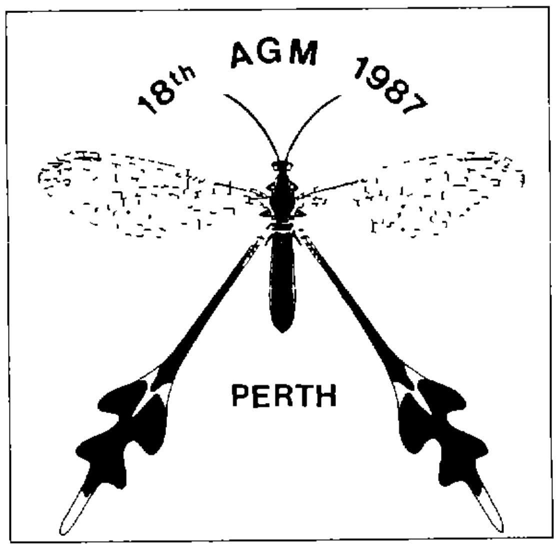
The Role of Invertebrates in Conservation and Biological Survey



Proceedings of a workshop held during the 18th Scientific Conference of the Australian Entomological Society,

Perth Western Australia,

18-20 August 1987

Edited by J.D. Majer

Department of Conservation and Land Managment

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RESEARCH REVIEWS

PREFACE

Until recently environmental impact studies and reports in Australia have largely overlooked the importance of terrestrial invertebrates in the ecosystem.

There is now a growing awareness amongst agencies concerned with the conservation and management of Australia's natural environment of just how important invertebrates are.

At its 18th scientific conference, held in Perth during August 1987, the Australian Entomological Society held a workshop titled 'The role of invertebrates in conservation and biological survey'.

The workshop was organised in response to the demand for information, and in recognition of the need to encourage further research into the conservation of invertebrates.

These proceedings contain most of the papers presented, and will hopefully stimulate further discussion and consideration. The papers have been edited to a common format, but remain much as they were orginally presented.

Although published by the Department of Conservation and Land Management, the views expressed in these proceedings are those of the authors, and do not necessarily reflect the policies of the Department.

Jonathan Majer, Editor
School of Biology
Curtin University of Technology

FOREWORD

The Department of Conservation and Land Management manages conservation lands in Western Australia, and is responsible for protecting the diverse range of native flora and fauna living throughout the State.

One of the most serious impediments to the successful protection of natural communities is the absence of sound information on which to base management practices. The Department has an active research programme designed to fill some of the gaps, but much more needs to be done.

These proceedings are a valuable step in providing information, and encouraging further research on a vital component of our natural ecosystems.

Roger Underwood
Acting Executive Director
Department of Conservation and Land Management

ACKNOWLEDGEMENTS

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OPENING OF THE 18TH SCIENTIFIC CONFERENCE AND AGM OF THE AUSTRALIAN ENTOMOLOGICAL SOCIETY

Speech by the Minister for Conservation and Land Management, the Hon Barry Hodge MLA, 16th August 1987

Ladies and Gentlemen

Man's first lessons in the results of over-exploitation of his environment were on a grant scale - they had to be, to make him take notice.

A chronology of major acts of environmental destruction would probably start in China, in the first three centuries A.D.

A booming population, dependent on an economic base of extremely intensive agriculture,, so denuded the once fertile lands of northern China that they could not support the population.

The solution we would now recommend, agricultural practices designed to conserve the soil, were not adopted for another sixteen hundred years.

Instead the Chinese started digging the Grand Canal, a waterway about 1600 km long, used to ferry the grain from the still fertile south to the populous north.

Apparently, the Grand Canal, still in use today, is one of only two man made objects visible from the moon. (The other is the Great Wall).

Solutions on that scale are no longer available to us.

Equipping several million people with shovels and buckets might ease the Western world's unemployment situation, but I don't think many people would find the wages and conditions satisfactory.

Man's next unpleasant lessons in his own, growing destructive powers followed the industrial revolution.

Increased demand for timber for fuel, mounting population pressure and the advent of industrial pollution led to a very significant degradation of Europe's and particularly Britain's once great forests. The consequences of that are still being felt.

Another painful lesson was the U.S. dustbowl of the 1930's, the result of over clearing and over cultivation.

Real progress towards conservation solutions has been made only recently.

This century, man's capacity to destroy the environment that supports him has taken quantum leaps forward. We now have the option of virtual annihilation of most life forms in a few hours of nuclear war, and we have the option of continued pollution of our air, land and water, from millions of often individually minor sources, until we reach the point where the entire system breaks down.

Fortunately we now know a good deal more about our environment, and what we can do to protect it. Increasing public awareness and concern is providing an impetus to action.

We know about soil conservation, about preserving forests and recognising those that are most environmentally sensitive, and about water cycles.

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Most important of all, we are beginning to learn about ecosystems. Ecosystems are generally dynamic, they are always in a state of flux, but the changes work to preserve a state of balance.

We are beginning to understand how our environment is made up of many complex, interacting ecosystems operating at different levels. We know to expect complex interactions when we tamper with any part of the system, and to look for unusual outcomes.

There's no need for us to get complacent though.

Anyone who wants to laugh at the early environmental excesses of China, Europe and America should take a trip around our State.

Take a look at land that was fertile so recently the fence posts are still standing, dividing salt lakes into neat squares. See where wind erosion exacerbated by over-clearing is still destroying good land.

Our basic tendency to let immediate economic needs and opportunities override long term considerations is as strong as ever.

Over the past four years the Government of this State has attained several major achievements in conservation planning and management.

We have introduced new legislation which formally makes polluting an offence, puts an onus on industry to ensure it does not pollute, and greatly strengthens the powers of the Environmental Protection Authority to take action against polluters.

Several new reserves have been created and existing reserves extended. Western Australia's first marine park has been established at Whitfords. A major milestone in conservation, this will also prove an invaluable tourist, recreational and research asset.

Through all these changes, we have attempted to shift the emphasis from confrontation between developers and protesters to consultation and objective assessment.

We have moved away from a piecemeal approach of ad hoc solutions to individual problems, and established integrated management plans for major regions. The forest management plans and timber strategy I launched earlier this year are a good example.

All these plans recognise the need for a balance between commercial, recreational and other uses, within a structure which ensures conservation of environmental value and protection of delicate ecosystems.

Western Australia has won a rightful place as a world leader and innovator in conservation.

Credit for that must go to the staff of the Department of Conservation and Land Management, to the Environmental Protection Authority, to the various conservation groups active in this State, to people in industry who have looked beyond the short term, and to ordinary men and women who have said, in effect, yes I think it's important to preserve the quality of our environment, I want my Government to persue such goals, and I'm prepared to pay taxes to support its efforts.

If however you were to ask me, are we winning? Have we halted the degradation of our environment? Are we now rebuilding its natural quality? Then I must admit I would have to hesitate. I don't think I would be too biased in my judgement if on balance I eventually answered yes for Western Australia.

There are still problem areas, but we are making encouraging progress. The problems we face are not as severe as in some parts of the world, and we are not subject to such great economic pressures as many poorer regions.

On a world scale though, I fear the answer would have to be no; we have not yet turned the corner.

There are some encouraging signs, but most of them result from forced action, the need to cope with symptoms of environmental disaster which can no longer be conveniently ignored.

The factors causing this situation are varied and complicated. One of the most important of particular concern here today, is ignorance.

For all our progress, we have barely scratched the surface of knowledge about our environment.

We have walked on the moon, drawn maps of its far side and analysed rocks from its surface, but there are species of insects living almost literally on our doorsteps which have never been described or even named.

What roles they play in which ecosystems, how their existences interact with ours, we can only guess.

I began by talking about large scale environmental disasters. I suggested that only major calamities could have attracted early man's attention to conservation issues.

Unfortunately, something of that attitude still prevails.

People are moved to action over the need to preserve our forests, conservation of our wildflowers is a major economic concern, there is unanimous public support for protection of endangered species of mammals and other higher vertebrates.

But midges? Mosquitoes? Ants? There are more species of insects than anyone can name, let alone count, they're the most numerous form of life on earth.

They are not cuddly or appealing, in fact most West Australians have quite an opposite experience of them.

In many parts of suburban Perth the lakes and wetlands that add so much to the city's appeal are also breeding grounds for thick swarms of midges.

They are a pest to us. Local authorities have for years responded to ratepayer complaints with spraying programmes intended to kill larvae in the water.

And that's where our ignorance catches us out. Mostly we have relied on pesticides, particularly one with the trade name Abate. This is a wide spectrum pesticide, quite undesirable from an environmental point of view. The full and long term consequences of its continued use are not known.

Not only that, continual exposure has led to midges developing some immunity to it, so that greater and greater quantities are being used to less and less effect.

What we now have to recognise is that insects are the cornerstones of many ecosystems. They are the main food of many species of bird, mammal and reptiles; certain groups are essential for the pollination of many native plant species; others are significant in decomposing dung and leaf litter, and thus recycling nutrients through the ecosystem.

In wetlands ecosystems, the humble and annoying midge is often vital.

We cannot afford to take note of our environment only when major disaster forces us to. Nor can we continue to think of the environment only in terms of trees, rare flowers, and unusual flowers. We must grasp more fully the concept of complex and interactive ecosystems, where every element seen and unseen, attractive and unattractive to man, has an important function.

For this to happen, at the level of environmental planning and management and at the level of public awareness, we need to know much more and especially we need to know much more about insects.

I've made a specific example of the midge, and the serious and escalating problems associated with its control. I'm pleased to be able to tell you the Western Australian government has initiated action to find a more effective and environmentally sound solution.

I can announce now a research programme to cost $60,000 which will commence shortly. It will be jointly funded by the State Government and the six local government authorities most affected.

As well as short term control solutions the series of studies will seek detailed ecological information that can be used for long term management planning, enabling us to control midge swarms while still preserving the ecological values of Perth's wetlands.

Much more research of this kind is needed. We must achieve a wider recognition of the importance of such research.

I believe we will turn the corner back from continual degradation of the world environment only when we have significantly improved our knowledge of how the system works, at all levels but especially in the neglected area of entomology.

That is why I am very pleased and encouraged that Perth is host to the 18th Scientific Conference of the Australian Entomological Society.

I hope that I and my colleagues who are charged with the responsibility of environmental conservation and management in this State - even conservation of insects that have never been named - will be able to derive direct and practical benefit from this Conference.

I also hope that it will have some impact on public awareness of the issues, for public understanding and support is perhaps the most vital ingredient in any conservation programme.

Ladies and gentlemen, I wish you every success in your work at this Conference and have great pleasure in declaring it open.

Thank you.

INSECT CONSERVATION IN AUSTRALIA: TOWARDS RATIONAL ECOLOGICAL PRIORITIES

T.R. New, Department of Zoology, La Trobe University, Bundoora, VIC., 3083

ABSTRACT

Limitations to an 'inventory approach' to insect surveys are outlined and problems of habitat evaluation for reservation discussed. The potential use of long term 'reference sites' is stressed, in conjunction with the development of replicable sampling set techniques for a series of ecologically informative priority groups of taxa. Logistic limitations to insect conservation are likely to remain formidable for the foreseeable future, and the wisest use of limited resources may involve considerable change from current all-embracing evaluation processes.

INTRODUCTION

The problems of determining invertebrate diversity in terrestrial and freshwater communities, let alone documenting the interactions between species or functional guilds, and the overall 'importance' of invertebrates as a basis for rational conservation management, are formidable and not likely to be entirely resolved for a very long time. The 'taxonomic impediment' (sensu Taylor 1976, 1983) is now well-appreciated, and is likely to remain an important factor limiting both estimates of diversity and our ability to communicate meaningfully about invertebrates to politicians and other decision-makers. Lack of ability to name any given invertebrate is still widely taken as symptomatic of uninterest, rather than of logistic limitation. Insect diversity is sufficiently high, even if all the species cannot be named, to ensure that any individual habitat patch is likely to be ultimately unique, and to contain many more localised and rare species than widespread and abundant ones. Further, we are not likely to know much about the ecology, life histories and resource needs of most of the common ones, let alone the rarer forms. Simply, the conventional conservationist approach for other taxa, of making a definitive species list and using this as a basis for ranking series of habitat areas for reservation suitability and conservation management is just not feasible for insects, especially in terrestrial communities. This paper explores some aspects of this 'ecological impediment' to constructive invertebrate conservation in Australia, and suggests some tentative approaches to setting ecological priorities in our little-known fauna. It builds on, rather than recapitulates, the broader account of New (1984).

LIMITATIONS TO INVENTORY

The limitations to total inventory, incorporating the restrictions imposed by imprecise taxonomy, are well illustrated by a recent account (Disney 1986a) dealing with the British Diptera. The British insect fauna is the most comprehensively recorded and documented in the world - keys to species level are available for most groups, illustrated handbooks are often available, early stages are commonly recognisable to species level, and distributions may be rather precisely known - especially for larger conspicuous insects such as Lepidoptera, Orthoptera, Odonata, some aculeate Hymenoptera, and others. Disney used a survey of the Diptera of a small area of Yorkshire, Malham Tarn, as background information to estimate the logistics of surveying the distribution of the order in the United Kingdom, using the 10 km square unit adopted for natural history recording in the region. His rather daunting figures, that with present effort it would take a minimum of 10,000 years to map the dipterous fauna of the United Kingdom even on this relatively coarse scale, highlight a number of the difficulties - collecting and sampling problems, identification problems and

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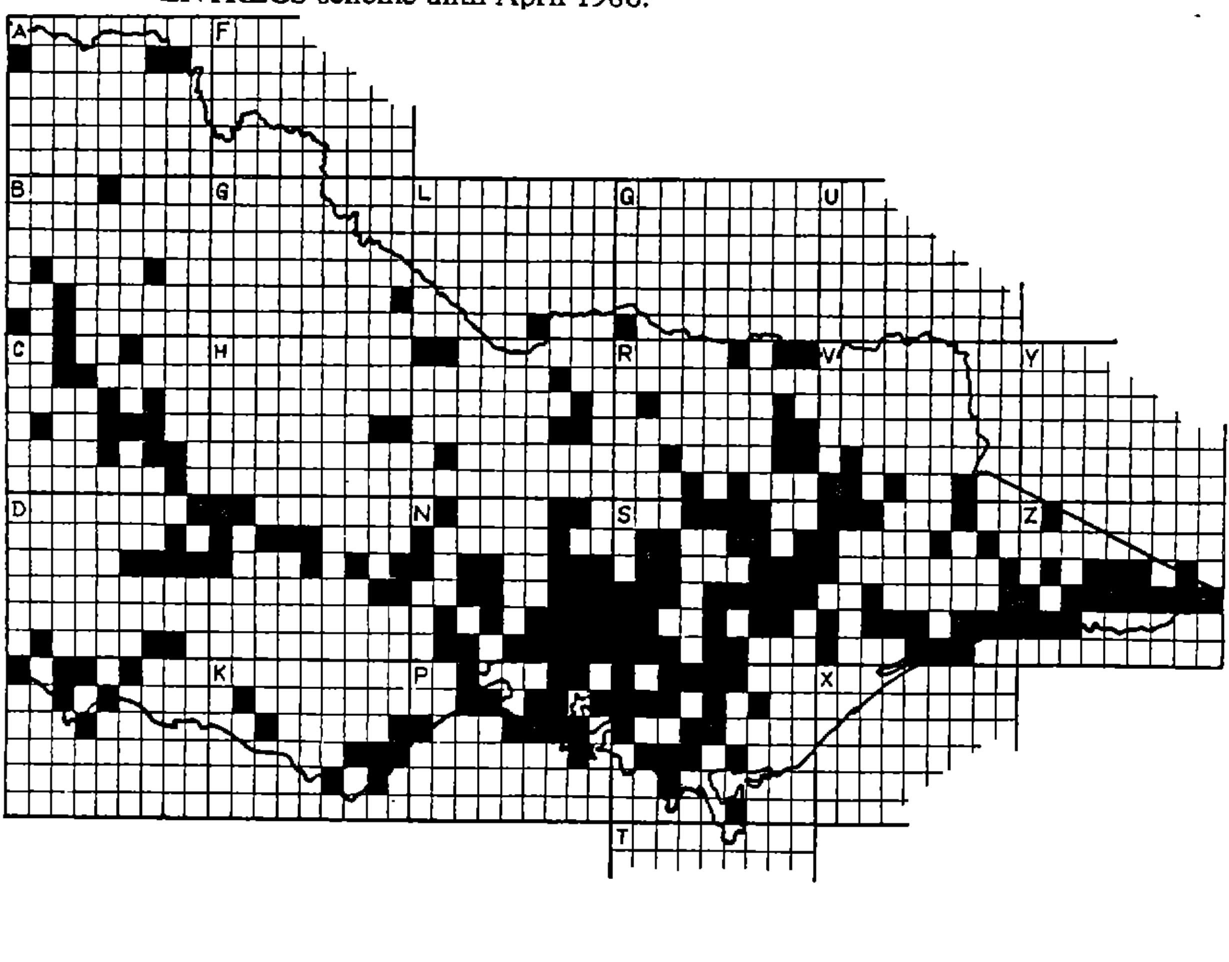
'collation' problems (such as misidentifications and changes in nomenclature). The colossal effort needed to compile even an approximate inventory of a major insect order on a single site, especially when placed within the comparative context of similar surveys at other sites for 'ranking', leads to the major conclusion that use of inventories as a tool for identifying sites of conservation interest is a lost cause (Disney 1986a) - even for a relatively well-known fauna.

Imagine the problems of attempting a similar project in this country, with our greatly restricted knowledge, little accessible non-specialist literature and keys, limited logistics to produce these and do the surveys, and lack of funds for personnel. Butterflies are by far the most charismatic group of insects to the amateur, and most species are readily identifiable through a series of excellent books culminating in Common and Waterhouse (1981). They are followed in Australia by Buprestidae and a few other families of relatively conspicuous insects. Victoria is arguably one of, if not the, most intensively collected States of Australia, with a long tradition of enthusiastic amateur entomological interest, which is as strong today as at any time of its history. Fig. 1 shows the regions (10 x 10 minute areas) of Victoria for which any butterflies have been recorded up to April 1986; many common and widely distributed species are 'formally' known from only very small parts of the State, so that quantitative replies to queries on a given species' distribution are difficult to make convincing. In contrast, detailed distribution maps are available for butterflies in Britain (Heath 1973). The collection resources for most other groups of insects in Australia are much less definitive than for butterflies. Admittedly, questions about (say) the distribution of Psocoptera in South Australia don't come very often - but I would not like to have to answer them - despite a useful account of the fauna of that region by Smithers (1982). Psocoptera have more practising specialist workers in this country, especially in relation to limited diversity (?300 spp.) than most other orders.

Fig. 1: Victoria, indicating areas (10 x 10 minute areas) from which butterflies have been recorded under the Entomological Society of Victoria ENTRECS scheme until April 1986.



There is another side to this - certainly for our butterflies, the distributions of many of the rarest species are known rather precisely over much of their range. The commonest ones will be of minimal importance in conservation activities. It is the 'intermediate' ones which may be important - they often have rather precise habitat requirements, but are too common to attract collector attention wherever they occur although sufficiently common for rather precise ecological/distributional assessment to be possible. Many skippers and satyrines fall into this category in the south east.

Increased interest in other insect groups can realistically be induced by the provision of 'secondary' publications with well-illustrated simple keys couched in non-specialist language. I am mindful of the impracticality of doing this for all groups, but many groups of insects are relatively well understood, and further accounts along the lines of Matthews' exemplary 'Guide to the Genera of beetles in South Australia' and the 'Fauna of Tasmania' series merit strong encouragement. I believe we have to start on this, however premature the accounts may seem to many systematists. Perhaps we should seek, rather than attempting inventory accounts for the whole of the Australian fauna, to organise our scattered resources more efficiently to produce identification guides to particular groups of insects of conservation value, and of relevance to environmental assessment and habitat/site 'ranking' for reservation.

Virtually any practising entomologist would have his or her individual priorities here.

HABITAT EVALUATION

I want now to move to a brief discussion of some of the needs of habitat ranking and assessment in relation to communities and single species, before treating some parameters of indicator species/insect priorities in a more rounded context. There are two very distinct situations in which habitat reservation, now universally accepted as the most important single provision for insect conservation, is contemplated:

i) To conserve relict populations of single notable taxa or groups of taxa. Often, these are small, highly localised populations of very rare taxa and the only chance for their survival depends on habitat protection against despoilation or development. The choice here is fundamental: to save the species or to let it become extinct. Often, this necessitates purchase of the habitat, which is expensive and may not have much public sympathy in the light of conflicting demands such as urbanisation, but which is a prelude to management of the species concerned. Two examples are discussed below, in the broader context.

ii) To ensure that adequate habitat patches are reserved to be representative of the greater area, and to conserve the biological diversity present. This approach tends not to be specifically species-orientated, and commonly involves making - or attempting to make - a rational selection based on ranking of a series of habitat patches or sites. How such ranking should occur, and the criteria involved, tend to be somewhat subjective, although the topics of considerable debate (Usher 1986). Amongst the common criteria applied for invertebrates are rarity, diversity, area and 'naturalness', and in Australia we are commonly attempting to rank climax and near-climax areas such as forests.

    'Rarity' and species richness and abundance are the most commonly used aspects, and can be rapidly amalgamated into a 'quick and dirty' mathematical model of diversity with quantitative values - whatever these may mean in practical terms. 'Diversity' is widely accepted as a good criterion, even if we have to rely on 'morphotypes' rather than 'species'. 'Rarity' assumes knowledge of status, and needs objective definition. Many very localised species are not endangered (although they may, under given circumstances, prove 'vulnerable'), and rarity needs very careful interpretation. The same applies to 'area', as even small areas may be very diverse. 'Naturalness' and 'typicalness' are especially difficult to evaluate - and there is a possible conflict with 'rarity'.

A range of other criteria have been used. 'Representativeness' is often implicit in evaluation, although it may be difficult to quantify, and needs to be evaluated on a broad range of taxa. For insects, 'endemicity' and 'type localities' are appealing criteria. The former is related to both rarity and fragility, and such taxa may often be specialised ecologically and thus particularly vulnerable to changes in land use. 'Type locality' (the locality from which the type material of a species was collected) sometimes closely reflects local endemicity and, therefore, can also be related to rarity. Care in interpretation is needed: many insect species are, in fact, known only from their type locality, but:

1. precise distributions are not usually known;
2. available data are not generally sufficient to state that the type locality supports a viable population or is even a breeding site, as at least some descriptions may be of 'tourists' (sensu Moran and Southwood 1982); and
3. for 'historical taxa', the locality may have changed substantially through vegetational succession.

However, type locality may indeed reflect 'uniqueness' in some instances.

Greenslade (1987) employed 'endemicity' in her survey of Tasmanian invertebrates and, where the term is accepted as valid in its application to the particular taxa by specialists in the groups concerned, it may be of considerable value for ranking sites and indicate foci for management plans.

Take the case, recently in the public eye in Victoria, of the Eltham Copper butterfly (*Paralucia pyrodiscus lucida* Crosby). This subspecies had been believed to be extinct in the Eltham/Greensborough area from which it was described. Specimens from the type locality closely resemble insects from parts of western Victoria (Dimboola, Kiata) and the extent of some of the western colonies also appears to be tenuous. *P. p. lucida* is now known to exist in the Eltham area: several colonies are very small and appear to be non-viable in the long term. Two large colonies - the only known ones which may be able to persist indefinitely - occur close together on land which has been subdivided and is threatened with imminent housing development. A search of many nearby areas which appear suitable has failed to yield other colonies (Crosby 1987), and there is little doubt that the insect is locally endemic and threatened with extinction. Population size is here a relevant criterion for ranking the sites in which the butterfly is known to occur.

Another example is the relict damsel fly, *Hemiphlebia mirabilis* Selys, now extinct over much of its former range but recently rediscovered (Davies 1985) on Wilson's Promontory, Victoria - within the boundaries of a National park. Survey work during the last year has shown that *Hemiphlebia* occurs in a number of swamps, and population sizes appear to differ substantially in different habitat patches. Unlike *Paralucia* though, *Hemiphlebia* does not appear to be in danger of extinction, although the swamp supporting the largest known colony was burned in May 1987! Management plans for both these species are being designed at present. In the contrast between their vulnerability, they well exemplify the (often not appreciated) situation that 'rarity itself is no criterion of risk' (White 1986). Whereas it is often the survival risks of individual species or populations that prompt the initial conservation interest, a population's risk is inherently an ecosystem consequence rather than a species property (White 1986). To this end, there is a need to rank survival risks as a first step in recognising local forms that merit conservation interest. To assess risk, on a comparative basis for a series of populations, their vulnerability needs to be estimated in relation to both demographic and habitat parameters - again, often drawing on data which are scanty or non-existent. White (1986) noted eight measurable criteria, treated in sequence:

1. Is the population strongly localised;
2. Have efforts to relocate former populations failed (range contraction);
3. Do numbers fluctuate significantly between years;
4. Are non-consecutive life stages present at any time;
5. Is the life cycle ever longer than one year;
6. Is abundance low relative to other local species;
7. Is the local abundance of endemic species small or declining; and
8. Have habitat changes lessened population abundance.

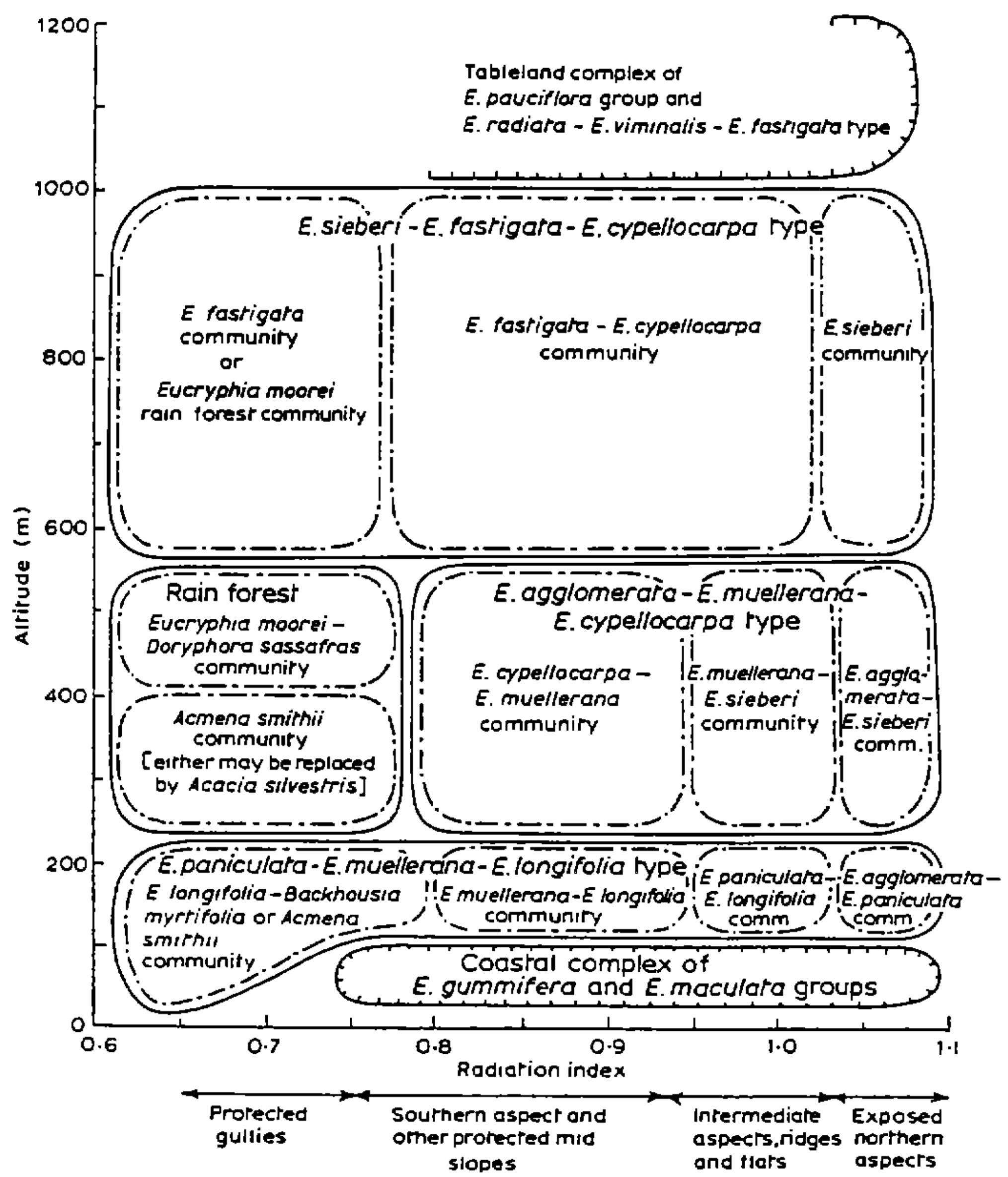
Applying these, however naively, to *P. pyrodiscus* and *H. mirabilis*, considerable concurrence is found. Point 3 remains an open question, and the major contrast occurs in points 6 and 7, for which *Paralucia* gains affirmative answers and *Hemiphlebia*, negative ones.

Such single species 'targetting' even for comparative ranking of populations is cost-intensive, and it is fair to claim that listing of species designated as 'protected' or of 'conservation interest' (be they charismatic, living fossils, local endemics, members of evolutionary significant groups, or notable ecological radiations) is little more than a placebo unless such a step is accompanied by research to investigate the species' ecology as a basis for sound management. Listing can even be detrimental (New 1984), because the public - even the entomological public - assumes that such studies are being undertaken, and can thus be lulled into a false sense of security over the population's (or species') welfare. The converse is more common, as habitat destruction may proceed unhindered.

Pending such studies, the immediate priority on listing is for habitat reservation, even if on unsound criteria: without a place to live, a population cannot persist. Diversity, together with the incidence of rare and/or notable species seems likely to remain the most useful criterion for ranking sites on 'invertebrate relevance' - itself an unusual and infrequent occurrence. However, as Webb and Hopkins (1986) have suggested for heathland invertebrates, 'diversity' alone is not particularly informative unless a set of species can be defined which are representative of the habitat. It may, indeed, be possible to define habitats by the presence of characteristic suites of insects (aquatic Coleoptera in Britain have been used in one such attempt: Eyre et al. 1986), as an alternative to the vegetational data usually forming the basis for conservation assessment, and which may form the basis of habitat diversity indices within an area.

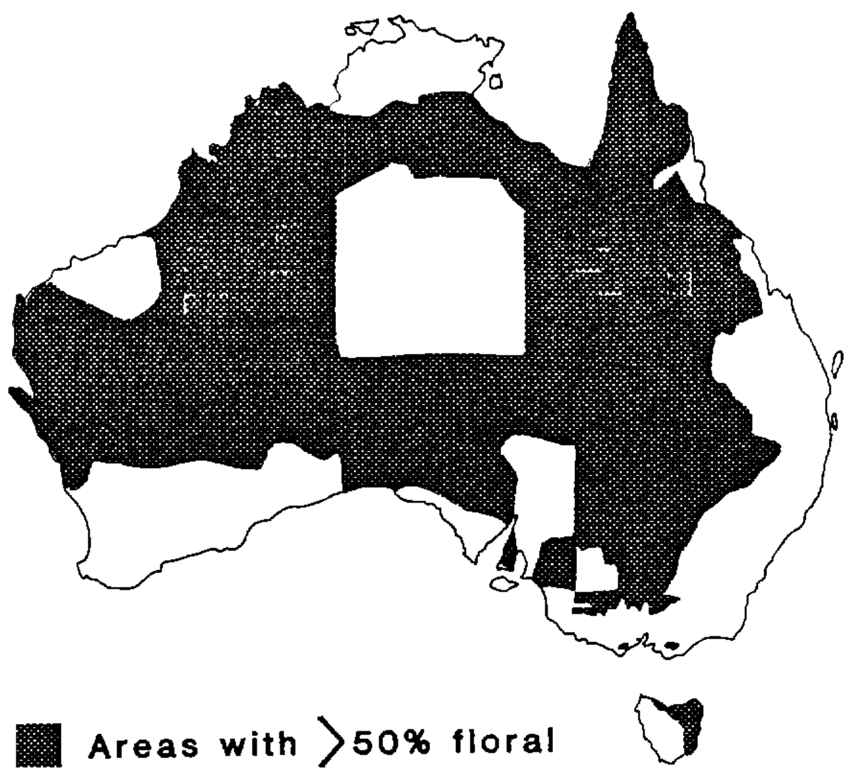
Complexity of vegetation delimitation in Australia is well exemplified by the work of Austin (1978 and later papers). The species composition of dominant forest vegetation in southern N.S.W. depends, inter al. on altitude and aspect (reflecting the degree of exposure) (Fig. 2). At its simplest, each vegetational alliance indicated in Fig. 2 may support a different suite of invertebrates linked in various ways along the environmental gradients and not necessarily (other than for phytophages) being strictly limited to plant species. More subtly, the degree of exposure may influence not only the species present, but their relative 'performance' in the habitats, and hence, their relative abundance and importance. Such gradient analysis of vegetation, though, is invaluable in indicating the diversity of habitats available for insects, and their relative representation in existing reserves may clarify the priorities for further reserve establishment (Austin 1984, Austin and Margules 1986). Our data-base for classification of plant communities is already considerably better than that available for many other parts of the world.

Fig. 2: Aspects of delimitation of vegetation communities in southern N.S.W. forests: the relationships of forest vegetation to altitude and aspect in an area south of the Corrowan Creek-Clyde River estuary line (from Austin 1978).



Austin (1986) referred to Specht et al.'s (1974) data showing that a large number of floral alliances are not included in reserves in Australia (Fig. 3). Although some augmentation has occurred during the intervening period, there is a long way to go to ensure that all major floral alliances are adequately represented, with the potential for management, in reserves in Australia. Without this, it is inevitable that many invertebrates will become extinct, and we have no realistic counter to this trend. Allied with lack of reserve representation is the continuing change to natural communities, ranging from exotic fish feeding on invertebrates (Fletcher 1986) to drastic vegetational conversion. The need to protect vegetation remnants, and to expand them by acquisition where possible is now widely recognised (see Busselton workshop report, Anon. 1986; Saunders et al. 1987). The additional importance of faunal conservation outside major reserves needs to be stressed, and an index of habitat diversity may therefore be useful in setting priorities (Levins 1968) for reserve augmentation.

Fig. 3: Australia, indicating areas in which less than 50% of the known floral alliances were not adequately represented in reserves (from Specht, Roe and Boughton 1974).



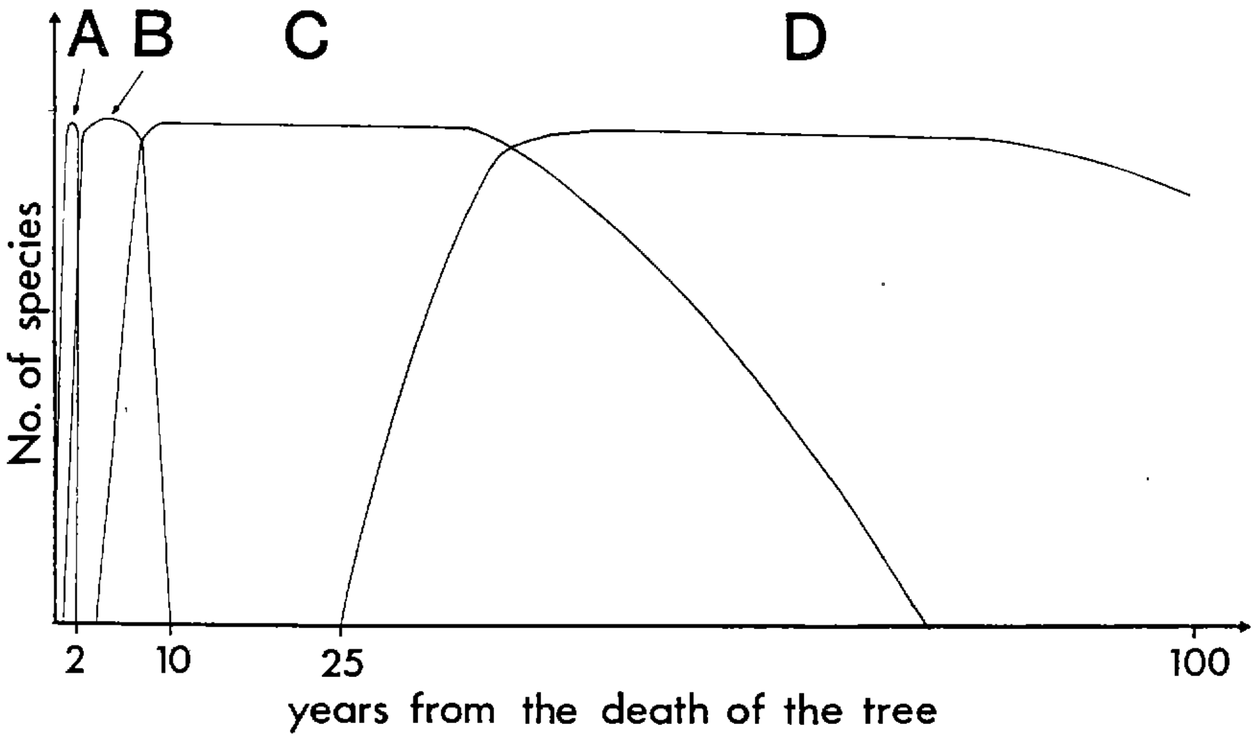
The above arguments have largely centred on the reservation of climax or near-climax communities and, once reserved, the fauna of such areas may remain in a relatively stable condition over long periods. This is not so for subclimax vegetation types and communities, and the conservation of particular plagioclimax communities and seral stages may require active management in order to ensure that such communities persist rather than being replaced by natural succession. Each such stage may have different management parameters. As emphasised by Morris (1986), the ecological nature of the communities to be conserved needs to be carefully appraised in conservation activities, however difficult such predictive planning may be.

Conservation measures need to be based on long-term sustainability of the systems and this is usually tacitly assumed. The importance of appropriate time frames in relation to fluctuating abundance of taxa is discussed by White (1987).

Forest conversion remains a prime environmental concern. Forestry practices affect insects in many ways, both directly and indirectly (Australian Government 1976). For northern Europe, Heliovaara and Vaisanen (1984) list a number of forestry-related influences, for example, that clearcutting may lead to changes in forest soil fauna because of microclimate changes, so that specialised forest soil invertebrates are eliminated and replaced by eurytopic species with considerable ecological plasticity. This can be reflected in an increase in the number of species. Huhta et al. (1967) noted the general trends of 1) rapid increase in dipterous larvae and adult Coleoptera; 2) slow increase in Nematoda, Enchytraeidae and Collembola; 3) increase followed by decrease of Oribatidae, other mites, and larvae of Coleoptera; and 4) decrease in Lumbricidae and spiders. An increased diversity without appreciation of the change in taxonomic content may lead to false inferences. It has been claimed, I think correctly for Europe, that such effects are striking but transient. They may not be so transient for Australia, because of the generally more impoverished soil types (see B. Springett 1978) and, generally we know far too little of the ecological roles of invertebrates in Australian forests to be complacent about any major changes apparent. After mild fires in jarrah and karri forests, species diversity and density are reduced, and J. Springett (1976) suggested that 5-7 year prescribed burning could permanently simplify the litter fauna and flora. These results were, in part, corroborated by Abbott (1984), although many taxa recovered to their former densities within three years of a moderately intense fire in jarrah forest. Short term effects of burning may well be important, although the range of responses by litter invertebrates (Majer 1984) indicates our lack of detailed knowledge of the biology of many of the taxa affected. There is, however, one strict parallel between European and Australian forest disturbances which should be noted - that insects associated with the 'wood system' as decomposers are particularly vulnerable to clear felling and increased frequency/intensity of burning. The taxa involved fall into four ecological phases (Ehnstrom 1979) (Fig. 4), and are vulnerable directly because of removal of habitat and its premature desiccation. In forests, the invertebrate fauna can possibly be used to indicate the extent to which a primeval forest remains in its original condition. In a cultivated forest, the pest fauna can be regarded as a test of the success of silvicultural practices (Heliovaara and Vaisanen 1984). Silvicultural practices can also have far-reaching effects on nearby freshwater systems (Michaelis 1986).

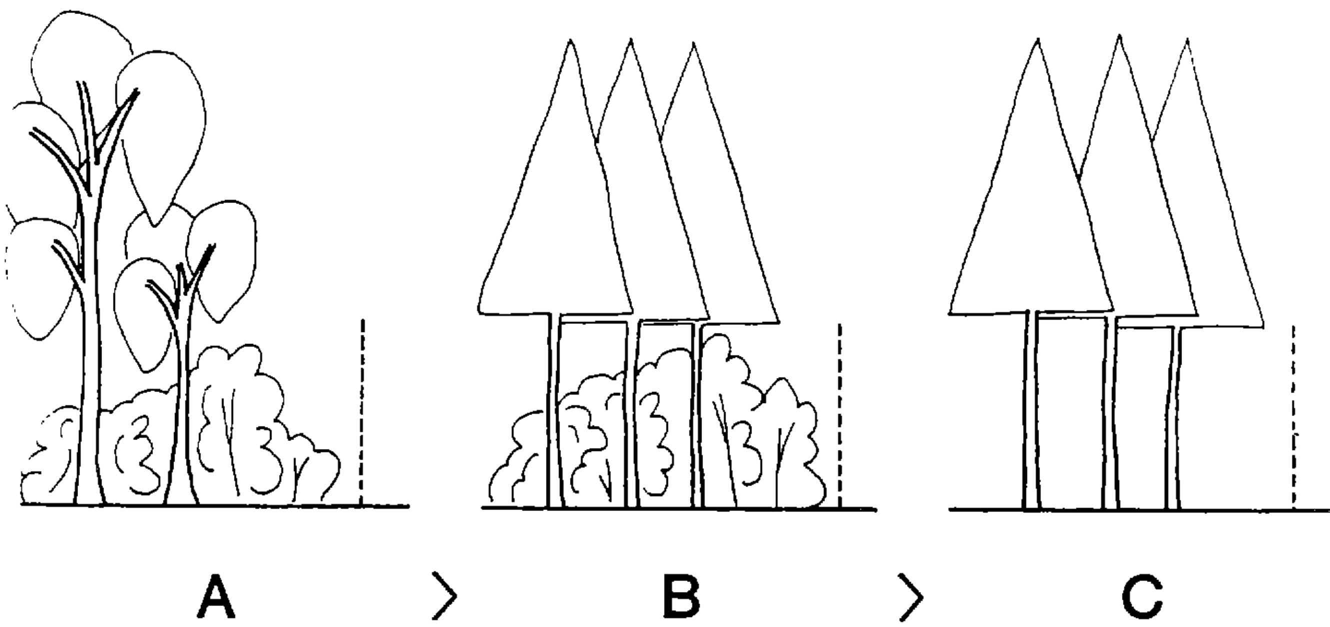
Values of forests to invertebrates may indeed by fostered by silviculture, the major detrimental effects being conversion to exotic monocultures and excessive sanitation. Native forests with 'natural' edge structure, possibly augmented by abundant nectar plants (Fig. 5) are clearly preferable.

Fig. 4: Invertebrate colonisation of dead wood. Successive phases (A-D) are (A) short duration bark-feeding species and their predators and parasites; (B) species which are subcortical or associated with surface timber of fungi; (C) after bark falls this long-term stage, which can last for several decades, consists of wood-inhabiting species; (D) is a long phase during which wood-inhabiting species are replaced by those living under the shelter of decaying logs, as the wood breaks up (after Ehnstrom 1979).



We thus have indications that diversity per se may not alone be sufficient for choosing reserves, as diversity may be increased by inclusion of numbers of 'generalists' or 'tourists' following disturbance. 'Representativeness' or 'typicalness' may dictate large reserve areas, whereas species richness may be high in only very small areas. Generally, though, in accordance with extrapolations from island biogeography theory, there seems to be a reasonable relationship between species richness and area. Faeth and Kane (1978) tested several aspects of habitat diversity as predictors of Diptera and Coleoptera richness in Ohio, and found that increased area alone was the major determinant, acting primarily to reduce extinction rates rather than to provide new habitats for specialised species. However, specialised habitats are more likely to persist in larger areas, where they may be better buffered and surrounded by greater heterogeneity. An important implication for invertebrate reserves from the study by Kitchener et al. (1980) on lizards in the W.A. wheatbelt is that a single large reserve possibly needs to be many times as large (for lizards, 600 times) to support the same number of species present in a series of small reserves totalling 1.78×10^4 ha. Both for species diversity and to counter inadequately known, but substantial habitat diversity, the preferred course for invertebrate conservation is to favour establishment of many small reserves (as long as they are large enough to maintain independent populations, and are adequately buffered), rather than a single large reserve.

Fig. 5: Forest edge structure and invertebrate diversity. Habitat A (native forest with understorey vegetation) is a richer habitat than B (introduced conifers with understorey conserved) which in turn is better than C (exotic conifers alone), reflecting diversity of available plant materials.



ALTERNATIVES TO INVENTORY

The alternatives to inventory now merit consideration in the context of constructive habitat ranking. Results of vegetation surveys are not always clearly extrapolable to generalisations about associated fauna, and there is no necessary correlation between 'high-rank vegetation' and a high rank for associated invertebrate fauna (Brooker 1982, Disney 1986b). Likewise, there seems to be little evidence of correlation of invertebrate faunas with other groups of animals. As noted earlier, for most groups of invertebrates, the amount of effort needed to achieve even a relatively complete species list which is ecologically interpretable for even a small site is unacceptable or logistically unattainable. In terms of comparative ranking of sites, sampling heterogeneity due to seasons, time of day, vagaries of weather and small scale vegetational change is of greater importance for invertebrates than for other biota. Nevertheless, the importance of insects in environmental impact assessment is now widely recognised, and their use in such studies seems likely to increase (Rosenberg et al. 1986).

REFERENCE SITES

The practicality of reference sites, preferably selected from currently reserved areas or capable of being reserved rapidly, merits very serious consideration. In Europe, intensive collecting over many years has led to the gradual buildup of relatively definitive data on invertebrate diversity for selected areas. In Australia, although some sites, especially in the south-east have been a focus of collector attention over a considerable period, there has been little attempt or opportunity to synthesise the accumulated information, although its importance is often acknowledged, however casually. The principle of using reference sites in invertebrate surveys can be summarised briefly as follows. In any comparative survey a series of sites for ranking (e.g. for possible reserve status), a given reference site containing a similar spectrum of vegetation types, and climatically typical of the other sites, is included as a standard. Ideally, knowledge should already be available on this site. Over the years, the same site could be independently included in, perhaps a dozen or more comparative surveys undertaken for different purposes, at different times of the year, and using widely disparate methodologies. This idea was proposed by Disney (1982) to overcome the problem of comparing rankings obtained from a particular series of sites on one occasion with those for a different series at another time. In a given series of sites, the mean numbers of species in sample from each individual site are divided by the mean for the reference sites in that survey. The reference site can always be given a rank value of unity and data sets can be compared objectively by applying the Mann-Whitney U-test to the sequence of means. In this way 1) limited surveys can be of use in ranking sites; 2) it may be possible to monitor changes; and 3) by assessing the accumulated data from the reference site a more comprehensive picture of the fauna of that habitat site will be gained and (hopefully) lead eventually to better ecological interpretation of survey data from other sites.

ECOLOGICAL METHODS

Disney (1986b) has also raised the important point that, with limited (i.e. non-inventory) sampling, the relevance of 'diversity' as an adequate reflection of conservation need depends on the selection of taxa used for evaluation. Ideally, taxa selected as a basis for evaluation should either reflect habitat features or show some of the characteristics of indicator species. As well as demanding understanding of the biology of the taxa involved (together with the ability to interpret them taxonomically), detailed understanding of the limitations of sampling techniques is needed. Ideally, these should be selected for high collecting efficiency. The methods employed need to produce replicated samples with high return for relatively little effort. Collecting efficiency must be equivalent in different sites - a parameter long recognised in freshwater studies but which has received much less attention in sampling from terrestrial communities. In conservation assessment we generally seek methods that yield sound data on several groups of organisms simultaneously. No single method may be suitable for this, and Disney has emphasised the simple solution to this dilemma - to ensure that a single 'sampling unit' consists of a set of different types of trap, rather than a single trap. He suggested that a white water trap, a yellow water trap, and 10 pitfall traps could constitute a single unit, which could itself be replicated 10 times in each site being sampled. In this way, the measure of diversity is the mean number of species per sampling set, rather than the mean per trap. Details of the trapping 'set' may differ according to the prime target taxa. The number of replicated sampling sets should reflect a compromise between an adequate number for valid statistical analysis, enough to allow for 'accidents' to some sets, and a minimisation of effort to achieve a valid result. Some other trapping techniques, such as Malaise traps, can yield vast numbers of specimens, but their catches are extremely difficult to compare between sites, as small siting differences can have dramatic effects on the catch size and composition. Their main use is as a collecting tool, and analyses of their bulk catches may reveal the presence of taxa with conservation value. Large variance of means between sites, characteristic of such traps, can be partially overcome by using more traps - with the attendant increase in labour and cost of sampling.

The approaches of recurrent observation in one site and sampling as many sites as possible are complementary, and both presence/absence data and the relative abundance of various taxa may be informative. Common species can identify the major habitat features, and rarer species (such as those indicating relict and undisturbed environments) can be used to rate the importance of any site within its habitat group, assuming that the habitat type has, in general terms, been sufficiently documented.

PRIORITY GROUPS

Virtually any insect ecologist would nominate different taxa as optimal community subunits for evaluation. In terrestrial systems, for example, a series of taxa selected rationally could encompass groups dependent on different habitat subunits and which are naturally relatively diverse - for example, Collembola (soil, litter), some families of beetles (litter), Homoptera, Orthoptera (various kinds of vegetation). It may also be useful to incorporate insects which produce persistent 'symptoms' (such as galls, mines) which are present at times beyond which the insects themselves are detectable, if such are readily recognisable.

Diptera and parasitic Hymenoptera have been nominated as especially useful indicators of conservation value (Disney 1986b), because of their involvement in a great range of ecological interactions. Diptera has the greatest diversity of larval habitats of any order of terrestrial invertebrates, and it is therefore likely that their assessment may reflect the ecosystem as a whole more fully than, for example, an assessment based exclusively on phytophagous taxa. Regarded somewhat cynically, the latter could provide little more than a list of plant taxa which could be gathered more easily and is of limited value for extrapolation to faunal parameters. If may of course, provide much more, and many phytophagous taxa reflect extensive endemic radiations in Australia, with many species of very limited host-spectrum and geographical range. Against the use of Diptera is the fact that many species are highly vagile, and the 'tourist' component may be high. Inclusion of parasitic Hymenoptera provides a package of ecologically diverse taxa for which the diversity values may be closely related to conservation values.

PROCEDURE

Selection of any such priority groups, following from Macleod's (1980) suggestions for the Canadian fauna, is one of the most important needs for approaching rational insect conservation in Australia. It has considerable problems in the present state of our knowledge and in pursuing it to an adequately responsible level. Initially, rational informed debate on what should constitute such groups is needed, perhaps with consideration of Speight's (1986) division into 'foundation groups' (sampled in all habitats) and 'auxiliary groups' (sampled in particular habitat categories). This is an entirely separate problem from species orientated conservation and should not obscure the need for a reserves system equivalent to the British 'Sites of Special Scientific Interest', which can be nominated for conservation of notable or threatened species or groups of species. The summit of Mt Donna Buang (Victoria) for stoneflies is one such example meriting firmer reservation. What we seek, in addition, is a series of groups which are easily sampled, biologically informative and which can be used as shortcuts to understanding of community complexity and dynamics. It makes sense, if possible, to include groups for which a reasonable amount of biological and taxonomic information are already available. Disney's (1986b) recommended groups for Britain, Diptera (other than aquatic forms) and parasitic Hymenoptera, currently do not really fall into this category of understanding in Australia. If these groups were selected for terrestrial communities, perhaps with Collembola, some families of beetles (?Scarabaeidae, Cerambycidae, Buprestidae, Chrysomelidae) and some other phytophages (?Psyllidae, Geometridae) to increase the data base for climax/subclimax native vegetation communities, let us examine the (utopian!) corollaries. Formicidae may also be of very considerable value as ecological indicators and freshwater ecosystems may be adequately reflected by Trichoptera and Ephemeroptera. The essential need is to develop methodologies and data bases that can be handled easily by trained support staff, so that invertebrate evaluation may be included routinely in faunal surveys (Speight 1986).

i) Standard replicable sampling techniques need to be developed. Disney's scheme could be transferable in its entirety, but would need to be augmented by litter/soil sampling and other unbiased methods, perhaps by insecticide knockdown from trees (fogging).

ii) Taxonomic work should be accelerated on the groups concerned, and resources made available to achieve this. It would clearly not be feasible to rely on existing practicing specialists, and the relevant Ministries in each State/Territory would need to fund at least one full-time Dipterist and one Hymenopterist in each such area under the umbrella of conservation assessment, as well as support staff. Amongst their responsibilities should be the organisation of workshops for other workers, including extension staff, along the lines of the annual hymenopterists' training courses held under the aegis of the Biosystematics Research Institute in Ottawa. With less experienced entomologists working under the guidance of the more expert, Disney claims (and, from instructing graduate students, I tend to agree) that much material can be readily sorted to species/species group on gross appearance, although formal identification may not be feasible.

iii) Preparation of working keys for use by non-specialists. These need to be very well illustrated, couched in relatively simple language, and generally intelligible. With careful attention to deposition of voucher material (working collections need to be readily accessible to those needing to refer to them), such publications can, with incorporation of voucher numbering systems, precede full taxonomic publication and naming (see Taylor 1983 for a discussion of relevant taxonomic practice). A national standardised provision for 'faunal assemblage collections', along the lines recently advocated for Canada by Danks et al. (1987) merits serious consideration here.

iv) In conjunction, ecological work should be accelerated on the key groups to enhance understanding of their role in communities.

CONCLUSION

Clearly, logistic packages of this sort are not likely to be attainable in the present economic climate, in which short term applied results tend to be sought at the expense of fundamental understanding. It must be continually emphasised to those who control the limited conservation purse that there is no simple, cheap short cut to understanding the roles of invertebrates (or others), and that taxonomic and ecological understanding need to be pursued hand-in-hand. Even though the roles of invertebrates in conservation evaluation are gradually coming to be more frequently discussed, in many parts of the world, the ideas that invertebrates merit conservation, and that understanding their ecological roles and diversity is of central importance to conservation of natural communities are still difficult to impart. 'Decision makers', within their beaurocratic briefs, tend to be constrained by the financial aspects of evaluation and implementation. As Ratcliffe (1986) has commented "The great strength of Nature Conservation is that it deals with things which are beyond pricing as market place commodities. Their ultimate values are transcendental, and cannot be compared with anything beyond themselves".

Lack of appreciation of this truism, coupled with inadequate logistic support, is likely to dictate practicality for the foreseeable future. In the meantime, consideration of invertebrates as vital components of our biota should increase, and reservation of natural habitat (be it to increase representativeness of currently inadequately reserved floral associations, marginal habitat, or refuge areas for other notable biota) should be accelerated wherever possible. Perhaps the easiest initial step for invertebrates is to rapidly promote a scheme equivalent to the Invertebrate Site Register of the British

Nature Conservancy Council. This Register seeks to 'catalogue local invertebrate biologists' best sites, identify the most significant elements of the fauna and habitat on those sites and then alert regional staff to the ecological requirements of that fauna' (Key 1985, Disney 1986a). But, again, the criteria for this need careful evaluation, and there seems little practical alternative in this country at present to a more species-based approach to insect conservation. At the very least, this should ensure the persistence of selected members of our most notable taxa. It will be for those who come after us to deplore our lack of appreciation of our great diversity of endemic insects, although habitat reservation may lesson the proportion of these which would otherwise become extinct. The vital implication, however (as voiced by a number of concerned entomologists recently), is that if we, as entomologists, are not willing to take positive steps to act to conserve insects, no one else is going to do the job for us, and we should not reasonably expect them to do so.

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AUSTRALIAN FEDERAL IMPORT/EXPORT CONTROLS ON INSECT SPECIMENS AND THEIR EFFECT ON INSECT CONSERVATION

G.B. Monteith, Queensland Museum, P.O. Box 300, South Brisbane, Qld, 4101

INTRODUCTION

The *Wildlife Protection (Regulation of Exports and Imports) Act 1982* is a recently introduced, comprehensive piece of federal legislation which regulates traffic across Australia's international borders of all native species of wildlife as well as of a list of non-Australian species agreed internationally to be endangered by unrestricted trade. It affects the activities of all persons who have cause to move animals or plants into or out of Australia. The wording and operation of the Act is extremely complex because it attempts to prevent certain undesirable movements of flora and fauna while allowing the legitimate export and import of specimens for such disparate purposes as scientific research, bee-keeping, private collecting, zoo displays, circus displays, biological control, plant propagation, disease diagnosis and approved commercial trade.

Its principal aim is to enhance wildlife conservation and while its obvious targets are the headline-catching activities of smugglers of astronomically-priced species of birds and reptiles its provisions apply equally to insects. To the extent that it curtails non-scientific traffic out of Australia of wild-caught insects it has a potential conservation effect on certain Australian species desired overseas. But this is gained at a considerable loss of freedom of insect movement across Australia's borders, particularly by persons without institutional backing.

This paper discusses the origin of the *Wildlife Protection (Regulation of Exports and Imports) Act 1982*, the way it operates with respect to both insects and entomologists, and speculates on its insect conservation potential in Australia and adjacent nations. For brevity, the legislation will be referred to as the *Wildlife Protection Act* and where numbered *Sections* or *Regulations* are referred to they should be assumed to be parts of that Act unless otherwise stated. Copies of the legislation in full can be purchased at Australian Publishing Service bookshops in capital cities and other major centres.

LEGISLATIVE ORIGINS OF THE WILDLIFE PROTECTION ACT

Previous Australian legislative controls on import/export of insects have been relatively few. For obvious reasons the import of live insects has long been prohibited except by extremely strict permit under the *Quarantine Act 1908*; this Act did not restrict import of dead specimens provided their preservation was adequate. The first federal export control of insects occurred as recently as 1973. This was the highly contentious addition of "Live or dead insects (including ticks and spiders)" to the schedule of prohibited exports under the *Customs Act 1901* and became notorious under the title of *Regulation 13A*. *Regulation 13A* had no conservation motive but was solely aimed at preventing the deposition of holotypes of Australian insects in overseas institutions. It was administered by a set of Guidelines formulated by the federal Department of Science. It suffered from the outset by being produced without adequate consultation and it never gained support of either entomologists or scientific societies. After years of debate (summarised by Marks 1978), including several revisions of the Guidelines, it was rescinded with the introduction of the new *Wildlife Protection Act.*

Holotypes are still mentioned in the new Act but in terms that allow some ethical judgement to be exercised. Thus *Regulation 10(1)c* requires that Australian scientific organisations "take whatever steps are scientifically appropriate" to have holotypes

Majer, J.D. (ed.), *The Role of Invertebrates in Conservation and Biological Survey.* (1987). Western Australian Department of Conservation and Land Management Report.

returned from material they export; similarly *Regulation 10(2)e* requires that overseas scientific organisations registered under the Act should, "where scientifically appropriate", return to Australia holotypes designated from material they receive from Australia; *Regulation 10(3)* requires that a holotype returned under the provisions of *Regulations 10(1)c* or *10(2)e* should be lodged in either the institution that originally exported the specimen or in a government museum.

Another piece of federal legislation has just been introduced which also has provisions concerning holotypes. This is the *Protection of Movable Cultural Heritage Act 1986* which is Australia's legislative follow-up to its signing of UNESCO's *Convention on the Means of Prohibiting and Preventing the Illicit Import Export and Transfer of Ownership of Cultural Material.* This act is designed to prevent the permanent export of objects judged by nominated experts to be part of Australia's cultural heritage. The Regulations to this Act have not been promulgated at the time of writing but are understood to include "holotypes of Australian origin". The *Movable Cultural Heritage Act* will not be retrospective but since it is linked to the UNESCO Convention there will be powers of international recovery of specimens exported in contravention of the Act.

The problem of export control of potential holotypes is really peripheral to considerations of insect conservation. However, another International Convention, of explicit conservation intent, forms the central theme of Australia's new *Wildlife Protection Act.* This is the CITES Convention and it merits closer examination.

THE CITES CONVENTION

Recognising that many wildlife species around the world were endangered by ruthless trade in the species or products derived from them, and that this situation was exacerbated because authorities were powerless to prevent species illegally collected or exported from a source country from being sold openly in other countries, the United Nations drew up an international convention in 1973. This was the *Convention on International Trade in Endangered Species*, or CITES for short, and its purpose was to produce mutual agreement between nations around the world to control this undesirable trade across their international borders. The Convention was opened for signature in Washington in early 1973 and the required ten signatory countries to bring it into force were soon achieved. Australia signed CITES in 1976 and today 95 nations are signatories.

The central core of CITES are two long Appendices of species of animals and plants. Appendix I contains species actually threatened with extinction now, while Appendix II contains species not necessarily threatened now but which may become so if trade is not controlled. The only insects currently listed are some butterflies in Appendix II, viz. *Parnassius apollo* and all birdwings in the genera *Ornithoptera, Trogonoptera* and *Troides.* The *Parnassius* is a relict montane species in Eurasia and does not concern us greatly. However the birdwings form a group of about 30 spectacular butterflies ranging from Asia through the Indonesian and Philippine archipelagos to New Guinea, the Solomons and Australia. Two species of *Ornithoptera* occur in north-eastern Australia. The birdwings are highly desired by collectors, command high prices and include extreme rarities such as *Ornithoptera alexandrae*, the largest butterfly in the world (Parsons 1984). CITES specifies that the genera of birdwings are to be interpreted as in D'Abrera (1975).

There are regular reviews of the species on the CITES Appendices and signatory countries have the opportunity to recommend changes. Currently there is a proposal from Great Britain for the following changes to the CITES butterflies: upgrading *O. alexandrae* from Appendix II to I; inclusion of *Papilio chikae, P. homerus* and *P. hospiton* on Appendix I; inclusion of *Bhutanitis* spp. and *Teinopalpus* spp. on

Appendix II (Anon 1987). The outcome of this proposal is unknown at time of writing. All these butterflies are members of the Papilionidae which reflects the interest in the conservation status of this group engendered by the recent IUCN Red Data Book (Collins and Morris 1985). The IUCN also produces a quarterly periodical, *Traffic Bulletin* which gives regular updates of CITES species lists and signatory countries.

It is incumbent on countries signing the CITES Convention that they adjust their own internal wildlife legislation so that they can enforce the trade regulation provisions specified by CITES Australia did this, as an interim measure, by issuing the *Customs (Endangered Species) Regulations* in conjunction with the existing *Customs Act 1901.*

THE AUSTRALIAN WILDLIFE PROTECTION ACT

This Act is Australia's much belated, definitive response to its obligations under the CITES Convention and replaces the earlier Endangered Species Regulations of the Customs Act. Although we signed CITES in 1976, the *Wildlife Protection Act* was not passed by parliament until 1982 and did not come into force until May 1, 1984 when the Regulations, under which the Act operates, were promulgated. These Regulations, known in full as the *Wildlife Protection (Regulation of Exports and Imports) Regulations*, are essential for an understanding of how the legislation operates. On April 30, 1987 numerous amendments to the original *Wildlife Protection Act* came into force and made substantial changes to it. These are contained in the *Wildlife Protection (Regulation of Exports and Imports) Amendment Act 1986*. Both the Regulations and the Amendment Act are obtainable from AGPS bookstores.

This body of legislation is administered by the Australian National Parks and Wildlife Service in Canberra under the authority of the federal Minister for the Environment. Enforcement is the responsibility of the Australian Customs Service and the Australian Federal Police; substantial penalties including fines of up to $100 000 and five years in prison are provided for breaches. The ANPWS provides several explanatory leaflets on the Act, those on "Commercial Trade" and "Scientific Research" being especially relevant to the issue of insect conservation. These, as well as the various application forms required to operate under the Act, are obtainable from: The Director, Australian National Parks and Wildlife Service, G.P.O. Box 636, Canberra, A.C.T., 2601. Brief accounts of the Act are given by Antram (1984) and Monteith (1984).

The most conspicuous feature of Australia's legislative response to CITES, compared to that of most other countries, is that Australia has chosen to prohibit (except under permit) the export not only of species listed in the CITES Appendices but also of all other native species of Australian flora and fauna. While there is undoubtedly an element of altruism in this decision there is also a degree of bureaucratic expediency involved because this blanket export prohibition of native wildlife means that Customs and Quarantine inspectors are thus not required to carry out precise identifications at export inspection points.

OPERATION OF THE WILDLIFE PROTECTION ACT

For simplicity, the following discussions will deal solely with aspects of the Act which affect insects (including other non-marine arthropods) and entomologists. It should not be assumed that statements made will apply equally to other groups of animals or plants.

The Act operates in conjunction with a series of Schedules (or lists) of animal and plant taxa for each of which the Act specifies selective export/import requirements. Schedule 1 contains those taxa on CITES Appendix I. As noted earlier these include no insects at present but there is a current application for the addition of four species of swallowtail butterflies to Appendix I. Schedule 2 contains those taxa on CITES Appendix II, namely *Parnassius apollo* and all birdwing butterflies. Schedule 5 lists living animals of which the import is not prohibited under the Act, and includes two categories of insects. The first are biological control insects approved for general release in Australia before the commencement of the *Wildlife Protection Act*. The import of these species is regulated by *Regulation 86* of the *Quarantine Act 1908*. The second category are live honey bees (*Apis mellifera*) and their introduction is strictly controlled under *Regulation 39* of the *Quarantine Act 1908*. The other Schedules have no relevance to entomology except that Schedule 8 gives the formal text of the CITES Convention.

A further exclusion from export/import controls under the *Wildlife Protection Act* is given by *Section 8(3)* and *Section 8(4)* which allow unimpeded export/import of specimens involved "in a diagnostic test ... to identify a disease of humans, animals or plants" or "an emergency involving danger to the life or health of a human or an animal". Such exports/imports may only be made by prescribed scientific organisations or the Director of Quarantine (*Regulation 4*).

Given the foregoing framework for dividing specimens into legislative categories the explicit prohibitions of the Act are then given in *Section 21* and 22 as follows:

Export Controls: *Section 21* prohibits, without permit, the export of:

(a) Species on Schedules 1 and 2. The only insects concerned are the CITES butterflies.

(b) All native Australian insects.

Import Controls: *Section 22* prohibits, without permit, the import of:

(a) Species on Schedules 1 and 2, i.e. the CITES butterflies.

(b) All live insects, except insect species on Schedule 5 which are regulated by the Quarantine Act 1908.

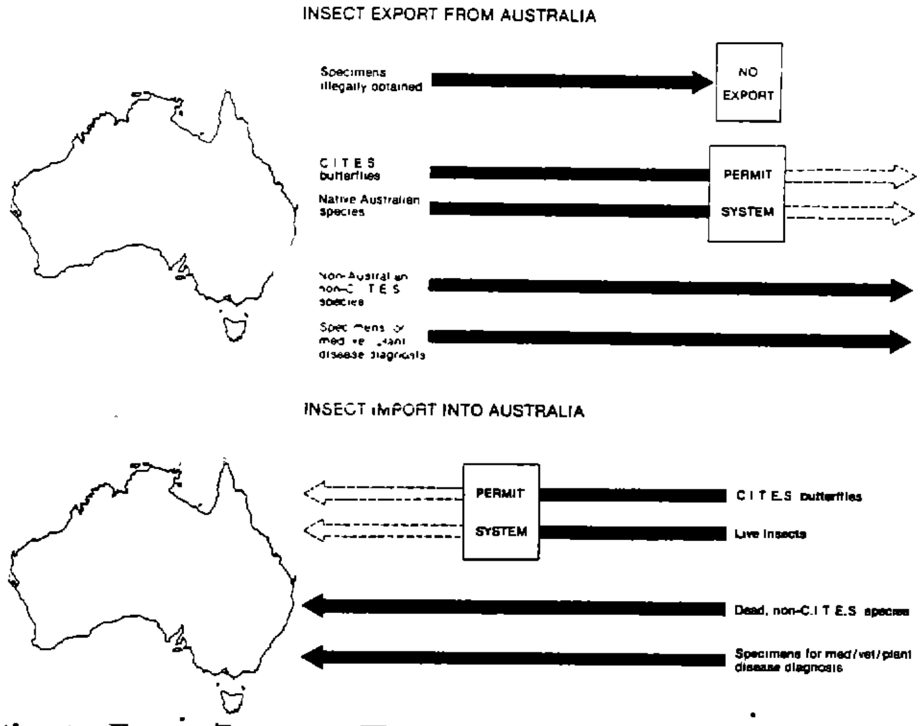
The nett effect of these provisions of the *Wildlife Export Act* on the movement of insects into and out of Australia is graphically shown in Fig. 1.

THE PERMIT SYSTEM AND ACCESS TO IT

The permit system defined by the Act and its Regulations is extremely complex. It outlines criteria for eligibility for import and export permits for different categories of specimens; and it defines criteria for eligibility for access to those permits by different categories of people, those without institutional backing having least access.

Permits may be granted in two ways. Certain special institutions may be granted an Authority which enables them to issue their own multiple, free, internal permits. Those not eligible for such an Authority must apply for individual Permits for each consignment and these permits attract a charge.

Fig. 1: Diagram showing the nett effect of the *Wildlife Protection (Regulation of Exports and Imports) Act 1982* on traffic of different categories of insects into and out of Australia. Uninterrupted arrows indicate no permit is necessary.



Authorities to Export/Import. These are available to certain institutions which apply on Form R4 to be classified as Registered Scientific Institutions and meet the criteria laid down in *Regulation 10*. Registration is available to both Australian and overseas institutions and it appears that most of the latter who had lodged Holotype Declarations under the old *Customs Regulation 13A* were automatically Registered. The criteria in *Regulation 10* are those normally associated with formal Museums, e.g. maintenance of permanent, professionally curated, catalogued, scientific collections used for internal, published research and available to outside scientists. Initially it seemed unlikely that many Australian institutions other than formal Museums would qualify, but *Regulation 10* has been administered leniently and today there are 63 Australian and 853 overseas Registered Institutions. Each receives a registration number preceded by a country code, thus the Queensland Museum is AU005 and the British Museum is GB001. More than half are not approved to export/import CITES species and have the letter "A" terminating their number.

Once Registered, an institution may apply under *Section 41* for an Authority to export/import. This Authority qualifies them to receive stocks of stickers which are affixed to consignments and act as export or import permits. Separate stickers are issued for CITES and Non-CITES species and a statement of contents is required on the sticker. *Section 41* spells out limitations on their use. Thus they can only be used for dead specimens being sent for scientific purposes as a loan, donation or exchange from one Registered Institution to another. Authorisation and book-keeping regarding use of the stickers is left to the internal arrangements of the institution. This sticker system is extremely simple to operate and endows a great deal of freedom and autonomy on workers in Registered Institutions. However, if they wish to export to individuals or to non-registered institutions, or if they wish to export live specimens, then they must apply to ANPWS Canberra for individual Permits as described later at the cost of $10 each.

Affiliation with a Registered Institution. An extremely useful device exists in *Section 41(7)* whereby an outside worker may become affiliated with a Registered Institution (in Australia or Overseas) if the institution wishes to foster his/her research. Such affiliates may then use the Institution's stickers to facilitate their own research exports/imports under the same *Section 41* criteria available to the institution itself. However, such affiliation is not automatic and under *Section 41(8)* the institution must gain written consent from the Director of ANPWS before accepting an affiliation application. Affiliation has provided relief to many serious, private or non-museum workers who were otherwise confronted with a slow, expensive, individual permit system. It should not be overlooked that affiliation is a privilege based on a considerable degree of trust, because *Section 48* sets out fines of $10,000 for the individual, and $20,000 for the institution for breaches of authority conditions.

Other Authorities. The new *Amendment Act 1986* to the *Wildlife Protection Act* introduces two new forms of Authorities which have potential use for export and import of insects. *Section 42A* outlines criteria for obtaining a 12 month, multiple-use Authority for prescribed specimens which could include both live and dead native insects which have been captive bred. Presumably this authority would be valuable for export of live stocks of Australian insects for biocontrol purposes. *Section 42B* gives criteria for obtaining a 12 month, multiple use Authority for importing prescribed specimens for prescribed research in an approved institution. Both these authorities would give considerable autonomy to persons not eligible for access to a Registered Institution's Authority.

Individual Permits. Persons not in a Registered Institution, and not affiliated with one, and persons in Registered Institutions who wish to interchange specimens with persons not in Registered Institutions or for other than scientific purposes, must apply for individual Permits to export/import specimens regulated by the *Wildlife Protection Act*. Application must be made to the Minister who shall convey his decision within 90 days, unless extended by the need to have an environmental impact statement prepared (*Sections 23 and 24*). Permits are valid for only one consignment and for up to six months after issue. Individual permit charges are set out in Schedule 3 of the Regulations and range from $10 for consignments for scientific purposes to $40 for commercial transactions. The fee structure is currently under review.

Some general criteria are laid out in the Act governing granting of Permits. Thus *Sections 25 and 33* prohibit export/import which would be "detrimental to survival" of the species involved. *Section 26* prohibits export of specimens obtained contrary to any Commonwealth or State law. This would include protected species illegally collected (see summary of insects protected by State laws in New 1984), specimens collected without permit in National Parks and other reserves, and CITES species illegally imported into Australia.

More specific criteria for Permits are also laid out in the *Wildlife Protection Act* which reflect the guidelines for permissible trade outlined in the CITES Convention. Since Australia has regulated all native insects under its Act many of these criteria will apply to native insects as well as to the CITES butterflies. These criteria, one or more of which may allow a Permit to be granted under *Sections 27 to 38* are as follows:

(i) **Specimen is for prescribed scientific research.** The only research which qualifies specimens for export/import permits under the Act is that undertaken in "prescribed scientific organisations" as defined by *Regulation 3*. This specifies that such organisations should be non-profit, have research as a major function, make research results available, not trade in restricted specimens, and use restricted specimens only for research or public education.

Such organisations may be in Australia or overseas. Dead specimens of Schedule 1 and 2 species (the CITES butterflies) may be exported (*Sections 28-29)* or imported (*Sections 36-37)* and dead or alive native Australian insects may be exported (*Section 31*) for such research.

(ii) **Specimen has been captive bred.** "Bred in captivity" is a CITES requirement which is defined by *Regulation* 8 of the *Wildlife Protection Act.* To be legally captive bred a specimen must have been raised in an enclosed, controlled environment, not regularly augmented from the wild, and in which its parents mated. The same export/import permit privileges apply for such captive bred specimens as stated above for prescribed scientific research. Two Australian dealers have successfully received export permits for their captive bred stocks of butterflies.

(iii) **Specimen has been removed from the wild under an approved managment programme.** If the Government is supplied with sufficient information defined under *Regulation* 5 for it to decide that the natural population of a species can sustain harvest of a proportion of specimens then it may declare an Approved Management Programme (AMP) for the species in the 'Gazette'. Harvesting of kangaroos, mutton-birds and certain Western Australian wildflowers for export takes place under such AMPs. There are no current AMPs for Australian insects. If there were so it would be possible to export dead specimens of Schedule 2 (*Section 29*) species and live or dead other native species (*Section 31*). Import of overseas Schedule 2 CITES butterflies is possible if they have been taken under an overseas AMP (*Section 37*), but would not be possible for species such as *Ornithoptera alexandrae* if it is transferred to Schedule 1.

(iv) **Live specimens to be exported/imported by an Approved Institution.** Organisations in Australia or overseas may apply under *Section 11* for listing in the 'Gazette' as Approved Institutions for keeping live animals. They must satisfy *Regulation 6* which specifies that they be equipped to house and care for the relevant animal. Import and export of living Schedule 1 and 2 species (including CITES butterflies) is only permitted by such institutions. *The Quarantine Act 1908* will also apply to live imports and negotiations are currently underway to overcome some of the anomalies caused by overlap of the two Acts.

(v) **Specimen is for transfer between zoos.** Transfer of almost all categories of live or dead native and CITES animals can take place between official zoos approved under *Section 12* and *Regulation 7*. Now that some Australian zoos are setting up butterfly houses (e.g. the Melbourne Zoo), there may be the possibility of such imports/exports of insects under this criterion. Undoubtedly the *Quarantine Act 1908* would be a severe barrier to zoo imports of live exotic species.

(vi) **Relevant authority in the other country has granted permit for the transfer.** CITES requires that signatory countries designate an authority to administer the provisions of CITES in that country. Thus in Australia the CITES authority is the Director of ANPWS. Export of Schedule 1 species from Australia is only permitted if the relevant authority of the receiving country has issued an import permit for the specimen (*Section 28*). Similarly, import of Schedule 1 and 2 specimens (including CITES butterflies) into Australia is only permitted if export has been approved by the country they are coming from (*Sections 36 and 37)*.

(vii) **Specimen is being re-exported from Australia.** *Section 32* specifies that Permits will be granted for export of dead specimens previously imported into

Australia, provided (i) that they were not illegally imported in the first place, and (ii) that an import permit has been gained from the importing country for any Schedule 1 species involved. This means, for example, that foreign CITES butterflies may be easily exported from Australia if they were acquired legally in the first place.

INSECT EXPORT/IMPORT FOR COMMERCIAL OR PRIVATE TRADE UNDER THE ACT

Under the *Wildlife Protection Act* the term "commercial trade" is used to mean all insect export/import for purposes other than scientific research or transfers between zoos. As we have seen scientific research prescribed under the Act is only that which goes on in "prescribed scientific organisations".

This means that "commercial trade" is that carried out not only by souvenir shops selling butterfly-wing trinkets and dealers who buy and sell specimens, but also by private collectors who exchange specimens overseas and whose research activities are either non-existent or do not warrant affiliation with a Registered Institution. A summary of the export/import activities permissible under the Act by such people is as follows:

Import. Commercial importers may bring in: (i) dead, non-CITES specimens freely without permit; (ii) under Permit, dead Schedule 2 butterflies provided they are captive bred or taken under a management programme and provided the source country has issued an export permit; (iii) under Permit, live Schedule 2 butterflies and other insects provided exporter and importer are approved institutions, the source country has issued an export permit and quarantine approval is gained.

Export. Commercial exporters may send out: (i) under Permit, dead, native CITES butterflies and other dead native insects, provided they are captive bred, taken under a management programme or are for prescribed scientific research by the overseas recipient; (ii) under Permit, live CITES butterflies under the same criteria as (i) provided exporter and importer are approved institutions; (iii) under Permit, non-native CITES butterflies, provided they were legally imported in the first place; (iv) dead, non-CITES, non-native insects, without Permit.

INSECTS IMPORTED IN PERSONAL OR HOUSEHOLD EFFECTS

The problem of CITES specimens being detected in the personal effects of persons arriving in Australia is covered in *Section 54* (temporary visitors), *Section 55* (arriving intending residents) and *Section 56* (returning residents). Examples include persons arriving in Australia with a CITES butterfly which they may have collected or bought as a souvenir unaware that it was a prohibited import. These are seized. Under the original *Wildlife Protection Act:* the owner of a specimen seized under *Section 54* was given the option of reclaiming the specimen on their departure from Australia; the owner of a specimen seized under *Section 55* had the option of sending the specimen to another country; specimens seized under *Section 56* were permanently forfeited to the Crown. A new *Section 56A* inserted into the Act by the Amendment Act of 1986 allows for a retrospective Import Permit to be applied for with respect to a specimen held in custody after seizure under *Sections 54, 55 or 56.* Such a Permit will be granted if the applicant can demonstrate either that the specimen was captive bred or taken under a management programme and was exported from the source country legally or that the specimen was collected before the species was listed as a CITES one (i.e. before 1973 for the CITES butterflies). This latter provision is a very important concession of the Amendment Act because it now means that a person coming to live in Australia can bring with them an insect collection containing old, treasured, CITES butterflies which would have been confiscated under the original Act. Similar amendments liberalising import of pre-CITES specimens have also been made to *Sections 36 and 37* which govern normal import applications of Schedule 1 and 2 species, respectively. But these will only be permitted if accompanied by a CITES clearance certificate as household effects issued by the country of origin

INSECT CONSERVATION EFFECTS OF THE WILDLIFE PROTECTION ACT

The Act severely limits the non-scientific export of native Australian insects and the import and export of the CITES butterflies. In this way it may affect collecting pressures on insects both within Australia and in adjacent nations where most of the CITES butterflies occur. The internal and external effects of the Act will be discussed as separate issues:

Effects of the Act on Australian Insects. Australia does not have a particularly showy or spectacular insect fauna. Hobbyist collecting of insects is not as frequent in Australia as it is in many northern hemisphere countries, and I believe it is fair to say that among our private collectors there is a much greater proportion of those devoted to serious insect study relative to those more ruthless collectors interested in building competitive show collections, than in most other countries. Nor is there a great demand overseas for Australian insects in comparison to that of nations such as Brazil, Papua New Guinea, Malaysia and that of Taiwan which sustain gigantic insect harvesting operations. For these reasons there has never been significant amounts of exploitative insect collecting in Australia for export.

Certainly there are Australian insects desired overseas by collectors prepared to pay for the rare and unusual. The highest price would be commanded by the North Queensland stag beetle, *Phalacrognathus muelleri*, at perhaps several hundred dollars for large males. Others include *Coscinocera hercules*, *Mecynognathus damelii*, our *Ornithoptera* spp., large Buprestidae, large Cetoniinae, etc. but few of these would reach $50. The Act curtails legal overseas trade in these native species except for captive bred specimens and the small volume of legal trade is indicated by the fact that only two dealers have applied for export of captive bred butterflies. Undoubtedly there is a small quantity of illegal export through the mail and the occasional open advertising overseas of wild-caught Australian insects. Leakage through the mails is difficult to police but there is little evidence to suggest that its volume is such that it is of real conservation concern.

Exchange of specimens with overseas colleagues has traditionally been the way private collectors have built up their collections and there is resentment that this activity is now denied them by the Act. The legitimate needs of serious collectors who are undertaking private research can be partly fulfilled by access to affiliation with Registered Institutions provided the collector is fully aware of his own obligations under affiliation.

Effects of the Act on Trade in Overseas Insects. Among overseas insects only the CITES butterflies are prohibited by the Act, but these may be imported if captive bred. An outstanding problem in international butterfly trade has been the high prices and attendant black marketeering of Papua New Guinea's birdwing butterflies. To counter this the PNG Government initiated a controlled harvesting operation whereby villagers encourage butterfly breeding by selective food plant growing. A proportion of the butterflies are collected for sale through the government controlled Insect Farming and Trading Agency (IFTA). This has been highly successful and two species of CITES birdwings (*Ornithoptera priamus* and *Troides oblongomaculatus*) are marketed in large numbers at low prices, many as tourist souvenirs in perspex display cases. The beneficial effect that this programme has had on birdwing prices is offset because many of the IFTA specimens returned to Australia are seized under the Australian Act because they do not fulfill the stringent "captive breeding" criteria of the Act. There is an urgent need for this anomaly to be resolved and also for other PNG birdwings to be brought into controlled harvesting.

Most of the countries adjacent to Australia which have natural birdwing populations are signatories to CITES (Papua New Guinea, Indonesia, Malaysia) so the fully bilateral effects of the CITES component of Australia's Act is able to operate with these countries. Additionally, Indonesia has now introduced internal protection for its birdwings, which include the highly-desired, high-priced species in West Irian (Anon 1984).

The Solomon Islands is not yet a signatory of CITES, yet it has announced recently (MacFarlane 1987) that it intends setting up a village butterfly breeding industry similar to that in Papua New Guinea. Two birdwings, *Ornithoptera priamus urvilliana* and *O. victoriae*, are planned to be part of this programme. Australia's Wildlife Protection Act will prevent import of these species until such time as the Solomons signs CITES and has its butterfly operation recognised as either captive breeding or an approved management programme.

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THE ROLE OF THE ODONATA AND AQUATIC COLEOPTERA AS INDICATORS OF ENVIRONMENTAL QUALITY IN WETLANDS

J.A. Davis, S.W. Rolls and S.A. Balla, School of Environmental and Life Sciences, Murdoch University, Murdoch, W.A., 6150

ABSTRACT

The macroinvertebrate fauna and water chemistry of ten wetlands in the Perth region, Western Australia, were sampled on a regular basis from April 1985 to June 1987 to determine spatial and seasonal variability and to provide a baseline against which future changes could be assessed.

A relative reduction in species richness and the apparent loss of invertebrate predators from several of the urban wetlands suggested a serious deterioration in the food chains of these lakes, and as a consequence, the environmental quality of the wetlands.

Both species richness and trophic structure are costly parameters to measure (in both time and money) because of the need to identify large numbers of invertebrates. The use of a single order or family would be less time-consuming, and so less costly, because fewer specimens would be involved.

The presence of high numbers of species of Odonata and Coleoptera in lakes with high species richness and complex trophic structure, and low numbers in lakes with low species richness and reduced trophic structure, suggested that these groups may be potential indicators of environmental quality in Perth wetlands, and possibly in other wetland systems.

INTRODUCTION

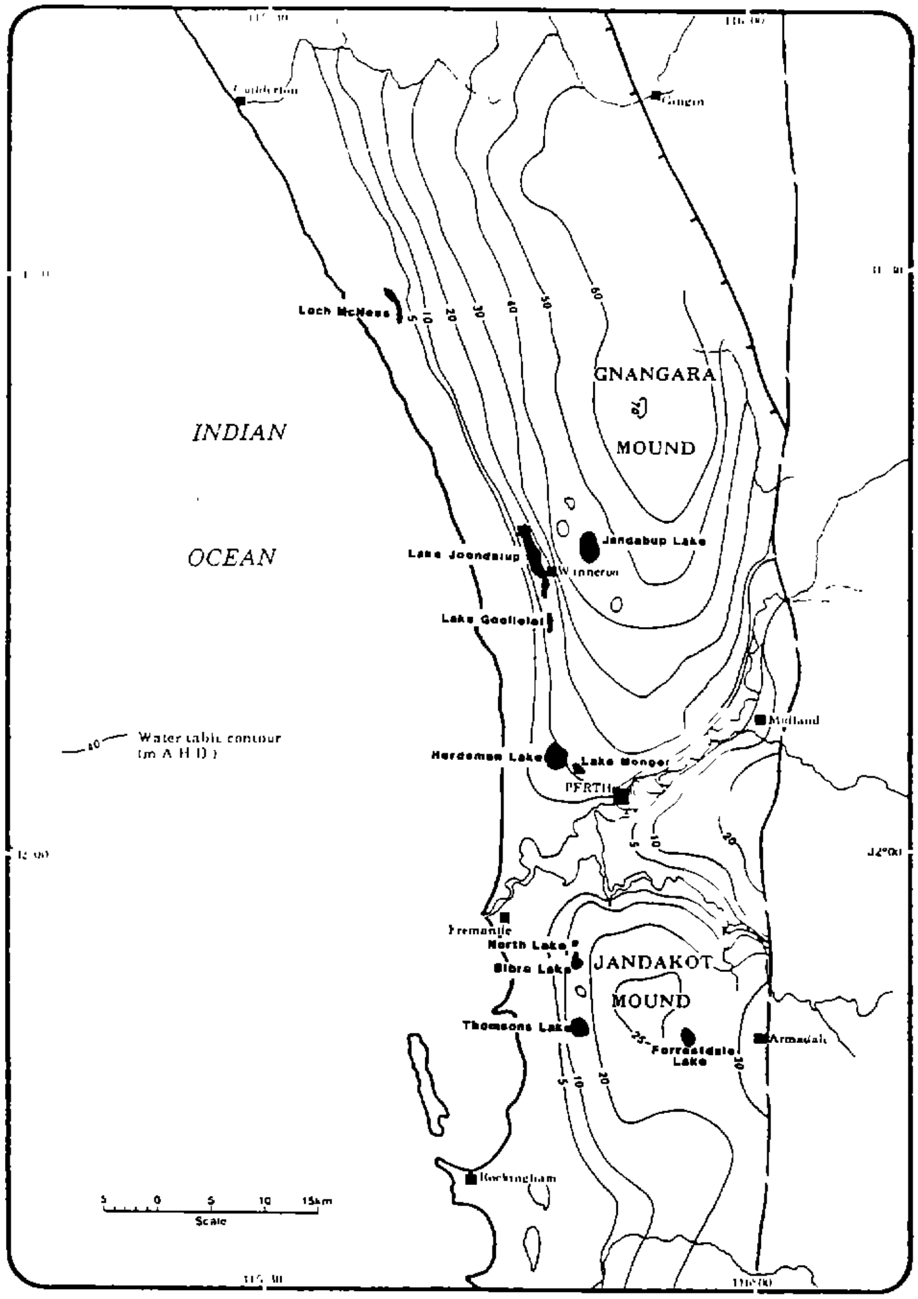
The wetlands of the Perth metropolitan region are surface expressions of the groundwater, or watertable, which underlies the region. The groundwater is an important resource which provides water for domestic, agricultural and industrial purposes (Cargeeg et al. 1987). In recent years attention has focussed on the management of the region's groundwater (Cargeeg et al. 1987) and, as a consequence, on the management of the wetlands which are an integral part of this resource. As a result, information was required regarding the environmental quality of wetlands in the Perth region to aid in the formulation of management policies for the urban wetlands.

To provide this information a baseline biological and chemical monitoring programme was undertaken for five lakes: Jandabup Lake, Lake Joondalup, Lake Monger and Thomsons Lake, for the 12 month period April 1985 to May 1986 (Davis and Rolls 1987). This study was extended at the end of the first year to include an additional five lakes: Loch McNess, Lake Goollelal, Herdsman Lake, Bibra Lake and Forrestdale Lake and the ten lakes were monitored for the 12 month period June 1986 to May 1987 (Davis, Rolls and Balla in prep.). The locations of the ten lakes on the Swan Coastal Plain are given in Fig. 1.

The use of biological data, in any form, as an indicator of water quality, is known as biological monitoring (Arthington et al. 1982). Biological monitoring techniques are well established in Britain, Europe and the USA, and reviews of various methods are given by Hellawell (1978) and James and Evison (1979). However, the application of biological monitoring in Australia, until recently, has been limited.

Majer, J.D. (ed.), *The Role of Invertebrates in Conservation and Biological Survey*. (1987). Western Australian Department of Conservation and Land Management Report.

Fig. 1: The location of the ten wetlands studied on the Swan Coastal Plain, W.A., and their relationship to the water table. Map provided by the Water Authority of Western Australia.



A wide range of physical and chemical parameters were measured and the results of the first year's study (1985-86) revealed that four of the five lakes (Lakes Joondalup, Monger, North and Thomsons) appeared to be excessively nutrient-rich by world standards.

The results of the first year's macroinvertebrate sampling programme revealed that both species richness (the total number of species) and the number of predatory invertebrates in two of the five lakes, Lake Joondalup and Lake Monger, were very low. The reduction in species richness and the loss of predatory invertebrates was considered to indicate a serious deterioration in the food chains of these lakes and, as a consequence, the environmental quality of the lakes. The basis of the biological monitoring programme was the measurement of macroinvertebrate species richness and trophic structure, however, species richness and trophic structure can be costly parameters to measure and assess because of the need to indentify large numbers of invertebrates. The use of only one invertebrate order or family would be less time consuming, and so less costly, because a fewer number of specimens would be involved.

The presence of high numbers of species of Odonata and Coleoptera in lakes with high species richness and complex trophic structure and low numbers in lakes with low species richness and reduced trophic structure suggested that these groups may be potential indicators of environmental quality in Perth wetlands. Data collected in both the first and second years of study were examined to determine the validity of this approach.

METHODS

The physico-chemical environment of each of the wetlands was assessed by measuring the following parameters: depth, light transparency, pH, conductivity, major ion concentrations (Na^+, K^+, Ca^{++}, Mg^{++}, Cl^-, $HCO_3^=$ and $SO_4^=$) and nutrient concentrations (total P, PO_4, total N, NH_4^+ and $NO_3^=/NO_2^-$). Chlorophyll a was measured to provide an assessment of the extent of algal blooms within each lake. All of the above parameters were measured at two sites within each of the five wetlands on a monthly basis for the 12 month period April 1985 to May 1986 and at each of two sites at the ten wetlands on a two monthly basis for the 12 month period June 1986 to May 1987. All analyses were undertaken at the Government Chemical Laboratories and the Centre for Water Research Nutrient Laboratory.

The macroinvertebrate fauna was sampled at each of two sites in each of the five wetlands on a three monthly basis from April 1985 to May 1986 and at each of two sites in the ten wetlands on a two monthly basis from June 1986 to May 1987. Six replicate samples using a pump sampler and two timed sweep samples were collected at each site in the first year's study. Four timed sweep samples were collected at each site in the second year's study. Samples were preserved with ethanol in the field and sorted at a later date in the laboratory.

All samples were identified to species level using available keys and a voucher collection containing specimens identified by specialist taxonomists.

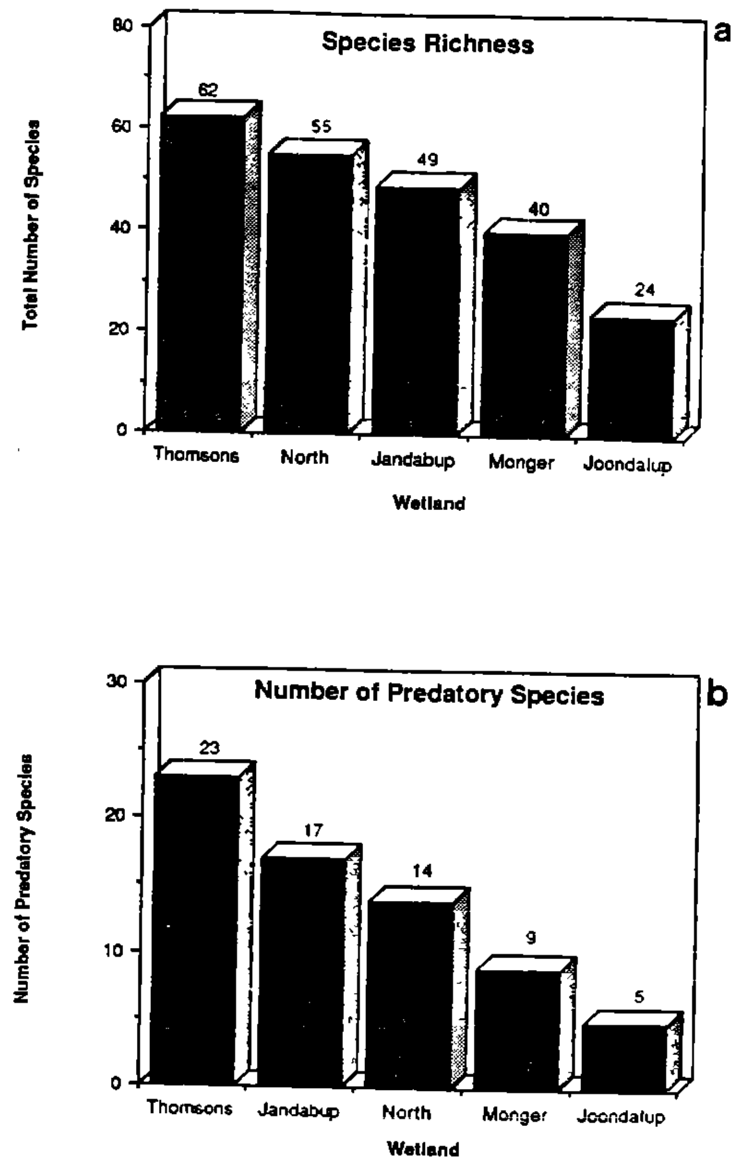
RESULTS

The nutrient status of each lake for the 12 month period June 1986 to May 1987 is summarised in Table 1. Some of the results of the biological monitoring programme undertaken in the first year of study are presented in Figs. 2a and 2b. A more comprehensive account of the results of the first year's physico-chemical and

Fig. 2: (a) The total species richness (number of species) recorded from five Perth wetlands during the 12 month period April 1985 to May 1986.

(b) The total number of predatory species recorded from the five wetlands during the same 12 month period.

(c) Predator:prey ratios for the five wetlands for the same 12 month period.



Predator:Prey Ratios	0.8:1	0.77:1	0.76:1	0.4:1	0.2:1

c

macroinvertebrate sampling programme are given in Davis and Rolls (1987) and data from the second year's study will be presented in Davis, Rolls and Balla (in prep.).

Table 1 AVERAGE NUTRIENT STATUS* OF URBAN WETLANDS FOR THE TWELVE MONTH PERIOD JUNE 1986 TO MAY 1987.

McNess	Jandabup	Joondalup	Goollelal	Herdsman	Monger	North	Bibra	Thomsons	Forrestdale
M	M	E	E	E	H	H	H	E	H

Classification based on Wetzel's (1975) criteria for total phosphorus

Category	ug/l
Meso-eutrophic (M)	10-30
Eutrophic (E)	30-100
Hypereutrophic (H)	>100

* Nutrient status based on total phosphorus of the lake for at least 8 months of the 12 month period.

A total of 87 invertebrate taxa were recorded from the five lakes and this is amongst the highest number of taxa recorded from Australian lakes. A total of 62 taxa recorded from Thomsons Lake represents the highest number recorded from a wetland on the Swan Coastal Plain. The total number of predatory species recorded from the five wetlands over the 12 month period displayed a similar trend to that for the total species richness, although the position of Jandabup Lake and North Lake were reversed with Jandabup having a higher number of predatory species (Figs. 2a and b). The lower number of predatory species in Lake Monger and Lake Joondalup could be considered to merely reflect the lower total numbers of species recorded from each lake. However, comparison of the predator-prey ratios for each lake (Fig. 2c) revealed a true decrease in the number of predatory species in the two lakes. The total number of species of Odonata and Coleoptera recorded from each of the five lakes for the 12 month period (1985-86) is given in Figs. 3a and b. In both figures the same trends, similar to that seen for the total number of predatory species (Fig. 2b) are evident. The correlation coefficients and R^2 values given in Table 2 indicate that both the number of species of Coleoptera and the number of species of Odonata were highly correlated with the total number of species of other predatory invertebrates. Thomsons Lake contained the highest number of species of Coleoptera and Odonata, whilst the lowest numbers were recorded from Lake Joondalup and Lake Monger. Total species richness and total number of species of predatory invertebrates have not yet been compiled from the second year's study of the ten urban wetlands, but data for the total number of species of Odonata and Coleoptera are available and are given in Figs. 4a and 4b.

Fig. 3: (a) The total number of species of Odonata and (b) the total number of species of Coleoptera recorded from five Perth wetlands during the 12 month period April 1985 to May 1986.

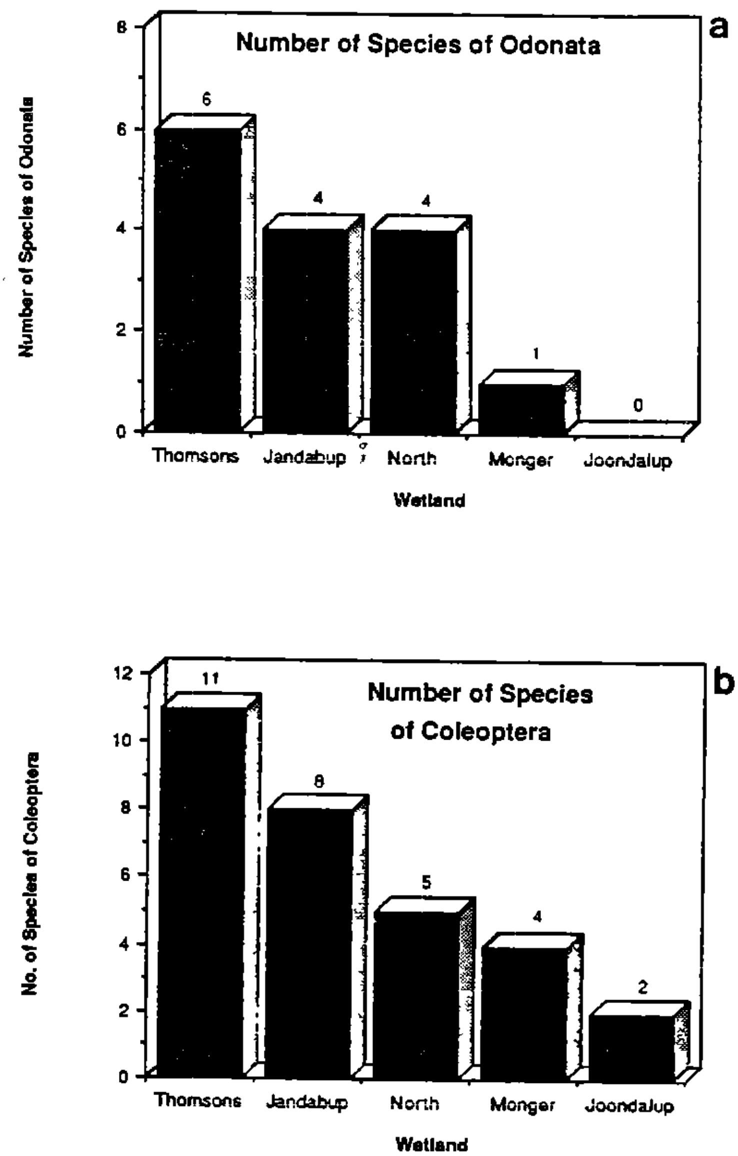


Fig. 4: (a) The total number of species of Odonata and (b) the total number of species of Coleoptera recorded from ten Perth wetlands during the 12 month period June 1986 to May 1987.

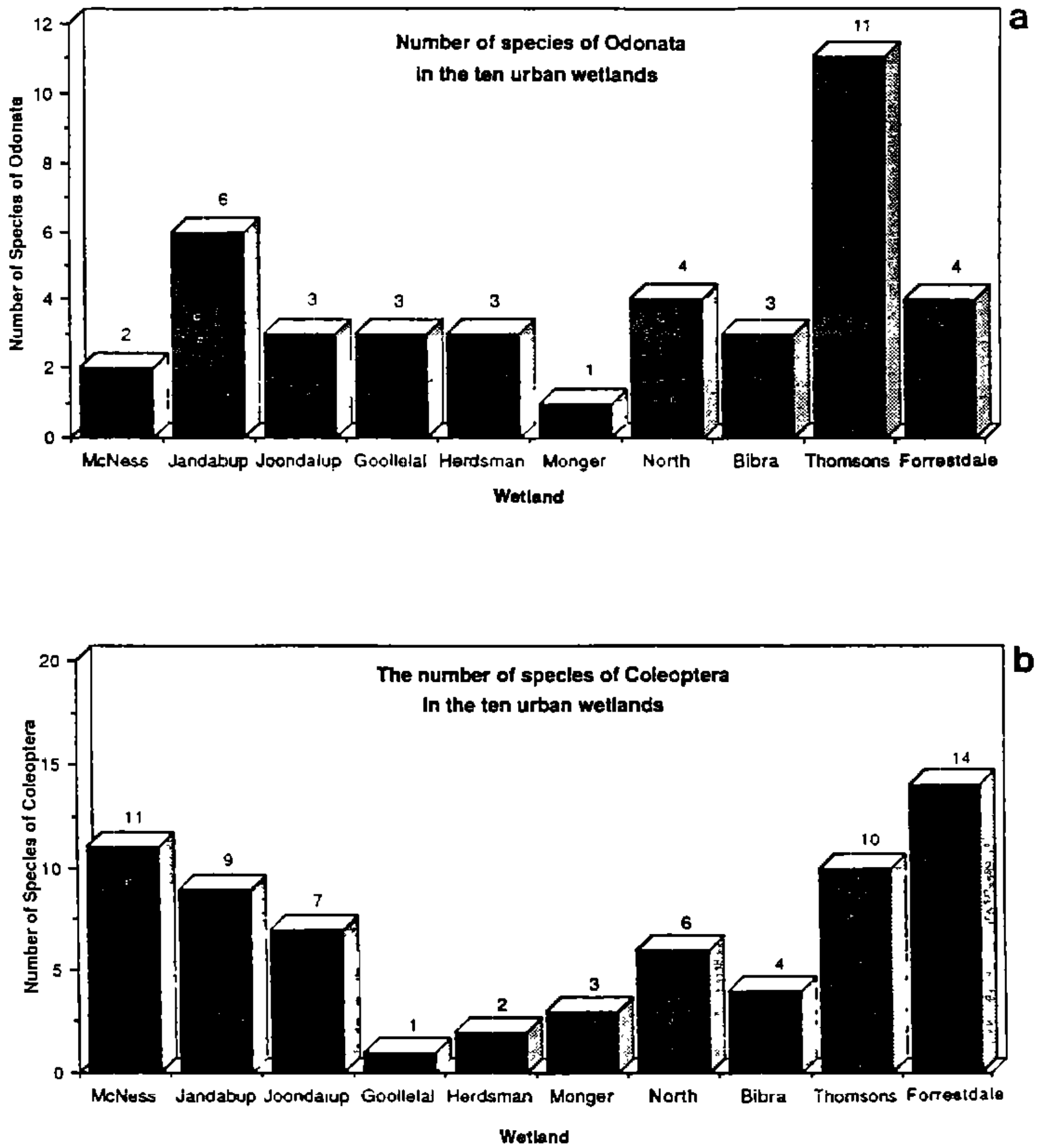


Table 2 CORRELATION COEFFICIENTS AND R^2 VALUES OBTAINED FROM CORRELATIONS OF THE NUMBER OF SPECIES OF COLEOPTERA OR ODONATA WITH THE TOTAL NUMBER OF OTHER PREDATORY INVERTEBRATES.

	Correlation coefficient	R^2
Number of species of Coleoptera vs. number of species of non-coleopteran predators	0.93	0.86
Number of species of Odonata vs. number of species of non-odonatan predators	0.95	0.90
Combined number of species of Coleoptera and Odonata vs. number of species of non-odonatan and non-coleopteran predators	0.97	0.94

Similar trends to those seen for the total number of Coleoptera recorded from the five wetlands in 1985-86 are also apparent for the data obtained for the ten wetlands in 1986-87. Four of the lakes: Forrestdale, Thomsons, McNess and Jandabup possess relatively high numbers of species, whilst few species were recorded from Goollelal, Herdsman, Monger and Bibra. A greater number of species (7) were recorded from Lake Joondalup in the second year of study (1986-87) than in the first (2) and this result may reflect the changes in lake water chemistry that occurred between the two years (Davis, Rolls and Balla, in prep.).

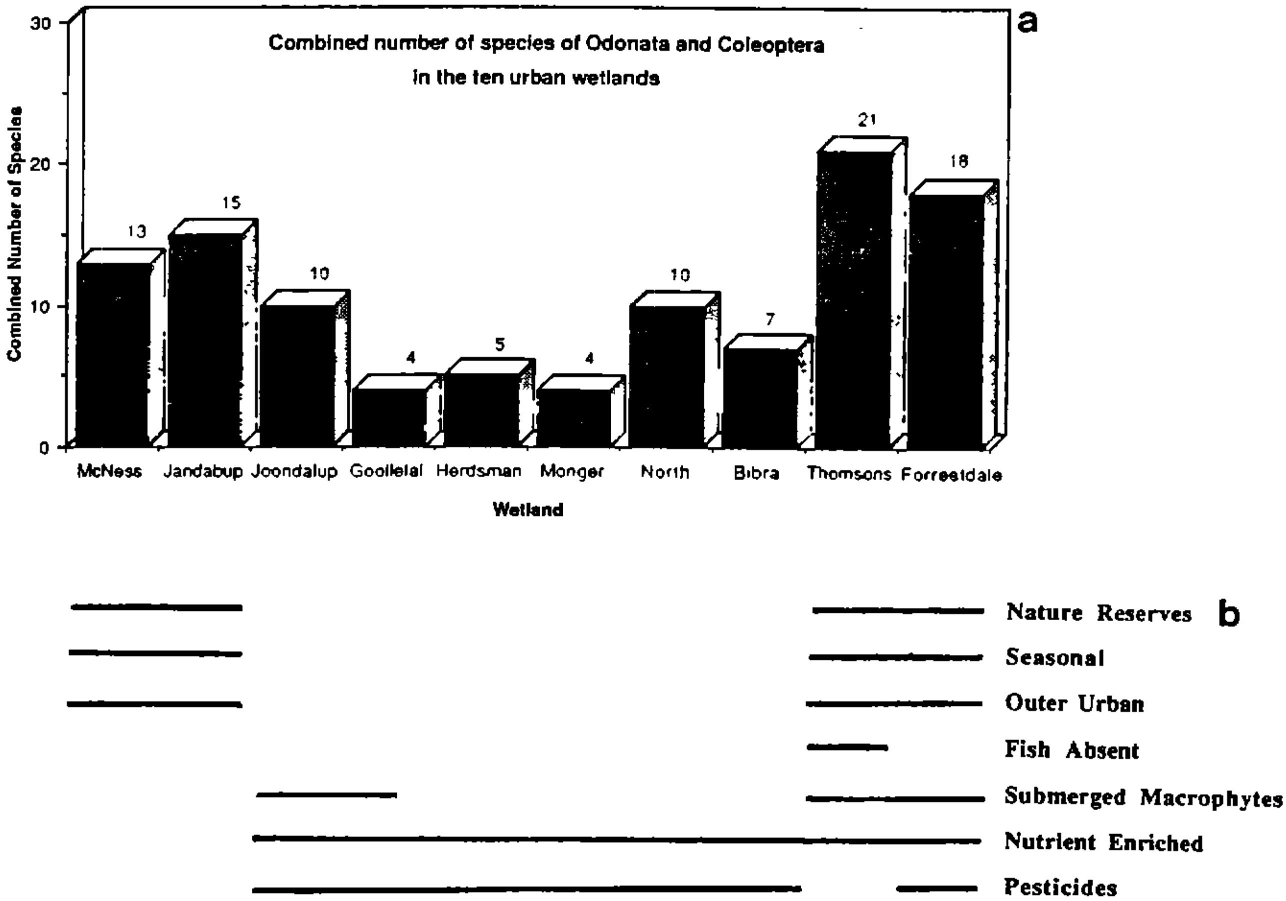
Both Thomsons Lake and Jandabup Lake contained the highest number of species of Odonata in both studies but higher numbers were recorded from Thomsons Lake (11) and Jandabup Lake (6) in the second year of study than in the first (6 and 4 respectively). This result may reflect the greater frequency of sampling in the second study compared to the first. The number of species of Odonata recorded in Lake Joondalup increased from zero to three in the second year of the study and this result mirrors the increase seen in the numbers of Coleoptera in the same lake. The number of species recorded from Lake Monger (1) and North Lake (4) remained the same in both years. The combined totals for the number of species of Odonata and Coleoptera recorded from the ten lakes are given in Fig. 5a. The various physical, chemical, biological and social factors that may be invoked to explain the differences between the lakes that contain high numbers of species and those that contain few are summarised pictorially in Fig. 5b.

DISCUSSION

The relatively high total number of species and number of species of predatory invertebrates recorded from Thomsons Lake and Jandabup Lake compared to the lower number of species and reduced number of predatory invertebrates recorded from Lake Monger and Lake Joondalup, during the first year of the study (1985-86)

Fig. 5: (a) The combined total number of species of Odonata and Coleoptera recorded from ten Perth wetlands during the 12 month period June 1986 to May 1987.

(b) Factors that may have influenced the presence or absence of macroinvertebrate species at each lake are indicated by vertical lines placed in a position beneath Fig. 5a to correspond with the lakes where they occur.



were considered to indicate that the environmental quality of the latter two lakes was considerably lower than that of the former two. The environmental quality of North Lake was considered to be at some intermediate level between the two pairs of lakes because although species richness was relatively high, some reduction in the number of predatory invertebrates appeared to have occurred.

The apparent loss of predatory invertebrates from a wetland must be considered to represent a serious change or deterioration within that wetland ecosystem.

No single factor can be isolated to explain the loss of invertebrate predators from the urban wetlands but rather this loss may be attributed to a combination of factors which have arisen from three primary causes: excessive nutrient enrichment: the use of pesticides directly on wetlands or within wetland catchments: and the presence of an introduced fish, the mosquitofish *Gambusia affinis*. Because many predatory invertebrates are visual predators, that is, they rely on seeing their prey to catch them, the loss of light within the first few centimetres of the water surface due to the presence of massive algal blooms may exclude many predators from lakes where this occurs (for example, Lake Monger).

Massive algal blooms also result in decreased oxygen levels in the lakes during the warmer summer months and this may effectively exclude the larger invertebrate predators (i.e. the larger larval odonatans and coleopterans which have high oxygen requirements). Algal blooms within the urban wetlands often comprise species of blue-green algae (or cyanobacteria) which are toxic and this toxicity may be transferred through the food chain to the predatory invertebrates. All of the above factors are a direct result of the excessive nutrient enrichment or cultural eutrophication of a wetland.

Pesticides used directly on a wetland for the control of larval chironomids (midges) may also kill many other non-target species of invertebrates and populations of the larger predatory invertebrates (such as the Odonata) with longer life cycles may take many months to return to pre-spraying numbers. Pesticides used within a wetland catchment, for example, organochlorines used for termite control or on household gardens, may also arrive at a wetland directly through surface drains or through subsurface water movement, and through bioaccumulation may have the greatest impact on the invertebrates at the top of the food chain.

The introduced mosquitofish *Gambusia affinis* may reduce the total numbers of predatory invertebrates and the numbers of species directly by predation or indirectly through competition for prey.

Because all of the species of larval odonatans recorded from the urban wetlands and most of the species of larval and some adult coleopterans are predators, it would seem reasonable to expect that the total numbers of each group may reflect the same trends seen in the total numbers of all the predatory species combined. The high correlation coefficients and R^2 values obtained from the correlations of both the Odonata and the Coleoptera with the total number of species of other predatory invertebrates (Table 2) suggests that either group would be suitable for use as an indicator of the overall number of predatory species in the system.

The use of subgroups of predatory species rather than the entire group should result in considerable savings in time and cost and eliminate the collection of redundant data within the biological monitoring programme. For example, in the first year of study a total of 23 species of predatory invertebrates were recorded from Thomsons Lake, whilst only 11 species of Coleoptera and 6 species of Odonata were recorded from the same lake. However, if this method is to be adopted it is very important that we know the exact ecological requirements of all species of Odonata or Coleoptera recorded from the urban wetlands and their tolerance to specific impacts. Until this information is available, it may be far safer to consider the combined total numbers of species of Coleoptera and Odonata rather than to rely on a single group.

It is important to note that it is the relative numbers of predatory species or groups (the high numbers versus the very low numbers) that probably provides the most reliable estimate of high or low environmental quality. Absolute numbers should not be considered when the actual causes for high or low numbers cannot be accurately identified. Further work is now required to ascertain the exact determinants of the presence and absence of species of Odonata and Coleoptera in the urban wetlands. The high numbers recorded from Thomsons Lake, Forrestdale Lake, Jandabup Lake and Loch McNess may reflect a number of factors (Fig. 5) many of which (for instance the presence of fringing vegetation and seasonal variation in water levels) may be a direct consequence of the protection they have received from urban land development and the attendant land clearing and modification of water cycles because of their vesting as Nature Reserves. The low numbers recorded from Lake Monger and Bibra Lake may be a result of the excessive nutrient enrichment that is present in both lakes and the massive algal blooms that occur as a consequence (Davis, Rolls and Balla in prep.). The low numbers recorded from Lake Goollelal and Herdsman Lake may reflect the high concentrations of organochlorine pesticides that have been recorded at the two lakes (Davis, Ebell, Halse and Blyth unpublished data).

Both the Odonata and the Coleoptera appear to have wide ecological tolerances and so the potential exists for them to occur in all wetlands. This is important because it is the presence of species in a wetland that will indicate that all their ecological requirements are being met, the absence of species is less useful as an indicator because it is not possible to say exactly which factor may have caused the absence (Jones and Walker 1979).

If the aquatic Coleoptera, which includes the Dytiscidae, Hydrophilidae, Haliphlidae and Curculionidae, are to be used as indicators of environmental quality in Perth's wetlands, further information is needed in a number of areas. This includes work on the taxonomy of local species (many of the larval and adult forms have not been linked) and information on life histories so that appropriate sampling strategies can be devised.

The data examined here suggest that both the Odonata and the Coleoptera would be useful indicators of environmental quality in the urban wetlands. The Odonata would be an ideal group to use as environmental indicators because their taxonomy is well known and keys exist to identify virtually all species that may be found in the urban wetlands. The Coleoptera would be less suitable because many species remain undescribed. However, if only one group were to be used the Coleoptera may be more suitable than the Odonata because a larger number of species are present and so the potential for greater discrimination between wetlands exists.

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ANT COMMUNITY ORGANISATION AND ENVIRONMENTAL ASSESSMENT

Alan N. Andersen, CSIRO, Division of Wildlife and Rangelands Research, Tropical Ecosystems Research Centre, PMB 44, Winnellie, N.T., 5789

ABSTRACT

An immediate goal of the those who recognise the importance of insect conservation is to have insects included in the environmental assessment and monitoring programmes of land managers. The most practical way of achieving this is to concentrate on a small number of insect groups that are likely to act as indicators of the status of insects in general (and possibly other faunal groups as well). Ants are ideal candidates for this role in terrestrial habitats: they are ubiquitous, extremely abundant and diverse, ecologically important, taxonomically tractable, easily sampled, and have a history of use as bio-indicators. Most importantly, however, ants are ecologically well known, so that information on the relative abundance of taxa can be interpreted in an ecological context. The use of a generalised model of ant community organisation provides a means by which both the great diversity of Australian ants can be handled, and the composition of species can be interpreted ecologically. For example, patterns of ant community organisation vary predictably with habitat, and have known responses to habitat disturbance. A case study is outlined whereby patterns of ant community organisation are used to demonstrate a faunistic response to habitat changes wrought by fire in a tropical dry forest. Unfortunately, the relationships between the distributions of ants and those of other insect groups are poorly known, and this should be a major focus of future research.

INTRODUCTION

Perhaps the greatest threat to the long-term conservation of Australia's invertebrate fauna is our extremely poor knowledge of it (cf Giles 1987). One way of simultaneously improving this knowledge, and directly enshrining invertebrates in the conservation process, is to have them included in the environmental assessment and monitoring programmes of land managers. This is therefore an immediate goal of the insect conservation movement.

Unfortunately, however, in dealing with invertebrates land managers are presented with two serious problems not posed by vertebrates or higher plants. First, their extreme diversity of form and habits makes it impractical to cover all invertebrate groups. Second, the very fact that so little is known about most Australian invertebrates means that it is difficult to make meaningful interpretations of the data collected on them. How can we judge whether or not a species is endangered when its distribution is unknown?

Clearly at this stage we cannot adopt a species-by-species approach to invertebrate conservation. In most cases the best we can do is to make sure that the interests of invertebrates in general are protected. One way to do this is to focus on a few invertebrate groups that are likely to provide an indication of the status of invertebrate communities in general (Majer 1985). These indicator groups need to be diverse, ubiquitous, ecologically important, easily sampled, readily identifiable to species level, and responsive to environmental change (Majer 1983, Greenslade 1984). In terrestrial habitats, the invertebrate groups meeting these requirements include ants (Majer 1983, Majer et al. 1984, Greenslade 1984, 1985), spiders (Coyle 1981, Mawson 1986), springtails (Mahoney 1976, Greenslade 1984, 1985), termites (Nichols and Bunn 1980, Greenslade 1985) and beetles (Greenslade 1985).

ANTS AS BIO-INDICATORS

Several other factors make ants particularly good candidates for use as bio-indicators. First, they have been widely used as such in the past, in such diverse areas as mining (Majer et al. 1984, Majer 1985), fire management (Majer 1980), pesticide contamination (Weir 1978), habitat disturbance (Yeatman and Greenslade 1980), and, most recently, in theoretical considerations of reserve design (Margules 1985). Second, ants occupy the full range of trophic levels from herbivore (e.g. seed harvesters) to specialist predator, so that they interact with (and presumably influence) a wide range of other faunal groups. Third, they are especially abundant, diverse and ecologically important in the Australian environment. Fourth, some introduced species have the potential to become serious pests. For example, the pugnacious *Pheidole megacephala* has displaced native ant faunas in coastal eastern Australia (Majer 1985) and in the Darwin region (Andersen unpubl. observ.). The Argentine ant (*Iridomyrmex humilis*) has invaded sclerophyllous vegetation in South Africa where it has seriously disrupted seed dispersal (Bond and Slingsby 1984): this ant is already abundant in urban centres throughout Australia, and could cause a similar problem in native vegetation here.

Possibly the most important reason why ants are ideal candidates for use as bio-indicators is that ecologically they are one of the best known groups of insects, meaning that information on the distribution and relative abundance of species can be interpreted in an ecological context. This is especially so when ants are considered at the community level.

ANT COMMUNITY ORGANISATION

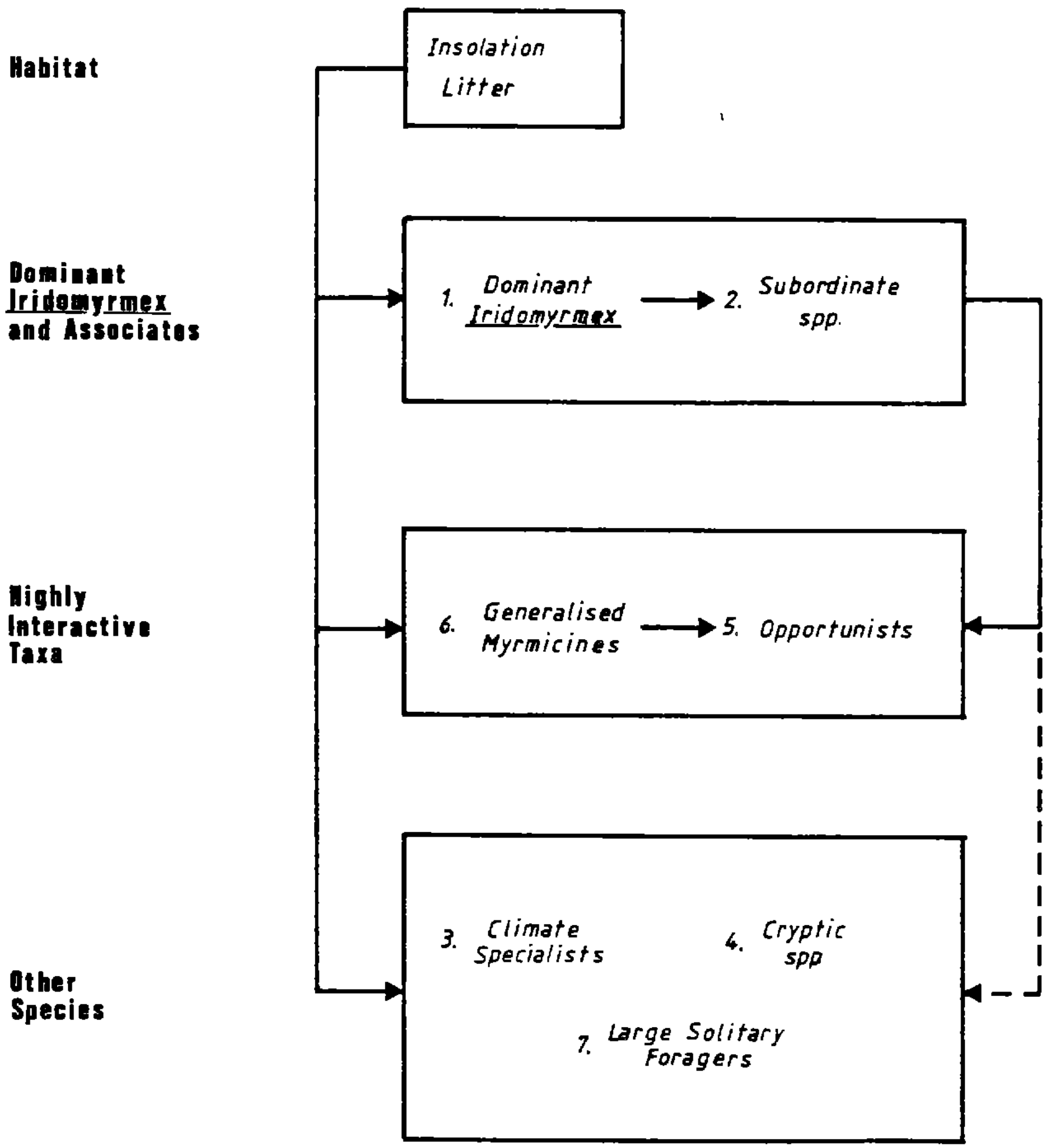
P.J.M. Greenslade has developed a model of ant community organisation in Australia where all taxa are classified according to their interactions with dominant species and to their habitat requirements (Table 1; Fig. 1: see Greenslade and Halliday 1983). This model is based primarily on studies in the arid zone, but also applies generally to mesic regions (Greenslade and Thompson 1981, Andersen 1986a, b). It allows almost all species of ants occurring in Australia to be classified according to their broad ecological role and requirements, although little might be known of their specific biology.

According to the model, Australian ants comprise seven main ecological categories (Table 1), which in turn can be grouped into three major components (Fig. 1). The most important category consists of dominant species, chiefly ants of the ubiquitous genus *Iridomyrmex*, which can exert a powerful influence on other ants because of their great abundance, high rates of activity, and aggressiveness (see Greenslade 1976). They are often associated with subordinate species, especially belonging to the genus *Camponotus*, which appear to coexist successfully with *Iridomyrmex* through specialised behaviour and morphology. Together they form a major component of Australian ant communities, and are a potential force shaping the composition of other ants (Fig. 1). The second component consists of two groups of ants ('generalised myrmicines' and 'opportunists') that are very unspecialised and therefore interact strongly with *Iridomyrmex* and associates. There is typically a strong inverse relationship between the relative abundances of these two components. The third component consists of three groups of more specialised taxa that are not so strongly influenced by other ants (see Table 1). The final element of the model is habitat, which obviously has a direct influence on all ants, but most importantly regulates the abundance of *Iridomyrmex* and associates, which then has important ramifications for other ants. *Iridomyrmex* is particularly favoured by open habitats with patches of bare ground; the high levels of insolation and unimpeded foraging surfaces allow for the high rates of activity upon which their dominance depends.

Table 1 P.J.M. GREENSLADE'S ECOLOGICAL CATEGORIES OF ANTS IN AUSTRALIA.

CATEGORY	MAJOR TAXA	RELEVANT FEATURES
1. Dominant species	*Iridomyrmex*	Highly abundant, active and aggressive; able to monopolise resources
2. Subordinate species	*Camponotus*	Large body size; polymorphic; submissive behaviour; nocturnal foraging
3. Climate specialists		
(a) Hot	*Melophorus* *Meranoplus*	Behavioural and morphological specialisations
(b) Cool	*Prolasius* *Notoncus*	Restricted to cool and wet regions where *Iridomyrmex* is at its climatic limit
4. Cryptic species	*Solenopsis*, many Ponerinae	Activity confined to soil and litter
5. Opportunists	*Rhytidoponera* *Paratrechina*	Unspecialised; likely to interact strongly with *Iridomyrmex*
6. Generalised myrmicines	*Monomonium* *Pheidole* *Crematogaster*	Unspecialised species, recently arrived in evolutionary time
7. Large, solitary foragers	*Myrmecia*	Large body size, low population densities; unlikely to interact strongly with other ants

Fig. 1: Simplified version of P.J.M. Greenslade's model of ant community organisation in Australia. Ecological categories are those in Table 1. Arrows indicate direction of influence. All ants are influenced to some degree by habitat variables, but habitat has a particularly important influence on the abundance of dominant *Iridomyrmex* and associated species. These in turn have a powerful influence on the abundance of highly interactive taxa, but a weaker influence on other ants (see text).



This model offers two important benefits to land managers wishing to use ants as bio-indicators. First, it provides a means of dramatically condensing the great diversity of Australian ants into a small number of functional categories. This not only simplifies data analysis, but can streamline data collection: in most cases ants need only be sorted to the generic level, and there is never the problem of deciding whether or not similar taxa constitute a single species, since these will always belong to the same ecological category.

Second, the model enables information on the distribution and relative abundance of species to be put into an ecological context, because patterns of ant community organization vary predictably with environmental variables. For example, the relative abundances of different ecological categories are closely tied to vegetation structure in southern Victoria: a broad range are represented in woodlands (and dry heathlands), but cool-climate specialists and cryptic species become increasingly important in more mesic sites, until they represent almost all ants in closed forests (Fig. 2). Further, patterns of ant community organisation are strongly influenced by habitat disturbance; in particular, the relative abundance of opportunists increases with level of disturbance (Fig. 3).

Fig. 2: Effect of habitat on patterns of ant community organisation. The relative abundances of different ecological categories are compared for different vegetation types in southern Victoria (based on Andersen 1986b).

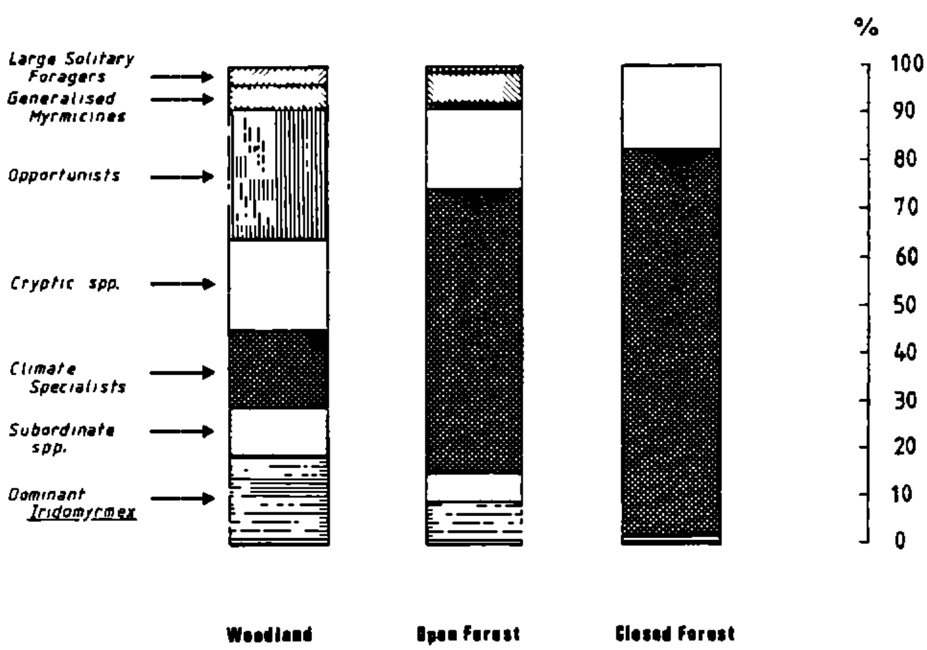
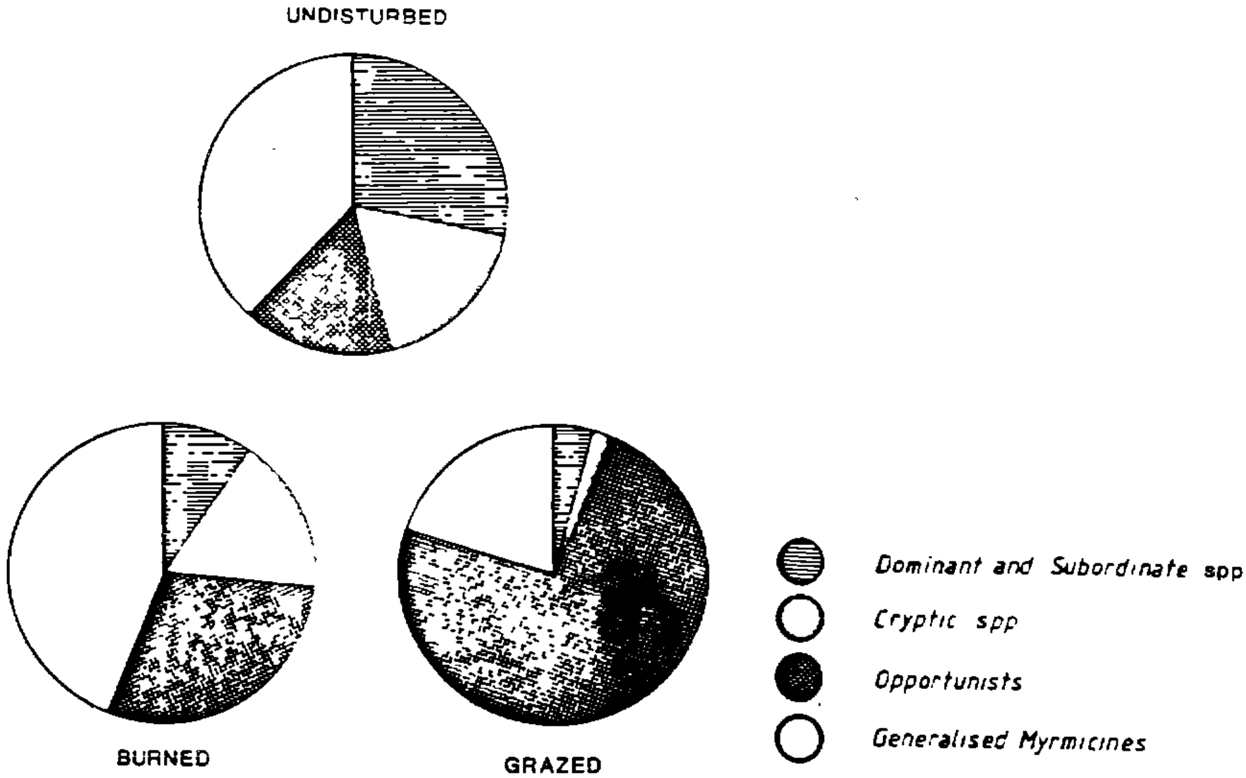


Fig. 3: Effect of disturbance on patterns of ant community organisation. The relative abundances of different ecological categories at an undisturbed site in southern Victoria are compared with those at nearby burnt and grazed sites (from Andersen and McKaige in press).



A CASE STUDY: EFFECTS OF FIRE IN TROPICAL OPEN FOREST

Fire is a dominant feature of the Australian landscape, and is a controversial land management tool. Nowhere is this more apparent than in the savannah woodlands and open forests of northern Australia, where many areas experience annual fire lit by land managers. In the early 1970's the Conservation Commission of the Northern Territory established a series of experimental plots at Munmarlary in Stage II of Kakadu National Park, to investigate the ecological impact of different fire regimes. In June 1986 I surveyed the epigaeic ant faunas of six of these plots using pitfall traps. Details will be published elsewhere, but the results are summarised here. The six plots (each 1 ha) were two replicates each of three burning regimes: annual, biennial and totally unburnt. There are some floristic differences between these plots (D. Bowman pers. comm.), but the most dramatic differences in vegetation are structural: the unburnt plots contain a well-developed mid-storey, which is virtually absent from the frequently burnt plots.

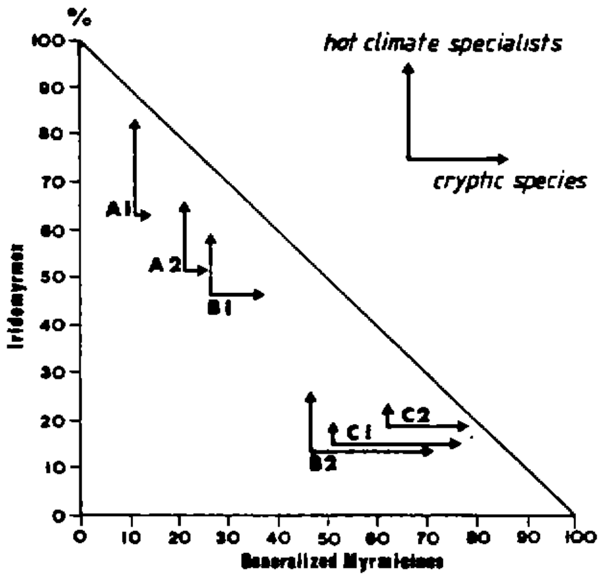
The data consisted of a list of about 100 ant species, with a measure of their abundance in each plot. Total numbers of individuals and species were both highest in the annually burnt and lowest in the unburnt plots, suggesting that frequent burning promotes overall ant activity. The distribution of certain species could be directly related to the effects of fire. *Meranoplus 'diversus'* for example, which feeds exclusively on the seeds of annual grasses, was not recorded in the unburnt plots and therefore reflected the reduction in annual grasses in the absence of fire. Unfortunately, however, the biology of most species is too poorly known to explain their distributions in similar detail.

An analysis of ants at the community level incorporates data for all species, but condenses them into a manageable form. In fact 95% of all the ants trapped fell into one of four ecological categories: dominant species, climate specialists, cryptic species and generalised myrmicines, so I will focus on these.

The six plots separate into two groups (Fig. 4) according to the relative abundances of dominant species (*Iridomyrmex* spp) and generalised myrmicines, the two most abundant categories. The plots supported either extremely large numbers of *Iridomyrmex* (c. 50% total ants) and relatively low numbers of generalised myrmicines (c. 20%) or these proportions were reversed. This inverse relationship is predicted by Greenslade's model, since the local distribution of *Iridomyrmex* is determined almost entirely by habitat properties, whereas generalised myrmicines are strongly limited by competition with *Iridomyrmex*. This means that in regions where *Iridiomyrmex* and generalised myrmicines are the most abundant ants, the latter are restricted by competition in habitats favourable to *Iridomyrmex*, but predominate elsewhere. *Iridomyrmex* was most abundant in the two annually burnt plots, which were the most open habitats. As mentioned previously, open habitats are most favourable to *Iridomyrmex*. Generalised myrmicines, on the other hand, were most abundant in the two unburnt plots, where the high levels of shade and litter development represented a comparatively unfavourable habitat for *Iridomyrmex*.

The abundance of hot climate specialists tended to increase with that of *Iridomyrmex* (Fig. 4). This is because hot climate specialists, like *Iridomyrmex*, are adapted to high levels of insolation, and are therefore probably also responding directly to the effects of fire on vegetation structure. In contrast to generalised myrmicines, they have morphological and behavioural specialisations which enable them to co-exist with *Iridomyrmex*. For example, species of *Melophorus* forage exclusively during the hot part of the day, when surface temperatures are too high for most other ants. The abundance of cryptic species increased with generalised myrmicines (Fig. 4), but

Fig. 4: Vector diagram illustrating relative abundances of major ecological categories in experimental fire plots at Munmarlary in Kakadu National Park (A1, A2: burnt annually; B1, B2: burnt biennially; C1, C2: unburnt).



whereas generalised myrmicines were probably responding to changes in the level of competition with *Iridomyrmex*, it is likely that cryptic species were responding directly to habitat, i.e. the accumulation of litter in the absence of fire.

Interestingly, the two biennial plots fell into different groups in Fig. 4. There are plot differences in soils which help explain this (D. Bowman pers. comm.), but it suggests that the switch between the two types of ant communities (i.e. *Iridomyrmex* and hot climate species, versus generalised myrmicines and cryptic species) is a highly sensitive one.

RELATIONSHIP BETWEEN ANTS AND OTHER FAUNAL GROUPS

The above analysis of ant community organisation successfully demonstrates a faunistic response to habitat changes wrought by fire. This satisfies one important criterion for any bio-indicator; that is, it must be sensitive to environmental change. But to what extent are these changes in ants likely to reflect changes in other faunal groups?

The following are reasons why ants should provide a good indication of the effects of environmental change on other faunal groups in this study. First, ants were easily the dominant invertebrate group. The region supports well over 100 ant species per hectare, and there were many more ants in pitfall traps than all other invertebrates combined. Second, ants represented the full range of trophic levels, from specialist herbivores (e.g. seed-harvesting *Meranoplus diversus* group) to specialist predators (e.g. species of *Bothroponera* and *Leptogenys*). This, combined with their great abundance and diversity, suggests that ants are of particular ecological importance in the region, and are likely to influence a wide range of faunal groups.

Unfortunately, however, actual relationships between ants and other faunal groups are poorly understood. This is a major problem facing the use of any invertebrate group as a bio-indicator. The concentration of cryptic species in the unburnt plots can be used to predict that other cryptic invertebrates would also be concentrated there, but this prediction is rather facile as it could have been made on the basis of habitat analysis alone. Of more importance is an understanding of how the distribution of ants affects their prey, their predators, and their competitors. For example, the observation that frequent burning promotes ant activity in general can generate opposing hypotheses concerning the effects of fire on other predaceous invertebrates (e.g. spiders, carabid beetles and scorpions). Other predaceous invertebrates may also respond favourably to fire-induced habitat change, or alternatively their abundance might be reduced because of increased competition from ants. Similarly, the responses of ant-eating vertebrates such as dragon lizards cannot be predicted until more is known of which species of ants they prefer. Unravelling the relationship between ants and other faunal groups should be the major focus of future research into the use of ants as bio-indicators.

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DEALING WITH DATA FROM EXTENSIVE INVERTEBRATE SURVEYS

J.D. Majer, School of Biology, Curtin University of Technology, Bentley, W.A., 6102

SUMMARY

There is an increasing tendency for invertebrate surveys to form an integral component of Environmental Impact Statement studies or other types of environmental surveys. Such surveys often sample a variety of taxa from a range of plots. The resulting data-set contains a wide spread of information which further increases in magnitude with:

- the number of plots surveyed;
- the number of collecting techniques used;
- the number of samples per plot;
- the number of seasons when sampling is performed; and
- the number of taxa which are scored.

Most scientists first enter the data onto especially prepared data sheets and then attempt to summarise the data by hand or with the aid of a computer. In the latter case it is usually first necessary to transfer the data on to computer coding sheets.

This paper describes a method for directly entering invertebrate survey data on to tailor-made computer coding sheets, thus eliminating the laboratory recording sheet stage. Data may be recorded at the order or species level. The raw data may then be analysed by an available, or specially written, computer programme to provide:

- mean, standard error and frequency values for each taxon for a particular plot;
- matrices of taxa means x plot surveyed;
- matrices of presence/absence values for each taxon x plots surveyed.

The matrices of taxa means or presence/absence values may then be directly analysed by ordination or classification analysis. The programme also enables presence/absence matrices to be amalgamated for separate sampling seasons and for different taxa-mean x plot matrices.

The use of this computer coding and analysis system saves a considerable amount of time and ensures an efficient analysis of data and display of results.

Majer, J.D. (ed.), *The Role of Invertebrates in Conservation and Biological Survey*. (1987). Western Australian Department of Conservation and Land Management Report.

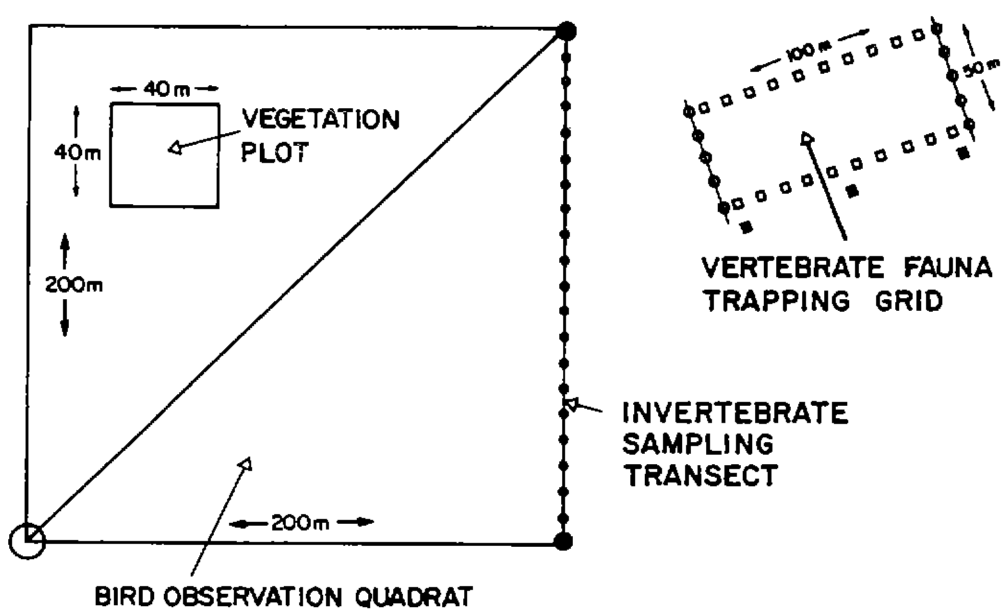
INTRODUCTION

Scientists (New 1984), conservation agencies (Wells, Pyle and Collins 1983) and semi-government institutions (Council of Europe 1987) are now aware of the need to consider invertebrates within the conservation schedules of regions, states or even entire nations. Despite this realisation, invertebrates have seldom been studied from the conservation point of view. Reasons why this is so have been outlined by Majer (1987) and include the fact that terrestrial invertebrates are extremely abundant and often difficult to study by all but specialised entomologists.

In the previous paper I attempted to counteract one of the excuses for not studying invertebrates by proposing a simple sampling scheme by which terrestrial invertebrates could be sampled during routine environmental surveys. This consisted of a 200 m Invertebrate Sampling Transect along which 10 or 20 pitfall trap, vegetation sweep and tree beat samples could be taken (Fig. 1). A second problem, which is often cited by those who attempt such surveys, is that of dealing with the extensive data which results from counting the various taxa obtained by such surveys. The resulting data-set contains a wide spread of information which increases in magnitude with:

- the number of plots surveyed;
- the number of collecting techniques used;
- the number of samples per plot;
- the number of seasons when sampling is performed; and
- the number of taxa which are scored.

Fig. 1: Design of intensive study locations used for systematic flora, vertebrate and invertebrate surveys by Worsley Alumina Pty Ltd (1985) in Western Australia.



Often the data are recorded in notebooks or on specially prepared data sheets such as the one shown in Table 1. The scientist then attempts to summarise such data using a pocket calculator or by transferring the data onto computer files for subsequent analysis. Both methods are vulnerable to transcription errors when the summary means and other data are collated between plots or when the data are transferred to the computer or on to computer coding sheets.

Table 1 — TYPICAL DATA CODING FORM FOR INVERTEBRATES OBTAINED FROM A SERIES OF TEN SAMPLES WITHIN ONE PLOT.

			SWEEP				NO					Totals
	TAXON	1	2	3	4	5	6	7	8	9	10	
7	Acarina	2			1				7	3	4	17
8	Araneae	5	5	1	3	2	9	5	3	5	3	41
14	Collembola Sminthuridae	2		1					3	1	1	8
18	Blattodea				2							2
22	Orthoptera - Gryllacrididae		1				1				1	3
26	Phasmatodea								1			1
31	Neuroptera										1	1
28	Homoptera	1	3		4	5	4	3	2	4	4	30
29	Heteroptera			2							3	5
27	Isoptera											
30	Thysanoptera	2						1		2		5
34	Coleoptera Curculionidae				1							1
37	" other	2										2
39	" larvae											
42	Lepidoptera				1							1
43	" larvae					1						1
40	Diptera	3		1	1		2		1	1	2	11
41	" larvae		1									1
44	Hymenoptera Formicidae	1	4		1			[illegible]		1		11
45	" other	4	2		1	2	1		2	3	3	18
											TOT	159
												4

This paper describes a method for directly entering invertebrate survey data onto tailor-made computer coding sheets in the laboratory, thus eliminating the preliminary recording stage. The raw data may then be analysed by an available, or specially written, computer programme to provide various summary data and data matrices which are available for more detailed analysis.

THE CODING PROCESS

A computer coding sheet should be designed at the outset of the project. Table 2 shows the format for the computer coding forms used during the Worsley Alumina Phase Two Flora and Fauna Project in Western Australia (Worsley Alumina Pty Ltd 1985). The coding sheet allows for up to 20 replicate samples to be taken by various sampling methods (e.g. pitfall trapping, vegetation sweeping or tree beating). The coding sheet has spaces for information on plot number, trip number, number of replicate samples per plot, study region, date and vegetation code.

Table 2 FORMAT DESCRIPTION OF COMPUTER CODING SHEETS USED FOR INVERTEBRATE SURVEYS.

Column	1	Sampling method:	P = pitfall-trap S = sweep B = beat
Columns	2-6	Plot number:	e.g. M01J, R15Y
Columns	7,8	Trip Number:	1-4
Columns	9,10	"Order" code:	listed below

"Order" Codes

01 = NEMATODA	26 = CAELIFERA
02 = ANNELIDA	27 = PHASMATODEA
03 = ONYCHOPHORA	52 = EMBIOPTERA
04 = SCORPIONIDA	28 = PSOCOPTERA
05 = PSEUDOSCORPIONIDA	29 = HOMOPTERA
06 = OPILIONES	30 = HETEROPTERA
07 = ACARINA	31 = THYSANOPTERA
08 = ARANEAE	32 = NEUROPTERA — ADULTS
09 = ISOPODA	33 = NEUROPTERA — LARVAE
53 = AMPHIPODA	34 = STAPHYLINIDAE
10 = DIPLOPODA	35 = CURCULIONOIDEA
11 = CHILOPODA	36 = CARABIDOIDEA
12 = SYMPHYLA	37 = SCARABAEOIDEA
13 = PAUROPODA	38 = TENEBRIONIDAE
14 = COLLEMBOLA	39 = COLEOPTERA — OTHERS
15 = PROTURA	40 = COLEOPTERA — LARVAE
16 = DIPLURA	41 = MECOPTERA
17 = THYSANURA	42 = DIPTERA — ADULTS
18 = ODONATA	43 = DIPTERA — LARVAE
19 = BLATTODEA	44 = LEPIDOPTERA — ADULTS
20 = MANTODEA	45 = LEPIDOPTERA — LARVAE
21 = ISOPTERA	46 = HYMENOPTERA — ANTS
22 = DERMAPTERA	47 = HYMENOPTERA — OTHERS
23 = GRYLLACRIDOIDEA	51 = HYMENOPTERA — LARVAE
24 = TETTIGONIOIDEA	48 = SKINKS
25 = GRYLLOIDEA	49 = FROGS
	50 = MISCELLANEOUS

Column	11,13	"Species" code:	see ant list
Columns	14-31	Name of taxon:	names for "order" codes above
Column	32	Card number:	1 or 2
Columns	33-72	Raw data:	twenty samples coded in I4 format on two cards.
Columns	73,74	Number of samples:	up to twenty
Column	75	Study Area:	A-G; parts of Worsley Alumina Project Area.
Columns	76-81	Sampling Date:	(last day of field sampling for each trip — YYMMDD)
Columns	82-86	Vegetation Code:	e.g. 23HDc

Inserted automatically by computer.

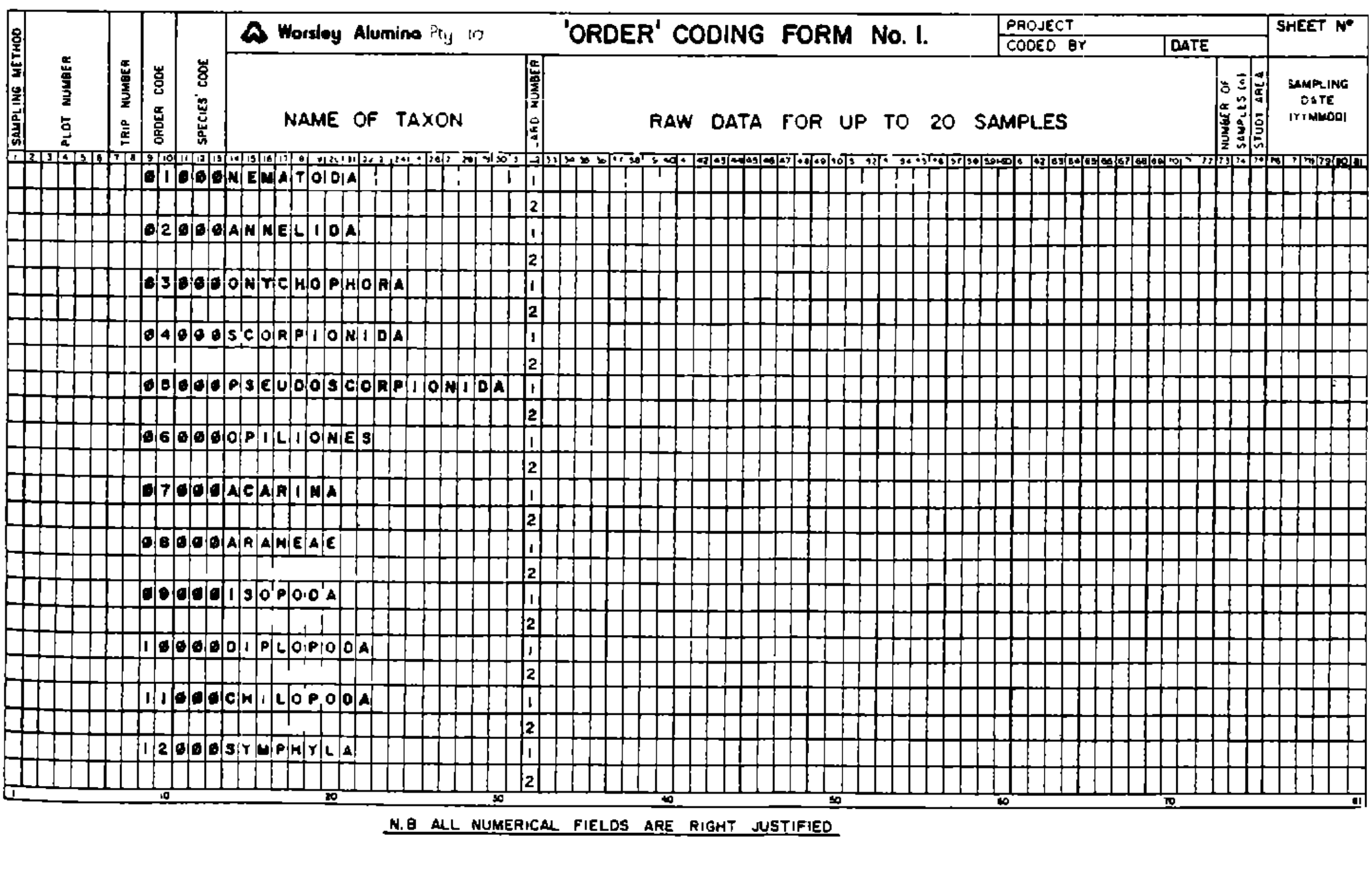
Three variants of coding sheet were used during the Worsley Alumina Pty Ltd (1985) study. The first allowed for the coding of invertebrates at the 'Order' level. This 'Order' coding sheet is shown in Fig. 2 and the numerical codes are explained in Table 2. Two zero's are printed under the 'Species' code columns (11-13) indicating that the taxa have not been sorted to species level.

In view of the fact that ants were to be identified to species level an 'Ant' coding form was prepared in advance (Fig. 3). This allowed for numerical codes (1-999) of the ants in the Worsley reference collection to be entered into columns 11-13. Columns 14-31 were available for entering the generic name of the ant if required.

A third 'Species' coding form was also prepared in which columns 9-31 were left blank. This allowed for the coding of any taxa which were subsequently identified to species level. For instance, had it been decided that Homoptera should be identified to species level, then 29001, 29002, etc. would be entered into columns 9-13 of the 'Species' coding form for species 1, 2 etc.

A computer programme should then be written which summarises the invertebrate data. For the project described here, Worsley Alumina Pty Ltd prepared a programme which is menu-driven and runs on a Facom M180NE machine. It processes bird, mammal and invertebrate data and is described in detail by Allen (1984). The programmes are written in Fortran 77 with approximately 35,000 lines of code. All files are standard sequential formatted files, although some have very long record lengths. The Invertebrate Master File has 126 characters per record. The system is relatively free of machine dependencies, except for the programmes that require terminal input/output, which make use of the Facom full screen processing capability to display menus and request information. The programme is run in one megabyte of virtual storage, as this is a relatively convenient size. The data may be loaded from magnetic tape, or keyed in directly via a VDU terminal.

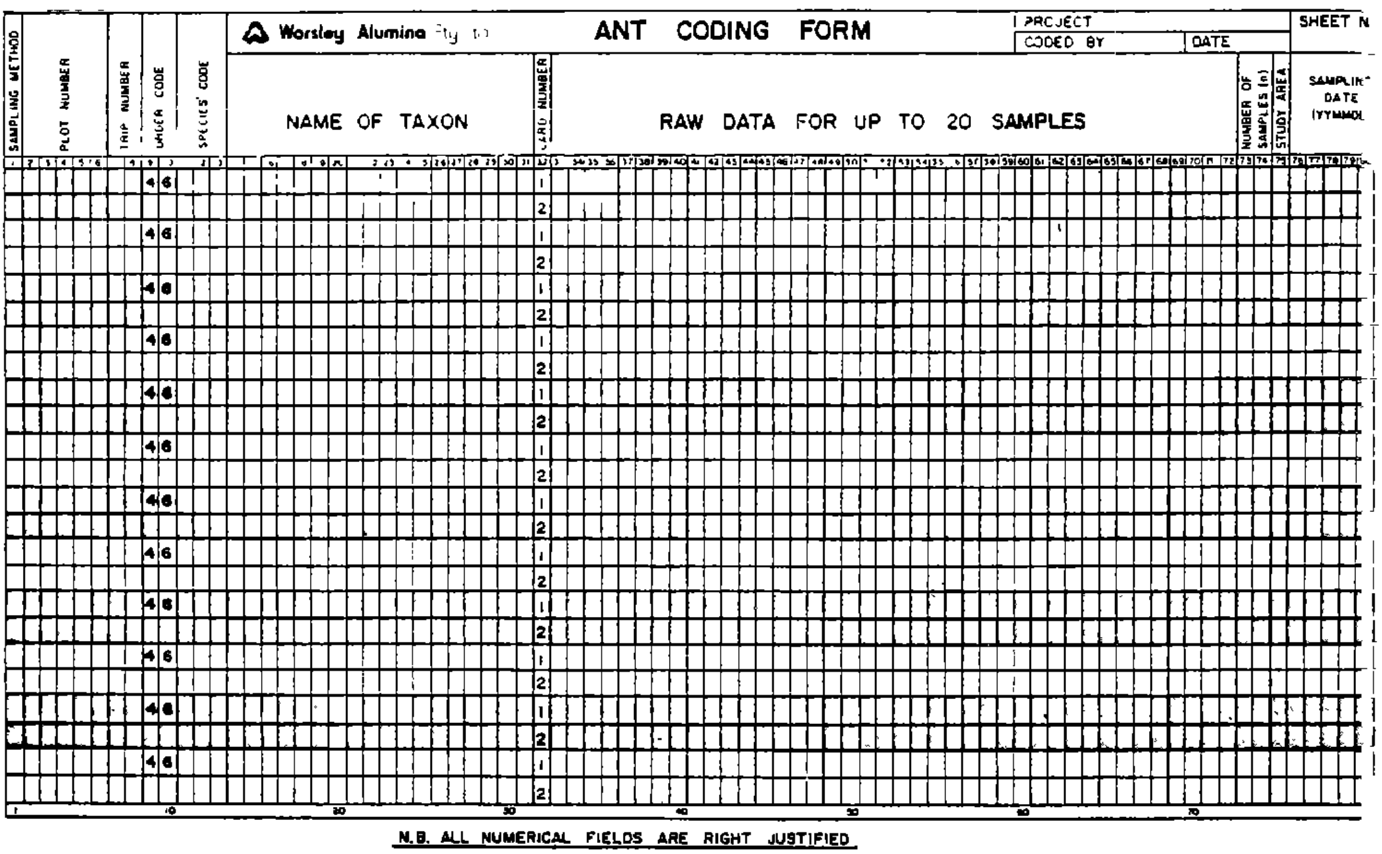
Fig. 2: Example of invertebrate 'Order' data logging sheets. The coding format is explained in Table 2.


Worsley Alumina Pty Ltd — 'ORDER' CODING FORM No. I. — PROJECT — CODED BY — DATE — SHEET N°

SAMPLING METHOD	PLOT NUMBER	TRIP NUMBER	ORDER CODE	SPECIES' CODE	NAME OF TAXON	CARD NUMBER	RAW DATA FOR UP TO 20 SAMPLES	NUMBER OF SAMPLES	STUDY AREA	SAMPLING DATE (YYMMDD)
			01	000	NEMATODA	1				
						2				
			02	000	ANNELIDA	1				
						2				
			03	000	ONYCHOPHORA	1				
						2				
			04	000	SCORPIONIDA	1				
						2				
			05	000	PSEUDOSCORPIONIDA	1				
						2				
			06	000	OPILIONES	1				
						2				
			07	000	ACARINA	1				
						2				
			08	000	ARANEAE	1				
						2				
			09	000	ISOPODA	1				
						2				
			10	000	DIPLOPODA	1				
						2				
			11	000	CHILOPODA	1				
						2				
			12	000	SYMPHYLA	1				
						2				

N.B ALL NUMERICAL FIELDS ARE RIGHT JUSTIFIED

Fig. 3: Example of 'Ant' species data logging sheet. Note that code 46 denotes ants in general (see Table 2). The species code number corresponds to that used in the reference collection and the genus name may be entered in columns 14-31.



THE DATA SUMMARIES

The interactive system then allows rapid sorting and reporting of full or partial data sets and produces catalogues of selected fauna records.

A summary table is first produced for each plot for each particular sampling method. Table 3 gives an example of one plot which was sampled by 10 tree beats. It includes data on 'Orders' and on five species of ants which were recorded in this plot (species 17, 20, 30, 32 and 14). Had other 'Orders' been identified to species level, these would also have appeared on the printout. The summary table is designed to produce major summary statistics such as maximum and minimum numbers, totals, means and standard deviations.

Table 3 SUMMARY OF INVERTEBRATE DATA OBTAINED FOR TEN TREE BEAT SAMPLES IN ONE PLOT.

W O R S L E Y   A L U M I N A   P T Y   L T D.

FAUNA SYSTEM REPORTING 19 MAR 85
PROG INSMRY INVERTEBRATE FAUNA SYSTEMS

BODDINGTON GOLD MINE INVERTEBRATE STUDY DATA SUMMARY FOR 1984.

SUMMARY OF RAW DATA FOR PLOT B501H FROM STUDY AREA OTHER MINERALS AREA FOR SAMPLING METHOD TREE BEATIN
VEGETATION 28H TRIP/S FIELD TRIP 8 - SPRING SAMPLING 1984

ORDER CODE	SPECIES CODE	TAXON DESCRIBED	MINIMUM NUMBER	MAXIMUM NUMBER	TOTAL COUNTED	NUMBER OF SAMPLES	MEAN OF SAMPLES	STANDARD DEVIATION
07	000	ACARINA	0	5	18	10	1.80	1.81
08	000	ARANEAE	0	5	18	10	1.80	1.81
14	000	COLLEMBOLA	0	5	13	10	1.30	1.83
28	000	PSOCOPTERA	0	11	14	10	1.40	3.41
29	000	HOMOPTERA	0	10	30	10	3.00	2.98
30	000	HETEROPTERA	0	1	2	10	0.20	0.42
31	000	THYSANOPTERA	0	2	3	10	0.30	0.67
34	000	STAPHYLINIDAE	0	3	9	10	0.90	1.20
35	000	CURCULIONOIDEA	0	1	2	10	0.20	0.42
39	000	COLEOPTERA-OTHERS	0	3	19	10	1.90	0.99
40	000	COLEOPTERA-LARVAE	0	2	4	10	0.40	0.70
42	000	DIPTERA-ADULTS	0	1	3	10	0.30	0.48
45	000	LEPIDOPTERA-LARVAE	0	1	4	10	0.40	0.52
46	000	HYMENOPTERA-ANTS	0	41	131	10	13.10	14.75
46	017		0	1	.1	10	0.10	0.32
46	020		0	8	10	10	1.00	2.49
46	030		0	1	2	10	0.20	0.42
46	032		0	38	116	10	11.60	13.86
46	114		0	1	1	10	0.10	0.32
47	000	HYMENOPTERA-OTHERS	0	2	7	10	0.70	0.82

The means of each taxa are cropped from the plot summaries so that they may be compared between plots. Tables 4 and 5, respectively, show the mean number of invertebrates per 'Order' and ants per species in a range of 10 plots which were sampled by tree beating. The generic names of the ants do not appear in Table 5 although they could easily have been included,if required, on the original data coding sheet.

The programme has the ability to add summary matrices together. For instance, if the cumulative number of invertebrates obtained from four separate sampling periods was required, the four matrices of means could be added together. In addition, matrices derived by separate collecting techniques may be added together. Table 6 shows a matrix of ant species sampled in each of four seasons by pitfall trapping, vegetation sweeping and tree beating. In view of the fact that the numbers derived by the three techniques are not directly comparable, the matrix has been converted to presence/absence values. This type of matrix is useful as an overall data summary and may also be used to generate a new data file for subsequent community analysis.

Table 4 MEAN NUMBER OF INVERTEBRATES PER 'ORDER' OBTAINED BY TREE BEATING IN A SERIES OF TEN PLOTS SITUATED THROUGHOUT A SERIES OF VEGETATION ASSOCIATIONS.

W O R S L E Y A L U M I N A P T Y L T

FAUNA SYSTEM REPORTING
PROG ORDSUM

INVERTEBRATE FAUNA SYSTEMS
****

INVERTEBRATE DATA SUMMARY - FIELD TRIP 1 (SUMMER) OF 1982.

ORDER/SPECIES SUMMARY FOR SAMPLING METHOD TREE BEATING

ORD/SPEC CODE	TAXON	MEAN NUMBER OF INDIVIDUALS IN EACH PLOT M10H	M08H	M07H	M09W	M06W	M01J	M04J	M02J	M05J	M03J
07 000	ACARINA	1.1	3.3	1.3	0.5	0.1	0.3	0.8	1.0	0.4	1.1
08 000	ARANEAE	1.3	2.0	3.8	1.5	2.4	3.0	3.1	2.9	2.8	2.0
10 000	DIPLOPODA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14 000	COLLEMBOLA	0.0	0.0	0.1	0.0	0.1	0.0	0.3	0.0	0.0	0.5
19 000	BLATTODEA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20 000	MANTODEA	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0
23 000	GRYLLACRIDOIDEA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25 000	GRYLLOIDEA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26 000	CAELIFERA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27 000	PHASMATODEA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28 000	PSOCOPTERA	0.0	0.4	1.1	0.0	0.4	0.2	0.9	0.5	0.6	0.1
29 000	HOMOPTERA	0.3	0.6	0.9	2.4	1.8	12.7	0.5	0.2	0.7	0.6
30 000	HETEROPTERA	0.2	0.4	0.7	0.4	0.2	0.1	0.2	0.3	0.3	0.0
31 000	THYSANOPTERA	0.0	0.0	0.9	0.1	0.2	0.0	0.0	0.1	0.0	0.0
32 000	NEUROPTERA-ADULT	0,0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
35 000	CURCULIONOIDEA	0.7	0.1	0.0	0.0	0.1	0.3	0.1	0.1	0.3	0.2
39 000	COLEOPTERA-OTHER	0.5	0.4	0.3	0.7	1.5	0.1	0.3	0.1	0.3	0.4
40 000	COLEOPTERA-LARVA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
42 000	DIPTERA-ADULTS	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.1	0.0	0.0
44 000	LEPIDOPTERA-ADUL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
45 000	LEPIDOPTERA-LARV	0.1	0.1	0.4	0.8	0.5	0.0	0.4	0.1	0.1	0.2
46 000	HYMENOPTERA-ANTS	0.3	7.6	0.5	4.4	6.7	0.8	0.6	0.2	5.5	1.0
47 000	HYMENOPTERA-OTHE	0.1	0.1	0.0	0.1	1.8	0.4	0.1	0.0	0.1	0.0
51 000	HYMENOPTERA LARV	0.5	1.8	0.0	1.7	5.4	0.0	0.0	0.0	0.0	0.0

Table 5 MEAN NUMBER OF ANTS PER SPECIES OBTAINED BY TREE BEATING IN A SERIES OF TEN PLOTS SITUATED THROUGHOUT A SERIES OF VEGETATION ASSOCIATIONS.

W O R S L E Y A L U M I N A P T Y L T D

FAUNA SYSTEM REPORTING
PROG ORDSUM

INVERTEBRATE FAUNA SYSTEMS
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FORMICIDAE (ANT) SPECIES DATA SUMMARY - FIELD TRIP 1 (SUMMER) OF 1982.

ORDER/SPECIES SUMMARY FOR SAMPLING METHOD TREE BEATING

ORD/SPEC CODE	TAXON	MEAN NUMBER OF INDIVIDUALS IN EACH PLOT M10H	M08H	M07H	M09W	M06W	M01J	M04J	M02J	M05J	M03J
46 014		0.0	0.0	0.0	0.3	0.0	0.5	0.0	0.0	0.0	0.0
46 015		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
46 017		0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0
46 020		0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
46 024		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
46 028		0.2	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
46 030		0.0	0.0	0.1	0.0	0.0	0.5	0.0	0.0	0.1	0.3
46 031		0.0	0.1	0.0	0.4	0.1	0.0	0.4	0.0	0.1	0.1
46 032		0.0	6.9	0.3	2.9	6.3	0.0	0.0	0.0	4.8	0.0
46 033		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
46 035		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
46 036		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
46 039		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
46 041		0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
46 051		0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.4	0.0
46 053		0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0
46 055		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
46 056		0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
46 062		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
46 063		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
46 064		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 6 ANT PRESENCE/ABSENCE DATA FOR FOURTEEN PLOTS WHICH WERE SAMPLED BY PITFALL TRAPPING, VEGETATION SWEEPING AND TREE BEATING. THE THREE MATRICES OF QUANTITATIVE DATA WERE FIRST SUMMED AND THEN CONVERTED TO PRESENCE/ABSENCE DATA.

INVERTEBRATE FAUNA SYSTEMS

FORMICIDAE (ANT) SPECIES DATA SUMMARY - FIELD TRIPS 1-4 OF 1982, ALL METHODS.

ORDER/SPECIES SUMMARY FOR SAMPLING METHOD ALL SAMPLE METHODS

PRESENCE TABLES FOR TAXONS ("1" GT 1 OCC, "-"= 1 OCC)

ORD/SPEC CODE	TAXON	M10H	M08H	M07H	M09W	M06W	M01J	M04J	M02J	M05J	M03J	R16J	R18J	R17B	R15Y
46 001		0	0	0	0	0	0	1	0	0	1	0	0	0	0
46 002		0	1	1	0	1	0	0	1	0	0	0	0	0	0
46 003		1	0	0	1	0	0	0	0	0	0	0	0	0	0
46 004		0	0	0	0	0	0	0	0	0	0	1	0	1	1
46 005		0	0	0	1	0	0	0	0	0	1	0	1	1	0
46 007		0	0	0	0	0	-	0	0	0	0	0	0	0	0
46 008		0	1	0	0	0	1	0	1	1	0	0	0	0	0
46 009		1	1	1	1	1	1	1	1	1	1	1	1	1	1
46 010		1	1	0	1	1	1	1	0	1	1	1	0	0	0
46 011		1	0	0	1	0	1	0	1	0	1	0	0	0	0
46 012		0	0	0	0	0	1	0	0	0	0	1	0	0	0
46 014		1	1	0	1	1	1	1	1	1	1	1	1	0	1
46 015		1	1	1	1	1	1	1	1	1	1	1	1	1	1
46 016		0	0	1	1	1	0	0	0	0	0	0	0	0	0
46 017		0	0	1	1	1	0	0	0	0	0	0	0	0	0
46 018		1	1	1	0	0	1	0	0	0	1	1	1	0	0
46 019		0	1	0	0	0	0	0	1	0	0	1	0	1	0
46 020		0	0	1	0	1	1	1	1	0	1	0	1	0	1
46 022		1	0	0	0	0	0	0	1	0	1	0	0	0	0
46 023		1	1	0	0	0	0	1	1	1	1	0	0	0	0
46 024		1	1	1	1	1	0	1	1	1	1	1	1	1	1
46 025		0	1	0	0	0	0	1	1	1	1	1	1	0	0
46 026		0	1	1	1	1	0	1	1	1	1	1	0	0	0
46 027		1	0	1	1	1	0	1	1	0	1	1	1	1	1
46 028		1	1	1	1	1	1	1	1	1	1	1	1	1	1
46 029		1	0	0	0	1	0	0	0	0	0	0	0	0	0
46 030		1	1	1	1	1	1	1	1	1	1	1	1	0	1
46 031		1	1	1	1	1	1	1	1	1	1	1	1	0	1
46 032		1	1	1	1	1	1	0	1	1	1	1	1	0	0
46 033		1	1	1	1	1	1	0	1	0	0	1	0	0	0
46 034		0	1	0	1	1	1	0	1	0	1	0	0	0	1
46 035		0	1	0	0	1	1	0	0	0	0	0	0	0	0
46 036		0	1	0	1	0	0	0	0	0	0	0	1	0	0
46 037		1	1	0	1	1	0	0	0	1	0	0	0	0	0
46 038		1	0	0	1	0	0	0	0	0	1	0	0	0	0
46 039		1	0	1	0	0	1	0	1	0	1	0	0	0	0
46 040		1	0	0	0	1	0	0	0	0	0	0	0	0	0
46 041		1	1	1	1	0	1	1	0	1	1	1	1	1	1
46 043		0	0	0	1	1	0	0	0	0	0	0	0	0	0
46 044		1	1	1	1	1	1	1	0	1	1	0	0	0	0
46 045		1	1	1	1	1	1	1	1	1	1	1	1	0	0
46 046		0	1	0	1	0	1	1	1	0	1	1	1	0	0
46 048		0	0	0	1	0	1	0	1	0	0	1	1	1	1
46 049		1	0	0	0	1	0	0	1	0	0	0	0	0	0
46 050		1	1	0	1	0	1	1	1	1	1	1	1	0	1

DISCUSSION

The advantages of this approach are threefold. Firstly, by structuring the coding form in advance, the person who does the sorting is directed in the way in which the taxa should be defined. For instance, in the scheme presented here, sucking bugs need to be recorded as either Homoptera or Heteroptera. If required, the coding form could be designed to code the data as Hemiptera or as the various families of Hemiptera. Whichever is the case, the recorder, or recorders, are denied the opportunity of varying the taxonomic schemes used for the various samples which are taken, without first consulting the controlling scientist.

Secondly, the elimination of the intermediate hand-recorded data sheets saves time and removes a stage at which data transcription errors can occur.

Thirdly, the resulting computer output is neat and may be designed to suit the purposes of the study. A high quality output may be obtained on a laser or daisy-wheel printer and this may be used directly in any reports or publications. Finally, the taxa x plot matrices of data means may form a new data base for more detailed analysis such as ordination or classification analysis.

The example presented in this paper involves the printing of tailor-made computer coding sheets and a specifically designed computer programme. Neither of these are necessary. A standard computer coding sheet may be modified using a black pen and 'white-out' fluid. This may then be photocopied to provide duplicate coding forms. A computer programme may be specially written (a graduate of mine took 2 days to prepare a basic programme similar to that used by Worsley Alumina Pty Ltd, although it should be recognised that the rather more 'user friendly' programme took longer to produce). Alternatively, the data may be analysed using a proprietary statistical package such as SPSS or SASS. Should the reader be interested in obtaining the original programme used in the study mentioned here, the software is the property of Worsley Alumina Pty Ltd; contact should be made to the Environmental Section, Worsley Alumina Pty Ltd, P.O. Box 344, Collie, Western Australia, 6225.

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POLEMICS, AQUATIC INSECTS AND BIOMONITORING: AN APPRAISAL

Leon A. Barmuta, School of Environmental and Life Sciences, Murdoch University, Murdoch, W.A., 6150

SUMMARY

Often managers are disenchanted with the results of aquatic biological monitoring. One major reason for this is that most management questions are about processes which are usually impossible to measure with any useful precision. Biologists are forced to use patterns to detect environmental changes and infer the cause of the change. Statistical designs are possible to overcome the objections of pseudoreplication and autocorrelation in before-and-after impact studies. For the more common "post-impact impact assessments", looser forms of inference can be employed to detect change from community patterns present in unimpacted sites.

The major failing of biological (and chemical) monitoring programmes is the lack of any direction in gathering data. In the short term biologists can simplify their task by first obtaining a well defined problem from their clients, and secondly by reducing the redundancies in their data when reporting the results. Conversely, managers need to realise that patterns are usually location-specific and cannot be extrapolated elsewhere without considerable extra expenditure. In the long term the best solution will be a better matching of pattern with process through long term research aimed at testing the robustness of patterns to the wide range of natural environmental fluctuations.

INTRODUCTION

The results of human activities such as point source and nonpoint source pollution, impoundment and river management are ultimately biological (Hynes 1960). The biota in a water body are present most of the time and should, therefore, be able to integrate all these various impacts to provide an overall picture of the conditions of a water body. The proponents of biological monitoring argue that biological variables will detect short term events that physicochemical procedures would miss (Hynes 1960, Campbell 1982), and this has proved to be so in practise (e.g. Arthington et al. 1982). The converse is also often true and most researchers in this field are careful to emphasise that biological and physicochemical procedures are complementary; neither is a complete substitute for the other.

Aquatic insects and other aquatic macroinvertebrates have been used in a particular form of biological monitoring. Changes in their relative abundance and various measures of community structure have been used as indicators of the 'health' or otherwise of water bodies. Aquatic insects have a number of features that commend their use for these sorts of studies: they are numerous, easily collected and relatively sedentary. Furthermore, they have been found to be sensitive to a wide variety of impacts including organic effluents (see Hynes 1960), heavy metals (e.g. Norris et al. 1982), sedimentation (e.g. Doeg et al. in press) and complex, mixed discharges and disturbances (e.g. Arthington et al. 1982). Obviously there are situations where other organisms (e.g. fish, phytoplankton) will be more appropriate (Herricks and Cairns 1982), while the small size and short life histories (typically < 1 yr) of aquatic insects precludes their use as bioaccumulators (Bayly and Lake 1979).

Nevertheless, some practical and conceptual problems complicate the application of aquatic insects (and most other organisms) to biological monitoring of water bodies. Its introduction in Australia has not been without its (largely undocumented) disagreements between managers and biologists. This essay describes what I think is

Majer, J.D. (ed.), *The Role of Invertebrates in Conservation and Biological Survey.* (1987). Western Australian Department of Conservation and Land Management Report.

the principal cause of disenchantment with biological monitoring and then proceeds to examine the scientific problems involved in monitoring change and the solutions that have been posed in the literature. I conclude with brief, opinionated prospectus on the interaction between managers and biologists. My main aim is to expose the problems inherent in biological monitoring and promote constructive debate and discussion.

THE BIOMONITORING CONUNDRUM

Essentially, both managers and biologists are hoping to achieve at least three major tasks when monitoring a river or lake:

i) detect deleterious or ameliorative changes in river or lake "health";

ii) identify the causes of degradation;

iii) provide information that will help decide between alternative courses of action.

Common management questions (when translated into the vernacular) include such items as:

> "If we build an impoundment here, will it become eutrophic?"
>
> "Will these stormwater retention basins harbour disease vectors or pests?"
>
> "To improve the environmental quality of this river what should we do first: improve sewage treatment or improve land management practices?"

These are all essentially questions about <u>processes</u>: productivity, population dynamics, sustainability of resources, etc. Unfortunately, processes such as productivity are notoriously difficult to measure reliably (Kokkin and Davis 1986) and biologists are often forced to use <u>patterns</u> in nature as a short cut to infer what might be going on.

Herein lies the biomonitoring conundrum: processes that interest us do not always map simply and predictably on to patterns. Cairns and Pratt (1986) posed the following scenarios for the linkage between pattern and process.

1. <u>A tight linkage</u>: A change in pattern automatically implies a change in some ecosystem or community process (e.g. removal of keystone species).

2. <u>A loose linkage</u>: which can be of two types:

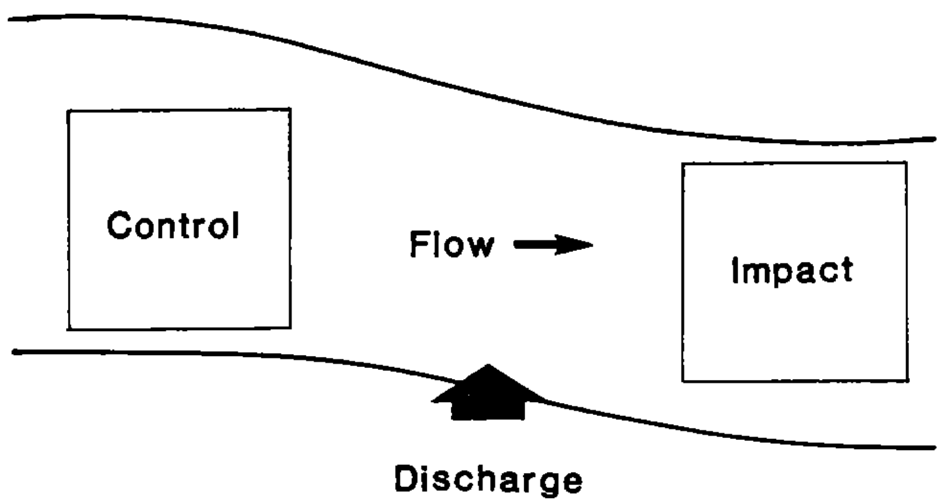
a) **Pattern may change without changing the process.** This occurs where many species may be functionally equivalent with the result that removal of one or two species has little effect on the process of interest.

b) **The process might change without affecting the pattern.** Cairns and Pratt (1986) suggested that it is not likely to occur in response to acute (short term) impacts where sublethal doses of some toxicant, for example, may depress community activity without actually causing any structural change. An example of a chronic impact might be where lowered temperature regimes (downstream of a hypolimnial release dam) might slow growth rates, thereby reducing productivity.

There are no easy solutions to this conundrum and it is often difficult to judge whether the indicators or indices selected will reflect the seriousness of the impact (Arthington et al. 1982). Also, because rivers and lakes differ considerably between catchments, the measures of pattern we use are more likely to be location specific: there are no "magic bullet" numbers with universal applicability (Washington 1984).

Since there are no universal laws that govern what aquatic communities should look like under pristine conditions, the most obvious resolution of the problem is to monitor a control and impact area before and after the impact happens and use the knowledge thus gained to reduce the redundancies in the data and inform the design of subsequent long term monitoring (Green 1979). However, even this ideal design has its problems.

Fig. 1: "Optimal" experimental design (after Green 1979). Samples are taken from control and impact areas both before and after discharge commences.



PSEUDOREPLICATION AND AUTOCORRELATION

Consider the circumstance in Fig. 1 where comparable control and impact areas exist upstream and downstream of a proposed discharge. We have been funded to take replicated samples from both areas before and after the discharge. The design appears to be a simple two-way analysis of variance (ANOVAR) with two factors with two levels each (Green 1979): Area (control and impact) X Time (before and after).

Unfortunately this design is not truly replicated. Eberhardt (1976) and Hurlbert (1984) labelled this as a "pseudodesign" or "pseudoreplication" respectively and repudiate the use of ANOVAR designs in these circumstances because our "replicate" samples are really only nested within each of the cells. It is possible that an event other than the discharge may affect the impact area but not the control making it difficult to conclude whether the discharge itself was responsible.

Stewart-Oaten et al. (1986) provide further lucid discussion of this problem. Their proposed solution relies on collecting a long series of observations before and after the discharge in both areas simultaneously. The mean difference in the population or other variable of interest between the two areas is compared before and after the discharge using a t- or U-test. Thus the observations are "replicated" in time. A number of assumptions must be met for the approach to be valid and all are testable as discussed by Stewart-Oaten et al. (1986). An important practical consideration is that several taxa should be monitored initially since some may show systematic inconsistent behaviour in the two areas which cannot be corrected for by transformation.

Alternative statistical procedures are also possible. Millard et al. (1985) discuss the problem of using changes in abundance (rather than changes in the difference of abundance) with data that are likely to be correlated in space or time. Such autocorrelated data violate assumptions of independence and may inflate the type I error rate (Eberhardt 1976). Millard et al. (1985) suggest that multivariate time series analysis be applied to data where frequent samplings result in temporal autocorrelations, while spatial autocorrelations may be dealt with using multivariate analysis of variance.

Even with such sophisticated designs the impact area may still be differentially affected by something other than the discharge. This only becomes a serious problem if the extraneous impact is localised, large and results in a long-lasting effect (Stewart-Oaten et al. 1986). In practical terms it is unlikely that such an event would go unnoticed by the experienced researcher and concurrent collection on non-biological information should further assist managers and project supervisors to hedge their bets. Unfortunately many of Australia's major aquatic ecosystems remain uninvestigated and even in the comparatively well studied temperate upland streams and salt lakes there are few long term studies or reports on the effects of natural disturbances such as droughts, floods or wildfire. Consequently, limnologists' ability to make qualitative judgements when something "goes wrong" in even a well designed study is limited.

However, most of us are aware that well designed temporally and spatially "controlled" impact studies are rare. A far more common set of questions managers ask concern impacts that have already happened or are continuing. Of what use are aquatic insects in post-impact assessment?

POST-IMPACT IMPACT ASSESSMENT

Conceptually it is easy to see why such studies are suboptimal (sensu Green 1979). The problem is not just trying to match pattern with process, but trying to imagine what either looked like before the impact commenced. However, I am not proposing that such studies are beneath the dignity of aquatic entomologists. Far from it; some of the most urgent and large scale problems facing us today (e.g. salinisation, eutrophication) stem from land use changes initiated before ecology existed as a discipline (Patterson 1985).

One approach to resolving this issue is to examine the fauna in pristine or high quality sites to gain an impression of what the faunal composition should be. The most spectacular example is the Fresh Water Biological Association's River Communities Project in Great Britain (Wright et al. 1984, Furse et al. 1984). Currently familial-level macroinvertebrate and physicochemical data have been amassed for 370 'clean water' sites (Armitage et al. 1987). Multivariate techniques have been used to group sites according to their faunal similarities, after which the physicochemical variables that best discriminate amongst these groups are selected. Armitage et al. (1987) have then used this information to predict what fauna should be present at 30 additional sites below impoundments. Their results indicate many sites are depauperate, with an over representation of fine sediment adapted animals. They suggest that "flushing" releases might restore the algal-feeding component of the fauna by removing the accumulated silt from the river bed. Thus it seems that a well designed goal-directed survey has provided an extensive usable database from which some predictions can be made. Again the assumption has been made that the patterns documented actually reflect underlying changes in processes. At the coarseness of the scale of these studies (i.e. changes in familial representation corresponding with changes in trophic structure) this seems justified.

This particular study is perhaps an exceptional example, but it illustrates two points often ignored. First, Armitage et al's study shows that for some questions relatively coarse taxonomic resolution is sufficient to demonstrate in an objective fashion that biological qualities have been altered and to indicate how they have been altered and how they might be remedied. Obviously there are situations where species level identifications are essential (Resh and Unzicker 1975), particularly for smaller scale site specific investigations. Nonetheless, the aquatic insect fauna is likely to contain a lot of redundant information and limnologists should perhaps follow the example of vegetation scientists (see Orloci 1978) and pick representative species or groups of species rather than trying to measure and report everything. Second, the British River Communities Project demonstrates that tremendous effort needs to be expended to arrive at large scale or regional measures of environmental or water quality: it is not a simple matter of computing a few diversity indices. There is a clear need for regional scale indicators to assist governments in directing funds to the most urgent problems and Paterson (1985, 1987) provides some constructive suggestions on marrying administrative structures and scientific information.

Thus far in this section I hope I have demonstrated that post-impact assessments are not necessarily a waste of time, provided assumptions hold about the role of habitat in structuring aquatic benthos, the representativeness of "control" or "pristine" sites and the numerical methods that underpin the analyses. There are of course numerous studies on a more modest, localised scale (e.g. Arthington et al. 1982, Marchant et al. 1984). However, there are numerous biological monitoring studies which are inadequate. The necessary ingredients for useful biological monitoring are outlined in the final section of this essay.

CONCLUSIONS

In a large review of the environmental assessment literature, Rosenberg et al. (1981) found that many of the worst studies were little more than aimless surveys. An essential first step in biological monitoring, whether it be for impact assessment or baseline monitoring, is to frame a scientific question that is both answerable and relevant to the tasks the managers have to carry out (Green 1979, Rosenberg et al. 1981). Even in baseline monitoring it is important to elicit from the client what deviations from "normal" system behaviour are essential to detect: it is always better to have specific alternative hypotheses to test for rather than a vague notion that rejecting a null hypothesis of no change will indicate that something is going on (Green 1979). Managers are not just interested in documenting change, they also want to know why a system has changed and how to remedy the situation.

Once a question has been framed, adequate time should be allowed for preliminary sampling and gathering background information so that appropriate statistical (or other) inferential procedures can be chosen. Aside from the topics mentioned already, Green (1979) provides a useful classification of the types of environmental studies which fall within the broad ambit of biological monitoring and the methods appropriate to each. Further references on the specifics of sampling design for aquatic studies include Elliott (1977), Resh and Price (1984), and Norris and Georges (1986), while Faith et al. (1987) and Minchin (1987) provide useful guidelines for the robust analysis of multivariate data.

Finally, after the full study has been executed, it is important to present the data in a form that is easily intelligible to the client. This may often be a much simplified version of what would ordinarily be necessary for a scientific publication; pages of dendrograms and F-tables faze hardened referees, let alone an uninitiated lay readership!

Such are the conditions for what I hope would be useful biological monitoring. Note that I am not against biological surveys per se: this is an essential preliminary for many of our aquatic systems. Surveys can provide invaluable background information to permit the selection of "indicator" species, assess the power of subsequent statistical designs and expose previously unknown biological features of the water body in question.

None of these ideas are new, of course (see Green 1979, Rosenberg et al. 1981, Cairns and Pratt 1986), although they bear reiteration.

The problems of sampling precision, experimental design and realistic predictive modelling are not unique to biologists (Bruton 1982). Indeed, large scale physicochemical water quality networks in the U.S.A. have failed to yield useful information for managers for similar reasons outlined above for biological studies (Ward et al. 1986).

Ultimately, we should all like to simplify matters by providing easily understood process-oriented accounts of what is happening, rather than reportage of patterns that seem anomalous to us as experienced biologists. However, until we have more basic long-term research into how Australian rivers, streams and lakes function, such objectives are unachievable.

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A PRELIMINARY ASSESSMENT OF THE CORRELATION BETWEEN PLANT, VERTEBRATE AND COLEOPTERA COMMUNITIES IN THE VICTORIAN MALLEE

A.L. Yen, Environmental Records Department, Museum of Victoria, 71 Victoria Crescent, Abbotsford, VIC., 3067

SUMMARY

The vertebrate and Coleoptera faunas of 32 sites from 8 vegetation communities were classified using TWINSPAN. The Coleoptera were classified into communities that reflect the vegetation communities more distinctly than the vertebrates. Vertebrate species tended to utilise more vegetation communities than the Coleoptera. There was no significant relationship between the number of species of vertebrates and the number of species of Coleoptera found in each vegetation community.

INTRODUCTION

To most land managers, the term "biological survey" is synonymous with plant, mammal, bird or reptile surveys. When the biological resources of an area are assessed and management plans developed, invertebrates are generally omitted. A key parameter is biological diversity, but managers ignore the fact that invertebrates contribute most to this diversity; the quantity of invertebrate species generally outnumbers the combined quantity of plant and vertebrate species (Greenslade and Greenslade 1984).

Invertebrate surveys are usually conducted independently of floral and vertebrate surveys, although occasionally they are combined. Even in the latter cases, invertebrates are usually considered secondary to the plants and vertebrates. Higher plants are easily seen, collected or identifiable in the field. Plant communities, admittedly, do provide an immediate indication of a particular habitat. Vertebrates are publically appealing, often easily collected and identifiable in the field.

Invertebrates are often ignored on the assumption that if a particular landscape, vegetation type or vertebrate habitat is conserved, these areas will carry their own characteristic suite of invertebrates (Greenslade and Greenslade 1984). This may not always be true. It cannot be assumed that all invertebrate communities are necessarily conserved if a particular plant or vertebrate community is conserved. Invertebrates may utilise environmental variables differently from plants or vertebrates, which may result in different distribution patterns for plant, vertebrate and invertebrate communities. Even if utilisation patterns are similar for plants, vertebrates and invertebrates, species interactions within each of these groups may result in different distribution patterns.

The Land Conservation Council of Victoria (LCC) has divided the State into several broad regions, and has been collating and publishing information on each region since 1972. From 1972-1985, the biological components of these reports involved plant and vertebrate surveys, with the inclusion of any readily available information on invertebrates (although no actual invertebrate surveys were conducted as part of these studies). All the major regions in Victoria have been studied once, and the LCC is now reassessing each of the regions. In 1985, the LCC decided to include an invertebrate survey in its reappraisal of the Victorian Mallee region.

The biological study of the mallee has involved an 18 month survey of the plants (Flora Survey Unit, Ministry for Conservation, Forests and Lands), vertebrates

Majer, J.D. (ed.), *The Role of Invertebrates in Conservation and Biological Survey*. (1987). Western Australian Department of Conservation and Land Management Report.

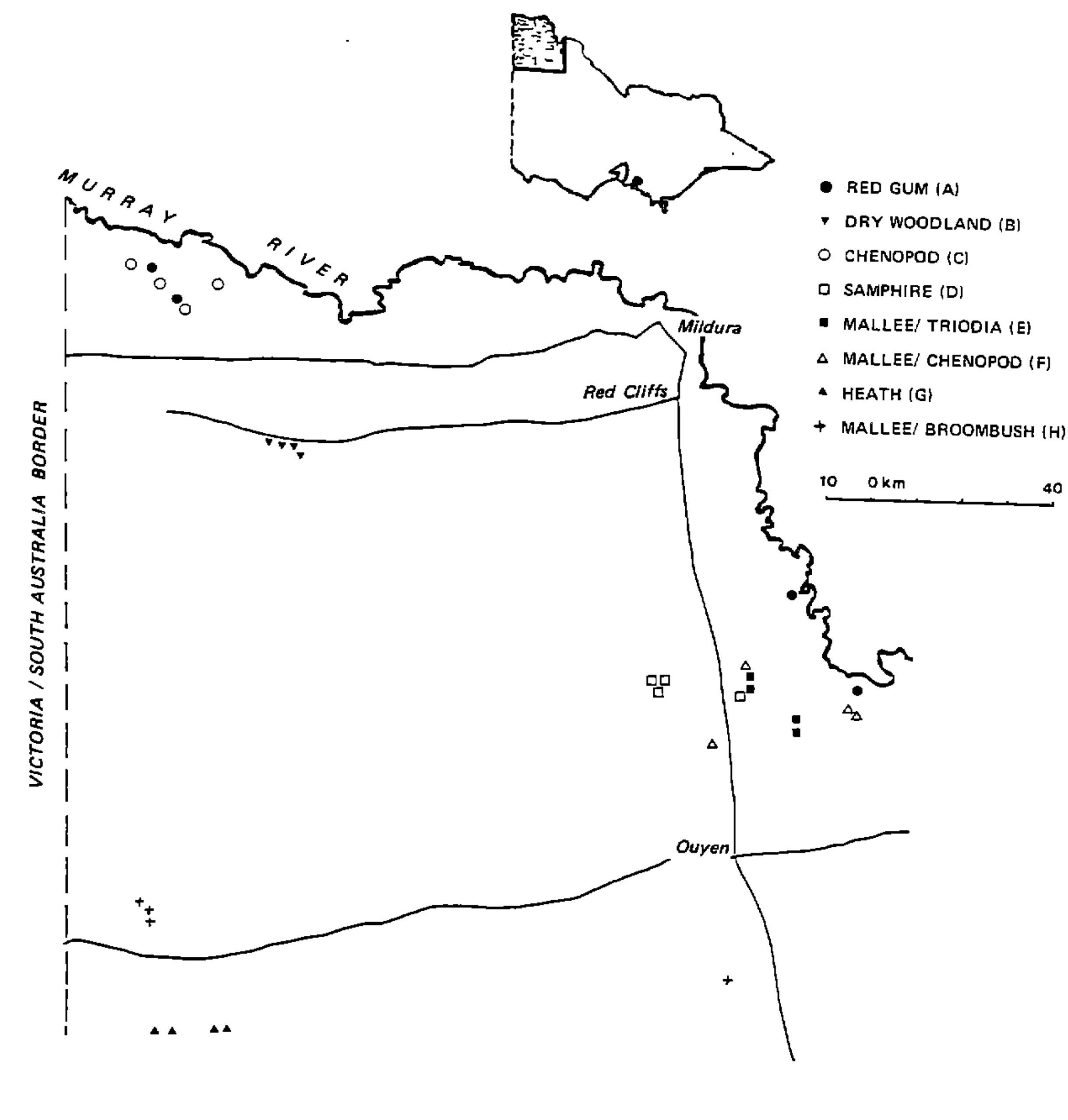
(Wildlife and National Parks Division, Ministry for Conservation, Forests and Lands), and invertebrates (Environmental Records Department, Museum of Victoria).

One of the aims of this joint study is to determine whether plant, vertebrate and invertebrate communities coincide in their distribution patterns. As field work was concluded in May 1987, material is still being identified and data analysed. Consequently, this contribution represents only a preliminary assessment of a subset of the total data collected.

METHODS

The Victorian Mallee area (as defined by the LCC 1974) is situated in the north west corner of the State, and includes the northern part of the Big Desert, the Sunset Country and the riverine areas south of the River Murray (Fig. 1). The climate is semi-arid, with average rainfall ranging from 350 mm in the south to 250 mm in the north (LCC 1974).

Fig. 1: The 32 study sites in the Mallee, Northwestern Victoria.



A total of 120 sites were selected for faunal monitoring. These were selected by zoologists on the basis of apparently different plant communities. Drift-fence pitfall traps were put in at all 120 sites. Each site had a 50 m drift fence (10 cm in height) linking 10 pitfall traps (each 25 litre volume) at 5 m intervals. Each set of traps was opened for 5 day intervals for 5 occasions during the period September 1985-February 1987. Due to the distances between the sites, only half the traps were operated on each field trip, and the second half opened on the following trip. Consequently, sites 1-60 were opened in October 1985, January 1986, May 1986, September 1986 and January 1987, and sites 61-120 were opened in November 1985, February 1986, June 1986, October 1986 and February 1987.

Mammals were also collected by trapping, birds censused visually and arboreal invertebrates by beating foliage. However, only drift-fence pitfall trap catches are considered in this study.

As 25 litre pitfall traps were used, only the larger mesoinvertebrates and the macroinvertebrates were collected. No baits or preservatives were used. Vertebrates were released after capture, but all invertebrates were collected for identification. All invertebrate material is deposited in the Museum of Victoria.

This present study considers the drift-force pitfall catches of vertebrates and Coleoptera in 32 of the 120 sites. These represent 4 replicates of each of the 8 most distinctive plant communities (i.e. a total of 32 sites). The 8 vegetation communities are:

A. Red Gum. Dominated by River Red Gum, *Eucalyptus camaldulensis*

B. Dry Woodland. Dominated by Belah, *Casuarina cristata*

C. Chenopod. Salt bushes such as *Atriplex, Rhagodia, Chenopodium, Maireana*

D. Samphire. Nitre bush, *Nitaria*

E. Mallee/*Triodia*

F. Mallee/Chenopod

G. Heath

H. Mallee/Broombush.

The ground dwelling Coleoptera are a major component of the fauna in the Mallee. Coleoptera are a good insect order to use because of their diversity, abundance, ecological importance, and they are easily collected and sorted. They are also amenable for longer term studies as some species are relatively long-lived and they can be marked. They are the largest order of insects (40% of known insect species, perhaps 33% of all animal species), and they interact with the ground habitat in a variety of ways (Greenslade 1985). All adult Coleoptera were identified to a species or morphospecies.

Although seasonal collections were taken, the data were bulked at each site for all seasons. Combining seasons' data generally enables better categorisation of communities than single season's results (Furse et al. 1984).

The possible correlation between plant and animal communities is sought by numerical classification of the Coleoptera and vertebrate faunas using the two-way indicator species analysis programme TWINSPAN (Hill 1979). If the plant and animal communities are closely correlated, then we should get the animals separating into 8 communities corresponding to the 8 selected vegetation communities.

RESULTS

The distribution of Coleoptera and vertebrate communities among the eight plant communities is summarised by amalgamating the results of the 4 sites of the 8 plant communities, and are presented in Tables 1 and 2 respectively. A total of 3,806 Coleoptera from 176 species in 14 families were collected. The main families are the predaceous and scavenging Carabidae (61 species), the live and dead plant feeding Scarabaeidae (35 species), the phytophagous Curculionidae (34 species), and the detritivorous Tenebrionidae (24 species). A total of 60 vertebrate species, involving 1,280 individuals were trapped. These included frogs (5 species), reptiles (46 species), and mammals (9 species).

The number of species of Coleoptera was higher in all Mallee and Heath sites (E, F, G and H), Chenopod sites (C) and Red Gum sites (B). The lowest number of Coleoptera species was found in Dry Woodland (B) and Samphire (B) (Table 1). In contrast, vertebrates had highest numbers of species in Mallee/*Triodia* (E) and Heath (G), and similar numbers of species in the remaining plant communities (Table 2).

The vertebrate and Coleoptera data were run separately on TWINSPAN. After four divisions on TWINSPAN, neither the vertebrate nor the Coleoptera faunas separated into 8 communities corresponding to the vegetation communities (Fig. 2). There are several major differences between the classifications of the vertebrates and the Coleoptera:

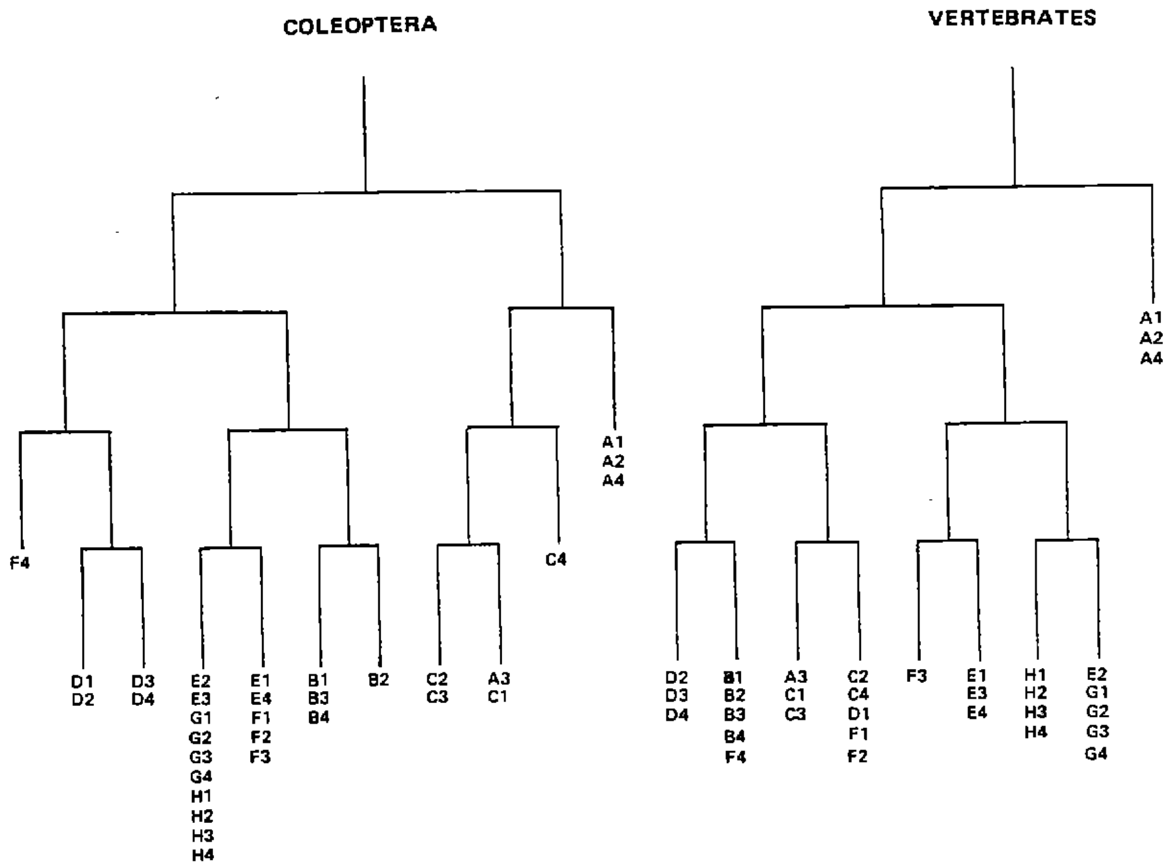
1. The Coleoptera fauna was classified into 11 communities, while the vertebrates had 9 communities.

2. Both the Coleoptera and vertebrate faunas divided into 2 early major divisions. In the Coleoptera, one branch contained all Red Gum and Chenopod sites (A and C), while in the vertebrates, the equivalent branch only contains three Red Gum sites (A1, A2 and A4); site A3 and the Chenopod sites are in the other division.

3. The Coleoptera fauna readily groups the Samphire (D) and Dry Woodland (B) communities, while the Mallee and Heath sites (E, F, G and H) are grouped into two closely related communities. There is one anomalous site, F4.

4. The vertebrate fauna does not group itself as neatly. There is much more mixing of the individual sites, resulting in communities that are mixtures such as Dry Woodland and Mallee/Chenopod (B1-B4 and F4), Red Gum and Chenopod (A3, C1, C3), Chenopod, Samphire and Mallee/Chenopod (C2, C4, D1, F1 and F2). Most of the Mallee and Heath sites do group together into 4 communities (Fig. 2).

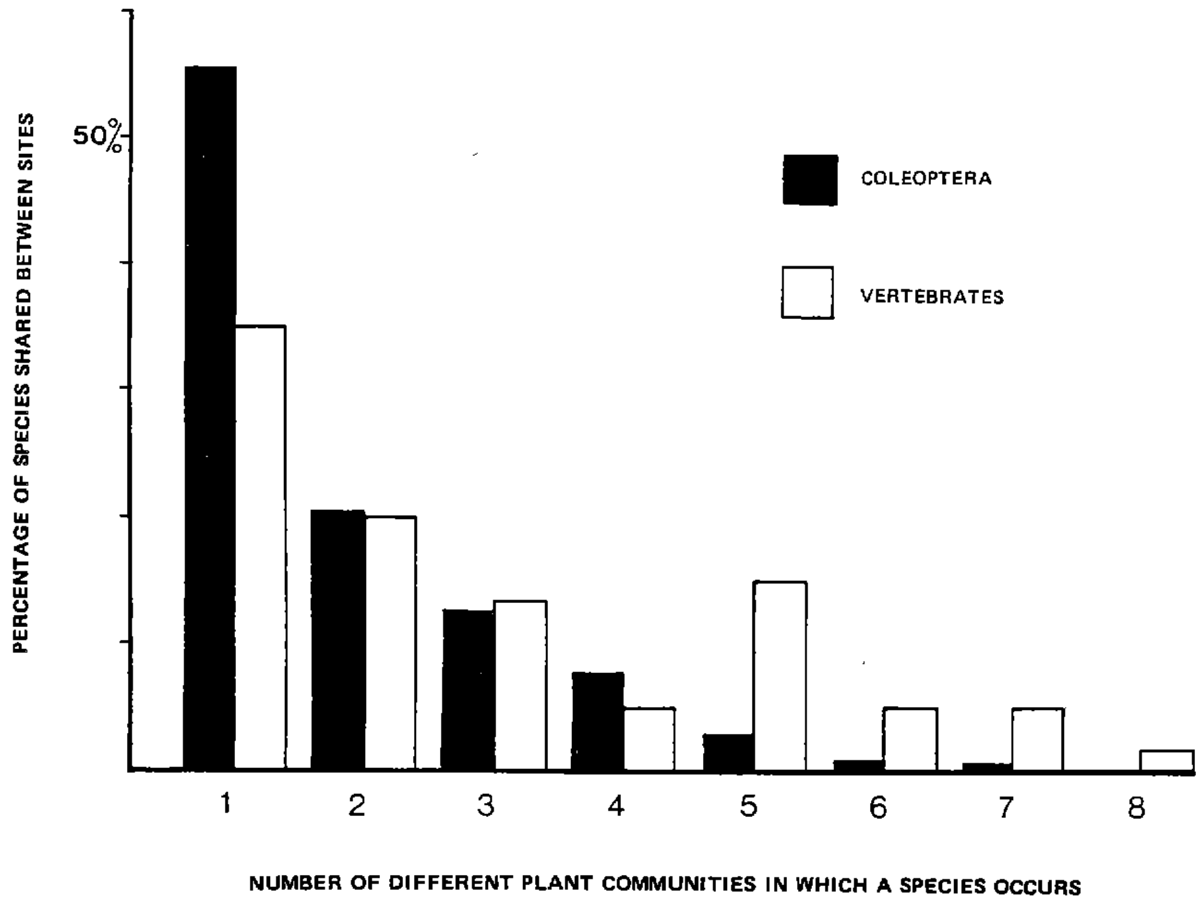
Fig. 2: Dendrogram of TWINSPAN end-groups of Coleoptera and vertebrates from 32 sites in the Mallee, Victoria.



A RED GUM, B DRY WOODLAND, C CHENOPOD, D SAMPHIRE, E MALLEE/TRIODIA
F MALLEE/CHENOPOD, G HEATH, H MALLEE/BROOMBUSH.

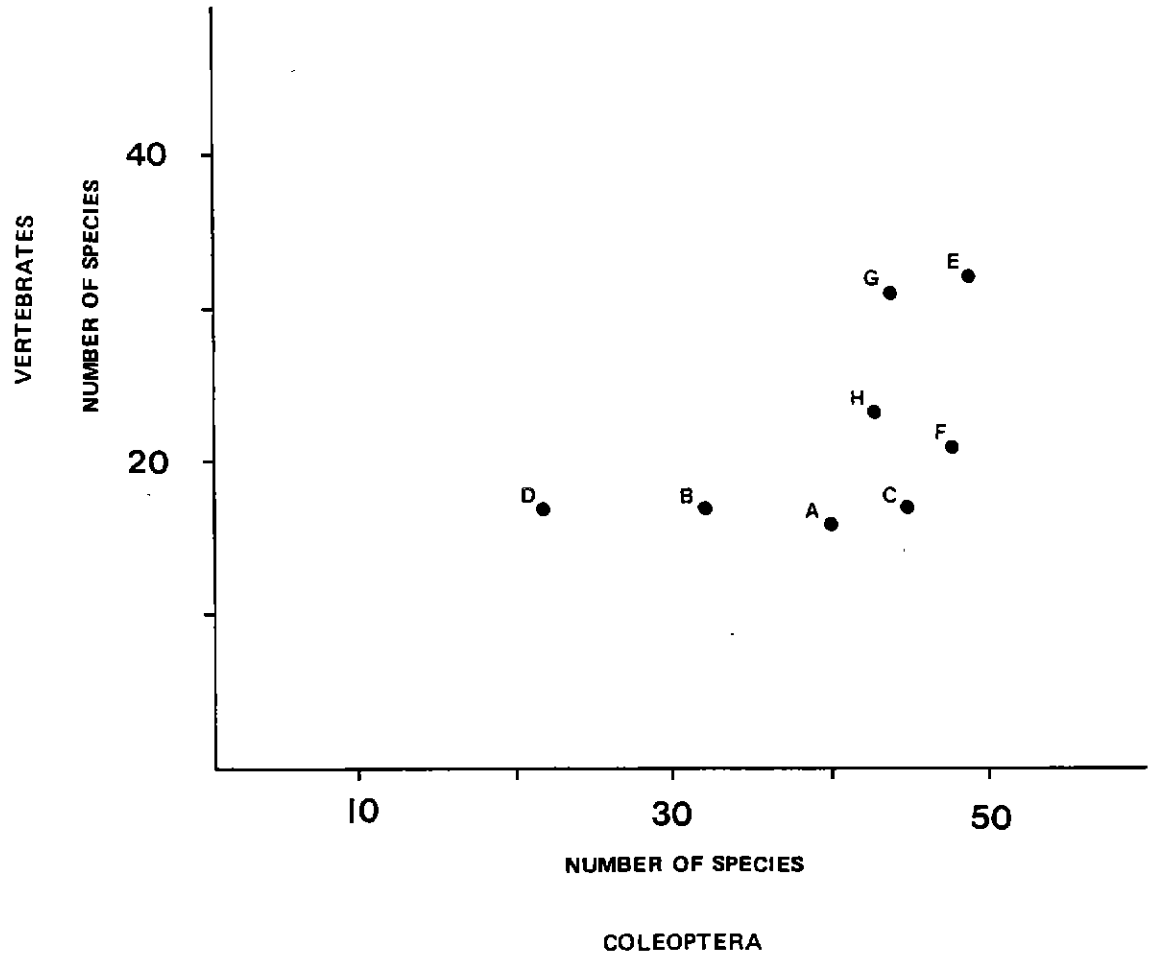
These results indicate that the Coleoptera have tighter communities than the vertebrates with regard to their distribution in different vegetation types. This is better illustrated by looking at the number of plant communities in which each species of vertebrate or Coleoptera is found (Fig. 3). A species that has relatively narrow habitat requirements would only be found in one plant community, while species with wide habitat requirements may be found in several plant communities. If vertebrates are less habitat specific than Coleoptera with regard to vegetation type, then a greater proportion of vertebrate species should be found in a larger number of plant communities. The distribution of faunal species over vegetation types is tested for differences in the vertebrate and Coleoptera distributions by using a 2 x 8 contingency table. The difference is significant ($X^2 = 20.49$, df=7, $0.001 < p < 0.005$), indicating that more vertebrate species are found in wider range of plant communities than Coleoptera species.

Fig. 3: The distribution of animal species over eight plant communities.



Another question that arises is whether plant communities are similar habitats for both Coleoptera and vertebrates. If this is the case then the number of species of Coleoptera and the number of vertebrate species found in each plant community should be significantly positively correlated. When plotted, the relationship is a positive correlation (Fig. 4), but it is not significant ($r = 0.55$, $df = 6$, $p > 0.05$). This means that if a particular plant community has a high number of vertebrate species, it does not necessarily have a high number of species of Coleoptera, or vice versa. There is no relationship between the number of vertebrate and Coleoptera species.

Fig. 4: Relationship between the number of species of Coleoptera and the number of species of vertebrates in each vegetation community. Correlation coefficient r = 0 55, NS. A, Red Gum; B, Dry Woodland; C, Chenopod; D, Samphire; E, Mallee/*Triodia*; F, Mallee/Chenopod; G, Heath; H, Mallee/Broombush.



DISCUSSION

This study is a preliminary look at the possible correlations between plant, vertebrate and invertebrate communities. The study has been made with selected plant communities. Although it would have been better not to have used pre-selected plant communities, the plant data was unavailable to analyse simultaneously with the Coleoptera and vertebrate data.

It would also be better to use more invertebrate groups. Three other groups predominate in the Mallee: Formicidae, Blattodea and Araneae, and these groups along with the Coleoptera make up approximately 80% of the fauna in terms of numbers of individuals.

The use of large pitfall traps resulted in only the larger mesoinvertebrates and the macroinvertebrates being collected. Different sized pitfall traps would most probably result different sized animals being collected, and although small invertebrates fell into the large pitfall traps, it was too time-consuming and physically difficult to collect them.

Even on the basis of these preliminary results, several conclusions can be made. When either vertebrate or Coleoptera faunas are classified, they give communities that broadly reflect the vegetation communities from which they came. However, there are important deviations. Although certain plant communities stand out markedly, there are some distributions that are difficult to explain botanically. In both Coleoptera and vertebrates, the Mallee and Heath sites are very close together, reflecting the difficulty in distinguishing these types of mallee vegetation.

The resultant classifications of the vertebrates and the Coleoptera are different. The Coleoptera communities are more distinct and more finely tuned than the vertebrate communities, and are more closely correlated to the vegetation communities. There are several possible reasons for this:

1. Coleoptera may be more specific to particular vegetation communities, so that a larger proportion of species are found in only one or a few different vegetation communities.

2. The higher species richness of the Coleoptera will result in the occurrence of more rare species, and this may permit a finer classification of the communities. In the 32 sites, 176 Coleoptera and 60 vertebrate species were found, compared to the 120-site total of 302 Coleoptera and 60 vertebrate species.

3. Vertebrates may be more mobile than Coleoptera and require greater home ranges that extend beyond particular vegetation communities. However, some Coleoptera can disperse by flight, although many of the ground-dwelling species are apterous.

Furthermore, the microhabitat components have to be considered. Some species of vertebrates and Coleoptera have restricted microhabitat utilisation patterns which may or may not be reflected in the vegetation structure of the habitat. For example, some species may be restricted to areas of deep litter or to Porcupine grass (*Triodia* species).

When species with more than 20 individuals collected are considered (Tables 1 and 2), the vertebrates had 6 species with narrow plant community distributions: *Limnodynastes tasmaniensis* (Spotted Grass Frog) is restricted to Red Gum sites near permanent water; *Amphibolurus fordi* (Mallee Dragon) is totally dependent on *Triodia* (Cogger 1983); *Morethia adelaidensis* is restricted to saline habitats such as Samphire; *Pseudomys apodemoides* (Silky Mouse) is restricted to Heath, while *Cercartetus lepidus* (Little Pygmy Possum) and *Notomys mitchelli* (Mitchell's Hopping Mouse) are found in Heath or Mallee communities. There are 13 vertebrate species with broad distributions: *Diplodactylus vittatus, Lucasium damaeum, Amphibolurus nobbi, A. pictus, A. vitticeps, Ctenotus regius, Lerista bougainvilli, Menetia greyi, Morethia boulengeri, M. obscura, Trachydosaurus rugosus, Ningaui yvonneae,* and *Mus musculus*. *Mus musculus* (House Mouse) is an opportunistic introduced species that has spread away from human habitation and established large feral populations (Strachan 1983).

Only 7 species of Coleoptera had a broad distribution: *Carenum elegans, C. tinctillatum, Neocarenum elongatum, Parroa apicalis, Scaraphites hertipes, Simondontus rotundipennis,* and *Helaeus scaphiformis*. Most of these species are found throughout Mallee and Heath communities. There are also 6 Coleoptera species with broad distributions but are predominant at only one or two plant communities: *Carenum* sp. 7 (predominant in Chenopod), *Ellopidia sloanei* (Dry Woodland and Chenopod), *Adelium* sp. 2 (Red Gum), and *Helaeus moniliferus* (Mallee/Broombush).

Nine species of Coleoptera were restricted to one vegetation type: *Arthropterus wilsoni* (Chenopod), *Megacephala australis* (Samphire), Sagrinae sp. 1 (Dry Woodland), *Catasarcus* sp. (Heath), Otiorhynchinae sp. C (Red Gum), Otiorhynchinae sp. G (Mallee/Triodia), *Liparetus* sp. 1 (Samphire), *Pectinopus* sp. 1 (Red Gum), *Saragus blackburni* (Heath and Mallee/Broombush).

There is no significant relationship between the number of vertebrate species and the number of Coleoptera species in each vegetation type. This indicates that a site rich in vertebrate species may not necessarily have a high number of Coleoptera species. From a management point of view, this is important because conservation measures are often based on faunal richness, especially with vertebrates, and an area reserved on the basis of a rich vertebrate fauna may not necessarily be a good reserve for Coleoptera.

CONCLUSION

There is some agreement between plant, vertebrate and Coleoptera community distributions. The Coleoptera are classified to communities that reflect the plant communities more accurately than the vertebrates. In land management decisions it is important to consider invertebrates, as these results suggest that plant or vertebrate communities need not necessarily reflect invertebrate communities accurately.

Large numbers of vertebrate surveys are conducted in Australia. It is not a particularly onerous task to expand these surveys to include invertebrates. Not only would this assist redressing our lack of information for our invertebrate fauna, but it would also provide land managers with a more comprehensive and more accurate data base on which to draw conclusions before implementing management plans.

ACKNOWLEDGEMENTS

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Table 1 COLEOPTERA FROM 8 PLANT COMMUNITIES IN THE MALLEE. A, RED GUM; B, DRY WOODLAND; C, CHENOPOD; D, SAMPHIRE; E, MALLEE/*TRIODIA*; F, MALLEE/CHENOPOD; G, HEATH; H, MALLEE/BROOMBUSH.

Coleoptera species	Plant communities							
	A	B	C	D	E	F	G	H
Alleucidae								
Melaps pilosus	2		4					
Belidae								
Belidae sp.A			1					
Buprestidae								
Stigmodera sanguinosa							1	
Carabidae								
Arthropterus sp.0	1	1	21			1	3	
Arthropterus sp.1	7	2						
Arthropterus sp.2		1	1					
Arthropterus wilsoni		2	32					
Carenum anthracium						1		
Carenum cordipenne				2	7	4		
Carenum elegans		30			5	29	44	33
Carenum iridescens			8	1	1	1		
Carenum rectangulare		3						
Carenum scaritoides							2	
Carenum tinctillatum	1		7	7	25	15		2
Carenum violaceum					3	1	1	1
Carenum sp.1					1		3	
Carenum sp.2							6	
Carenum sp.4					2	10		
Carenum sp.5					6	4	4	2
Carenum sp.6				1	13	1		
Carenum sp.7						1		
Carenum sp.8						1		
Cenogmus sp.1			4					
Cenogmus sp.2			1					
Cenogmus sp.3			3					
Cerotalis semiviolaceum						3		
Clivinia planiceps	2							
Conopterum riverinae				1	6	4		
Conopterum superbum			1		5		3	3
Craspedophorus australiasiae				1		1		
Epilectus mastersi					4	1		1
Euryscaphus obesus				2		1		
Gigadema bostocki		1		1		14		
Gigadema sp.1						7		
Gigadema sp.2		1		1	5			
Gnathophanus melbournensis		1	1			8		
Gnathoxys humeralis							16	1
Gnathoxys sp.1					12	4		1
Homethes sp.1					1			
Hypharax sp.1		1			5	3		
Hypharax sp.3	1							

	A	B	C	D	E	F	G	H
Hypharax sp.4			1					
Laccopterum sp.1							1	
Mecyclothorax sp.1				1				
Megacephala australis				1454		2		
Neocarenum elongatum					20	13	49	36
Neocarenum sp.1					3			3
Neocarenum sp.2					3			
Notogonum sp.1				1				
Parroa apicalis					9		1	12
Philophloeus sp.1							1	
Philoscaphus tuberculatus				3				
Phorticosmus felix			8				1	
Phorticosmus grandis			10					
Platycoelus sp.1	1							
Prosopogmus sp.1								1
Rhytisternus sp.1				2				
Sarticus sp.1							1	
Sarticus sp.3								12
Scaraphites hertipes					5		21	12
Scaraphites lenaeus					1			
Silphomorpha sp.1						1		
Simodontus rotundipennis					20	7	25	35
Simodontus sp.2	1	9	8					
Cerambycidae								
Corrhenes crassicollis			5	4		4		
Microtragus mormon		1				1	6	1
Chrysomelidae								
Chrysomelinae sp.1		4				13		
Ellopidia sloanei		92		6	6	12		
Sagrinae sp.1		27						
Cleridae								
Eunatalis sp.1			1					
Coccinellidae								
Coccinella transvasalis	1	1	12					
Curculionidae								
Acantholophus sp.A							11	
Acantholophus sp.B							7	
Amorphorhinus sp.	1			1	1	4	2	
Amycterinae sp.B					1			
Amycterinae sp.D			1					
Amycterinae sp.E	6							
Amycterinae sp.G								2
Amycterinae sp.J					2		2	
Amycterinae sp.K	3	9	25			5		
Amycterinae sp.M		1						
Catasarcus sp.							20	1
Haplonyx sp.A	2					4		
Leptopius sp.					12			

	A	B	C	D	E	F	G	H
Mythites sp.							1	
Otiorhynchinae sp.A	1	6			6		1	
Otiorhynchinae sp.B	1		11					
Otiorhynchinae sp.C	34		2					
Otiorhynchinae sp.D			3	2	1			
Otiorhynchinae sp.E					4			
Otiorhynchinae sp.G					21			
Parrahyborrhynchus sp.							1	1
Prosayleus sp.							1	
Rhinaria sp.B							1	
Unknown sp.A						1		
Unknown sp.H				1				
Unknown sp.K								1
Unknown sp.M			1					
Unknown sp.N	1		8					
Unknown sp.O			5					1
Unknown sp.R			1					
Unknown sp.T					1			
Unknown sp.V			4					
Unknown sp.W	1	165	355	4	2	11	1	
Unknown sp.Z	1					4		
Elateridae								
Agrypnus sp.1			1		1			1
Conoderus commodus			1					
Conoderus sp.	1	2						
Conoderus sp.1	1							
Chrostus quadrifoveolatus					2			
Melyridae								
Carphurus sp.1		1						
Scarabaeidae								
Anoplognathus montanus	1							
Colpochila bella								2
Colpochila bimucronata					1			
Colpochila longiclava	1							
Colpochila mixta					1			
Colpochila opaca					1			2
Colpochila pulchilla						1		3
Cryptodus caviceps		5				1		
Cryptodus piceus						1		
Hemichnoodes mniszechi								1
Hemichnoodes nigriceps								1
Heteronyx insignus		1						
Heteronyx normalis					2			
Heteronyx piceus								2
Heteronyx pustulosus								1
Heteronyx sp.1	2						1	4
Heteronyx sp.5		1				1		
Heteronyx sp.7		1	1					
Heteronyx sp.8	4							

	A	B	C	D	E	F	G	H
Heteronyx sp.9	1							
Heteronyx sp.10					1	8		2
Heteronyx sp.11					1			4
Heteronyx sp.12					1			
Heteronyx sp.21			2					
Heteronyx sp.22	5							1
Liparetrus abnormalis	1							
Liparetrus lissapterus	1							
Liparetrus nudipennis					1			
Liparetrus sp.1				21				
Maechidius sp.1								1
Onthophagus sp.2	3							
Onthophagus sp.3	1							
Pectinopus sp.1	33							
Semanopterus sp.1	1							
Semanopterus sp.3	2		1					
Tenebrionidae								
Adelium sp.							1	
Adelium sp.1							1	
Adelium sp.2	96		1			1	1	
Adelium sp.4			7					
Adelium sp.6	2							
Aethalides punctipennis			8					
Amphianax westwoodi							1	
Brises acuticornis			1					
Cestrinus sp.1	2	1					2	1
Chalcopterus sp.2		1						
Chalcopterus sp.3					1			
Helaeus castor		8				1	2	9
Helaeus moniliferus					3	2		29
Helaeus scaphiformis		7			14	1	3	7
Hypaulax orcus					1		2	1
Onosterrhus acuticollis							2	
Onosterrhus rotundatus						1		
Onosterrhus stepheni		2	4			4		
Otrintus behri	4	2	11					
Pterohelaeus sp.1			5	1				
Saragus blackburni							34	4
Saragus infeux							2	1
Saragus laevis						1	1	
Saragus limbatus			5					
Trogidae								
Omorgus alterans	1		3				1	
Omorgus australasiae	2							
Omorgus euclensis			1					
Omorgus pellosomus					1			
Omorgus sp.2					1			1
Total no. species	40	32	45	22	49	48	44	43
Total no. individuals	296	390	597	1518	252	220	289	244

Table 2 VERTEBRATES FROM 8 PLANT COMMUNITIES IN THE MALLEE. A, RED GUM; B, DRY WOODLAND; C, CHENOPOD; D, SAMPHIRE; E, MALLEE/*TRIODIA*; F, MALLEE/CHENOPOD; G, HEATH; H, MALLEE/BROOMBUSH.

Vertebrate species	Plant communities							
	A	B	C	D	E	F	G	H
Frogs								
Limnodynastes dumerilii	8						3	
Limnodynastes tasmaniensis	41				1			
Neobatrachus pictus								1
Neobatrachus sudelli					2		1	
Neobatrachus sp.1					2	1	1	1
Reptiles								
Chelodina longicollis	1							
Diplodactylus intermedius		4		1	3		3	3
Diplodactylus tesselatus	3		11					
Diplodactylus vittatus		8			1	9	2	8
Gehyra variegata	2	3				2		
Heteronotia binoei	2		2					
Lucasium damaeum	1		7	1	19	11	19	8
Phyllodactylus marmoratus	3							2
Rhynchoedura ornata		5						
Aprasia inaurita					6		7	2
Delma australis				1	1	2	8	1
Delma inornata					3			
Delma sp.1			1					
Lialis burtonis					2			
Pygopus lepidopodus							1	
Amphibolurus fordi					77		94	
Amphibolurus norrisi							1	
Amphibolurus nobbi		6		1	13	2	7	4
Amphibolurus pictus				4	9	7	8	
Amphibolurus vitticeps			3	2	5	4	4	1
Varanus gouldii					1	1	1	
Cryptoblepharus carnabyi	4							
Ctenotus brachyonyx				2	4			
Ctenotus brooksi					1		16	
Ctenotus regius		14	22	8	8	3		
Ctenotus robustus							11	
Ctenotus uber	6	1			5	3	4	
Ctenotus sp.1			1					
Egernia inornata					7		1	1
Egernia striolata	3							
Lerista bougainvilli			1		8	2	7	6
Lerista punctatovittata	2	1	1	1	1	2		
Menetia greyii		2	6	2	6	9	14	10
Morethia adelaidensis				16				
Morethia boulengeri	56	6	9		1	5		
Morethia obscura					6		16	6
Tiliqua occipitalis					2		1	
Trachydosaurus rugosus		7	11	3	17	19	4	11

	A	B	C	D	E	F	G	H
Ramphotyphlops bituberculatus	1	4	1	3		2		
Ramphotyphlops australis					4	2		
Drysdalia mastersi							2	
Pseudonaja nuchalis		1						
Pseudonaja textilis	1	1						2
Simoselaps australis		1			3	5		1
Suta suta			4					
Unechis nigriceps		7		1	1	1		1
Mammals								
Trichosurus vulpecula	10							
Ningaui yvonneae				2	16		2	
Sminthopsis crassicaudata			14					
Sminthopsis murina				1				
Cercartetus concinnus							7	7
Cercartetus lepidus							8	15
Mus musculus	2	46	19	23	25	31	10	20
Pseudomys apodemoides							37	
Notomys mitchelli					4		3	31
Total no. species	16	17	17	17	32	21	31	23
Total no. individuals	140	122	114	72	259	125	302	146

ECOLOGICAL DISTURBANCE AND CONSERVATION OF SPIDERS: IMPLICATIONS FOR BIOGEOGRAPHIC RELICS IN SOUTHWESTERN AUSTRALIA

Barbara York Main, Department of Zoology, University of Western Australia, Nedlands, W.A., 6009

SUMMARY

Earlier studies in southwest Western Australia have noted recolonisation by spiders of disturbed habitats. Differential reinvasion by spiders with disparate life style needs has not previously been considered. It is proposed here: that relic groups of spiders and others with poor powers of dispersion cannot readily re-establish in areas disturbed by felling and burning, clearing and agriculture (even if rehabilitated); that certain Gondwanan relics, e.g. those with taxonomic affinities with spiders in rain forests of eastern Australia, Tasmania, New Zealand, Madagascar or Chile pre-date fire as a natural phenomenon and are therefore endangered by fire as a management tool (or otherwise) unless the timing of burning is coincident with the low-risk time (dormancy) of such taxa.

INTRODUCTION

The conservation value of spiders in southwestern Australia is implicit in the growing recognition of their functional role in ecosystems (Curry et al. 1985) and their convenience-use in monitoring aspects of ecosystems (Main 1977, 1987; Ridsdill-Smith 1987). Furthermore, as will be shown in this essay, the significance of spiders as biological indicators of former environmental scenarios is demonstrated through the occurrence of geographic relics.

Several studies using spiders alone or as a component of arthropod communities to ascertain the effect of disturbance ranging from fire in management to destruction through bauxite mining followed by rehabilitation, have been undertaken in forests. Recovery of species richness in the short term after drastic disturbance by clearing, burning and replanting in karri forest was noted by Curry et al. (1985). Similarly, Mawson (1986) noted that following rehabilitation of bauxite mined jarrah forest, species richness comparable to adjacent forest was restored in about eight years. Local studies have not considered the long term effects of such disturbances whereas in some studies elsewhere the implications are that species richness is restored or increased in a few years after disturbance but declines as the habitats return to maturity (Huhta 1971, Coyle 1981, Bultman et al. 1982). However, this species diversity did not always have the same representation - Coyle (1981) noted that terrestrial web weavers declined while hunting spiders increased due to immigration. Similarly, Huhta (1971) showed that mobile hunting spiders were responsible for the post-disturbance diversity while sedentary species declined. Merrett (1976) noted a differential species recovery rate after fire in Dorset heathland.

The above projects have been concerned with the generalised responses of the total spider community. Repopulating or invasion by spiders of moderately disturbed or devastated areas whether by burning, mining, etc. which are subsequently restored through natural means (slow resuscitation) or rehabilitated (rapid revegetation) depends on:

1. persistence of a nucleus population in refugia through the disturbance with a following expansion and spread of the population, and/or

Majer, J.D. (ed.), *The Role of Invertebrates in Conservation and Biological Survey*. (1987). Western Australian Department of Conservation and Land Management Report.

2. colonisation through invasion by another population source from a locality outside.

The above W.A. studies have generally indicated colonisation from outside, primarily an adjacent undisturbed source. However none of the foregoing (or indeed any) studies have addressed the long term effect of disturbance on (a) taxa with a long life cycle and/or poor dispersion capacity, e.g. mygalomorphs generally, or (b) geographically restricted relic species with special microhabitat and life style needs. It is the problems facing these two categories of spiders that this paper addresses.

OBSERVATIONS, RECORDS AND DISCUSSION

MYGALOMORPHS

All mygalomorphs have a long life cycle and may not mature for at least five or more years. Most are sedentary and destruction of soil/litter profiles through agriculture or mining causes total destruction of a population. Only two genera in W.A. are known to disperse on gossamer, *Conothele* and *Missulena* although it is possible that the web weaving *Cethegus* may also disperse aerially over short distances. Thus in general, dispersion is limited and does not occur far across unfavourable sites. In the foregoing studies none of the included mygalomorphs were aerial dispersers.

In the rehabilitated bauxite mined sites in jarrah forest (Mawson 1986) males and dispersing juveniles, both ambulatory groups, were caught. Since mining destroys spider burrows, it is obvious that both these groups ran into the site from adjacent forest. While the juveniles could slowly re-establish a population, presence of the wandering males gives a false indication of persistence or successful reinvasion. Similarly the study by Curry et al. (1985) noted relatively high numbers of male *Chenistonia villosa* Rainbow and Pulleine. The few females collected were probably associated in courtship with male spiders. The suggestion that surface moving mygalomorphs, particularly males, indicates rapid re-establishment of disturbed areas, is spurious.

Wheatbelt areas cleared and cropped (only once) and left to regenerate naturally over about twenty years show almost no recolonisation by mygalomorphs from adjacent bush (Heitman's Scrub, N. Bungulla). Conversely an area at Durokoppin appears to have been successfully recolonised by *Cethegus* in a regrowth area of heath/woodland which suggests that the genus is aerially dispersed (see earlier).

Main (1987) suggested that occurrence of mygalomorphs, which may be very long lived, in precarious fragments of bush such as road verges may not guarantee persistence since individual spiders (perhaps over 20 years old) sometimes outlive the viability of a habitat, while even juvenile dispersion may be abortive. A notable example is that of scattered populations of *Aganippe castellum* Main in the wheatbelt. In many shires, gravel/sand pits have been excavated upslope from the favoured habitat (poorly drained sites or summer-dry 'bogs') thereby altering the surface and subsurface drainage. These trapdoor spiders build extensions from their burrows against the butts of shrubs (Fig. 1) thus avoiding surface flooding. Their fringe of twig lines draped from the burrow rim directs prey past the burrow opening which faces up the butt of the supporting shrub. Although avoiding surface sheet flooding, the spiders are nevertheless dependent on the underlying moisture held by the poorly drained soil. A shift in the drainage due to upslope quarrying at sites in the N. Bungulla Reserve and Heitman's Scrub nearby has caused total mortality of emergent juveniles over the last ten years although several adults in the affected area are persisting.

Fig. 1: *Aganippe castellum* Main, nest against butt of shrub. Door opens away from stem; tube extends about 5.0 cm above ground (see text).

GEOGRAPHIC RELIC SPECIES

The potential for re-establishment in disturbed areas by this second category (ignored in the earlier cited studies) is considered in the following. Conservation of relic spiders must first be viewed in the context of current management practices which are largely determined by procedures acceptable for forest management. This frequently involves fire - both bushfire fighting and induced 'control' burning. The former concerns attempted subjection of accidental fires which usually occur during summer, either lightning induced or due to human activities; the second involves deliberate burning to reduce hazardous fuel (litter and dry vegetation) and usually takes place during autumn or spring. Control burning, because less intense and apparently less destructive to vegetation would appear to be less inimical to the fauna. While this may be true for vertebrate fauna it need not be so for some of the invertebrate fauna. Furthermore, the periodicity of burning, i.e. period of resting or recovery between burns is important for the re-establishment of the fauna.

The forested southwest corner and southern coastal area of the state harbour taxa that are closely related to eastern Australian rainforest forms (Orsolobidae, Archaeidae, Anapidae, Symphytognathoidea and others), particularly of southeast Queensland and Tasmania, as well as New Zealand, Madagascar and Chile. Many genera are clearly Gondwanan relics. Most of these taxa are small, less than 5 mm and are confined to microhabitats in litter, moss, humus, under bark at tree butts and in hollows and overhangs of rotten logs. Although some of these taxa have representatives living in epiphytes or tree moss in rainforests in Queensland, in southwest W.A. they are terrestrial (even the web weavers) a concomitant of summer drought. Life histories have been recorded for only a few species of Tasmanian representatives (Hickman 1939, 1944, 1945). Few eggs are laid and dispersion is restricted. Forster (1975) commented on the general lack of aerial dispersal of New Zealand forest terrestrial spiders.

Few of the southwest Australian relic species have been named and several families have not been formally recorded or have been cited only in ecological papers, e.g.

Archaeidae, Mimetidae and Toxopidae (Main 1987). It is argued here that fire is inimical to many relic species (see Tables 1 and 2).

Table 1 LITTER-DWELLING RELICT SPECIES REPRESENTED IN HEATH/SHRUB HABITATS BURNT 2, 4 AND 17 YEARS* PRIOR TO SAMPLING IN STUDY SITE IN TORNDIRRUP NATIONAL PARK. TOTAL NUMBER OF SPECIMENS SAMPLED IN PITFALL TRAPS OVER 24 WEEKS, JUNE 1ST - NOVEMBER 9TH, 1983. APART FROM SOME OF THE SYMPHYTOGNATHOIDEA SPECIES, ALL ARE NON-WEB WEAVING SPECIES AND THUS ARE PRONE TO PITFALL CAPTURE.

TAXON	YEARS SINCE BURNT TWO	FOUR	SEVENTEEN
Oonopidae			
Gamasomorpha (?) sp.	-	-	2
Archaeidae			
Austrarchaea sp.	-	2	1
Pararchaeidae			
Pararchaea sp.	-	2	-
Toxopidae			
Toxops sp.	-	2	-
Laestrygones sp.	-	2	3
Mimetidae			
Species 1	-	2	3
Species 2	-	1	2
Hadrotarsidae			
Gmogala (?) sp.	1	29	7
Orsolobidae			
Tasmanoonops mainae	22	28	76
Australobus (?)	2	5	2
"Symphytognathoidea" and Micropholcommatidae	3	3	52

* Burnt mid-February (2 year site), late April (4 year site); season not known for 17 year site.

Some such taxa are relics of *Nothofagus* dominated associations, which, unlike eucalypts, are not fire resistant. In southwestern W.A. the tingle forest (*Eucalyptus guilfoylei* Maiden and *E. jacksoni* Maiden) at Nornalup and Walpole simulates the *Nothofagus* forests of eastern Australia and Tasmania. In fact the wet sclerophyll tingle association was probably the successor in southern W.A. of the now extinct *Nothofagus*. As such the tingle forest as an association and its complementary microfauna (arthropods etc.) is unlikely to be fire resistant or fire adapted as are some eucalypt associations, e.g. karri, jarrah and certain mallees. Even though much of the south west sclerophyll vegetation, including jarrah, is fire resistant, at least to the extent that the forest survives in spite of some damage it is believed that "severe fire damage was not experienced by jarrah trees before European settlement" (Abbott and Loneragan 1986, p. 102) and this in spite of the natural incidence of lightning induced fires and burning practices of Aborigines. Gray (1841) cited jarrah forest near the headwaters of the Harvey River as having the ground "so encumbered by the fallen trunks of these forest trees, that it was sometimes difficult to pick a passage between them" thus suggesting absence of fire even though nearby the tableland areas were indeed fired by Aborigines. Furthermore, Hallam (1975, p.26) interpreted early historical records as indicating that the southern jarrah forests were not habitually burnt by Aborigines. If jarrah was not subjected to catastrophic fires then the other eucalypt forests particularly tingle in the southwest were even less likely still to have suffered damaging fires in the pre-European settlement times.

Table 2 POSTULATED SEASONAL VULNERABILITY AND/OR RESISTANCE TO FIRE OF SELECTED RELIC SPIDER TAXA AND A "RECENT" SPECIES. CLEARLY LIFE CYCLE AND BEHAVIOUR OF INDIVIDUAL SPECIES NEED TO BE KNOWN BEFORE AN APPROPRIATE FIRE MANAGEMENT REGIME CAN BE APPLIED. V, MOST VULNERABLE TIME, ACTIVE LIFE HISTORY PHASE; R, RELATIVELY MORE RESISTANT TIME, SPIDERS DORMANT OR IN RETREAT IN DEEP LITTER (OR AS FOR SOCIAL *DIAEA*, ACTUALLY FIRE RESISTANT, SEE TEXT).

Habitat	AUTUMN		WINTER	SPRING	SUMMER		TAXA
	Early	Late			Early	Late	
Foliage	V*/R	R	R	V*/R	V*/R	V*/R	*Diaea* sp.[1]
Bark	R	V	V	V	V	R	*Toxops*
Logs/ Buttresses	V	V	V	V	V	V	Mygalomorphae- *Chenistonia villosa*[2]
	V	V	V	V	V	V	Anapidae (see text)
Litter/ Humus	V	V	V	V	V	V	Orsolobidae[3]
	R?	V	V	V	V	R?	Micropholcommatidae[4] Hahniidae[4] Mimetidae[4] Archaeidae[4] Toxopidae[4]

1 Social *Diaea* sp. with a 2 year life cycle, vulnerable during early stages of colony formation in first year, thereafter fire resistant; the non-social species vulnerable throughout life.

* time of incipient colony formation.

2 Unlike other species of genus which are burrowers, *villosa* makes silk tubes in bark, moss, under logs, etc. thus vulnerable all year.

3 Mature generally early summer to early autumn when move about, probably do not retreat to deep litter.

4 Possibly retreat deep into litter during later summer/early autumn.

Associated with the persistence of tingle are relictual spider taxa which inhabit the litter, leaf mould and humus, logs and tree buttress hollows while in addition some taxa have been found in microhabitats in coastal heaths, particularly where summer fog is prevalent. Most notable are: representatives of the Gondwanan families Archaeidae (Legendre 1970, 1977; Forster and Platnick 1984), Orsolobidae (Forster and Platnick 1985), certain genera of the Anapidae; families characteristic elsewhere in Australia only of eastern Australian rainforests and Tasmania, e.g. Micropholcommatidae, the endemic Australian family Toxopidae (sensu stricta Hickman), the Pangaean family Hahniidae (restricted to moist areas); representatives of families with broader ecological needs, e.g. Hadrotarsidae, and *Dardarus* Davies, the latter recently found at Walpole.

The seasonal resistance to fire of jarrah, and the low vulnerability times of many invertebrates, particularly spiders are completely opposite. Thus, fire management regimes oriented to the advantage of jarrah or indeed any other forest association are deleterious to at least some of the terrestrial spiders. For example, the control burning of jarrah timed to coincide with the period of greatest resistance (spring) (Abbott and Loneragan 1986, p. 111) is effectively the most inimical time for some spiders. The low risk time for such fauna is probably early autumn following the end of summer when they may be still in retreat in the lower litter/humus layers or buried in the soil. If so then even a hot burn at this time is less deleterious than a spring or early summer burn when the fauna is active and likely to be in the top layers of litter or moss. This contention is supported by Majer's records which suggest that spring burns are more detrimental to invertebrates than autumn burns (Majer 1980) and Abbott's demonstration that burning in January did not affect density of most invertebrate taxa (although identified generally only to broad or ordinal level) (Abbott 1984). While various studies propose that low intensity (spring) burns do not affect "frequency of occurrence" of invertebrates, e.g. Abbott et al. (1984), they do not discriminate taxa below the broad level.

Considering the taxonomic affinities of some of the micro-spider fauna of both tingle and south coast heath (Augusta, Nornalup/Walpole, West Cape Howe and Torndirrup, and Two Peoples' Bay) and their Gondwanan counterparts in Chile, Tasmania, New Zealand and Madagascar, it is argued that such fauna pre-dates the occurrence of fire as a natural phenomenon of the Western Australian landscape and that it is now at risk from the prevalence of fire.

A striking example can be drawn from Walpole. The tiny lungless spiders, *Chasmocephalon* (less than 3.0 mm) of the family Anapidae occur here where they make minute horizontal orb webs in eroded buttresses of trees and overhanging sides of old logs or similarly sheltered sites on the forest floor in permanently shadowy, moist situations. The spiders are active during autumn, mature mid-winter and presumably lay eggs in the spring (as related species do in Tasmania). Hickman (1944) noted that *C. minutum* lays only two to four eggs and is confined to damp places of the forest floor. Dispersion is minimal for such spiders which do not appear to retreat to deeper layers of litter; possibly they are dormant during the summer through the egg phase which however is exposed on moss or debris. One site at Walpole has apparently not been burnt for over 30 years. A *Chasmocephalon* species has also been found in a residual microhabitat in a wet gully at Two Peoples' Bay which has been unburnt for about fifty years. If the spiders are to persist they need to be protected from fire in selected, planned refugia. Large scale fires with no allowance for "saviour" patches would destroy such relics.

Results of a six month study in Torndirrup National Park in which arthropods were sampled weekly in pit traps in contiguous sites in coastal heath, burnt two, four and 17 years previously indicate that relic families of spiders (as defined earlier) were more abundantly represented in "older" sites (Table 1). All sites had the advantage of relatively close-by reservoir habitats.

It is also pertinent that in an analysis of spider presence before and after felling, burning and regrowth of planted karri near Pemberton (Curry et al. 1985) the relict families Micropholcommatidae (3 specimens at one site) and *Tasmanoonops australis* Forster and Platnick (Orsolobidae) (1, 2 and 4 specimens in three sites) occurred only in the undisturbed sites.

Analogous to these studies are the results obtained in an Honour's student project (Barendse et al. 1981) in King's Park in which post fire occurrence of spiders in soil, litter and shrub foliage was sampled. Several relict families were represented as follows: Hahniidae, Micropholcommatidae, Mimetidae and Toxopidae (*Laestrygones*) as well as genera, e.g. *Phoroncidia* (Theridiidae) known elsewhere only from W. Cape Howe or wet forest sites as at Jarrahdale. All of these were predominantly confined to deep *Allocasuarina fraseriana* Miq. litter (unburnt for over 20 years) or prostrate shrubs of *Jacksonia sericea* Benth. Such litter retains moisture, while *Jacksonia* shrubs do not burn readily. The Mimetidae are rare in W.A. and confined to caves and humid microhabitats. Elsewhere in W.A., *Laestrygones* has only been collected from Torndirrup (see Table 1) and W. Cape Howe. Various workers have noted the importance of deep litter in maintaining certain sedentary spiders (see Coyle 1981 for references).

Although we are gradually finding more relict species in southwestern W.A., phenology of their vertical movements in the litter in response to environmental changes needs to be studied before their vulnerability to fire at different seasons can be confirmed.

Finally from an understanding of the life styles of not only litter/humus spiders but also bark and foliage dwelling forms, it should be possible to predict low to high risk times of burning for different groups of spiders (Table 2). A special instance of partial resistance to fire, i.e. at certain periods of the life cycle is demonstrated by the social thomisid *Diaea* sp. (see Main 1986 and in press for behaviour and life history). These spiders have a two year life cycle during which colonies begin within a single curled eucalypt leaf nest, and develop through a few leaves to large cartons of web-bound leaves. The colonies are vulnerable to fire during the first summer and autumn (one-to-several-leaves stage of nest) but after about the eighth month (multiple-leaves stage) the nests are fire-resistant due to their compact structure. Indeed it is postulated (Main in press) that the social habit may have evolved partly in response to fire. It must be borne in mind that the evolution of this species is probably relatively recent in contrast to the early Tertiary relics discussed above.

CONCLUSIONS AND RECOMMENDATIONS FOR MANAGEMENT

In conclusion, if we are to actively strive to retain spiders, particularly relic species, as components of the indigenous, indeed in many cases endemic fauna, then an understanding of their present distribution, biogeographic history and their life styles, life history pattern in relation to season, and microhabitat needs can serve as a guide to protective management of the wider habitat to ensure their persistence.

If burning as a management tool has become so fixed in the philosophy of practising conservationists then a modification of a recommendation proposed by the aforementioned Honours project in relation to King's Park could well be heeded for forest and heath of the lower southwest: that small areas (less than 1 ha to several) be burnt at 4 to 10 year intervals along with areas kept unburnt for long periods, in order to maintain both high diversity and enclaves of rare and relict species.

ACKNOWLEDGEMENTS

The data in Table 1 are derived from a collection of spiders made by P.H. Dyer and J. Lyon in Torndirrup National Park with permission from the National Parks Authority, forerunner of the relevant administration within the Department of Conservation and Land Management of Western Australia. Dr G.T. Smith collected the *Chasmocephalon* from Two Peoples' Bay. The Western Australian Museum is acknowledged for assistance to the survey conducted by Dyer and Lyon in Torndirrup National Park.

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SHORT TERM VARIATION IN THE COMPOSITION AND ABUNDANCE OF LARVAL CHIRONOMIDS (DIPTERA: CHIRONOMIDAE) IN A WESTERN AUSTRALIAN WETLAND AND IMPLICATIONS FOR MIDGE CONTROL

S.A. Balla[1], J.A. Davis[1], F. Christidis[1] and G.B. Pearson[2], (1) School of Environmental and Life Sciences, Murdoch University, Murdoch, W.A., 6150 (2) Department of Conservation and Land Management, Woodvale, W.A., 6026

ABSTRACT

Swarms of adult chironomids (midges) from Forrestdale Lake have reached nuisance proportions in the adjacent suburb of Forrestdale. The problem is treated by aerial application of the larvicide Abate to the lake several times during spring and summer. The effectiveness of this control method appears to be declining with the development of resistance to the pesticide. Alternative physical, chemical and biological control methods are available for reducing population numbers. However, the source of increasing chironomid numbers appears to be decreasing water quality as a result of nutrient enrichment. Long term solutions require reduction of nutrient inputs to the lake so that the pest species cannot sustain their large populations.

INTRODUCTION

Forrestdale Lake is a shallow, temporary lake of 244 ha on the Swan Coastal Plain (Fig. 1). It is vested in the Department of Conservation and Land Management as a Nature Reserve for the conservation of flora and fauna. In recent years swarms of adult chironomids have reached nuisance proportions particularly in the adjacent suburb of Forrestdale. Population numbers increase in September and remain high until the lake dries or the temperatures drop in autumn.

Chironomid problems of this nature also occur in the United States, England, France, New Zealand, Africa and Japan. Swarms are common on the Swan Coastal Plain but as yet are not as serious as in Florida where some lakes support over 40,000 larvae per square metre (Patterson 1964). The maximum number of larvae recorded from Forrestdale Lake varied between one and two thousand per square metre. Nevertheless, they are a nuisance and an economic burden for both nearby residents and local councils who are responsible for controlling them.

The adults are attracted by house lights at night. Some species are so small that they pass through mesh screens defacing indoor walls, ceilings and furnishings and cause discomfort. Accumulations of dead midges require frequent removal. The dead adults smell similar to rotting fish and this odour persists for several days even after they have been removed.

An economic impact study by the Sanford Chamber of Commerce, Florida, revealed that midges emerging from Lake Monroe and nearby habitats inflict a loss of $3-4 million annually on the adjacent city of Sanford. One lakefront hotel expends $50,000 each year on property maintenance and control attempts (Patterson 1964).

CONTROL MEASURES

To control the chironomid populations at Forrestdale Lake the Armadale Shire applies the larvicide Abate 5SG (Temephos) by plane. In the spring of 1985 a biological sampling program was undertaken to determine the densities, species composition and distribution of the larval chironomid communities within the lake and to monitor

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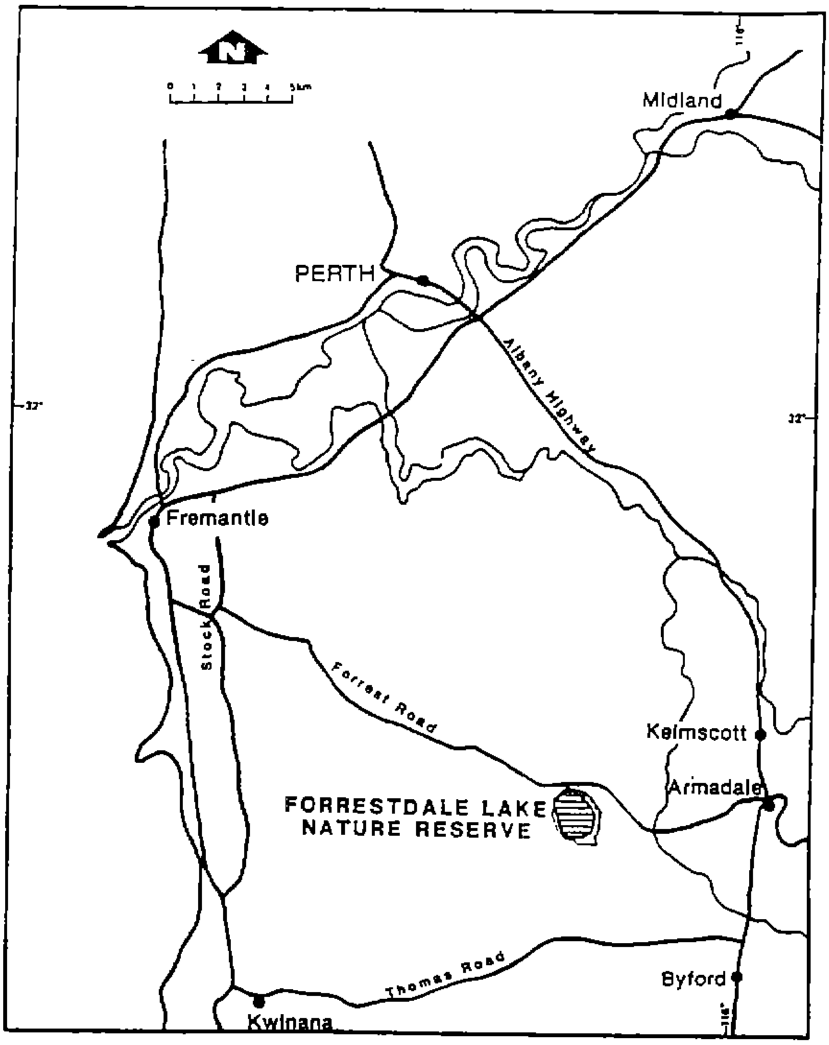
Fig. 1: Location of Forrestdale Lake on the Swan Coastal Plain W.A. Map from Bartle et al. 1986.



the effects of Abate treatments on the communities. Monitoring of chironomid populations continued for a second year from the spring of 1986 to March 1987. The major objective of the study was to provide baseline information which would be of use in formulating a management policy for the control of nuisance midge swarms. This study must be regarded as a preliminary one because nothing at all was known about the chironomid fauna of the lake prior to this work. Since this project was concerned only with monitoring larval numbers (the limited funding available did not permit an experimental approach), there were no controls against which the effects of Abate could be judged. However, the presence of dead and dying larvae in the water after each Abate application were considered to be a result of the spraying treatment. The major objective of the study was to provide baseline information which would be of use in formulating a management policy for the control of nuisance midge swarms. Monitoring of chironomid populations continued for a second year from the spring of 1986 to March 1987.

RESULTS OF SAMPLING PROGRAM

Nine species of chironomid larvae were found in Forrestdale Lake, however, only four species were abundant (Fig. 2). A regular pattern of succession occurred in the lake with *Dicrotendipes conjunctus* most abundant in November-December,

Fig. 2: Mean number of larvae collected per 60 sec. sweep and percent contribution by each species of chironomid in Forrestdale Lake for summer 1985-86. Solid vertical lines represent standard errors and broken vertical lines represent Abate applications.

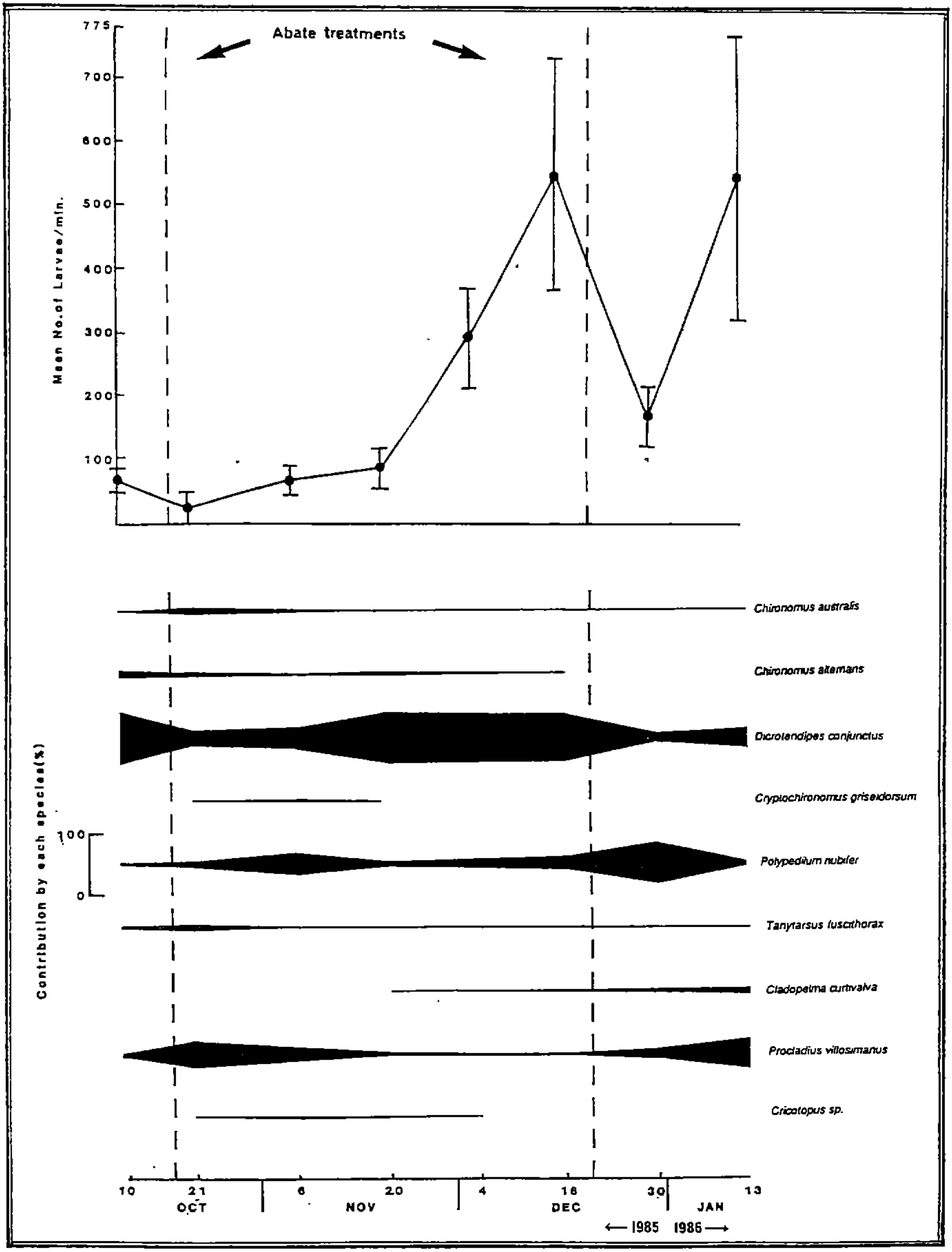
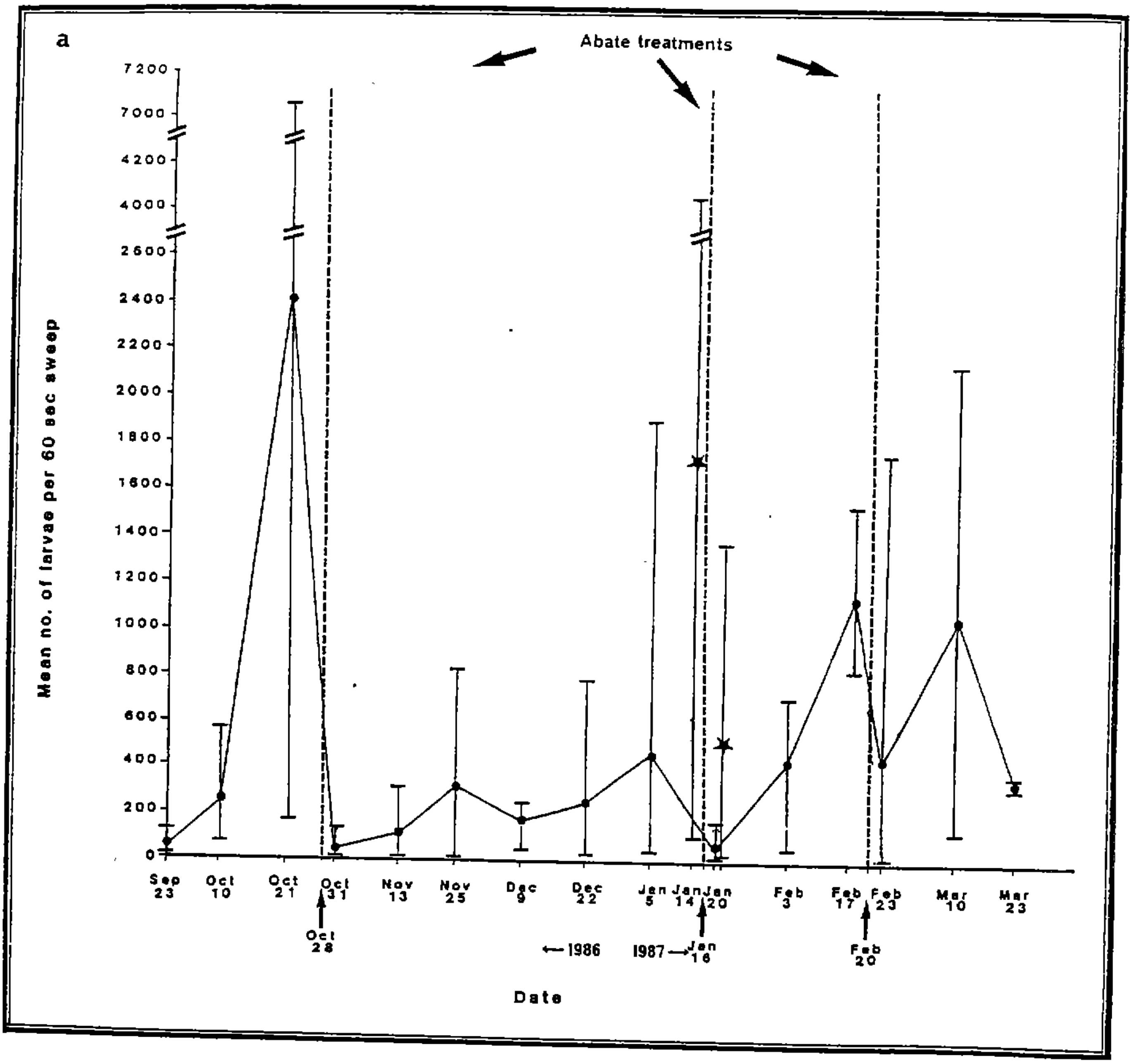
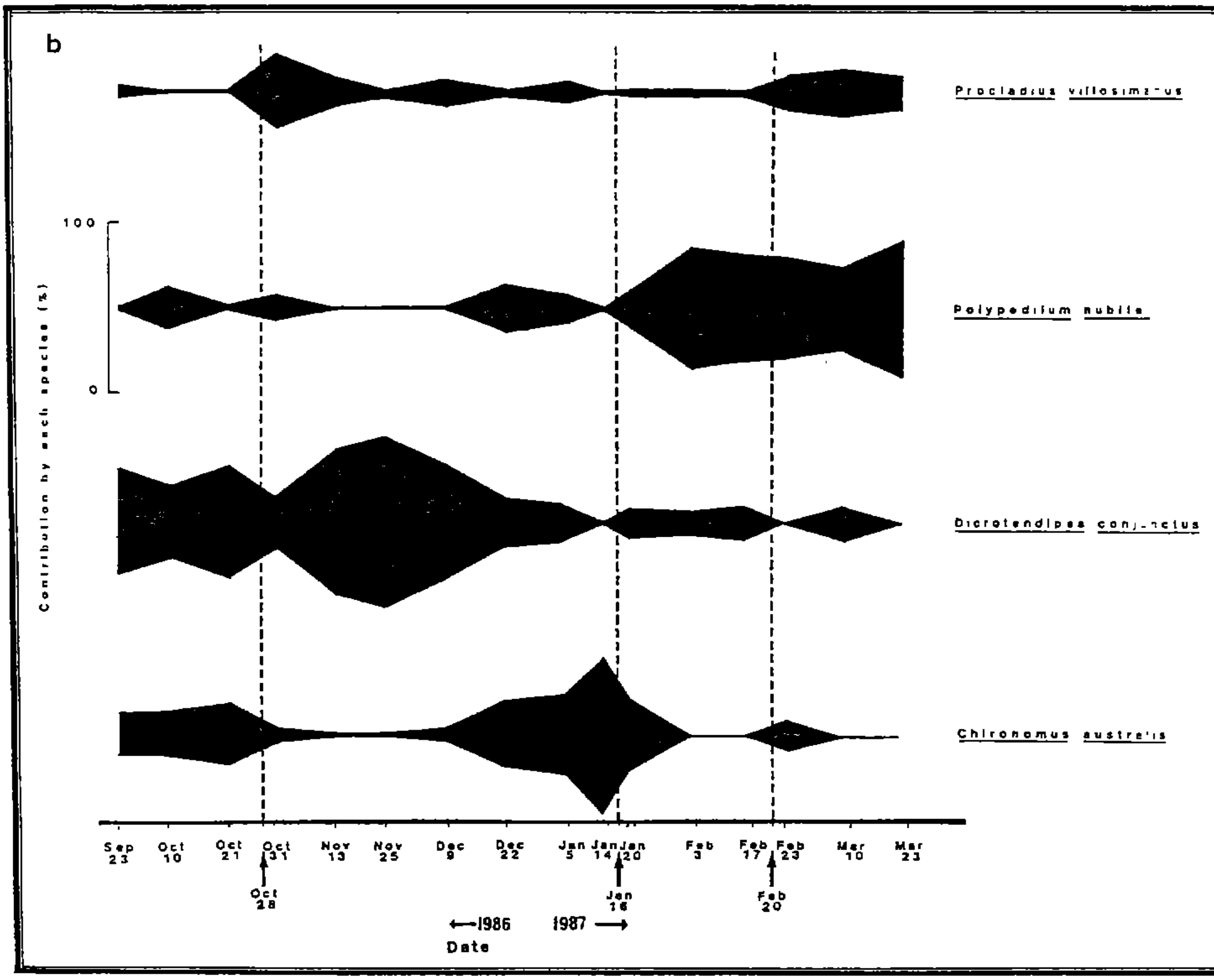


Fig. 3: Mean number of larvae collected per 60 sec. sweep for summer of 1986-87. Solid vertical lines represent the range (maximum and minimum number of larvae per sweep) and broken vertical lines indicate Abate treatment. Samples from *Typha* beds are denoted by *.



Chironomus australis dominant in January and *Polypedilum nubifer* most abundant in February and March. Fig. 2 shows a 60% reduction in the total number of larvae after both the first and second applications of Abate in 1985-86. While *Dicrotendipes conjunctus* numbers decreased in response to Abate, *Polypedilum nubifer* increased in numbers. The results of the second year (1986-87) (Fig. 3) show that while the first and second Abate applications produced a 90% reduction in the number of larvae, the third treatment produced only a 50% reduction. Fig. 4 shows that the first and second treatment successfully reduced larval numbers of *Dicrotendipes conjunctus* and *Chironomus australis* respectively, while the third treatment had little impact on

Fig. 4: Percent contribution by each chironomid species to the total number of larvae at Forrestdale Lake for the summer of 1986-87. Vertical lines indicate Abate treatments.



Polypedilum nubifer which was dominant at the time. Although on every occasion, application of Abate was followed by a reduction in the total number of larvae in the lake, *Polypedilum nubifer* larvae were less affected by Abate than the other species. Field observations revealed the presence of dead and dying larvae in the water after Abate application, but the nature of the sampling technique (a correlative method) meant that we could not discount the fact that the decrease in larval numbers could also be due to the synchronous emergence of a cohort of larvae.

The reaction of individual species to the larvicide Abate is variable. *Procladius villosimanus* is not affected by Abate and has survived 5000 times the recommended application rate in laboratory experiments (Unpublished data, Pearson and Davis 1987). There is also evidence that *Polypedilum nubifer* from Forrestdale Lake has become resistant to Abate in comparison to populations of the same species from lakes that have never been sprayed. Alternatives to Abate are needed. The use of pesticides in general is not a long-term solution to the nuisance swarms of midges because of the development of resistance to pesticides which progressively reduces their effectiveness.

THE IMPACT OF ABATE ON NON-TARGET FAUNA

The chironomid fauna is an important component of both the detrital and grazing food chains within the lake and undoubtedly forms part of the diets of resident waterbirds. The lake is valued as a waterbird habitat, and because of its status as a wetland Nature Reserve the use of pesticides which effectively destroys an important portion of the wetland's food chains each spring and summer must, in principle, be considered undesirable.

There is some evidence that Abate has an impact on the non-target invertebrates in Forrestdale Lake. Abate application causes large fluctuations in several invertebrate groups, but the variation is exceedingly complex. In North America researchers have found that Abate reduces cladoceran, copepod and amphipod populations.

The deaths of waterfowl in February 1984 occurred after the application of Abate granules when the lake depth was below 30 cm. The birds were believed to have consumed the granules exposed on the mud at the edges of the lake (Davis et al. 1987).

ALTERNATIVES TO ABATE

There are chemical, physical and biological alternatives to the use of Abate. Abate is an organophosphate and a common fault with organophosphates is the development of resistance in the pest species. This has been documented in North America. where it was shown that Abate had a shorter useful life than other organophosphates. A more recent alternative developed in North America are the synthetic pyrethroids, which are extremely toxic to midges. They appear to offer potential short-term solutions to the problem at Forrestdale. However, short-term chemical solutions are not satisfactory for a number of reasons, not the least being that they require continuous and large inputs of money to remain effective.

Physical solutions to chironomid problems require a more inventive approach. One current idea for testing in the near future at metropolitan lakes is the use of lights to attract the swarming adults away from adjacent suburbs. The planting of bands of fringing vegetation around the lakes to prevent swarming adults reaching nearby residents appears to be effective. However, residents may complain that they are no longer able to see the lake.

Biological solutions are many. Unfortunately, some are not applicable to this lake or are totally undesirable (e.g. introduction of "mosquitofish" *Gambusia affinis*). The introduction of any species as a biological control agent will require careful and extensive experimental work to ensure that the introduced animal will not be detrimental to non-target animals. The natural predators on chironomids probably suffer from Abate applications since by consuming poisoned larvae they receive concentrated doses of pesticides. The most desirable biological control appears to be BTI, a bacterium which is specifically toxic to mosquito larvae and might also be toxic to chironomids.

The common characteristic that lakes with chironomid problems share is reduced water quality (Ali 1980). Lakes on the Swan Coastal Plain are becoming more nutrient enriched as housing developments continue to be built around metropolitan lakes. The pest species appear to be able to exploit the increased nutrient concentrations in the lakes while the non-pest chironomids do not. A long-term solution to the chironomid problem in lakes such as Forrestdale Lake may be to reduce the nutrient input into the lake and thereby improve the water quality so that the pest species cannot attain their large populations.

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INSECT CONSERVATION RESEARCH BEING UNDERTAKEN BY DEPARTMENT OF CONSERVATION AND LAND MANAGEMENT WESTERN AUSTRALIA

Compiled by I. Abbott, Department of Conservation and Land Management, Como, W.A. 6152

CALM has not yet become fully involved with insect conservation, mainly because there are no known urgent conservation problems with insects, in contrast to the well documented plight of the indigenous plants and vertebrate animals of Western Australia.

CURRENT RESEARCH

There are five projects being investigated by CALM research staff.

I. Abbott - Como Research Centre

The thrust of this research is towards containing the expansion of two forest insect pests (Jarrah Leafminer and Gumleaf Skeletonizer) and thereby limiting the damage to foliage of jarrah, the principal tree species of Southwestern Australia. In the course of sampling these pests, vast numbers of other invertebrates are collected. Three projects are relevant to insect conservation.

1. Effect of fire on leaf-dwelling invertebrates in pole crowns of jarrah (*Eucalyptus marginata*) in the southern jarrah forest.

   Three treatments are involved: prescribed low intensity fire (November 1986); moderate intensity fire (complete crown scorch, scheduled for Autumn 1987 but weather unsuitable; rescheduled for Autumn 1988); and forest unburned since 1975. Sampling (branchlet removal from cherrypicker) is done each January. Commenced: January 1987.

2. Annual cycle of abundance and composition of the invertebrate fauna of pole crowns of jarrah in the southern jarrah forest.

   This involves quarterly sampling (branchlet removal from cherrypicker) since January 1986. From 1988, sampling will be done in January only.

   It is hoped to examine whether infestation of foliage by Gumleaf Skeletonizer and Leafminer caterpillars is detrimental to other groups of invertebrates such as spiders, beetles and bugs, and consequently to bird populations.

3. Comparison of abundance of invertebrates in crowns of jarrah poles and in foliage of jarrah ground coppice in the southern jarrah forest.

   Fifteen locations throughout the southern jarrah forest were sampled (branchlet removal) in September 1985. Only two significant differences were found: ants were more abundant on ground coppice than pole crowns, and Gumleaf Skeletonizer caterpillars were more abundant in pole crowns than on ground coppice.

J.A. Friend - Woodvale Research Centre

Effect of spring and autumn prescribed fire on activity of termites.

This project is part of a research program to enhance the conservation of the Numbat (*Myrmecobius fasciatus*).

Termite activity in the top 3 cm of soil was measured in two experimental plots and one control plot at Dryandra Forest before, immediately after, and at subsequent intervals following autumn (April) and spring (October) burns in wandoo woodland. Termite activity is measured by digging furrows and counting the number of occupied termite galleries during the daily peak period of termite movement.

No significant effects of the fires have been noted after two years of monitoring.

Commenced: April 1985; Completion: October 1990.

G.R. Friend - Woodvale Research Centre

Part of a research project on small terrestrial vertebrates involves the study of short and long term effects of fire on selected invertebrate groups (Coleoptera and ground dwelling spiders) and the effects of fire on the abundance of invertebrates as a food resource for vertebrates.

Three locations are being studied, Tutanning Nature Reserve near Pingelly and Durrokoppin and East Yorkrakine reserves near Kellerberrin (in conjunction with CSIRO Wildlife and Rangelands), and the Perup MPA (in conjunction with CALM Research Staff at Manjimup).

At each location a simple experiment was set up with plots to be burnt and unburnt controls which are monitored between 4 and 6 times a year for 2-3 years pre and post fire followed by less frequent longer term monitoring.

The Perup site was burnt in late February 1987 and was sampled only once immediately pre fire. The Durrokoppin site is planned to be burnt in Autumn 1988 and the East Yorkrakine site in 1990; sampling at both sites has been carried out since July 1986. The Tutanning site is planned to be burnt in 1989 and invertebrate sampling will commence there in late 1987.

Sampling involves pitfall trapping, sweepnetting and beating of the lower vegetation. Soil data, vegetation structure, floristics and climate are recorded at each location.

PAST RESEARCH

Research into the impact of forest management practices such as fire, logging and reforestation with *Pinus radiata* as well as deforestation caused by mining and agriculture begun in the 1950's. Abstracts of relevant papers by I. Abbott, S. Curry, P. McNamara, S Shea and J. Springett, when on the staff of the Forests Department (before its amalgamation with other agencies to form CALM in 1985), will be found in:

Abbott, I., Majer, J.D. and Mazanec, Z. (1986). Annotated bibliography of forest entomology in Western Australia to 1985. CALM Technical Report No. 14 (71 pp.).

Most of this research examined the soil and litter fauna only.

DISCUSSION PAPER ON A CONSERVATION STRATEGY FOR NATIVE NON-MARINE INVERTEBRATES AND NON-VASCULAR PLANTS IN VICTORIA

P.J. Vaughan, Ecological Survey Unit, Museum of Victoria, 71 Victoria Crescent, Abbotsford, VIC., 3067

The above discussion paper is being prepared to provide appropriate guidelines for the Victorian Native Flora and Fauna Guarantee Act 1987 which will be presented to Parliament this spring. It is imperative to collate information on the identity, distribution, ecology and cause of decline of potentially endangered species, communities and habitats, so that priorities for conservation can be recognised and appropriate management implemented.

The major aims of the discussion paper are:

i) to assess the current status of our knowledge regarding the taxonomy and ecology of Victorian invertebrates and non-vascular plants;

ii) to develop a strategy for conservation in the absence of a detailed knowledge of the taxonomy, ecology, biology, distribution and abundance of the above;

iii) to assess priorities for conservation with due consideration to the importance of community and habitat preservation;

iv) to assess the adequacy of current institutional arrangements for invertebrate and non-vascular plant conservation, and to identify areas where research and survey techniques need to be improved;

v) to identify where invertebrate and non-vascular plant conservation can be integrated into efforts to conserve other species;

vi) to identify the benefits that flow from such conservation;

vii) to suggest ways in which public understanding and concern for invertebrates and non-vascular plants might be improved; and

viii) to identify the educational and training needs.

Achievement of the above will require a thorough examination of published material but will also rely heavily on the input from both professional biologists and amateur naturalists.

Majer, J.D. (ed.), *The Role of Invertebrates in Conservation and Biological Survey*. (1987). Western Australian Department of Conservation and Land Management Report.

A POSITION STATEMENT ON INVERTEBRATE CONSERVATION RESEARCH IN VICTORIAN COMMERCIAL FORESTS

F.G. Neumann, Department of Conservation, Forests and Lands, Sherbrooke, VIC., 3789

INTRODUCTION AND OBJECTIVES

Victorian hardwood forests and softwood plantations support large populations of invertebrates. Many thousands of species have been discovered, with up to 10,000 individuals per m^2, have been found in forests. The importance of these species is not well understood: most have not been adequately described taxonomically and knowledge of the effects of management practices (such as clear-felling and regeneration operations) on invertebrate populations is very limited. Research is required on the ecology of invertebrates in commercial forests that are periodically disturbed by man. Because of the long maturation periods of our forests (30-40 years for *Pinus radiata* plantations, and 80-100 years for eucalypt forests), this research needs to be medium to long term, with sampling extending over a minimum of one year prior to a major disturbance, and several years thereafter.

To address this research requirement, long term objectives of the Department's Forest Management and Research Branch include the following:

1. To assess the short term and long term impacts of various forest management practices on the terrestrial invertebrate mesofauna in soil/litter and other strata in indigenous forest and exotic radiata pine plantations; and

2. To prescribe strategies for the amelioration of any adverse effects in these forest types.

COMPONENT PROJECTS

Three major projects are being pursued viz. (1) the effects of clear-felling, artificial regeneration and wildfire on mobile litter-frequenting arthropods in wet sclerophyll *Eucalyptus regnans* forest of the Victorian Central Highlands; (2) the effects of periodic fuel reduction burning on annelid and arthropod populations in dry sclerophyll mixed eucalypt forest (mainly *Eucalyptus obliqua, E. radiata* and *E. rubida*) in west-central Victoria; and (3) the impact on airborne insect populations of *P. radiata* establishment in poor quality indigenous mixed eucalypt forest (*Eucalyptus dives, E. macrorhyncha, E. radiata, E. rubida* and *E. viminalis*) in northeastern Victoria.

METHODS

Project 1 (Clear-felling, artificial regeneration and wildfire effects)

Sampling was done three times each season over three years by means of 20 pitfall traps (standard test tubes 15.5 cm long x 1.8 cm internal diameter in PVC sleeves and 3/4 filled with 70% C_2H_5OH) at each of eight sites covering a range of forest age classes, and also low and high elevations, respectively < 700 m and > 700 m above sea level. Exposure duration was 14 days. The data are being analysed by reference to the standard diversity indices used in ecology (the Shannon-Wiener function, a modified Simpson's index, the Margalef index and Pielou's evenness index).

Majer, J.D. (ed.), *The Role of Invertebrates in Conservation and Biological Survey*. (1987). Western Australian Department of Conservation and Land Management Report.

Project 2 (Fuel reduction burning effects)

A 76 ha area of forest, free of any fire effects since 1935, has been subdivided into five treatment blocks, each c. 15 ha in area, and fairly uniform with respect to litter depth, vegetation cover, topography, aspect and elevation. The treatments prescribed for the blocks being: (1) control (unburnt); (2) burning every 3-4 years in spring; (3) burning every 10 years in spring; (4) burning every 3-4 years in autumn; and (5) burning every 10 years in autumn. Annelid and arthropod populations are being sampled monthly within a 1 ha permanent plot in each treatment block for one year before burning and for up to 12 years thereafter. The techniques being used are: (1) pitfall trapping (20 tubes per 100 m transect per plot, 7 day exposure); (2) extraction over 7 days at 30-40°C with Berlese-Tullgren funnels of 10 composite litter/soil samples (19 x 19 cm down to mineral earth, soil core 20.6 cm diam. and 5.5 cm depth) per 100 m transect per plot; (3) UV-light trapping (12 Volt DC) after nightfall for one hour from centre of each plot; and (4) visual examination in the field for annelids of 20 soil samples (19 x 19 cm in area x 5 cm in depth) along a 100 m transect per plot. The contemporaneous application of these techniques ensures that a wide spectrum of invertebrate types are being trapped.

Project 3 (Pine establishment effects)

Airborne insects were sampled within 2.4 m from the ground by means of Malaise traps (2.4 m high x 2.4 m long x 1.8 m wide) during dry weather between 10 am and 4 pm at a fixed site at least 1 km within the boundaries of four study areas (young, intermediate-age and mature planted *P. radiata*, and mature eucalypt forest). Sampling was conducted up to seven times in all four seasons over the period 1972 to 1977. Thus, sampling was replicated mainly through time only. Standard indices of diversity were calculated.

CURRENT STATUS

Project 1 (Clear-felling, artificial regeneration, and wildfire effects)

Field sampling was terminated in February 1985, exactly three years after commencement. The collections are being processed with emphasis on samples from the high elevation sites, and on the following taxa: Arachnida (Scorpionida, Pseudoscorpionida, Phalangida, Acarina, Araneae), Crustacea (Anaspidacea, Amphipoda, Isopoda, Decapoda), Diplopoda, Chilopoda, Collembola and Insecta (Blattodea, Dermaptera, Orthoptera [Gryllidae and Acrididae], Psocoptera, Hemiptera, Thysanoptera, Neuroptera, Coleoptera, Mecoptera, Diptera, Trichoptera, Lepidoptera and Hymenoptera [Formicidae and wasps]).

Several papers are in preparation. The first describes the response of ant populations (principally of *Prolasius? pallidus* (Formicinae), and *Iridomyrmex foetans* (Dolichoderinae)) to harvesting and regeneration practices; the second examines the broad arthropod spectrum in relation to harvesting, regeneration works and the 1982 wildfire; and the third focuses on the impact of the wildfire on the diverse beetle fauna inhabiting the forest floor.

Project 2 (Fuel reduction burning effects)

Field sampling for annelid and arthropod populations, now in its third year, has progressed according to schedule. The tallying and identification of samples will commence in spring 1987.

Project 3 (Pine establishment effects)

Field sampling was completed in 1977 and about 40,000 specimens have been pinned. The general insect fauna (21 orders), and in particular, the Coleoptera have been analysed. Order Hemiptera (about 1,200 specimens) has been partially analysed to family level. Analyses that remain concern the Diptera (29,500 specimens) and Hymenoptera (3,020). The results so far have refuted claims that pine plantations are biological deserts incapable of supporting any indigenous insect communities. A high level of flight activity was found in mature and young, although not in intermediate-age pine forests, probably because of lower diversity of flowering plants and lower light intensity in such stands. Eucalypt forest, by comparison, supported more stable and diverse populations of Coleoptera than pine plantations, because in pine very high populations of some species occurred more readily than in the eucalypt forest. It appears that any detrimental effects of forest conversion on the insect fauna can be ameliorated by retaining extensive tracts of eucalypt forest near the plantations, and by leaving small patches of native flora throughout plantations.

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A NEW APPROACH TO THE STUDY OF RURAL DIEBACK OF EUCALYPTS: A REPORT ON THE INITIATIVE BY CSIRO DIVISION OF ENTOMOLOGY

R.A. Farrow and P.B. Edwards, CSIRO Division of Entomology, P.O. Box 1700, Canberra City, A.C.T., 2601

INTRODUCTION

Repeated defoliations by herbivorous insects, particularly by pasture breeding Christmas beetles (Scarabaeidae) are reported to be the prime cause of dieback of eucalypts in partially cleared savannah woodlands of south-east Australia (Carter et al. 1981). It has been proposed that outbreaks of such herbivores are caused by the lack of natural enemies in parkland and cleared areas, compared with woodlands, where a more complex plant and insect community is present (Davidson 1982).

The first hypothesis has proved difficult to establish, despite considerable experimentation in the period 1980-86, because of the difficulty of separating the stress induced by insect attack from possible existing stress due to other factors. These include exposure, salting, cultivation, exotic grass competition, application of phosphorus, and general senescence. Curry (1981) suggested that insect feeding was concentrated on trees that were already stressed by other physical factors.

The existing 'parkland' structure of much of our grazing land is clearly not sustainable because of natural senescence, dieback and lack of natural replacement except in the most favourable sites. Nevertheless, the deterioration in the quality of our agricultural land has clearly demonstrated the need for trees to restore agricultural productivity, and active programmes to re-establish native trees are underway in all States. These concentrate on the establishment of specially designed shelter belts and woodlots to provide shelter, combat soil erosion and salting through the control of the water table, in ways compatible with modern agricultural practices.

The success of such programmes has invariably been adversely affected by the susceptibility of newly planted trees to attack by native insect herbivores. At the same time, concern over the possibility that such plantings will eventually succumb to dieback has also affected acceptance of such programmes in the farming community.

With these problems in mind, the CSIRO Division of Entomology in 1983 initiated a programme to study the impact of insects on the establishment of eucalypts in plantations in pastures of the Southern Tablelands. The programme aims to understand the three following processes: 1) immigration and colonisation of experimental trees by herbivorous insects and their natural enemies, including the formation of insect guilds; 2) factors regulating the numbers of herbivorous insects including weather, natural enemies, food quality and movement, and 3) impact of insect feeding on eucalypt growth and survival in terms of biomass removed and compensatory regrowth. These studies will in turn provide answers to the two questions posed earlier on the role of herbivorous insects in dieback and the role of natural enemies in the control of herbivores.

EXPERIMENTAL DESIGN

Large scale field trials were specially designed with the help of Mr R. Morton (CSIRO Mathematics & Statistics), to measure insect/eucalypt interactions at a series of levels:-

Majer, J.D. (ed.), *The Role of Invertebrates in Conservation and Biological Survey.* (1987). Western Australian Department of Conservation and Land Management Report.

1. Intraspecific effects: phenotypic and genotypic differences between individual trees of a given species. **Replications of a single species.**

2. Interspecific effects: differences between species in relation to growth rate, architecture, leaf type, etc. **Replicates of mixed species of contrasting characteristics.**

3. Seasonal effects: differences between years in trees of the same age. **Replicate plantings every two years.**

4. Geographic effects: **trials established in four different regions of the Southern Tablelands.**

All treatments in which eucalypts are naturally exposed to insect attack are compared against eucalypts free of insects through insecticide treatment.

Weather is monitored at all four sites to assess its impact on development and survival of both insects and eucalypts.

APPLICATION TO PRIMARY INDUSTRY

The project aims at:

1. Identifying the criteria that should be used in the selection of eucalypt species for establishing shelter belts and woodlots with reference to resistance or tolerance to insect attack and other stress inducing factors. Although primarily applicable to the harsh Southern Tablelands habitat of south eastern Australia, the principles should have wide application to many agricultural areas of temperate Australia.

2. Producing appropriate designs of shelterbelts and woodlots in terms of species composition and location to minimise insect attack.

3. Identifying key pests and providing information on the most appropriate way of managing such pests.

ESTABLISHMENT OF THE TRIAL

A preliminary planting in 1984 indicated that several of the chosen species were unsuitable due to susceptibility to severe cold. Species with a greater tolerance to cold replaced these in the main plantings in 1985 and 1987 Final plantings will occur in 1989 and 1991 by which time the oldest trees will be six years old and vary between two and ten metres in height

COLONISATION

There are five main patterns of colonisation:-

1. By immature stages which are carried on the wind, e.g. spiderlings, some lepidopterous larvae, mites and some Homoptera in which the females are sessile, e.g. *Eriococcus*.

2. By weak flying adults, which are mostly carried by the wind, e.g. parasitic micro-Hymenoptera, Psyllidae.

3. By actively flying adults which arrive, feed, depart, and oviposit elsewhere, e.g. Scarabaeidae.

4. By actively flying adults which arrive, oviposit and leave or die, leaving immature stages to develop on the host. The adult progeny of these larvae may depart or recolonise the same hosts, e.g. Lepidoptera.

5. By actively flying adults, which arrive and feed, oviposit and overlap with immature stages, e.g. Chrysomelidae, Eurymelidae.

The main colonisation patterns between 1984 and 1987 were as follows:

FIRST YEAR	Summer	- spiders, psyllids
	Winter	- autumn gum moths (*Moesampela*)
SECOND YEAR	Summer	- eurymelids, ants
	Winter	- sawfly
THIRD YEAR	Summer	- leaf beetles, weevils, scarab beetles, eriococcids, moth caterpillars, parasitic wasps.

Among the factors influencing colonisation were 1) tree height (the most important variable influencing distribution of egg clusters of autumn gum moth); 2) architecture, e.g. rolled juvenile leaves of forest eucalypts attracting psyllids; 3) leaf type, e.g. leaf tiers showing a preference for flexible leaf types; 4) stress, the attraction of some ovipositing moths to trees which had grown poorly and appeared to be stressed; 5) aggregation responses in Christimas beetles and chrysomelids; 6) edge effects, influenced distribution of Christmas beetles over the plots.

The immigration of potential colonisers is being monitored by a wind-sock trap, using a new design developed by the authors. This intercepts a range of small flying insects and drifters so that the numbers of potential colonisers can be compared with the actual colonisers.

POPULATION REGULATION

Juvenile mortality from hymenopterous and dipterous parasites and from predation by spiders, was high in all primary herbivores. Egg parasites were particularly important in the multivoltine Chrysomelidae where percentage parasitism increased from 0 to 100% during the course of a season. Many of the tachinid parasites did not kill their hosts until after a considerable amount of larval feeding had occurred. Spiders were observed to consume many first instar larvae as they hatched from egg masses. Early frosts also killed certain herbivores such as cup moth larvae (*Doratifera*). An example of contrasting strategies was presented by two species of autumn gum moth. One species lays large egg batches (> 100), larval survival is low (< 1%) and during the day it rests in shelters of tied leaves. The other lays small batches of eggs (< 10), larval survival is high (> 10%), and during the day larvae are exposed on the leaves. The former species is common while the latter is rare, suggesting that the first species is more productive on trees surrounding the plots.

HERBIVORY

A wide range of insect feeding patterns is observed, the effects of which are often difficult to quantify in terms of overall impact on tree growth. The following categories have been distinguished. **Chewers** - the classical method of assessing the effect of this activity is to measure the area of leaf removed but difficulties arise when a) leaf growth occurs after feeding, b) entire leaves are consumed, and c) dehiscence of partially eaten leaves occurs. **Skeletonisers** - often early instars of chewers which only remove part of the leaf surface. **Miners** and **Tipfeeders** - it is difficult to measure consumption of terminal buds and shoots and the response by the tree to this type of damage. **Leaf-tiers** - problems associated with the measurement of the reduction of photosynthetic area as a result of tying has not yet been resolved. **Sap-feeders** - it is difficult to quantify the effects of sap removal on tree growth. **Stemborers** and **Girdlers** - can result in death of branches. Some of these problems are being overcome by destructively sampling trees to determine annual growth increments of infested and control trees; undertaking regular damage assessments after periods of feeding but before tree regrowth; assessing the impact of artificial defoliation on tree growth. Crown density of selected mature trees in the vicintiy of the experimental plots is being measured photographically, to correlate defoliation in mature trees with that observed in the experimental trees, and to relate this to seasonal changes in insect numbers in the plots.

CONCLUDING REMARKS

The experimental plots are rapidly acquiring a natural insect community which is superficially similar to the communities observed in natural regrowth nearby. Numbers of herbivores are highly regulated by natural enemies even in the absence of ground and shrub cover. Some trees are showing poor growth and these are less able to recover from insect damage when attacked. Major damage on healthy trees is rapidly compensated for by regrowth.

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INVERTEBRATE CONSERVATION IN THE ANTARCTIC AND SUBANTARCTIC

Penelope Greenslade, C/- CSIRO Division of Entomology, Canberra City, A.C.T., 2601

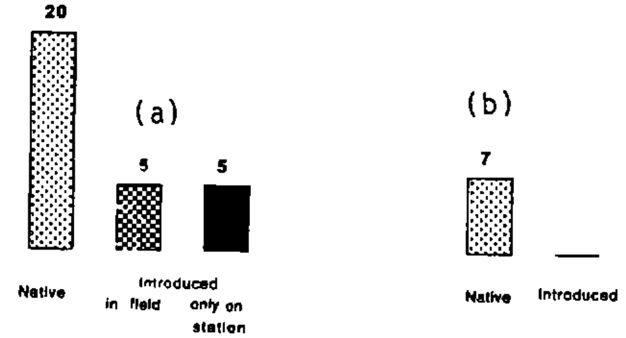
In the southern polar region, the climate is severe, invertebrate diversity is low and native communities are susceptible to invasion by exotic species (Block 1985). The greatest threat to the integrity of these communities is the accidental introduction of exotic species. This is inherently different from mainland Australia where habitat destruction is the major threat to the native fauna.

Until now there had been few records of exotic invertebrates becoming established on Australian antarctic stations (Rounsevell 1978), and only one record far from a station (Greenslade and Wise 1984). It was believed that breeding populations could not persist as the climate was too severe for the survival of species that were accidentally introduced by man. Now there are signs of a possible global warming of climate (Adamson, Selkirk and Whetton in press); because of this and of increased movements of scientific personnel, equipment and stores in the Antarctic, there is an increased risk of exotic invertebrates being both introduced and becoming established.

In the summer of 1986-7, exotic species were found in the buildings of two Australian stations, Davis and Macquarie, which has focussed attention on this problem. At Davis, two cosmopolitan species were breeding in the hydroponics room and in the soil of potplants. They were the onion thrip, *Thrips tabaci* Lindeman, and a collembolon, *Lepidocyrtus pallidus* Reuter. Both species are known to occur in greenhouses in warmer climates but the thrip has been recorded from alpine New Zealand (Mound and Walker 1984) and from other cool climates, and it may have a cold tolerant egg stage (Lewis 1973). The coastal habitats of the Vestfold Hills near Davis station are young (9,000 years) (Adamson and Pickard 1986) and depauperate as far as invertebrates are concerned (Rounsevell and Horne 1986), so that any species tolerant of cold conditions, such as this thrip, might be able to establish populations there.

On Macquarie Island, in addition to the 25 species found in the field, five exotic species, *Sminthurinus quadrimaculatus* Ryder, *Sminthurides* sp., *Tullbergia krausbaueri* Borner group, *Onychiurus* sp. and ?*Proisotoma* sp. occurred in the greenhouse in breeding populations, but were not found away from the station (Fig. 1). They had survived several months during 1986 in the building when it was neglected, and established fairly large populations within a month of horticultural activities recommencing. These species were certainly introduced to Macquarie by human activities and with the development of a marginally warmer climate could probably establish populations away from the station.

Fig. 1. Numbers of collembolon species at (a) Macquarie Island and (b) Heard Island, grouped according to origin.



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Macquarie Island has had a permanent base since 1948, and of the 25 collembolon species found in the field, five are almost certainly recent introductions, i.e. they arrived after man first discovered the island about 160 years ago. There is some evidence that two of these at least (*Hypogastrura (Ceratophysella) denticulata*) (Bagnall) and *Lepidocyrtus* sp. cf. *violaceus* (Geoffroy) are definitely associated with man and have spread over the island only in the last 25 years (Greenslade and Wise 1986). In contrast, Heard Island, another Australian subantarctic island but with less ice free area than Macquarie, has a small fauna of seven Collembola all of which are native (Greenslade 1986) and there are no records of other exotic species, either plant or animal (Fig. 1) (Brown 1964). There was a permanent base on Heard Island for a short period of seven years from 1947-1955 and there have been only irregular short visits since then. Heard Island certainly needs to be protected carefully from transport to it by man of species present in Australia or other parts of the Antarctic or Subantarctic (H.R. Burton and D.L. Williams unpublished report on the ANARE expedition to Heard Island 1985).

In view of this it is clear that efforts should be made in the region to conserve invertebrate fauna by eliminating exotic species and by taking preventive measures to stop further introductions. Quarantine should be adopted and fumigation carried out on all materials entering. Station and ship rubbish should be returned to Australia for disposal. New developments need to be carefully controlled and monitored.

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