episode, the collections indicate that the insect assemblages associated with fungal fruiting bodies differ considerably between different categories of woodland. There are numerous reports of insect diversity being positively related to floral diversity, and native insects being more frequent in areas containing indigenous vegetation (*e.g.* Crisp *et al.*, 1999; Watts & Gibbs, 2000). Although the Coleoptera were more abundant and diverse in the native woodland sites, some groups, such as the parasitoid Hymenoptera, had greater abundance and diversity in the pine plantations, where the vegetation had low diversity and was dominated by exotic tree species. These Hymenoptera are all native species, and this result reinforces recent findings that these plantations (especially when mature) can provide suitable habitat for indigenous insects (Berndt *et al.*, 2008; Pawson *et al.*, 2008). Other species, such as some species of Heleomyzidae and Sphaeroceridae, were most abundant in the small restoration/remnant sites than in the other classes of forest. As found previously, although these reserves might generally be considered to have low overall species diversity (due to area effects and distance from other habitat patches) they can still provide a valuable refuge for indigenous species at a local level (Godefroid & Koedam, 2003; Watts & Lariviere, 2004).

Our results indicate caution should be employed if using summary assemblage data (such as abundance, species richness, diversity indices) to evaluate site quality, as the choice of insect order used would greatly affect what conclusions might be drawn. From our data, the most useful indicators of site quality appear to be the presence of individual species, such as the conspicuous native beetles *Zeanecrophilus prolongatus* and *Saphobius,* which were consistently recorded in the native forest sites, and also in mature stands of pines near to native forest edge. The occurrence of these species in the urban forest remnants or restoration sites would likely represent a good indication of site quality.

Another factor relevant to the faunistic surveying of small nature reserves, or sampling invertebrates on sites where populations of rare or endangered species are present, is that it is often undesirable to use broad-spectrum, lethal monitoring techniques, such as pitfalls and Malaise trapping, where large numbers of superfluous individuals are likely to taken (Bowie *et al.*, 2006). If feasible, techniques aimed at catching only certain indicator taxa or functional groups should be encouraged. With this form of baited-trap technique most specimens are captured alive and unwanted individuals could be released if the samples were sorted in the field. Also, the insects can escape the vessels if they persist, and any consistent and repeatable association that occurs with particular baits can be inferred to provide additional information on the species' habits and natural history.

Over 20 species of *Agaricus* occur naturally in New Zealand, although most species are associated with pastures/grassland habitats rather than forest (Mitchell & Walter, 1999). The use of commercially-produced mushrooms has obvious advantages when attempting to standardize field surveys, examine seasonal patterns of insect activity and for use in any controlled laboratory investigations that follow on from field observations (Bingley & Shorrocks, 1995). However, the use of mushroom baits does not provide detailed information on specific fungus-insect associations, and using *Agaricus* baits could limit the catch to those species able to utilize this class of fungi. Any native species of New Zealand fungi that are produced commercially would provide interesting alternative – or complementary – baits for comparison.

The fungal floras in the different categories of woodland are likely to differ quite considerably, as many species of forest fungi are associated with only a narrow range of tree species or require rotting wood of a certain age and/or stage of decomposition (*e.g.* McKenzie *et al.*, 2000; Hood *et al.*, 2004; see Selonen *et al.*, 2005). More well-defined insect-fungus associations can be investigated by rearing insects from naturally-occurring fungi but our initial attempts at this process were not successful as the fungi rapidly liquefied and the insect larvae quickly drowned (Hodge & Andrew, *pers. obs.*). This seems a common occurrence (Wade Worthern *pers. comm.*; Steve Hartley *pers. comm.*) but some success can be achieved in rearing adult insects from fungal bodies with the use of compost or coir fibres to soak up the excess liquid (Wertheim *et al.*, 2000; Webb, 2007). The insect fauna occurring on naturally occurring fungi may be very different from that collected on our mushroom baits, and rearing from wild fungi would provide a means of comparing the two. Additionally, rearing insects from mushrooms exposed to natural insect populations in the field would also help determine which species use the fungi as an adult feeding resource and which use it as a breeding site. Although larvae were not an object of this study, the finding of larval Trichoceridae and Psychodidae in the mushroom baits indicates that at least these dipteran families had used the mushroom for breeding within the short time they were exposed in the field (Andrew & Hodge *pers. obs.*)

This study has provided a list of insect taxa associated with decomposing *Agaricus* fruiting bodies, and identified differences in the insect assemblages in different categories of New Zealand woodland. As many of the Coleoptera species collected are predatory, further work is required to clarify the trophic networks that might occur within the fungus resource patch, and also identify any specific relationships between the hymenopterous parasitoids and the various species of dipteran larvae. The methodology could be extended to examine ecological phenomena such as the sequential arrival of insects on decomposing fungi and in a broader context to investigate processes such as the effects of logging, forest fragmentation and patch size on fungus-insect associations (*e.g.* Jonsson & Norlander, 2006). The results verify that the use of somewhat alternative collecting techniques such as baited traps can result in more well-defined functional assemblages of insects being recorded, help to extend site-species inventories and provide useful additional information on the natural history of the species observed.

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Table 3. Numbers of (*a*) Hymenoptera, (*b*) Coleoptera and (*c*) Diptera collected in one week using mushroom baited traps at 17 woodland sites across South Island. [KE – Kellys Creek; HE – Mount Hercules; WG – Willberg Reserve; OV – Okuti Valley; CR – Crate Creek; DU – Duggans Creek; MA – Maruia Springs; HA – Halpins Creek; SH – Slab Hut Creek; LR – Little River; MC – 'Macrocarpa' copse; BA – Balmoral; QU – Quigleys Road; KO – Korimoko; AS – Ashgrove Reserve; RC – Riccarton Bush; KG – King George V Reserve]

(a)

			Mixed				Beech					Exotic				Conservation				
Order	Family	Taxon	KE	HE	WG	OV	CR	DU	MA	HA	SH	LR	MC	BA	QU	KO	AS	RC	KG	Total
Hymenoptera	Braconidae	*Aphaereta aotea* Hughes & Woolcock	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	1
		Asobara sp	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1
	Figitidae	Nr. *Trybliographa* sp	-	-	-	3	-	-	-	-	-	42	16	44	-	-	-	-	15	120
	Diapriidae	*Stylaclista* sp	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	1
		Trichopria sp	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	1
	Scelionidae	*Idris* sp	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	1
	Total		**0**	**0**	**0**	**4**	**0**	**0**	**0**	**0**	**0**	**42**	**18**	**44**	**1**	**0**	**0**	**1**	**15**	**125**

b)

			Mixed				Beech					Exotic				Conservation				
Order	Family	Taxon	KE	HE	WG	OV	CR	DU	MA	HA	SH	LR	MC	BA	QU	KO	AS	RC	KG	Total
Coleoptera	Agyrtidae	*Zeanecrophilus prolongatus* (Sharp)	18	126	93	1	20	8	10	6	34	-	-	-	4	-	-	-	-	320
	Corylophidae		-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	1
	Hydrophilidae		6	-	11	-	4	-	8	-	-	-	-	-	3	-	-	-	-	32
	Leiodidae	(5 RTUs)	-	14	7	10	13	13	15	-	12	30	-	-	14	-	-	-	-	128
	Mycetophagidae		-	-	-	2	-	-	-	-	-	-	2	1	-	-	-	-	-	5
	Nitidulidae	(4 RTUs)	-	-	-	7	-	-	-	-	-	9	2	3	-	-	1	2	-	24
	Ptiliidae	(3 RTUs)	-	1	-	1	3	-	6	-	-	-	-	1	-	-	-	-	-	12
	Scarabaeidae	*Saphobius* sp	23	30	49	-	42	-	-	10	45	-	-	-	2	-	-	-	-	201
	Staphylinidae	Aleocharinae (14 RTUs)	-	9	17	47	10	77	67	20	37	17	4	5	34	1	-	-	-	345
		Omaliinae (2 RTUs)	-	-	-	4	5	2	-	1	28	93	3	2	11	-	4	6	14	173
		Oxytelinae (1 RTU)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	-	-	9
		Staphylininae (1 RTU)	-	-	-	32	-	-	-	-	-	-	-	-	-	-	-	-	-	32
	Total		**47**	**180**	**177**	**104**	**97**	**100**	**106**	**37**	**156**	**149**	**11**	**12**	**68**	**1**	**15**	**8**	**14**	**1282**

(c)

			Mixed				Beech					Exotic				Conservation				
Order	Family	Taxon	KE	HE	WG	OV	CR	DU	MA	HA	SH	LR	MC	BA	QU	KO	AS	RC	KG	Total
Diptera	Anisopodidae	*Sylvicola notata* (Hutton)	-	-	-	-	-	3	-	-	-	1	-	-	1	-	1	-	-	6
	Anthomyiidae	*Anthomyia punctipennis* (Weidemann)	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	1
	Calliphoridae	*Calliphora hilli* Patton	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	2
		Xenocalliphora sp	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
	Chironomidae	sp1	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	3
	Choropidae	*Gaurax flavoapicalis* (Malloch)	-	-	-	20	-	-	-	-	-	-	-	-	-	-	-	-	-	20
	Drosophilidae	*Drosophila busckii* Coquillett	-	-	-	-	-	-	-	-	-	4	32	-	-	-	-	-	-	36
		Drosophila immigrans Sturtevant	-	-	-	-	-	-	-	-	-	36	21	-	-	-	-	-	-	57
		Drosophila neozealandica Harrison	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	6	7
	Heleomyzidae	*Allophylopsis distincta* Tonnoir & Malloch	-	-		-	-	-	-	-	-	6	-	-	-	24	-	-	-	30
		Allophylopsis fulva (Hutton)	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	3	3
		Allophylopsis scutellata (Hutton)	1	-	1	2	1	3	-	-	-	-	-	-	-	-	-	9	-	17
		Fenwickia claripennis Malloch	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	1
		Fenwickia hirsuta Malloch	-	1	-	1	-	-	-	-	-	-	-	-	-	-	16	-	-	18
		Xenura picata (Hutton)	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	1
	Mycetophilidae	*Mycetophila* sp	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	1
		Zygomyia sp	-	-	-	-	1	-	1	2	-	-	-	-	-	-	-	-	-	4
	Phoridae	*Aphiura breviceps* Schmitz	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	1
		Beckerina polysticha Schmitz	-	-	-	-	-	10	-	-	-	1	-	-	-	-	-	-	-	11
		Megaselia halterata (Wood)	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	1
		Megaselia impariseta Bridarolli	-	-	-	-	-	-	-	-	-	-	-	1	-	2	-	-	-	3

Table 3 Continued

	Megaselia sp3	-	-	-	-	-	-	-	-	-	2	-	-	1	-	-	-	-	3
	Metopina sp	-	-	-	-	-	-	-	-	-	-	2	3	-	-	-	-	-	5
	Minicosta sp	-	-	-	2	1	8	1	-	8	-	-	-	65	-	-	-	-	85
	'Nodifera' sp	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	1
	Phorinae sp	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	2
	Triphleba sp	-	-	-	2	4	1	2	2	4	-	-	3	8	-	1	1	-	28
	Wharia sp	-	-	-	24	-	-	-	-	-	-	-	-	-	-	-	-	-	24
Psychodidae	*Psychoda harrisi* Satchell	-	1	1	1	-	5	10	1	-	-	22	-	50	4	2	-	-	97
	Psychoda surcoufi Tonnoir	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1
	Psychoda sp3	-	-	-	-	17	-	-	-	14	1	1	4	-	-	-	-	-	37
Sciaridae	*Ctenosciara* sp1	-	-	-	-	-	-	-	-	-	-	-	-	1	-	2	-	-	3
	Ctenosciara sp2	-	-	-	1	-	-	-	-	-	-	-	1	-	-	-	-	-	2
	Lycoriella castanescens (Lengersdorf)	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	1
	spp unknown	-	-	-	-	-	-	-	-	-	-	-	7	4	-	-	-	-	11
Sphaeroceridae	*Biroina* sp	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-	2
	Coproica hirticula Collin	-	-	-	-	-	-	-	-	-	-	3	2	-	-	-	-	-	5
	Ischiolepta pusilla (Fallen)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1
	Minilimosina glabrigena Marshall	-	-	-	-	-	-	-	-	-	-	5	-	-	-	-	-	-	5
	Minilimosina knightae (Harrison)	-	-	-	1	1	-	-	-	10	-	-	-	56	-	-	-	-	68
	Opalimosina mirabilis (Collin)	-	1	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	2
	Phthitia emarginata Marshall	-	-	-	-	-	-	-	-	-	1	4	1	-	35	1	-	6	48
	Pullimosina heteroneura (Haliday)	-	-	-	-	-	-	-	-	-	-	4	-	-	-	-	-	-	4
	Telomerina flavipes (Meigne)	-	-	-	3	-	-	-	-	-	5	9	7	-	-	-	-	-	24
Trichoceridae	*Trichocera annulata* Meigen	-	-	-	-	-	-	-	-	-	-	-	2	-	-	1	-	-	3
	Zedura curtisi (Alexander)	-	-	-	-	2	-	1	-	-	-	-	-	290	-	-	-	-	293
	Zedura lobifera (Alexander)	-	-	-	3	-	-	-	-	-	2	-	-	-	16	1	19	1	42
Total		**1**	**4**	**3**	**64**	**28**	**30**	**18**	**5**	**37**	**59**	**104**	**35**	**478**	**82**	**27**	**30**	**17**	**1022**