AN OVERVIEW OF THE TERRESTRIAL INVERTEBRATES IN THE VICTORIAN NORTH CENTRAL REGION

NICK G. COLLETT[1,3] & ALAN L. YEN[2]

[1]Department of Forest and Ecosystem Science, The University of Melbourne,
500 Yarra Blvd, Richmond, Victoria, 3121.
[2]Department of Primary Industries, 621 Burwood Highway, Knoxfield, Victoria, 3180.
Email: alan.yen@dpi.vic.gov.au
[3] Current Address: Department of Primary Industries, 621 Burwood Highway,
Knoxfield, Victoria 3180. Email: nick.collett@dpi.vic.gov.au

COLLETT, N.G. & YEN, A.L., 2010. An overview of the terrestrial invertebrates in the Victorian north central region. *Proceedings of the Royal Society of Victoria* 122(2): 100-110. ISSN 0035-9211.

Invertebrates are the dominant faunal group in most terrestrial habitats. They play important roles, often incompletely understood, in maintaining essential ecosystem services. Despite the enormous environmental changes to the North Central Region of Victoria since European settlement, and despite the lack of information about how these changes affected the native invertebrate fauna, it is not too late to include invertebrates in the management and restoration of native habitats in the region. This paper provides an overview of our understanding about terrestrial invertebrates in the region, and provides some suggestions on how to elevate the profile and utility of invertebrates in conservation management.

Key words: North Central Victoria; invertebrates; insects

THE invertebrate fauna inhabiting terrestrial ecosystems in Australia is abundant, diverse, and fulfils a variety of ecological roles (Austin et al. 2004). Invertebrates include over 1.2 million described species alone encompassing over 95% of all described animal species on Earth (IUCN 2008). They represent the overwhelming majority of species in forest and other terrestrial ecosystems and thereby comprise a significantly major component of ecosystem biodiversity (Schowalter 2000; Taylor & Doran 2001). Invertebrates are functionally diverse and contribute to ecological processes by facilitating nutrient cycling, pollination, seed dispersal, soil aeration, food sources for higher level animals, and by acting as biological control agents (Seastedt 1984; Wilson 1992; Packham et al. 1992; Taylor & Doran 2001). These processes are essential to maintaining sustainable ecosystem processes. Any changes in the absolute and relative invertebrate abundance and alteration or loss of some or all of these processes may result in ecosystem collapse, adjustment of invertebrate contributions to critical processes or simplification of processes that are subsequently maintained by exotic or more common species, with resultant loss of biodiversity (Seastedt 1984; Schowalter 2000). Maintaining invertebrate biodiversity is in some respects an 'insurance policy' to allow adaptation to environmental change, whether human-induced or the more subtle changes associated with climate change.

Very few parts of Victoria have had the benefit of having substantial inventories conducted of their terrestrial invertebrate fauna prior to large-scale change being imposed following European settlement. The main exceptions are the Victorian Mallee regions (Yen et al. 2006), East Gippsland, the Central Highlands and the alpine regions, where the impacts have either been minimal or thinly spread across the terrain. The North Central region, especially within the regionally characteristic Box-Ironbark forests, underwent massive changes associated with vegetation clearance and gold mining long before any consideration was given to systematic invertebrate surveys being conducted (Yen & Hinkley 1997). The once widespread Box-Ironbark forests are now restricted to small non-contiguous areas within national parks and other protected areas, surrounded by exotic pastures, land cleared for other agriculture or other human disturbed areas. These remnants also typically suffer from the loss of a major structural component, namely large old trees (Mac Nally et. al. 2000), which are substantial habitats for invertebrates.

This paper will review current knowledge of invertebrate fauna of the North Central region and attempt to determine whether it has been adversely or otherwise affected by past and present land use practices. It is hoped this review will both provide direction and highlight knowledge gaps in our understanding of the invertebrate fauna of this region and how we can use this information to adapt to future changes in both land use and climatic settings.

CURRENT KNOWLEDGE STATUS

Historical and Collections Data

A characteristic of biological studies in Australia is that environments developed after European settlement were heavily disturbed before any sort of systematic inventory was undertaken. This was the case with Victoria's lowland grasslands, with the enormous changes associated with agriculture and grazing in the western basalt plains (Barlow & Ross 2001), and in the areas where alluvial gold was found, enormous vegetation clearance and soil disturbance occurred. Consequently, any information on invertebrates within the North Central region is based on anecdotal observations by settlers and field naturalists. Examples include: invertebrates (Halford Hennell 1890); beetles and moths (Anderson 1891); molluscs and butterflies (Billinghurst 1893, 1895); beetles and butterflies (Best 1898); moths and butterflies (Haase 1900); beetles (Paton & Daley 1922); and spiders (Perry 1952). The vast majority of quantitative scientific research has been in the last 30 years, and in many cases it has involved research focused on heavily disturbed environments.

Museum collections are one source of information about invertebrates collected within the region. Museum Victoria has 862 species of arachnids and insects listed as having type specimens from within the North Central region. This list is dominated by beetles (316 species), flies (154), moths (154) and bees, wasps and sawflies (105). Based on collection specimen records, the Museum Victoria Bioinformatics database also lists 71 species of butterflies from the region: Hesperiidae (17 species); Lycaenidae (24); Nymphalidae (20); Papilionidae (4); and Pieridae (6). This database is based on a 1.5° x 1° grid system, and the North Central region fits into 18 grids (although it should be noted the grid boundaries and the boundaries of the North Central region do not correspond precisely at the edges). When the number of grids within which each butterfly species has been recorded was determined: 17 species were found in only one grid, 16 in 2 grids, 10 in 3 grids, 9 in 4 grids, 2 in 5 grids, 7 in 6 grids, 5 in 7 grids, 3 in 8 grids, 2 in 9 grids, and 3 species were found in more than 9 grids. The most widespread species in terms of number of grids was the introduced vegetable pest Cabbage White butterfly, *Pieris rapae rapae*.

The ultimate aim of invertebrate biologists is to be able to identify specimens in their group of interest and relate their abundance and distribution to habitat condition. For the North Central region, this has been attempted with ants, although this information is not readily accessible (Hinkley, unpublished data; Horrocks & Brown 2008; Yen, unpublished data). At least one regional identification guide has been published for spiders (Shield 2001).

Surveys and Research

The surviving forest remnants are highly disturbed habitats and present fundamental problems for use in baseline studies of invertebrate fauna in the region. Such studies or data that do exist are generally based on historical information collected by field naturalists, by type insect specimens residing within museum collections, and through research conducted for specific land use purposes such as impacts of fuel reduction burning on litter invertebrates, pest invertebrates of native forests and plantations and the impact of Box-Ironbark regeneration on litter invertebrates (Collett 2001, 2003; Yen & Hinkley 1997). All these studies were generally conducted on an individual needs basis, with little coordination between them. Nonetheless, despite the paucity of data and other relevant information as well as the problems involved in obtaining reliable baseline information, it is important we attempt to understand whether these land-use change processes have impacted adversely or otherwise on the invertebrate fauna of the North Central region. We discuss the extant data drawn from natural landscapes, agricultural landscapes and land managed for forestry.

(a) Natural Environment. The Victorian Government review of the Box-Ironbark forests during the 1990s led to the first broad scale invertebrate survey in the region (Environment Conservation Council 1997). However, as this was restricted to Box-Ironbark forests, other vegetation types were not included, so the

regions's remnant northern plains grasslands and the River Red Gum forests, for example, were not assessed. In this survey, pitfall trapping (9 cm diameter) of ground active invertebrates was undertaken at 80 sites, all of which were located in Box-Ironbark forests (although not all of these sites were in the NCCMA region). The invertebrates were identified to the higher taxonomic level (orders), and the most abundant group, the ants, were identified to species. A total of 37 orders was caught in the pitfall traps, and the main invertebrate orders by species richness, were Hymenoptera (ants); Coleoptera (beetles); Diptera (flies) and Hemiptera (bugs). Ants were the dominant group, representing over 55% of all individuals collected and a total of over 200 species (Yen & Hinkley 1997). While ants dominated the sites, species composition was highly variable, with only one species of *Rhytidiponera* found in all 80 sites and 164 species found in less than 10% of the sites.

One of the recommendations of the Environment Conservation Council study (ECC 1997) resulted in the creation of new parks within the Box-Ironbark forests, and part of this involved an experiment to ascertain the effects of thinning of selected trees to promote faster growth of larger trees (Pigott et al. 2010). As with the earlier invertebrate survey, this study involved pitfall trapping of ground-dwelling invertebrates (although traps of 2 cm diameter were used). A total of 26 invertebrate orders was collected, with six groups dominant: ants (Hymenoptera), springtails (Collembola), mites (Acarina), beetles (Coleoptera), spiders (Araneae) and flies (Diptera). Once again, ants dominated the fauna, representing around 70-80% of all individuals at most sites if springtails were excluded, and a total of more than 100 species. The dominant ant genera were *Rhytidiponera* (represented by only one species), *Iridomyrmex* (six species but dominated by *Iridomyrmex* spp. 1 and 3), *Monomorium* (eight species, with dominance by *Monomorium* spp. 1, 2 and 4), *Pheidole* (three species, all in large numbers), *Melophorus* (five species, dominated by *Melophorus* spp. 1, 2 and 3), *Doleromyrma* (one species), *Crematogaster* (three species) and *Notoncus* (four species, dominated by *Notoncus* spp. 1 and 2).

An indication of the relationship between ants found within the North Central region and other parts of Victoria can be gleaned when the compositions of the functional groups are compared. Data are available from the drier Mallee region (Andersen 1984) and a wetter open forest at Wilsons Promontory (Andersen 1986). The results of these papers suggest that the Box-Ironbark forest is intermediate between the drier and wetter environments.

In an ecological thinning study undertaken between 2004-2007 in Box-Ironbark forests, correlations were sought with invertebrate order data (number of orders, total abundance, abundance of individual orders) and ants (ant species richness and ant total abundance). Significant correlations were found with five key environmental factors: Litter depth is significantly correlated with seven invertebrate groups, coarse woody debris (CWD)<10 cm diameter with three invertebrate groups, CWD>10 cm diameter with six invertebrate parameters, understorey cover with five invertebrate groups, and understorey richness with four invertebrate parameters. Surprisingly, despite the large number of ant species collected, there were no significant correlations with any other factors except ant abundance with CWD >10 cm diameter. The results indicate that for some invertebrate orders, the structure of the ground layer (litter area, litter depth and CWD) is important in providing suitable habitat. Understorey cover and richness may influence ground layer invertebrates through provision of shade, but they can also be an important source of leaf litter and CWD (Palmer et al. 2010). There were also several significant correlations between ordinal and ant data and environmental factors. These included significant correlations with litter area, litter depth, CWD (both <10 and >10 cm in diameter), understorey plant cover and richness. The number of invertebrate orders whose abundance was correlated with litter or CWD factors indicates the importance of these ground elements for invertebrates. Management of these factors, either through controlling timber harvesting or fire, could have a significant effect on the development of the ground dwelling invertebrate fauna, and this is a management area that requires careful consideration and planning (Palmer et al. 2010).

Invertebrate studies in vegetation types that were not Box-Ironbark forests include grassy-woodlands and native grasslands. Yen et al. (1996) conducted a survey of remnant blocks of grassy-woodland dominated by River Red Gum *Eucalyptus camaldulensis* Dehnh. or Grey Box *E. microcarpa* Maiden in the northern plains. This study involved several different collecting methods, so the range of invertebrates collected was greater than in the pitfall trap surveys discussed earlier. Ward et al. (2002) examined the beetle data from this survey in greater detail and 342 morphospecies from 46 families of beetles were found.

While pitfall trapping caught the greatest number of families (72%), morphospecies (56%) and specimens (50%), direct searching and sweep netting yielded a large number of morphospecies not caught by pitfall trapping. Horrocks and Brown (2008) conducted an ant survey of the Korrak Korrak Grassland Reserve, a small area of native grassland owned by Trust for Nature that has never been cultivated. The results of pitfall trapping showed that ants were the numerically dominant arthropod present, and a total of 51 ant species from 17 genera were recorded from pitfall traps. Opportunistic searching yielded an additional two species.

(b) Agriculture. Much of the region was developed for grazing or cropping very early after European settlement. This involved the clearance or selective destruction of native vegetation, resulting in either monoculture systems of exotic plants or a mixture of remaining native plants with exotics. The effect on native invertebrates would have varied according to the ecosystem changes and to their dependence on habitat factors. For example, loss of native plant species could have seen the loss of plant-species-specific insects such as herbivores and pollinators. More generalist native invertebrates capable of surviving in simplified habitats or able to feed on a wider range of plant species could also increase in abundance. The latter includes native insect herbivores that used exotic agricultural plants. Conversely, introduced exotic invertebrates would have affected remnant native vegetation. Agriculture has also seen the introduction of 'beneficial' invertebrates for biological control (parasitoids of plant-feeding insects), and decomposers (such as dung beetles and earthworms). Control of agricultural pests includes use of insecticides, with potential adverse effects on non-target invertebrates. The greater use of herbicides to control weeds may have adverse effects on invertebrates. A recent study showed that herbicides caused metabolic stress in a species of earthworm (Rochfort et al. 2009) although the longer-term effects on earthworm function are not known.

The integration of native vegetation (remnants, shelterbelts, roadsides) with production systems could be seen as potentially both conflicting and complementary: native plants are seen as habitat for potential crop pests such as insects and birds, yet on the other hand, they can act as a habitat for beneficial invertebrates and vertebrates (Yunusa et al. 2002). Opportunities also exist to use insects and birds in integrated pest management to the benefit of agricultural systems. Sislov (1998 cited in Yunusa et al. 2002) gives examples of birds feeding on insects, and suggests that the use of native plants to provide resources to beneficial invertebrates could reduce pests such as Light-brown Apple Moth *Epiphyas postvittana*, Apple Dimpling Bug (*ampylomma liebknechti*; Elephant Weevil *Orthorrhinus cylindrinostris* and the Two Spotted Mite *Tetranychus urticae*.

(c) Forestry. In terms of quantitative studies within forestry, most have concerned three main areas, namely: (1) the impacts of fuel reduction burning on litter invertebrates in dry sclerophyll eucalypt forests; (2) pests of exotic softwood and native hardwood plantations; and (3) pest complexes within remnant native forests in the region. Following the devastating 1983 Ash Wednesday fires, multidisciplinary studies were established within the Wombat State Forest south of Daylesford to examine the impacts of repeated fuel reduction burning on a variety of terrestrial groups including invertebrates. Research by Neumann and Tolhurst (1991) and Collett (1998, 1999, 2003) covered fire impacts on a range of ordinal invertebrate groups, while Collett and Neumann (1995) and Neumann et al. (1995) conducted more detailed research into fire effects on individual species level taxa following on from the findings of the initial ordinal level studies. Softwood and hardwood plantation research has focused specifically on pest issues causing mortality at the initial plantation establishment phase and damage causing loss of incremental growth in the first three years after planting (Farrow et al. 1994; Floyd et al. 1994; Neumann & Collett 1997a, b; Collett & Neumann 2002), while past studies in native forests have focused predominantly on damaging pest outbreaks, particularly by psyllid *Cardiaspina* spp. and the gumleaf skeletoniser *Uraba lugens* in River Red Gum *Eucalyptus camaldulensis* forests lining the major waterways of the region including the Murray River (Harris 1972; Harris et al. 1977; Collett 2001). As previously indicated, this research, particularly within plantations and native forests, was generally in response to specific pest issues rather than as part of a coordinated ongoing regional research strategy. The fire effects study however, could be viewed in a more regional and statewide context as the findings have potential application not only within the north central region, but in other forest types also affected by fire.

HOW MAJOR ENVIRONMENTAL CHANGES HAVE AFFECTED THE INVERTEBRATE FAUNA

As previously acknowledged, the lack of adequate, or indeed in most cases, any pre-existing baseline data, makes it difficult to determine first the extent to which any change has occurred, or second if a change has occurred at all. Consequently the following discussion is based upon predictions from the broader scientific knowledge of the effects of habitat changes in invertebrates.

Habitat changes

No doubt the first major change to the north central region after European settlement was native vegetation clearance, either associated with grazing, or other forms of agriculture or with gold mining. Vegetation clearance immediately removed the habitat of plant-dependent invertebrates (herbivores and their associated natural enemies and plant pollinators) because of the loss of both overstorey and understorey plants. This has flow-on effects: first, reduced resources to flower-feeding species including pollinators; and second, loss of food for ground and soil active plant decomposers. The removal of large trees and the lack of replacement also mean that there is little CWD of larger diameters acting both as habitat and as a food source.

While some areas were not subjected to wholesale clearance, fragmentation can have more subtle but equally detrimental effects on invertebrates. The extent of these effects depends upon the size and shape of the fragments, and the dispersal abilities of the invertebrates. Invertebrates with low dispersal powers left in small sized remnants could decline over time due to inbreeding depression. Other factors that influence plant physiology, such as the effects of long-term drought on flowering, can also result in pollinator decline if the pollinators are unable to disperse to find floral resources.

Gold mining has had obvious effects through loss of vegetative cover and often the areas that were heavily mined have effectively no top soil. This loss occurred very early in the gold rush, and therefore it is likely that the associated soil fauna was also lost during this initial stage. The slow rate of plant growth in these areas means that the natural system of organic input from plants to the ground layer is also very slow. Consequently the area is characterised by a lot of bare ground on exposed rocks and very thin litter layers.

Agriculture (in terms of grazing and cropping) has resulted in a simplified habitat often dominated by exotic plant species. Amongst other things, it has profoundly modified the indigenous vegetation both structurally and in plant species composition. Depending on the type of agriculture and the management undertaken, invertebrates can be affected by: (1) simplification of habitat; (2) a more gradual loss (compared to rapid loss during mining) of top soil (through erosion); (3) addition of artificial fertilisers; (4) introduction of exotic invertebrates; and (5) increased use of pesticides and its detrimental effects on non-target groups and selection for pesticide-resistant biotypes in the target pests.

As previously indicated, the lack of baseline data in the region makes it difficult to place change in context. In terms of changes in hydrology regimes, however, available information suggests that the shallow-rooted pasture plant species which have replaced forests following clearing are less effective in removing moisture from the sodic subsoils. The deep percolation of water has resulted across the region in the raising of groundwater tables, leading to saline discharges in lower parts of the landscape, accounting for increased stream salinity, and increased salinity of bore water used for plant and tree irrigation (Dyson & Jenkin 1981; Bren et al. 1993; Baker et al. 1994). With increasing water volumes moving through the soil in cleared regions, soluble salts have been more effectively leached through to the underlying bedrock groundwater system, leading to situations where cleared lands may contain up to half the salts present in adjacent forested areas (Dyson & Jenkin 1981). However, the range of soil types across the region makes it difficult to ascribe a single hydrological regime as typical across the region.

Threatened invertebrate species

The sometimes poor knowledge of invertebrates in the region makes it highly likely that past land management regimes and practices may have resulted in species declining and/or disappearing without our knowledge of their existence and subsequent decline.

The North Central region has nine Victorian *Flora and Fauna Guarantee Act (1988)* listed species of invertebrates. These include five species of butterflies (Large Ant Blue *Acrodipsas brisbanensis*, Fiery Jewel *Hypochrysops ignitus ignitus*, Icilius Blue *Jalmenus icilius*, Southern Purple Azure *Ogyris genoveva araxes,* Eltham Copper Butterfly *Paralucia pyrodiscus lucida*), two species of moths (Sun Moth *Synemon theresa*, Golden Sun Moth *Synemon plana*) and two species of ants (*Myrmecia* sp. 17, *Peronomyrmex bartoni*). The Golden Sun Moth is also listed under the Commonwealth *Environment Protection and Biodiversity Conservation Act (1999)* as Critically Endangered. For most of these species, habitat loss, degradation and fragmentation is listed as the cause of decline (Webster 1992; Jelinek & White 1996; O'Dwyer et al. 2000; Douglas 2003). Virtually nothing is known about the ant *Peronomyrmex bartoni* except that it is very rare: this species is known only from two individuals (Shattuck & Hinkley 2002). On the positive side, the Eltham Copper Butterfly has been recorded in new locations at Castlemaine and at Bendigo in recent years (Canzano et al. 2007; J. Barker, pers. comm. 2010).

DISCUSSION

The lack of baseline information on the invertebrate fauna of the north central region means that many environmental management decisions impacting upon invertebrates (when invetebrates are even taken into consideration) are made based on some assumptions including:

(1) The high number of invertebrate species means that the loss of some species may not adversely affect ecological processes. We do not know how many species can actually be lost without adverse effects on these processes, but certain functions (such as plant species-specific pollinating species) will be affected with the loss of one species.

(2) Vegetation communities are an adequate and effective surrogate for invertebrates. Mac Nally et al. (2002) showed that Box-Ironbark forest Ecological Vegetation Communities (EVCs) are not good surrogates of most animal groups. It is assumed that the fauna associated with vegetation communities is the same throughout the range of those communities; this does not consider the spatial species turnover of diverse groups such as invertebrates where the invertebrate species composition may be very different within the same vegetation community.

(3) As long as ecological processes are maintained, it does not matter if it is an exotic species that performs the function. Exotic species have been introduced to increase productivity without assessing possible long-term effects, such as honeybees for pollination, earthworms for soil fertility, biological control agents and dung beetles.

Knowledge gaps and future directions for invertebrate research

The following highlights some of the current knowledge gaps, and potential future research directions to address invertebrate issues in the north central region.

(1) Important remnant habitats. There is an urgent need to study invertebrates within good quality remnants representative of significant habitats in the region, such as older Box-Ironbark forests (with large old trees), and the Northern Plains grasslands. There are also some larger less disturbed areas in the western parts of the region that require study. While many environments have been permanently lost or altered, protection of the best remnants will require inventories of selected groups of invertebrates, and an adequate understanding of ecological processes for maintenance and restoration of these systems. Remnant older forests are important because they provide the opportunity to assess the invertebrate fauna and associated processes in systems with larger old trees, larger coarse woody debris, and more leaf litter. This information is important to assist with restoration aims. As an example, there is virtually no information currently available regarding Northern Plains grasslands invertebrates on which to base ongoing management programs, highlighting the requirement of such information. However, some important and high quality remnants may only survive in small remnant reserves such as roadside, rail and other reserves, and these will require studying with a greater emphasis on their longer term viability because of their greater vulnerability.

(2) Habitat gaps. Invertebrate fauna studies in the region have involved primarily ground active species (predominantly collected using pitfall trapping means only) and pests of agricultural or forest systems. There is a dearth of knowledge on the canopy faunas of overstorey and major understorey plants, especially eucalypts and wattles. Furthermore, the loss of topsoil in the gold digging regions means that we have little understanding of the role of invertebrates in nutrient cycling in those environments, an important component of studies examining ecosystem restoration.

(3) Significant invertebrate groups. There is an urgent need for an increased understanding of the role of functionally significant invertebrate groups such as the termites, where little information exists on the role this important group plays in the region. While there have been several ant studies, there is a need to establish a uniform identification (voucher) system for ants in order to more effectively utilise and manage data (both past and future). The oecophorid moths, very important in decomposition of eucalypt leaves, also require us to develop a more detailed understanding as to their role. Finally, we also need a greater understanding of processes affecting threatened invertebrate species, in order to develop monitoring programs and management systems to facilitate more selective and effective conservation management.

4) Ecological interactions. Further research is required on a number of significant ecological interactions such as those between the invertebrate fauna of overstorey and understorey plants (both of which are important for habitat and food). For example, some species may live in the overstorey at certain times of the year and rely on understorey resources at other times as driven by different flowering times or the availability of prey resources.

The invertebrate fauna of the canopy is generally not well known in the region except for production forestry in the region. River Red Gum elsewhere has a very rich and diverse canopy invertebrate fauna (Yen et al. 2002). Such studies are required in the north central region to more accurately assess richness of canopy invertebrate fauna, while more work is also required on the saproxylic fauna as little is known about this fauna due to the destruction of large older trees.

In terms of ecological linkages between flowering plants, insects and birds, the following illustrate some ecological interactions requiring examination to facilitate greater understanding of such processes in the region. The following are examples that illustrate the dependence of vertebrates on invertebrates: (1) Regent Honeyeater *Xanthomyza phrygia*. Insects are a necessary dietary component, especially during breeding, are gleaned from foliage and bark, and also taken in flight (Menkhorst 2003); (2) Brush-tailed Phascogale *Phascogale tapoatafa* are arboreal mammals that forage for predominantly large insects, spiders and centipedes, on the trunks and major branches of rough-barked trees and fallen logs. Eucalypt nectar may be taken when ironbarks or boxes are flowering (Humphries & Seebeck 2003); (3) Use of invertebrates by hollow-dependent vertebrates (Alexander 1997): Powerful Owl *Ninox strenua*, Brush-tailed Phascogale *Phascogale tapoatafa*, Squirrel Glider *Petaurus norfolcensis*, Barking Owl *Ninox connivens*, and (4) In Terrick Terrick National Park, Michael (2001) noted the importance of spider burrows as habitat for some lizards.

(5) Effects of land use. The way in which different intensive land uses affect invertebrates requires assessment in order to develop more ecologically sustainable practices that benefit both native biodiversity and farm productivity. This includes the processes within production systems (crops, grazing lands, production forests), as well as adjacent remnant native vegetation. While there is considerable support for revegetation (restoration) projects, there needs to be a clear picture of what the aims of such programs are for invertebrates, and how they can be achieved without unforeseen adverse consequences. For example, while revegetation involving corridors is seen as beneficial for native biodiversity, if not planned or implemented correctly they can act as corridors for the movement of pests and diseases.

(6) Effects of introduced invertebrates and pest management. The effects of deliberately or accidentally introduced invertebrates on native flora and fauna requires urgent assessment. While the European Honeybee *Apis mellifera* is now naturalised in Australia, there is ongoing discussion and controversy about its environmental effects, especially with reference to management of feral bee colonies (Paton 1996; Paini 2004). One aspect of pest management practices that requires immediate attention is the inappropriate use of chemicals to control these feral colonies. There are not only issues with the residues and other associated longer-term consequences, but also, the impact of their inappropriate use on non-target groups, especially on beneficial invertebrates.

(7) Effects of fire on invertebrates. A recent review by Tolsma et al. (2007a,b) of fire and associated fauna issues in the north central region found that research into the effects of fire on invertebrates is often confounded by high natural variability, and it is often difficult to determine the pre-European climax community involved in such settings. Furthermore, such studies are generally only in response to meeting the needs of sometimes strict ecological and/or manage-

ment parameters and generally applicable within a relatively narrow range of situations and land use types. Studies by Collett (1998, 1999, 2003) and Collett and Neumann (1995) have established some tentative baseline data concerning burning frequency and seasonal impacts, as well as potential key indicator invertebrate taxa. However, more research is required on lower taxonomic levels (i.e. genus and species), as well as into the effects of fire on termites, known to be key drivers of secondary productivity in these forests.

(8) Climate change. All the above issues have the significant potential to be affected by future climate change. Climate change has the ability to break synchronous relationships (such as pollinator-flower relationships, parasitoid-host relationships), and also affect the population dynamics of different invertebrate species, resulting in either the range expansion or contraction of invertebrates. The impacts of climate change on native and exotic pest complexes is also little understood, requiring the ongoing development of surveillance and predictive modelling tools to quantify their impacts more accurately.

(9) Understanding and acceptance of invertebrates. While there is a lot to be done to raise our understanding of invertebrates to a level where this can be effectively used in management decision-making in the region, there are a few priorities that require immediate consideration. Firstly, known important 'bioindicator' groups representative of broader invertebrate taxa need to be selected and routinely used in land management decisions. However, for this to be effective, there is a need to standardise collecting/monitoring techniques, as well as the initial selection of suitable indicator species. Secondly, the invertebrates of good quality remnant habitats need to be assessed in order to assist determination of restoration targets and baselines (i.e. establishing invertebrate benchmarks). Finally, the profile of invertebrates needs to be raised with the key message that only a very small percentage are potential pests and that the vast majority of species in the region are essential and important in maintaining ecosystem services.

It is evident that there are still major knowledge gaps for the terrestrial invertebrates in the north central region of Victoria. These gaps inhibit the management of the ecological systems in the region. Invertebrates represent the most substantial, if not the key faunal component of terrestrial ecosystems and they need to be considered when issues such as reserve management, habitat restoration and development decisions are under discussion. The future challenge is determining how much knowledge of invertebrates is essential to make these decisions and to prioritise the required research for resourcing.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the assistance of Dr Ken Walker, Museum Victoria, for information on type species of insects and Bioinformatics data base information on butterflies.

REFERENCES

Alexander, J.S.A., 1997. Threatened hollow-dependent fauna in Box-Ironbark forests of Victoria Bendigo Forest Management Area. Department of Natural Resources and Environment Victoria Forests Service Technical Reports 97–3, 39 pp.

Andersen, A.N., 1984. Community organization of ants in the Victorian mallee. *The Victorian Naturalist* 101: 248-251.

Andersen, A.N., 1986. Patterns of ant community organization in mesic southeastern Australia. *Australian Journal of Ecology* 11: 87-97.

Anderson, F., 1891. Club excursion to Macedon. *The Victorian Naturalist* 8: 52-54.

Austin, A.D., Yeates, D.K., Cassis, G., Fletcher, M.J., La Salle, J., Lawrence, J.F., McQuillan, P.B., Mound, L.A., Bickel, D.J., Gullan, P.J., Hales, D.F. & Taylor, G.S., 2004. Insects 'Down Under' – Diversity, endemism and evolution of the Australian insect fauna: examples from select orders. *Australian Journal of Entomology* 43: 216–234.

Baker, T., Bail, I., Borschmann, R., Hopmans, P., Morris, J., Neumann, F., Stackpoole, D. & Farrow, R., 1994. Commercial tree-growing for land and water care 2: Trial objectives and design for pilot sites. A report to the Trees For Profit Board, Centre for Forest Tree Technology, Melbourne, 33pp.

Barlow, T.J. & Ross, J.R., 2001. Vegetation of the Victorian volcanic plain. *Transactions of the Royal Society of Victoria* 113: xxv-xxviii.

Billinghurst, F.L., 1893. Notes on the land and freshwater Mollusca of Castlemaine. *The*

Victorian Naturalist 10: 61-64.

BILLINGHURST, F.L., 1895. The fauna of Castlemaine district – butterflies. *The Victorian Naturalist* 12: 91-93.

BEST, D., 1898. Notes of a visit to Logan. *The Victorian Naturalist* 15: 35-38.

BREN, L., HOPMANS, P., GILL, B., BAKER, T. & STACKPOLE, D., 1993. *Commercial tree-growing for land and water care 1: Soil and groundwater characteristics of the pilot sites.* A report to the Trees For Profit Board, Centre for Forest Tree Technology, 46pp.

CANZANO, A.A., NEW, T.R. & YEN, A.L., 2007. The Eltham Copper Butterfly *Paralucia pyrodiscus lucida* Crosby (Lepidoptera: Lycaenidae): Local versus State conservation strategies in Victoria. *The Victorian Naturalist* 124: 236-242.

COLLETT, N.G., 1998. Effects of two short rotation prescribed fires in autumn on surface-active arthropods in dry sclerophyll eucalypt forest of west-central Victoria. *Forest Ecology and Management* 107: 253-273.

COLLETT, N.G., 1999. Effects of three short rotation prescribed fires in spring on surface-active arthropods in dry sclerophyll forest of west-central Victoria. *Australian Forestry* 62(4): 295-306.

COLLETT, N.G., 2001. Biology and control of psyllids, and the possible causes of defoliation of *Eucalyptus camaldulensis* Dehnh (River Red Gum) in south-eastern Australia – a review. *Australian Forestry* 64(2): 88-95.

COLLETT, N.G., 2003. Short and long-term effects of prescribed fires in autumn and spring on surface-active arthropods in dry sclerophyll eucalypt forests of Victoria. *Forest Ecology and Management* 182: 117-138.

COLLETT, N.G. & NEUMANN, F.G., 1995. Effects of two spring prescribed fires on epigeal Coleoptera in dry sclerophyll eucalypt forest in Victoria, Australia. *Forest Ecology and Management* 76: 69-85.

COLLETT, N.G. & NEUMANN, F.G., 2002. Effects of simulated chronic defoliation in summer on growth and survival of blue gum (*Eucalyptus globulus* Labill.) within young plantations in northern Victoria. *Australian Forestry* 65(2): 99-106.

DOUGLAS, F., 2003. Five threatened Victorian Sun-moths (*Synemon* species). *Flora and Fauna Guarantee Action Statement No. 146.* Department of Sustainability and Environment, Victoria: East Melbourne, 11 pp.

DYSON, P.R. & JENKIN, J.J., 1981. *Hydrological characteristics of soils relevant to dryland salting in central Victoria.* Soil Conservation Authority Report October 1981, 28pp.

ENVIRONMENT CONSERVATION COUNCIL, 1997. *Environmental Conservation Council Box-Ironbark Forests and Woodlands Inverstigation Resources and Issues Report*. Environment Conservation Council, Fitzroy.

FARROW, R.A., FLOYD, R.B. & NEUMANN, F.G., 1994. Inter-provenance variation in resistance of *Eucalyptus globulus* juvenile foliage to insect feeding. *Australian Forestry* 57: 65-68.

FLOYD, R.B., FARROW, R.A. & NEUMANN, F.G., 1994. Inter- and intra-provenance variation in resistance of red gum foliage to insect feeding. *Australian Forestry* 57: 45-48.

HAASE, J.F., 1900. A lepidopterist at Gisborne and Macedon. *The Victorian Naturalist* 17: 22-24.

HALFORD HENNELL, E., 1890. Notes of a collecting trip to Pyramid Hill. *The Victorian Naturalist* 7: 92-95.

HARRIS, A.J., 1972. The Effect of Flooding on Population Density of Gum leaf Skeletonizer moth, *Uraba lugens* Walker, in Barmah State Forest. Forests Commission, Victoria Research Branch Report No. 25.

HARRIS, J.A., NEUMANN, F.G. & WARD, B., 1977. An Outbreak of the Gum Leaf Skeletonizer, *Uraba lugens* Walker, in River Red Gum Forest Near Barmah. Forests Commission, Victoria Research Branch Report No. 87.

HORROCKS, G. & BROWN, G., 2008. The ant fauna of the Korrak Korrak Grassland Reserve, north-western Victoria. A report to the North Central Catchment Management Authority. Arthur Rylah Institute for Environmental Research, Department of Sustainability and Environment, Heidelberg. 25 pp.

HUMPHRIES, R. & SEEBECK, J., 2003. Brush-tailed Phascogale *Phascogale tapoatafa*. *Flora and Fauna Guarantee Action Statement No. 79.* Department of Sustainability and Environment, Victoria, East Melbourne, 10 pp.

IUCN, 2008. International Union for the Conservation of Nature (IUCN) Red List of Endangered Species – Table 1. Numbers of threatened species by major groups of organisms (1996-2008). http://www.iucnredlist.org/documents/2008RL_stats_table 1 vl223294385.pdf

Jelinek, A. & White, M., 1996. Large Ant-blue Butterfly *Acrodipsas brisbanensis*. *Flora and Fauna Guarantee Action Statement No. 70.* Department of Sustainability and Environment, Victoria, East Melbourne, 6 pp.

Mac Nally, R., Bennett, A.F., Brown, G.W., Lumsden, L.F., Yen, A.L., Hinkley, S., Lillywhite, P. & Ward, D., 2002. How well do ecosystem-based planning units represent different components of biodiversity? *Ecological Applications* 12: 900-912.

Mac Nally, R., Bennett, A.F. & Horrocks, G., 2000. Forecasting the impacts of habitat fragmentation. Evaluation of species specific predictions of the impact of habitat fragmentation on birds in the Box-Ironbark forests of central Victoria, Australia. *Biological Conservation* 95: 7–29.

Menkhorst, P., 2003. Regent Honeyeater *Xanthomyza phrygia*. *Flora and Fauna Guarantee Action Statement No. 41*. Department of Sustainability and Environment, Victoria, East Melbourne, 8 pp.

Michael, D.R., 2001. *Vertebrate fauna in a semi-arid grassland at Terrick Terrick National Park, Victoria: distributions, habitat preferences and use of experimental refuges*. Honours thesis, Faculty of Science and Agriculture, Charles Sturt University, 133 pp.

Neumann, F.G. & Collett, N.G., 1997a. Insecticide trials for control of the steelblue sawfly (*Perga affinis affinis*), a primary defoliator in young commercial eucalypt plantations of south-eastern Australia. *Australian Forestry* 60(2): 75-83.

Neumann, F.G. & Collett, N.G., 1997b. Insecticide trials for control of the Autumn Gum Moth (*Mnesampela privata*), a primary defoliator in commercial eucalypt plantations prior to canopy closure. *Australian Forestry* 60(2): 130-137.

Neumann, F.G. & Tolhurst, K., 1991. Effects of fuel reduction burning on epigeal arthropods and earthworms in dry sclerophyll eucalypt forest of west-central Victoria. *Australian Journal of Ecology* 16: 315-330.

Neumann, F.G., Collett, N.G. & Tolhurst, K., 1995. Coleoptera in litter of dry sclerophyll eucalypt forest and the effects of low-intensity prescribed fire on their activity and composition in west-central Victoria. *Australian Forestry* 58(3): 83-98.

O'Dwyer, C., Hadden, S. & Arnold, A., 2000. Golden Sun Moth *Synemon plana*. *Flora and Fauna Guarantee Action Statement No. 106*. Department of Sustainability and Environment, Victoria, East Melbourne, 7 pp.

Packham, J.R., Harding, D.J.L., Hilton, G.M. & Stuttard, R.A., 1992. *Functional Ecology of Woodlands and Forests*. Chapman Hall, London.

Paini, D.R., 2004. Impact of the introduced honey bee (*Apis mellifera*) (Hymenoptera: Apidae) on native bees: A review. *Austral Ecology* 29: 399-407.

Palmer, G., Brown, G., Gibson, M., Pigott, P., Tolsma, A., Wainer,. J. & Yen, A., 2010. Box-Ironbark Ecological Thinning Trial: Integrated Analysis and Projected Changes. *Parks Victoria Technical Series No. 58*. Parks Victoria, Melbourne.

Paton, D,. 1996. *Overview of the Impacts of Feral and Managed Honeybees in Australia*. Australian Nature Conservation Agency, Canberra.

Paton, D.J. & Daley, C., 1922. Excursion to Bendigo. *The Victorian Naturalist* 38: 86-88.

Perry, W., 1952. Communal spiders. *The Victorian Naturalist* 69: 23.

Pigott, J.P., Palmer, G.P., Yen, A.L., Tolsma, A.D., Brown, G.W., Gibson, M.S. & Wright, J.R., 2010. Establishment of the Box-Ironbark Ecological Thinning Trial in north central Victoria. *Proceedings of the Royal Society of Victoria* 122(2): 112-123.

Rochfort, S.J., Ezernieks, V. & Yen, A.L., 2009. Indicators of soil health by NMR metabolomics: Earthworms as potential biological indicators for soil health. *Metabolomics* 5: 95-107.

Schowalter, T.D., 2000. *Insect Ecology: An Ecosystem Approach*. Academic, San Diego, California.

Seastedt, T.R., 1984. The role of microarthropods in decomposition and mineralisation processes. *Annual Review of Entomology* 29: 25-46.

Shield, J.M., 2001. *Spiders of Bendigo*. Bendigo Field Naturalists Club, Bendigo.

Shattuck, S.O. & Hinkley, S., 2002. Second species in the Australian ant genus *Peronomyrmex* Viehmeyer (Hymenoptera: Formicidae). *Australian Journal of Entomology* 41: 104-105.

Taylor, R. & Doran, N., 2001. Use of terrestrial invertebrates as indicators of the ecological sustainability of forest management under the Montreal Process. *Journal of Insect Conservation* 5: 221-231.

Tolsma, A., Cheal D. & Brown, G., 2007a. Ecological burning in Box-Ironbark forests Phase 1 – Literature review. Report to North Central Catchment Management Authority. Arthur Rylah Institute for Environmental Research, Department of Sustainability and Environment, Heidelberg, 97 pp.

Tolsma, A., Cheal D. & Brown, G., 2007b. Ecological burning in Box-Ironbark forests Phase 2 – Management strategy. Report to North Central Catchment Management Authority. Arthur Rylah Institute for Environmental Research, Department of Sustainability and Environment, Heidelberg, 59 pp.

Ward, D.F., New, T.R. & Yen, A.L., 2002. The beetle fauna of remnant eucalypt woodlands from the Northern Plains, Victoria, Australia. *Journal Insect Conservation* 6: 39-45.

Webster, A., 1992. Eltham Copper Butterfly *Paralucia pyrodiscus lucida*. Flora and Fauna Guarantee Action Statement No. 39. Department of Sustainability and Environment, Victoria, East Melbourne, 9 pp.

Wilson, E.O., 1992. *The Diversity of Life*. Norton, New York.

Yen, A.L. & Hinkley, S., 1997. *Invertebrate fauna.* In *Environmental Conservation Council Box-Ironbark Forests and Woodlands Investigation Resources and Issues Report.* Environment Conservation Council, Fitzroy, pp 112-115.

Yen, A.L., Ewart, D. & Walker, K., 2006. Mallee eucalypts, hummock grass and social insects – key elements of the Victorian Mallee. *Proceedings of the Royal Society of Victoria* 118: 281-293.

Yen, A.L., Hinkley, S.D., Horne, P.A., Milledge, G.A. & New, T.R., 1996. Development of invertebrate indicators of remnant grassy-woodland ecosystems. Unpublished report to the Australian Nature Conservation Agency save the Bush Program.

Yen, A.L., Hinkley, S., Lillywhite, P., Wainer, J. & Walker, K., 2002. A preliminary survey of the arboreal invertebrate fauna of two River Red Gum trees *Eucalyptus camaldulensis* near the Murray River. *The Victorian Naturalist* 119: 180-185.

Yunusa, I.A.M., Brown, G.W., Kwong, R.M., Ronnfeldt, G.R., Slater, T., Crouch, A. & Unkovich, M., 2003. Integrating biodiversity and productivity on intensive farms: a potential role for shelterbelts in the Victorian Riverina. In *Agriculture for the Australian Environment. Proceedings of the 2002 Australian Academy of Science Fenner Conference on the Environment,* B.P. Wilson & A. Curtis, eds, The Johnstone Centre, Charles Sturt University, Albury, NSW, 255-277.