ACT PARKS and CONSERVATION SERVICE

INVERTEBRATES OF LOWLAND NATIVE GRASSLANDS IN THE AUSTRALIAN CAPITAL TERRITORY:

CONSERVATION AND RESEARCH STRATEGIES FOR A RECOVERY PLAN

D. A. DRISCOLL

TECHNICAL REPORT 9

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ISSN 1320-1069

ISBN 1 86331 277 3

ACT GOVERNMENT

Department of the Environment, Land and Planning
ACT Parks and Conservation Service
P.O. Box 1119 Tuggeranong ACT 2901

Printed on recycled paper

ACKNOWLEDGEMENTS

This report was prepared in 1991 with funding received from the Australian Nature Conservation Agency, Endangered Species Program as part of the Recovery Plan for lowland native grasslands in the ACT. It has been reproduced with the permission of the Australian Nature Conservation Agency. The views expressed in this document are not necessarily those of the Australian Nature Conservation Agency.

The advice and information provided by the following people is gratefully acknowledged: Dr Andrew Calder, CSIRO; Dr John Dearn, University of Canberra; Mr Ted Edwards, CSIRO; Ms Penelope Greenslade, CSIRO; Dr Ken Key, CSIRO; Mr Kruno Kukolic, ACT Parks and Cons. Service; Dr John Lawrence, CSIRO; Dr Chris Margules, CSIRO; Dr Tim New, La Trobe University: Mr Peter Ormay, ACT Parks and Cons. Service; Dr Will Osborne, ACT Parks and Cons. Service; Dr Chris Reid, ANU; Dr David Rentz, CSIRO; Dr Reg Roberts, consultant; Dr David Rowell, ANU; Dr David Shaw, ANU; Dr Mick Tanton, ANU; Dr Bob Taylor, consultant; Mr Macomus Taylor, COG; Dr Elwood Zimmerman, CSIRO. Ms Sarah Sharp provided information on the vegetation of grasslands in the ACT. Dr Will Osborne, Ms Sarah Sharp and Dr Keith Williams commented on earlier drafts.

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ABSTRACT

This report formulates conservation and research strategies to conserve native invertebrates of lowland native grasslands in the ACT and region. It reviews seven criteria commonly used in conservation evaluation: naturalness, representativeness, area, diversity, rarity, landscape criteria and threat of interference and discusses their practical application to invertebrates of grasslands in the ACT. Conservation and research strategies are then synthesised based on conclusions drawn from the review.

An assessment of representativeness should be the first stage in conservation evaluation. This would involve the identification and mapping of all native invertebrate habitats. If all sites cannot be reserved, selection of priority areas may be required, which can be done initially by assessing the naturalness of each site and by using area, presence of rare species, bioindicators, landscape criteria such as connectivity, and threat of interference, as selection criteria. Research on native invertebrates to refine and expand the applicability of these criteria needs to be carried out, particularly in relation to bioindicators. This research should concentrate on beetles, ants and grasshoppers, responses of invertebrates to disturbance, dispersal abilities, connectivity requirements, minimum useful area, coevolution between plants and invertebrates, and the relationship between gene flow, genetic variability and the long term persistence of populations. A general survey of invertebrates would aid in much of this research. It would also enable other species at risk of extinction to be identified and a field guide to common invertebrates of native grasslands could be produced, enhancing the community's knowledge and appreciation of invertebrates in grasslands. Following the general survey, long-term monitoring of invertebrate populations should be undertaken, focussing particularly on groups chosen as bioindicators. This would provide 1) a way of gauging the success of the reserve system, 2) a means of identifying species at risk of extinction, and 3) an understanding of the population biology of many species, thus enabling reserve systems to be improved in the future.

1. INTRODUCTION

There is inadequate information available regarding the invertebrates of grasslands in the Australian Capital Territory (ACT) and region to be of use in conservation planning. This is typical of the state of knowledge of invertebrates throughout Australia. Greenslade and New (1991) estimated that in Australia, there are probably more than 125,000 species of insects and probably twice that number of invertebrates altogether. It is likely that more than half of these are undescribed and "for the great majority of Australian insect species, detailed distributional and general biological information is virtually non existent" (Greenslade and New 1991).

In Australia, native grasslands are the most poorly represented community in reserves (Hill and Michaelis 1988) and in temperate areas only exist as isolated patches (Groves 1979). Hogg (1990) pointed out that the low altitude grasslands in the ACT are the communities most at risk of destruction and therefore the organisms which rely on them for habitat are at risk of extinction. Active conservation measures are required to avoid such extinctions. Given the lack of knowledge of invertebrates that may depend on grasslands, this will have to be done without knowing what occurs in grasslands nor what their precise requirements are. Which places are the most valuable in maintaining populations of grassland invertebrate species? What criteria can be used to select areas for a conservation reserve system?

This review aims to discuss the criteria which may be useful in answering such questions by considering the advantages and limitations of criteria commonly used in conservation evaluation with particular reference to studies of invertebrates.

Margules (1986) suggested that six criteria account for most of the variation in conservation value: representativeness, diversity, rarity, naturalness, area and threat of interference, although he suggested there may often be a need to substitute or add criteria. The relative merits and disadvantages of each in relation to invertebrates of grasslands in the ACT is discussed. This is followed by a consideration of how those criteria can be used in constructing a research strategy to conserve invertebrates native to grasslands in the ACT. The recovery plans for three invertebrate species that are thought to have restricted distributions and deserve research attention are appended.

2. ASSESSING NATURALNESS

Naturalness is frequently used as a criterion in evaluating potential reserves. Usher (1986) noted that naturalness is generally defined as an absence of human interference, with the exception of the influence of human populations that are totally dependent on and limited by their environment. He suggested that in Australia, naturalness can be regarded as the state of the biota at the time of European settlement.

It is not known what constitutes a natural invertebrate community for grasslands. In the absence of research into the invertebrate fauna of a suitable reference area, against which the invertebrate faunas of potential reserves can be compared, the potential for assessing the naturalness of invertebrate communities is limited. Nevertheless, there are other ways of assessing naturalness. In Australia, most land management practices used since European settlement must be regarded as unnatural. By referring to published results of the impacts on invertebrates of practices such as burning, grazing, fertilising and pasture improvement, some assessment can be made of the degree to which this is likely to degrade the native invertebrate fauna. Using all available means, such as the current state of the site, recorded history and bioindicators, aspects of the management of sites could be determined.

This section discusses the potential for bioindicators to be used in assessing the naturalness of invertebrate faunas of grasslands, and reviews some of the impacts that management practices can have on invertebrates.

2.1 Bioindicators

There are two approaches to the use of indicator groups or species in assessing the conservation status of biotic communities. One is in an assessment of naturalness, the other is in the assessment of diversity. The use of bioindicators to assess naturalness is discussed here.

If members of a taxonomic group are known to respond in particular ways to environmental changes, their presence or absence can be used to indicate if the environment of the organism has been altered. For example, in Britain, species of carabid beetles are known to prefer particular vegetation types, particular water regimes and particular altitudes, and so may be useful bioindicators (Dufrene *et al.* 1990; Maelfait *et al.* 1990; Eyre and Luff 1990). Yeatman and Greenslade (1980) have suggested that ants may be useful in defining habitats because they respond to variations in soil, aspect and shade. Earthworms may be useful indicators of certain agricultural practices (Daugbjerg *et al.*1988).

There are many ideas regarding the desirable characters of a bioindicator and some of these are summarised in Table 1. It appears that the most desirable indicator group will have known responses to environmental variables and be abundant, diverse, identifiable and easy to sample.

There are a number of problems and limitations associated with the use of indicator species. Key (1978) cautioned that invertebrate surveys need to consider seasonal and annual population fluctuations; variation in abundance may simply reflect short term weather fluctuations or other environmental cycles and so may indicate nothing about the conservation value of a particular site. Majer (1987) noted this problem and added that we don't know if it is valid to apply the habits of one species to others. Information about one invertebrate species may not be able to be extrapolated to others, even if they are closely related (Yen *et al.* 1990).

Table 1. Features that have been considered desirable in bioindicators.

Desirable feature	Authors*
Responsive to environmental variables	1;4;5;6;7;8;9;10
Abundant	1;2;5;8;9
Diverse	1;2;4;5;10
Identifiable	1;3;4;8
Easy to sample	1;3;4;8
Widely distributed taxonomic group	4;8;9
Occupy high trophic levels	1;3
Wide range of trophic levels	5;2
Important in ecosystem functioning	3;4
Changes may be assessable by remote sensing	8;9
Indicator not target species in cases of chemical control	8;9
Many specialists	1
Present all the time	2
Concentrated near soil surface	4
Substantial but not excessive diversity	4
Rare species	2
Large invertebrates of restricted distribution	2

*1. Majer 1983; 2. Majer 1987; 3. Margules 1985; 4. Greenslade and Greenslade 1984; 5. Andersen 1987; 6. Erhardt and Thomas 1991; 7. Eyre and Luff 1980; 8. New 1984; 9. Jenkins 1971; 10. Keals and Majer 1991

The problem of population fluctuations can be overcome by identifying changes in abundance as cycles rather than assuming they reflect a major change in habitat quality. This could be achieved by surveying several times throughout the year, over a number of years and sampling replicate sites. The second problem relating to the validity of applying the habits of one species to others may always be true, however bioindicators may provide an idea of the range of habits to expect amongst invertebrates, thus providing a useful guide to management. Bioindicators may never be able to provide immutable rules applicable to all species.

Drawing correlations between potential indicators and their environment has major limitations. To date, most claims that particular taxa can be used as bioindicators have been based on measured correlations between abundance and environmental parameters such as vegetation types. In many cases it could be easier to measure the environmental features directly rather than infer them after sampling invertebrates. Useful indicators will be those that reflect aspects of a habitat patch which can not be assessed easily. For example, historical events such as a chronic period of grazing by livestock may have irreversibly altered the invertebrate fauna of a site but the disturbance may not be readily detectable by, for instance, surveying the vegetation or analysing soil properties. However, a species known to be susceptible to heavy grazing and expected to occur in a particular habitat could be used to indicate the disturbance history of the site.

2.2 Effects of Management

People exert a variety of unnatural influences on native grasslands in Australia. This section reviews the effects of grazing by livestock, pasture improvement, fertilizers and other chemicals, and fire on the invertebrate fauna of grasslands.

Grazing

Grazing of livestock alters the species composition and abundance, and may reduce the diversity, of invertebrates in grasslands. Grazing influences invertebrates by a number of mechanisms. Hutchinson and King (1980a), in describing invertebrates of improved pastures on the New England Tablelands, N.S.W., suggested that the invertebrate community is likely to be influenced by the change in microclimate associated with grazing. They found that as the stocking rate of sheep was increased, the amount of above and below ground vegetation and soil porosity decreased, while the maximum soil temperature increased. King and Hutchinson (1983) found the abundance of arthropods, nematodes and enchytraids decreased as grazing intensity increased. They suggested that the change was due to a reduction of living space associated with loss of up to 64 per cent of the litter and changes in soil microclimate, with higher rates of evaporation and greater temperature fluctuations at high stocking levels. Duffey *et al.* (1974) also suggested that the diversity of habitats available to invertebrates was reduced by the compaction of soil resulting from trampling by livestock. Hutchinson and King (1980b) found that the abundance of ants increased with an increase in sheep grazing levels, possibly due to increasing openness of the pasture. Scarab larvae and large oligochaetes peaked in abundance at intermediate grazing levels, associated with a peak in pasture productivity. All other groups decreased as stocking levels increased (Coleoptera adults and larvae excluding scarabs, Hymenoptera excluding ants, Lepidoptera adults and larvae, Orthoptera, Diptera adults and larvae, Hemiptera, Diplopoda, Dermaptera, Aranea, Chilopoda).

Trampling by livestock adversely influences trap door spiders by destroying the structure of the litter layer and increasing erosion (Marks 1969; Main 1991). Maelfait and DeKeer (1990) found that the spider fauna of grazed pastures had a higher proportion of opportunistic species compared to ungrazed areas adjacent to pastures and suggested that "species composition of the pasture is an impoverished version of the border zone".

Although grazing at a moderate level was considered important to the survival of the Checkerspot Butterfly, *Euphydryas editha*, because it maintains the required successional stage (Murphy and Weiss 1988), grazing during drought periods was detrimental to the survival of the butterfly because cattle destroyed its food plants (Ehrlich *et al.* 1980). Thomas (1983) drew similar conclusions in regard to the butterfly *Lysandra bellargus*, with some grazing necessary to maintain a suitable habitat, but overgrazing was a threat to the survival of populations. Grazing of chalk grassland in Britain is essential to prevent woody species from becoming established (Morris 1969). To prevent a reduction of invertebrate diversity, however, it is necessary to graze on a rotational basis. This ensures the variety of habitats required by different taxa are maintained (Morris 1969; Rushton 1988).

New (1984) suggested that mowing may be a better way to manage chalk grasslands to provide short swards for thermophilous insects because it can be done at the best time and to an optimum height. Morris and Rispin (1987) demonstrated that different assemblages of Coleopterans were found on chalk grassland patches mowed at different frequencies. Rotational mowing may therefore maintain a greater proportion of the native species in a grassland, without some of the detrimental effects of grazing. In addition, mowing frequency can readily be reduced during drought periods to prevent land degradation and reduce competion for food amongst herbivores whereas livestock cannot be relocated easily.

Pasture improvement

Many pastures have been sown with exotic plants to increase productivity. These practices alter the composition and diversity of the invertebrate fauna. On the New England Tablelands, Collembola were three times as abundant on improved pastures than on native pastures (King 1991). The composition of the microarthropod fauna (Collembola and Acari) differed between the native and improved pastures with the improved pastures dominated by introduced Collembola (King 1991; King *et al.* 1985). Rushton *et al.* (1989) found that the diversity of spiders and ground beetles was reduced when Northumberland pastures were improved to increase livestock production. Greenslade (1982) considered that the same reaction occurred for ants: "In Australia, the replacement of native vegetation with exotic pasture species generally results in a decline in ant diversity". Earthworms are also affected by the change in vegetation associated with artificially increased pasture productivity. Lee (1985) noted that as the proportion of native vegetation decreased, the number of exotic lumbricid earthworms in the soil increased. Improved pastures are of little conservation value.

Fertilizers and other chemicals

Pastures are often fertilized to improve or maintain productivity which can influence the arthropod fauna. For instance, in two studies, the proportion of introduced Collembola was higher on fertilized pastures (Greenslade and Mott 1982; King *et al.* 1985). Earthworms show varying responses to fertilizer application. Lee (1985) suggested Lumbricids (exotic in Australia) are particularly likely to increase in abundance. Titlyanova *et al.* (1990) reported changes to many taxonomic groups following the application of fertilizers to a grassland, with changes in the biomass of Oligochaeta, Diptera, Hemiptera, Hymenoptera and Coleoptera. They concluded that fertilizers decrease species diversity, simplify the trophic structure of animal populations, increase the rate of organic matter decomposition and decrease the regulatory functions of heterotrophs.

Biocides can also alter the composition of the invertebrate fauna, as shown for mites and Collembola by Malinda *et al.* (1982) and for earthworms by Lee (1985). In addition, pollution from motor vehicles may influence the arthropod fauna (Przybylki 1979). Although Muskett and Jones (1980) did not find any effect of lead, cadmium or nickel from motor vehicles on the invertebrate macrofauna, they analysed the responses of groups of species and admitted that they could not rule out the possibility of effects on individual species.

Fire

Fire is generally regarded as an integral part of many Australian plant communities, and is frequently used as a management tool, yet its impact on invertebrates is not fully understood.

In a review of the responses of grassland arthropods to burning, Warren *et al.* (1987) concluded that many factors influenced the impact of fire. These included the patchiness of the burn, the timing of the burn relative to the phenological stage of individual arthropod species, and post-burn weather. Springett (1976) claimed that prescribed fuel reduction burns in forests in Western Australia were too frequent (4–5 years) to allow full recovery of the invertebrate fauna. However, Campbell and Tanton (1981) refuted this claim, stating that Springett's (1976) work "should be considered cursory and superficial". Majer (1980) reported that most invertebrates recovered after 4–8 months of a forest burn in Western Australia. In tall grass prairies, annual and biennial fires may have reduced grasshopper species richness indirectly by reducing forb diversity, however, areas that were burnt every four years had grasshopper assemblages that were not very different from unburnt areas (Evans 1988). Campbell and Tanton's (1981) results from a study of invertebrates in forest, indicated that there is substantial spatial and temporal variation both in invertebrate communities and in litter (fuel) distribution. They found that the invertebrate fauna in burnt areas rapidy recovered to within the range of variation found amongst invertebrates in the unburnt areas. They emphasised the difficulties inherent in studies of the impact of fires on invertebrates and concluded that the effects of fire cannot be predicted. The impact of fire on grassland invertebrates in the ACT is yet to be investigated.

Ability to recover

Usher (1986) pointed out that most criteria used in conservation evaluation are based on "snapshots" of the potential reserves, and no allowance is made for dynamics. In assessing naturalness, it may be pertinent to ask: Will this site, given time, revert to a near natural state? Titlyanova *et al.* (1990) suggested that grassland ecosystems are intrinsically stable and that they can "recover rapidly if the basic structure of the ecosystem has not been destroyed. Compared with other ecosystems they can sustain heavy impact". However, these comments were made in regard to vegetation recovery.

Very little work has been done on the recovery of invertebrates following unnatural disturbance. Roberts *et al.* (1982a) found, in *Lolium/Trifolium* pastures in Western Victoria, that the Oecophorid moth *Philobata* sp. increased in abundance with increasing time since the application of superphosphate. Roberts *et al.* (1982b) reported that the number of scarab larvae in improved pastures recovered from the effects of drought in two to four generations (4–8 years). The ability of populations of invertebrate species to recover from disturbance needs to be investigated before the dynamics of a patch of habitat can be properly considered in an assessment of naturalness.

Summary of management impacts

Livestock grazing can reduce the number of places available for invertebrates to live, and livestock can outcompete invertebrates for food. All grasslands need to be managed, such as by grazing or mowing (Sharp 1994). To best conserve invertebrates it is better to maintain grasslands by mowing rather than by grazing. Invertebrate faunas on improved pastures and fertilized land have high proportions of introduced species, and reduced species richness. Biocides and pollutants can also unnaturally alter the species composition of the invertebrate fauna. These changes all reduce the naturalness of the invertebrate fauna, and therefore an assessment of how frequently or severely grassland sites have been influenced by these practices will be useful in assessing the naturalness of the site.

The effects of fire on the invertebrate fauna are unclear. Sharp (1994) concluded that burning may have been an important process in the maintenance of grasslands, but that fires were probably patchy in nature. It is therefore reasonable to predict that invertebrates will exhibit a range of responses to fire, from those that depend on fires for survival to those that are fire tolerant. Research into the responses of invertebrates in grasslands to fire needs to be carried out to investigate this prediction, as it has important implications for management.

3. ASSESSING REPRESENTATIVENESS

"The criteria of diversity and rarity are seen to be important where the biota are well known, representativeness is seen to be important in areas such as Australia, where many of the species may well be undescribed" (Austin and Margules 1986). Austin and Margules (1984; 1986) suggested that to assess representativeness there are four requirements:

1. A hierarchical system of ecological units;
2. A definition of the relevant properties of such units;
3. A method of allocating potential reserves to such units; and
4. A means of evaluating the representativeness of potential reserves.

As a hypothetical example, if we wished to conserve forests, we would need to classify them into a hierarchy (Figure 1).

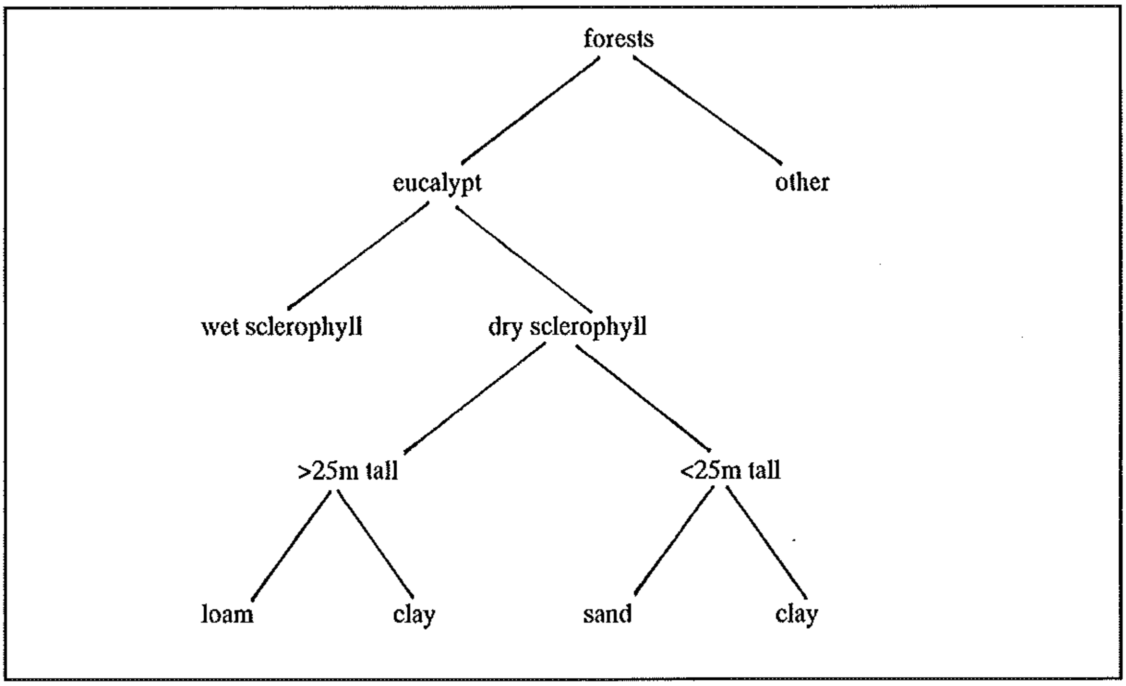

Figure 1. Hypothetical hierarchy for forests, which could be used in assessing the representativeness of a patch of forest.

The ecological units shown in Figure 1 need to be explicitly defined, then potential and existing reserves can be allocated, based on an assessment of the vegetation and soils present. It will then be clear which ecological units are under-represented in an existing reserve system, and it will be apparent which additional sites should be included in reserves to ensure the range of variation of the desired ecological unit is conserved adequately.

As an example, if the aim was to conserve dry sclerophyll eucalypt forest, all sites within a particular geographic range (say, the ACT or South-east Australia) where dry sclerophyll forests occur should be listed under one of the four categories which they represent (bottom row of heirarchy, Figure1). It should then be possible to assess the extent of reserves for each of the four ecological units and identify sites which are a priority for reserving. It is therefore possible to ensure all of the variation of dry sclerophyll forest is conserved.

Classification of ecological communities is generally based on the dominant vegetation and, given the lack of knowledge of invertebrates in Australia, we are unlikely to establish a hierarchy for invertebrates that is analogous to the forest hierarchy above. However, Austin and Margules (1986) argued that classifying ecosystems by their vegetation is acceptable given our lack of knowledge of the rest of the biota. Thus, the criterion of representativeness can only be used if we define potential invertebrate habitats using the vegetation.

A number of authors have suggested that preserving plants and vertebrates may be of some use in conserving invertebrate diversity, but often the distribution of invertebrates is more restricted than those of the plant communities in which they are found (Key 1978; New 1984, 1987; Williams 1990). If factors other than the vegetation are also taken into account, the reserves based on representativeness may conserve invertebrates more effectively than those based on vegetation communities alone. To determine which factors may be important, we need to know what type of parameters delimit the habitats of particular invertebrates.

3.1 Characteristics of Some Invertebrate Habitats

It is not known which invertebrate species occur in grasslands in the ACT or what they require of their environments for survival. It is therefore instructive to consider the biology of other invertebrate species because this provides some idea of the range of requirements that species native to grasslands may have. A few examples will suffice to bring out the key issues; there is enormous variation in the needs of individual species, and there can be substantial specialisation by some species to exploit a narrow range of resources.

Vegetation structure

Some invertebrates are dependent on a particular vegetation structure. For example, many butterflies and moths are thermophilous and depend on open spaces to obtain warmth (Warren and Key 1991). Warren and Key (1991) also point out that many butterfly species breed in woodland but rely on open areas for their abundant food supply. Both woodland and grassland may be essential for some species. Short, open pastures appeared to enable a larger population of the moth *Philobata sp.* to survive (Roberts *et al.* 1982a). This contrasts with the requirements of some beetles for long grass which they use as overwintering sites (Duffey *et al.* 1974).

Ground litter

Litter structure is important for collembola, woodlice and other litter dwellers that require cool, humid conditions near the ground (Duffey *et al.* 1974). Spiders are also responsive to litter structure. Uetz (1979) found that different species of spiders responded in different ways to a gradient of litter depth, and suggested they were influenced by litter complexity and moisture, temperature and prey abundance within the litter.

Soil

Soil characteristics can also evoke species specific responses. Wood (1974) found that three subsoil earthworm species characterised three soil types in Kosciusko National Park. Two topsoil species and one subsoil species were widespread. Earthworm communities are typically stratified, with different species occurring at different depths in the soil (Lee 1985). Nutritional properties of the soil influences some species. For example, rare Ciccadelids are often found on common plants which are growing on uncommon substrates (Whitcomb 1987). Yeates (1982) found that activity of some soil nematodes may be related to food plant quality, which in turn is related to nitrogen levels.

Host plant specialists

Prestidge and McNeill (1983) found that some leafhoppers (Auchenorrhyncha) were monophagous; they fed on only one taxonomic group of plants. They also observed that some oligophagous leafhoppers were associated with particular nitrogen levels in the grasses they fed on, and that as the nitrogen levels in the grasses changed, the leafhoppers would change host plant. Key (1978) noted that substitution of a *Stipa–Danthonia* grassland for a *Themeda triandra* grassland resulted in a complete change of grasshopper fauna, which indicated that many grasshoppers depend on particular species of grasses or associated herbs for food or for the type of habitat they provide. Shading out of grasshopper food plants by planted exotic pines may have been responsible for the decline in grasshopper abundance and diversity observed in a South African grassland (Samways and Moore 1991). Whitcomb (1987) reported that while grass and forb species had characteristic arthropod assemblages, the fauna varied geographically; arthropods were tending to specialise at a local geographic scale.

Topography

The interaction of topography with moisture levels and temperature can determine whether a site provides suitable habitat for a particular species. For instance, local topography influences soil temperature and therefore the duration of diapause of the Bay Checkerspot Butterfly, *Euphydryas editha bayensis* (Murphy and Weiss 1988). Timing of emergence is crucial for this species because of the need to synchronise with the availability of its food plant. During droughts, mortality of larvae may be high because the food plants senesce earlier. Under those conditions, the shortened diapause on sunny aspects could ensure the persistence of a population.

Invertebrate habitat: Conclusion

To delimit the potential habitats of invertebrates, much more than just the dominant plant species needs to be considered. Vegetation and litter structure, soil types, soil and plant nutritional properties and topography are features which need to be measured when assessing potential invertebrate habitats. It is desirable that all of the measured variation in habitat for invertebrates is represented in conservation areas.

4. WHAT IS A REPRESENTATIVE AREA?

When the bottom of the heirarchy shown in Figure 1 is reached, the size of the area needed to ensure the long term persistence of what is being represented needs to be established. Representativeness cannot be used as a criterion for conservation evaluation without referring to area.

The use of area as a criterion is derived from Island Biogeography Theory (MacArthur and Wilson 1963, 1967). This theory, also known as the area per-se hypothesis, predicts that larger islands will have more species because the island can support larger populations of each species, which reduces the probability of extinction. Other researchers have proposed that higher numbers of species will occur in larger areas due to larger areas containing a greater diversity of habitats (habitat heterogeneity hypothesis: Williams 1964), or simply due to a passive sampling effect (passive sampling hypothesis: Connor and McCoy 1979). Regardless of which hypothesis is correct, it is clear that larger areas are preferable because they are more likely to represent the diversity of the fauna before the habitats were fragmented.

This is not to say that relatively small areas are of no value. Some species of trapdoor spiders, grasshoppers and moths are known to be able to persist for many years in very small areas (Main 1987; Key 1978; New 1984; Edwards 1991).

Determining the size of area below which a native grassland in the ACT has no conservation value for invertebrates is not possible given the lack of knowledge of the needs of invertebrates. More research is required.

5. ASSESSING DIVERSITY

Diversity is the most frequently used criterion in conservation evaluation (Usher 1986). In order to assess diversity, it is necessary to survey the set of organisms, the diversity of which one wishes to conserve. For invertebrates in Australia, this is a difficult task; not only are there enormous numbers of them, but over half are undescribed and very little is known about them. Indicators of diversity may be a way of overcoming these problems.

Taxonomic groups that have a diversity of life histories and trophic levels amongst their component species, or species that are high in the trophic heirarchy, can be used to indicate how diverse their environment is. Greater complexity has been equated with a healthier community and higher conservation value. For instance, Main (1987; 1991) argued that a diverse spider fauna is a useful indicator of "the general balance of the community" (Main 1987). Majer (1983) and Andersen (1987) made similar cases for ants as indicators of community well-being. Disney (1986) and Moore (1991) suggested that surveys of Diptera, exclusive of some 'tourist' families, and parasitic Hymenoptera, would provide the best assessment of the conservation value of particular sites.

There are, however, a number of limitations in the use of diversity as a criterion for conservation evaluation. Usher (1986) noted that the number of species sampled increases with the size of the sample and suggested this was unfortunate because in practice sample sizes are usually different. Margules and Usher (1981) cautioned that an index based on the number of species present could be misleading if the sample size was small and one species was very abundant on one site, but not on the others. They also suggested that natural fluctuations in population sizes could influence estimates of diversity.

Another major problem with using diversity in conservation evaluation is that there is no reason to assume that greater diversity equates with higher conservation value. Mader (1984) found that smaller areas of native vegetation had fewer individuals but more species of carabid beetles than some larger areas due to an influx of weedy, widespread species. Areas that were larger had fewer species but were of higher conservation value as the fauna was more distinct. New (1987) also suggested that the actual species present need to be considered. He reasonably suggested that the species which are characteristic of a habitat should be conserved. In addition, diversity measures may overestimate the conservation value of a site if some of the species sampled do not have self-sustaining populations (Mader 1990).

Invertebrates of the grasslands of south eastern Australia have never been surveyed, so we have no idea what constitutes a desirable composition of species. This does not mean that diversity is of no use as an index of conservation. In an earlier section it was apparent that a variety of unnatural influences could decrease diversity. Therefore in some situations, greater diversity may correspond to higher conservation value. If weedy, widespread species, introduced invertebrates and taxa which are likely to be passing through the grasslands but are not resident, can be identified, then they could be excluded from the estimate of species richness. Weedy and exotic species may be used to devalue a site. Thus, estimates of the diversity of both desirable and undesirable species in different patches of the same habitat type could be useful in conservation evaluation, especially where sampling techniques are standardised and when samples are taken over a few years.

6. ASSESSING RARITY

Usher (1986) suggested that rarity is of little scientific importance in conservation evaluation, but that it is of critical practical importance because it is easy to conceptualise and is therefore important when political decisions are made. However, rarity is of scientific importance if it is equated with proneness to extinction. A rare biological entity could be defined as one that is at risk of extinction as a result of the interaction between its frequency of occurrence and its inherent ability to persist. Thus, to determine rarity, research into the distribution and persistence of the entity of interest is required. In addition, some weighting system is required to ensure greater importance is placed on entities that are rare in a large geographical area (e.g. Australia), compared to those that are rare only in a more limited geographic area (e.g. ACT).

Rarity can be applied either to habitats, or to species. Invertebrate habitats can be defined on the basis of vegetation and other quantifiable parameters (see section 3) and thus habitat rarity may be a useful criterion for assessing the conservation values of grassland patches. This is provided that the distribution of each habitat and its ability to persist without detrimental modification as that particular habitat can be determined. Relative rarity could be used as a guide to assessing habitat rarity.

Rarity may also be a useful criterion in the few cases where distributions of particular taxa appear to be restricted and may therefore be at risk of extinction, such as the golden sun moth, *Synemon plana*, which occurs in grasslands in the ACT (see Appendix) and could be used as a criterion for prioritising research. In contrast, the use of rarity for most invertebrates is not so simple given the lack of knowledge of the distribution and population biology of invertebrates in Australia.

However, another concept related to rarity may be useful in aiding, or substituting for, the assessment of rarity. Usher (1986) suggested endemism may be a useful criterion in conservation assessment, and that it deserved more research. In regard to Australian insects, Greenslade and New (1991) suggested that conserving endemism needed to be considered alongside the more commonly used criteria of naturalness, diversity and representativeness. T. Edwards (CSIRO, pers. comm.) speculated that grasses of Gondwanan origin, such as *Danthonia* spp., may have many endemic invertebrate taxa dependent on them for survival because they have evolved together. In contrast, grasses that have reached Australia relatively recently from the North, such as *Themeda triandra*, are likely to have fewer species dependent on them for their survival. This hypothesis suggests that Gondwanan habitats may be of higher conservation value because a high proportion of endemic species with restricted distributions occur there. If correct, the implications for reserve selection are profound.

7. SELECTING RESERVES, LANDSCAPE CRITERIA

All the criteria that have so far been considered in this report have been directed towards assessing the relative merits of isolated patches of natural habitats, without consideration of the spatial arrangement of other patches. However, the distribution of patches throughout a landscape is an important consideration as it may have implications for the population biology and the genetics of the species occupying the patches.

7.1 Population Biology

It is self evident that to ensure the survival of a species, its populations need to be conserved. In order to do this we need to understand how populations are sustained. White (1987) suggested that the study of population fluctuations over tens or hundreds of years is needed to understand how they operate and to conserve them adequately. Solid, detailed knowledge of a species is required to produce reliable population viability analyses (Shaffer 1990). A good example of the kind of detailed study that is needed is the research into the conservation of the Bay Checkerspot Butterfly, *Euphydryas editha bayensis* (see Murphy and Weiss 1988). Research into this species has spanned three decades and led to the formulation of a sound conservation strategy. Without access to such detailed ecological data, we can only consider what has been found for other invertebrates and expect that invertebrates native to grasslands have at least a similar range of requirements, and plan conservation reserve systems to cover that variation in needs.

The size of invertebrate populations can fluctuate dramatically (Yen et al. 1990; Bell 1985; Jaenike 1978). Fluctuations are often driven by the prevailing weather. For example, Crosby (1990) suggested that populations of the Altona Skipper Butterfly, *Hasperilla flavescens flavescens*, crash under unfavourable weather conditions. Ehrlich *et al.* (1980) reported that populations of *Euphydryas editha* were reduced during drought periods and concluded that "the disappearance of local populations is a frequent and significant feature of the biology of populations".

Species whose populations fluctuate in size will frequently exist only in small populations. Small populations are prone to stochastic extinction (Klein 1989). Den Boer (1985) found that extinction of carabid beetle populations commonly occurred and suggested the populations were intrinsically unstable, a result of high dispersal rates. Dempster (1991) argued that populations persist more through repeated recolonization after extinction than by internal population regulation. New (1984) noted that populations may not be self-perpetuating, with some requiring immigration from other populations. The set of populations involved in the processes of extinction followed by recolonization are known as a metapopulation (Levins 1970). Merriam (1991) suggested that habitat fragmentation may lead to the formation of metapopulations in animals that once had a more continuous distribution.

A good example of a metapopulation is that of *Euphydryas editha* (Murphy and Weiss 1988). Murphy and Weiss (1988) reported that small populations often became extinct but the habitat patch could be recolonized from a large centrally located population. Den Boer (1990) found a similar reliance on exchanges between populations for carabid beetles, and suggested that metapopulations spread the risk of extinction over "interconnected and differently fluctuating local groups".

Habitat fragmentation disadvantages species which have functioning metapopulations (den Boer 1990; Bennett 1990), thus investigation of the dispersal powers and inclinations of a species relative to habitat distribution is essential if those species are to be adequately conserved.

In the conservation prescriptions for *Euphydryas editha*, Murphy and Weiss (1988) recommended that all suitable habitat patches need to be reserved, regardless of whether the butterfly occurred there or not, because unoccupied patches may be recolonized at a later stage, or may be an important stepping stone between habitat patches. It is highly probable that some invertebrates of native grasslands rely on metapopulations for their persistence. As an example, populations of *Caledia captiva*, a grasshopper that is commonly found in pastures along the east coast of Australia, frequently become extinct but are soon recolonized, with rivers providing particularly useful corridors for dispersal (Dr. D. Shaw, RSBS, ANU, pers. comm.). In the absence of knowledge of every species that may require a functioning metapopulation for their persistence, it can only be concluded that all native grassland patches may be important.

7.2 Conservation Genetics and ACT Grassland Invertebrates

Individuals in small, isolated populations have little opportunity to breed with non-kin. Metapopulations restrict the flow of individuals, and therefore affect gene flow throughout the whole set of populations. Does the design of an optimum landscape of reserves need to take into account these types of genetic consequences of population structure?

Inbreeding can lead to homozygosis. This may reduce the fitness of homozygous individuals compared to heterozygotes, either by the expression of deleterious homozygous recessive alleles, or simply by heterozygotes being superior (Charlesworth and Charlesworth 1987). These authors suggest that the genetic value of inbred progeny is substantially reduced by inbreeding depression. Despite this, inbreeding may still evolve provided the organism has a polygynous mating system, or has a high cost of dispersal (Dawkins 1979; Waser *et al.* 1986). Additionally, the deleterious effects may not be particularly serious, as expressed by Bateson (1983): "Some of the genetic costs of inbreeding are short lasting in evolutionary terms. The probability of damaging genes being expressed goes up, of course, as inbreeding takes place. But once fully revealed, they are eliminated from the population and fitness rises once again". Therefore, inbreeding is not an unnatural process and is not necessarily a phenomenon that conservation strategists need plan to avoid.

Inbreeding does reduce genetic diversity and Partridge (1983) suggested that this may result in the loss of some potential for evolution. Lande and Barrowclough (1987) point out that without genetic variation there can be no evolution and therefore "genetic variation should be a central theme of plans for the long term maintenance of populations". Nevertheless, genetic variation is useless if the population becomes extinct and Lande and Barrowclough (1987) argue that the proximal focus for conservation should be the short term persistance of populations.

Two practical examples of invertebrate conservation support the argument that inbreeding is of little importance in conservation planning. Murphy and Weiss (1988) suggested that inbreeding depression was of little importance in the extinction of local populations of *Euphydryas editha*. Environmental fluctuations were most important. Thomas (1983) also concluded that inbreeding was unlikely to cause extinction of populations of the butterfly *Lysandra bellargus*, because there was no correlation between the extinction of populations and the degree of isolation.

Inbreeding is one extreme in a continuum of amounts of gene flow. The importance of gene flow in evolutionary processes is currently in a research phase and therefore this field offers little practical help to conservation planners. Yen *et al.* (1990) stated that "conservation genetics of invertebrates is in its infancy and is unlikely to be employed as a conservation tool in Victoria for the foreseeable future". In addition, as pointed out in relation to inbreeding, the effects of environmental stochasticity on populations are likely to swamp any genetic problems (Lande and Barrowclough 1987; Shaffer 1987). Management of species for conservation should focus on ensuring the persistence of populations. However, the amount of gene flow, genetic variation and its consequences for population survival and the continuing evolution of the species offer enormous scope for research.

7.3 Dispersal and Connectivity

If local populations are subject to frequent extinctions, the ability of a particular species to recolonize the formerly inhabited area may be crucial to the long term survival of the metapopulation. Two factors will influence their ability to do so; the dispersal powers of the invertebrate in question, and the connectivity between habitat patches.

Dispersal ability

Jermy *et al.* (1988) suggested that, with the exception of bees, very little is known about the behavioural responses involved in spatial manoeuvring of insects. However, consideration of only a few examples leads to the conclusion that we should expect an enormous range of species specific dispersal behaviour amongst the invertebrates. Morrow *et al.* (1989) found that dispersal of Golden Rod Leaf Beetles, *Trirhabda canadensis*, was influenced by chemical cues from nearby host patches and demonstrated that wind direction could therefore influence their dispersal. Earthworms show a diverse range of dispersal techniques, such as crawling over the soil surface, being carried along by water, or by being transported by birds (Lee 1985). Kareiva (1985) suggested that dispersion of flea beetles (*Phyllotreta* sp.) resulted from random wandering, a process of dispersal Kareiva dubbed the diffusion model. In a study of colonization of potted cabbages, Cromartie (1975) observed that different species had different colonization success in different situations, which is probably typical of all invertebrate faunas in patchy landscapes.

Fahrig and Paloheimo (1988) point out that the mode of dispersal is crucial to understanding the effects of patchy habitat distribution on invertebrate populations. For instance, if an organism moves along corridors, then the spatial arrangement of patches will be important. However, if an organism, such as *Pieris rapae* (Cabbage White Butterfly) in a study by Fahrig and Paloheimo (1988), disperses long distances in random directions, without detecting patches from a distance, the arrangement of patches will have less effect on population dynamics.

Some invertebrate species may not need to move frequently between habitat fragments. Main (1987) has argued that prior to fragmentation of the wheat belt in Western Australia, a natural mosaic of vegetation, soil and topography created naturally fragmented habitats and Main suggested that as a result, much of the invertebrate fauna is already adapted to surviving in isolated sites. Edwards (1991) suggested that *Synemon plana*, a moth native of *Danthonia* grasslands in the ACT, is also pre-adapted to surviving in isolated patches.

Connectivity

Although there is still a lot to learn about the effects of fragmentation on plants and animals (Saunders et al. 1991; Bennett 1990; Soule and Kohm 1989), and while there are some possible disadvantages of linking habitat patches (Panetta 1991), connectivity is generally regarded as desirable and conservation reserves should be designed to reflect this (Saunders and Hobbs 1991; New 1984). The variation in dispersal behaviours of animals led Soule and Gilpin (1991) to suggest that corridors need to be designed on a species specific basis. Corridors are generally thought of as strips of natural vegetation linking fragments of native vegetation. Saunders and Hobbs (1991) argue connections of this nature should be straight, wide, of native vegetation and continuous.

Linear corridors are not the only means of connectivity between fragments. For example, Klein (1989) noted that the barrier effect of clearcuts surrounding patches of rainforest decreased as secondary growth became established, illustrating that vegetation discontinuities are not necessarily always the barriers they appear to be. Merriam (1991) made the same point, using the example of the White-footed Mouse, which dispersed linearly along wooded corridors and non-linearly through corn and cereal crop fields. Modified land separating native vegetation may therefore provide a connection between fragments for some species.

7.4 Landscape Criteria: Conclusions

In the management of fragmented natural habitats for conservation of invertebrates, one must expect to find a variety of dispersal modes and a range of connectivity requirements. Some species may persist for long periods in one small area, while others may have localised populations that frequently become extinct and so they need to be able to recolonize suitable habitat fragments. Investigation of the dispersal abilities and requirements of a small number of invertebrates that vary substantially in their life strategies would provide some indication of the range of connectivity required for the persistence of their metapopulations. Long term studies of population fluctuations and their causes will ultimately provide the strongest basis for formulating conservation strategies.

In the meantime however, connectivity between reserves should be maximised by concentrating efforts on reserves that are geographically close together or connected by native vegetation, and avoiding sites that are a long distance from others, or that are divided by roads or rail lines, as these can inhibit movement of some animals (Duelli 1990; Mader *et al.* 1990). The recreation of grasslands may be a useful way of improving connectivity between isolated grassland patches.

8. THREAT OF INTERFERENCE

Margules (1986) suggested that pragmatic criteria such as threat of interference should be the final stage in the assessment of potential reserves. This criterion can be readily assessed for native grasslands in the ACT and is highly likely to be useful in prioritising conservation action.

9. RESEARCH STRATEGY FOR CONSERVING INVERTEBRATE DIVERSITY IN GRASSLANDS

9.1 Short-term Assessment and Research

The argument by Margules (1986) that the criterion of representativeness should be the first stage in conservation evaluation is indisputable. Not only does it ensure that the same habitat types are being compared at later stages in the assessment of potential reserves, but it also provides a framework for specifically defining and identifying habitat that is appropriate to the biota of interest.

The objective is to conserve invertebrates that are native to natural grasslands in the ACT, so it is implicit that invertebrate habitats will only need to be identified in areas that qualify as natural grasslands. Once these areas have been identified, the hierarchy needed to assess representativeness can be formulated. If the hierarchy takes into account vegetation composition and structure (including the woodland/grassland ecotone), soil types and parent material, and topography (aspect and slope), then most of the variation in invertebrate habitats should be covered.

It will be useful to have reached this stage in the assessment for two reasons: Firstly, if all of the areas are able to be conserved and no further choice of areas is required, the hierarchy of invertebrate habitats will be essential if rotational mowing or burning is required within a particular habitat. The hierarchy will also be the basis of further research into the invertebrate community. The second reason is if there are more areas identified than can be incorporated into a conservation reserve system (due to competing interests for the same areas), some choice will need to be made as to which areas are the most important for conservation. Each habitat category (the bottom of the heirarchy) can then be separately subjected to other criteria so that the most important areas can be identified. However, it must be emphasised that all native grassland patches may be important and that all that remain should be considered important enough to warrant reservation.

Margules (1986) argued that the next stage in conservation assessment, assuming a choice of sites is to be made, should be the use of "threshold criteria" to completely eliminate some sites from consideration, and he suggested that area or naturalness could be used. It was pointed out in an earlier section, that we do not know enough about the requirements of invertebrates to use area as a criterion. Perhaps the minimum grid size on the Landsat map of vegetation in the ACT (Ritman and Lees 1990) of 10x10m could be arbitrarily defined as the minimum useful area, simply to enable representativeness to be used sensibly as a criterion.

Naturalness, based on floristics will have been used already as a threshold criterion by this stage; it was used to identify native grasslands.

Margules' (1986) fourth stage in conservation assessment is the use of "ranking criteria" to prioritise the sites. Many criteria could be used at this stage, and they would need to be scored in such a way as to make them comparable with one another. It may be possible to assess the relative intensity of management for each site and use this as a ranking criterion as discussed previously. It is important that the same means of assessment be used for all sites in the same habitat category (bottom of heirarchy). Information on stocking rates or frequency of fertilizer application for example, could be assigned subjective scores related to the degree they were thought to reduce the naturalness of the invertebrate fauna.

A little is known of the ecology of some individual species that occur on grasslands, and this information can be used to infer particular things about the naturalness of the site. For example, *Keyacris scurra*, the wingless grasshopper, has limited dispersal abilities and populations of this grasshopper can be exterminated by heavy grazing. If *K. scurra* is found on an isolated site, it can be assumed that the site has not been overgrazed for at least the duration of isolation of the patch. Therefore, any other invertebrates which are sensitive to grazing may also occur on the site. In this sense, many invertebrate species could be used as indicators of naturalness, depending on knowledge of their requirements and responses to disturbance.

A consideration of rarity could also be incorporated at this stage. Sites where species or habitats known or suspected of having a restricted distribution occur could be given a high ranking.

Landscape criteria could also be incorporated, and it was suggested that connectivity and distance to other patches could be assessable criteria. Area could be used as a ranking criterion, with larger areas ranked more highly. The threat of interference should be incorporated into the ranking procedure directly, or used afterwards to prioritise the short term conservation demands of priority sites.

When sites of importance have been selected, the invertebrate habitats must be maintained. This will involve declaration of new reserves, liaising with landholders to encourage favourable management practices and restricting some management practices where necessary. All management practices that are known to be deleterious should be halted, such as heavy grazing and fertilizer application. While some sites should be used in manipulative experiments the management regime currently used on the remaining sites should be continued to avoid the possibility of a sudden change in vegetation composition, something which could drastically alter the invertebrate fauna. If a habitat patch is large enough and the current management regime incorporates some variation, different areas should be subject to different management intensities (eg. mowed at different times or to different heights) to ensure there is a range of microhabitats within the patch.

9.2 Medium-term Assessment and Research

All of the short-term assessments have been based on little more than informed guesswork as to which places may be the most important for conserving the invertebrate faunas of grasslands. It would be far more reliable to concentrate on using the invertebrates themselves.

In making assessments at this time scale (3–10 years) there is still a need to compare sites which are the same, so the hierarchy for invertebrate habitats will be required. Following this assessment, the use of bioindicators would be the best way to assess how natural the communities are. Assessment of diversity may be useful in comparing sites with the same habitat, provided any undesirable species can be identified and sampling problems minimised. Again, bioindicators could be used.

Bioindicators for ACT grasslands

Many invertebrate groups have been espoused as good indicators. Which groups may be useful bioindicators in ACT grasslands and therefore deserve research attention? Spiders offer excellent opportunities, as they vary from annuals to long-lived species, have an array of dispersal strategies, occupy a high trophic level, are very abundant and are relatively well known taxonomically (Dr. C.R. Margules, CSIRO, pers. comm.; Driscoll 1991). However, as with all invertebrates, they require the assistance of taxonomists for identification and currently there is no one available in the ACT.

Beetles are also particularly diverse and occupy a range of trophic levels, but don't have the variation in dispersal modes that spiders have (Dr. C.R. Margules, CSIRO, pers. comm.). Beetles have the advantage however, of being identifiable, with a strong Coleopteran taxonomic group at the Australian National Insect Collection in Canberra. Dr Chris Margules of CSIRO Wildlife and Ecology, Gungahlin, is addressing the impact of forest fragmentation on animals, and is following the changes of some invertebrates, particularly Coleoptera. A substantial knowledge base of Coleoptera therefore exists in Canberra. In addition, Dr. Chris Reid (Division of Botany and Zoology, ANU) is keen to be involved in a study of grassland beetles.

Ants have received some attention as indicator species. Although ants are unlikely to be very diverse in ACT grasslands, they have the advantages that they are ubiquitous, relatively well known taxonomically, their ecology is better known than most groups, and there is help available to identify them in Canberra (Dr. B. Taylor, consultant, pers. comm.). Dr. Margules is also investigating the impact of fragmentation on this insect group.

Collembola can be used as indicator species since the proportion of native and exotic collembola is generally correlated with the proportion of native and exotic grasses. However, they are unlikely to be useful indicators of differences in quality between native grasslands and are not well known taxonomically (Dr. P. Greenslade, CSIRO, pers. comm.). It may be simpler to survey the vegetation than the collembola as a measure of the degree of disturbance.

Samways and Moore (1991) used grasshoppers to investigate the impact of exotic conifer patches on grassland invertebrates in South Africa because they were conspicuous, abundant, present consistently throughout summer and autumn and because they are important primary consumers and generators of nutrients. This is also true for grasshoppers in ACT grasslands. In addition, grasshoppers show a range of dispersal abilities, vary substantially in size, the basic life cycles of many are known, and they show substantial variation in host plant use (Dr. K. Key, CSIRO, pers. comm.). Although they do not occupy a diverse range of trophic levels, grasshoppers may also be useful bioindicators. One example of using a grasshopper, *Keyacris scurra*, as an indicator of naturalness was given in the previous section. There are two taxonomists available to aid identification of Orthoptera: Dr. Ken Key and Dr. David Rentz at the Australian National Insect Collection. In addition, ecological and genetic work is being carried out on some common grasshoppers: Dr. John Dearn, UCAN, and Dr. David Shaw, RSBS, ANU.

Beetles, ants and grasshoppers would be useful groups to use as bioindicators. These would need to be surveyed regularly throughout the year, for a minimum of three years. Other research that would also need to be done to maximise the value of such a survey includes:

- Experiments to determine the responses of beetle, ant and grasshopper faunas to unnatural disturbances, such as heavy grazing and pesticide, herbicide and fertilizer application. These experiments could be monitored over a longer time period to investigate rates of recovery following disturbances. The same manipulative experiments could be used in assessing plant responses to management.

- Investigations to determine which elements of the fauna are desirable. This would involve
  a) identification of weedy and widespread species, and
  b) a thorough survey of suitable reference areas if they exist.

General survey and field guide

A general survey of invertebrates of grasslands would involve extensive sampling using a variety of techniques, and would require taxonomists to be funded to identify specimens collected. However, besides collecting the beetle, ant and grasshopper data for use as indicators of site quality, ecological knowledge of particular species may be gained, enabling better assessment of the conservation needs of those species, and other species known to be of conservation value may be identified in the grassland sites.

The results from a general survey could also be used to produce a field guide to common and interesting invertebrates of grasslands. Such a field guide could readily be expanded to include lowland woodlands, as there is already some knowledge of the invertebrates that occur in local woodlands (Dr. Mick Tanton, ANU; Dr.Chris Reid, ANU; Dr. Jill Landsberg, CSIRO Gungahlin; Driscoll 1991). New (1987) argued that a basic field guide to insects would aid the collection of distribution data by encouraging amateurs to become involved in the study of insects. A field guide would increase the appreciation of invertebrates and grasslands held by many people. This would facilitate the conservation of invertebrates and grasslands directly by having people want to retain native invertebrate habitat on their properties, and indirectly by creating the political basis for the preservation of those habitats.

Responses to fire

It was argued earlier in this report that some invertebrates may depend on fires for survival while others may be completely fire intolerant. This prediction could be investigated experimentally on a medium to long-term basis. Because of the problems associated with attempting to sample the entire invertebrate fauna, it may be best to concentrate on the three indicator groups: ants, grasshoppers and beetles.

Dispersal

The dispersal abilities and inclinations of particular species could also be researched in the medium term. This would be useful in establishing which species are unable to recolonize suitable, unoccupied habitat and therefore are at risk of extinction, particularly if the size of their populations fluctuate markedly. Research into dispersal behaviour would also permit the connectivity requirements of some species to be investigated. Although only a few species could reasonably be investigated, if those selected represented a range of taxonomic and functional groups, it would be possible to obtain an idea of the range of requirements of different invertebrates. The results of a general survey may assist in the choice of species to use.

If research indicates that the connectivity requirements of some taxa are not being met, and that this may place some species at risk of extinction, it will be necessary to modify the land between the habitat patches to permit the animals to move between sites.

Gondwanan relationships

Another medium-term line of research is into the relationship between plant communities of Gondwanan origin and endemic fauna. Results from a general survey would be useful here. In addition, the nature of the relationship between Gondwanan plant communities and resident invertebrates (such as host plant specificities) would need to be investigated. This research may prove to be very important as it could provide a reliable short cut to choosing areas that are likely to have a fauna most in need of protection.

Minimum area

Data derived from a survey of beetles, ants and grasshoppers, could permit the minimum useful area for conservation to be assessed. If the proportion of desirable to undesirable species is correlated with patch size, an arbitrary decision would need to be made as to where the cut off point is going to be. Such a correlation may be difficult to establish if different sizes of the same habitat type and quality are not available. In addition, the opportunities for manipulative studies using the uncommon native grasslands are limited.

Genetic studies

It was argued that there is currently inadequate knowledge of the importance of genetic variability to the survival of populations. Research needs to be carried out to investigate the relationship between the rate of gene flow between populations, genetic variability and the long term persistance of populations.

9.3 Long-term Assessment and Research

Understanding the population biology of a species is important in enabling the formulation of management plans to conserve a species in the long term. To obtain such data, research over decades is required. Long term monitoring of population fluctuations for many species should be possible. This could provide: 1) a way of gauging the success of the reserve system; 2) a means of identifying species which may be at risk of extinction and in need of a more detailed study; and 3) an understanding of the population biology of many species, thus enabling reserve systems to be improved in the future.

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APPENDIX: THREATENED SPECIES

This section provides examples of recovery plans for three insect species. Two of these, *Keyacris scurra* and *Synemon plana*, have received some attention from conservation interests. It is impossible, given current funding prospects, to study all of the invertebrates. Concentrating on a few species that may be in danger of extinction ensures that those animals most in need of attention receive it and it provides a focus for grassland invertebrate conservation, which is critical to stimulate further interest in the project.

Keyacris scurra

Description

Order: Orthoptera

Family: Eumastocidae

Subfamily (endemic Australian): Morabinae

Keyacris scurra (formerly *Moraba scurra*) is a small (up to 25mm in length), wingless grasshopper with short antennae and a thin, elongate head and body. Its colouring and overall appearance make it difficult to distinguish from the dry grass and litter amongst which it is found. The grasshoppers in the subfamily Morabinae are all wingless, slow moving and have specialised habitat requirements (Key 1978). Key (1978) suggested they are a primitive Australian taxon.

Distribution

K. scurra was widely distributed throughout south eastern Australia before the destruction of its habitat by sheep grazing and pasture improvement (Dr. K. Key, CSIRO, pers. comm.). White *et al.* (1963) collected *K. scurra* from three sites in the ACT (Hall cemetery, North of Royalla, Williamsdale) and from five sites in NSW (Michelago, Murrumbateman, Tarago Swamp, Wombat and Wallendbeen). Key (1981) suggested that *K. scurra* is now restricted to areas that have never been severely grazed such as rural cemetery reserves, the fenced margins of railway lines, and occasional paddocks. In 1988, *K. scurra* was only known from three sites in the ACT (NCDC 1988). However, since then a number of other sites have been located. The grasshopper has been noted to occur in shrubland near Gibralter Rocks in Tidbinbilla Nature Reserve, in grassland and woodland near Kambah Pool, and near *Eucalyptus dives* forest in the Naas Valley (Dr. K. Key, CSIRO, P. Ormay, ACT Parks and Conservation Service, pers. comms.). Only the Kambah Pool population is known to be extensive. The extent of the populations at the other two new sites is unknown. Small populations of *K. scurra* have also recently been confirmed to be extant in two of its previously known locations; the Hall Cemetery and along a railway reserve North of Royalla. Increased mowing at the cemetery has reduced the size of the K. scurra population (Dr. K. Key, CSIRO, pers. comm.). White *et al.* (1963) collected *K. scurra* from Williamsdale, but the fate of that population is unknown as is the fate of the others that these authors used in NSW. The grasshopper was recorded in one location in NSW in 1988, near the Taemas Bridge on the road through Uriarra Crossing. However, it is not known if this population still exists. Efforts by the NSW National Parks and Wildlife Service failed to reserve this area for *K. scurra* and a second Morabine species of restricted distribution, *Achurimima* sp.P42, because the landholder was uncooperative (Dr. K. Key, CSIRO, pers.comm.).

Habitat

K. scurra requires tall vegetation in which to shelter and the grass *Themeda australis* is frequently used, but others can be used, including *Chrysocephalum semipapposum*. *K. scurra* occurs in woodland and grassland where its food and shelter requirements are met (Dr. K. Key pers. comm.).

Life history/ ecology

K. scurra eggs are laid in the soil and hatch around February. Males mature by March or April, while females generally do not mature until August or September. All life stages are wingless. Eggs are laid from August to October, and the adults die out over that period. It's preferred food plants are *C. semipapposum* and *C. apiculatum*, but other food plants have been recorded (Dr. K. Key, CSIRO, pers. comm.).

Reasons for listing

K. scurra is one of two invertebrate species that has received the attention of conservation bodies in the ACT. It was believed to be restricted to road, rail and cemetery reserves, and therefore, combined with its limited dispersal abilities, may have been in danger of extinction in the ACT. *K. scurra* was also the focus of important cytogenetic studies (White *et al.* 1963; White 1963), which showed "chromosomal polymorphism with adaptive value (that was) associated with particular geographic localities. (The) chromosomal structure (was) studied to demonstrate that recombination of large segments of chromosomes, then thought to be an insignificant rarity, was a normal mechanism leading to genetic change in species" (Ingwersen and Williams 1990).

Existing conservation measures

The Kambah Pool population is entirely within the Murrumbidgee River Corridor, and NCDC (1987) had the land marked as "proposed nature reserve" and "vegetation restoration area". The population near Gibralter Rocks is in Tidbinbilla Nature Reserve. The remaining populations have no formal protection, although the Hall Cemetery site is to managed to promote the survival of the grasshopper (City Parks 1991).

Research strategy

The populations of *K. scurra* used by White *et al.*(1963) are of substantial scientific value. The state of the populations at each of these sites should be determined and if the grasshopper is present, management practices facilitating the survival of this species should be employed. The Hall Cemetery and Royalla sites, are also important for survival of the rare plant *Swainsona recta* (NCDC 1988). The extent of the populations at Kambah Pool, in the Naas Valley and near Gibralter Rocks should be determined as these sites are most likely to ensure the long term survival of the species. The Taemas Bridge site may also be important for both *K. scurra* and *Achurimima* sp.P42. and so should be investigated.

All populations should be monitored for at least ten years to determine if they are adequately stable to ensure their long term persistence. During this period, ecological studies should be carried out to aid interpretation of the population data. This research should include investigation of the food requirements of *K. scurra*, factors influencing mortality at all life stages, and the impact of management techniques, such as grazing, burning, mowing and herbicide application.

Synemon plana

Description

Order: Lepidoptera

Family: Castniidae

Synemon plana, a day flying moth, is about 3.5cm across, brown, orange and black dorsally, with a white ventral surface. It has pale green eyes (Falconer 1991) and clubbed antennae. Females have bright orange hind wings, used to attract males, and long ovipositors for inserting eggs deep into grass tussocks or soil. Females are poor fliers, but males are capable of sustained flight. The family Castniidae is of Gondwanan origin. In Australia, the members of this family are known to feed only on sedges and grasses and are most diverse in south west Western Australia (T. Edwards, CSIRO, pers. comm.).

Distribution

S. plana was widely distributed throughout south-eastern Australia at the time of European settlement. However, the moth is now known from only eight sites in the ACT and from one other site, which is in Victoria. In the ACT the sites are all in suburban areas as these are the only places that have not been subject to deleterious agricultural practices. Four of the sites in the ACT are small (average 30x20m) and the long term survival of the moth on those sites is unlikely. Four other sites may be large enough, provided the areas are not further reduced (T. Edwards, CSIRO, pers. comm.).

Habitat

S. plana requires *Danthonia carphoides* and *D. auriculata* grassland for survival. Grasslands dominated by other species, either exotics or natives, are unsuitable.

Life history/ ecology

The complete life cycle of *S. plana* is unknown. Adults emerge from the soil and fly during November and December, the exact timing of which is dependent on spring temperatures and rainfall and the aspect on which they occur, with individuals on the northerly and westerly aspects flying approximately a week earlier than those on cooler aspects. Adults have no mouthparts and do not feed, so the timing of emergence from the soil is not critical in relation to food availability. It is not known how long the moths spend as larvae, however, 21-22 months seems likely. Larvae tunnel in the soil and feed on the underground parts of *Danthonia carphoides* (Silvertop Wallaby Grass).

The poor powers of dispersal of females suggest that this species has evolved under conditions that did not require colonization of disjunct areas; the species is not adapted to persist as a metapopulation.

S. plana is able to survive light grazing or mowing and may be resistant to fires, especially if the larvae do remain underground for up to two years (T. Edwards, CSIRO, pers. comm.).

Reasons for listing

Despite efforts in NSW, SA and Victoria to locate the moth, only nine sites are known, suggesting it has a severely restricted distribution. The plant community on which *S. plana* depends is endangered. Although the majority of the former range of *S. plana* was destroyed by the improvement of pastures, threats to extant populations are weed invasion and urbanisation.

S. plana is only one, conspicuous, member of the invertebrate fauna found in *Danthonia* grasslands. Many other species may also rely on this vegetation community for survival (T. Edwards, CSIRO, pers. comm.).

Existing conservation measures

Danthonia carphoides grasslands are not represented in any nature reserves. All ACT locations are on ACT or Federal Government land. However, three sites are to be managed by the City Parks branch of ACT Parks and Conservation Service, to favour the survival of the moth. This includes one of the largest known areas in which the moth occurs, at York Park (City Parks 1991).

Research strategy

To ensure the survival of the moth, the moths habitat must be conserved. This can only be achieved by negotiating with the relevant government departments to ensure the sites on which it occurs are listed permanently as conservation areas. Funding should be made available for a survey of all potential sites in the moths former range, as this is the only way to assess the importance of the sites where it is currently known to occur.

When habitat has been secured, research into the moths responses to management practices and its biology and ecology is essential. This should concentrate on:

1) The variation of habitat that *S. plana* can tolerate. This research should be aimed at characterising the habitat of the moth, particularly in relation to vegetation composition and structure, soil types, drainage and solar radiation. Experiments should be performed to confirm any correlations.

2) The resposes of *S. plana* and *Danthonia* grasslands to a range of mowing, grazing and burning regimes. This will determine the type of management that can be used in maintaining suitable habitat. In addition, since all of the sites are near to residential areas, there is a high risk of fires occurring. Therefore, the impact of fire needs to be understood so that precautions can be taken if the moth is particularly vulnerable at some times during the year.

3) The moths complete lifecycle and its relationship with its food plants. This information will be essential in interpreting the results of management experiments and it will enable the moths responses to particular perturbations to be predicted.

4) To progressively accumulate data on natural population fluctuations, and their causes with a view to modelling population dynamics so as to be able to predict population viability under different conditions.

Coorabboorama canberrae

Description

Order: Orthoptera

Family: Gryllacrididae

A description of the wood cricket, *C. canberrae* is provided in Rentz and John (1990). It is very large, with a body length of about 4cm, but the cerci are elongated and almost double the animals' length. It is pale yellow brown or straw brown, with black eyes and has an off-white ventral surface.

Distribution

C. canberrae is known only from the collection of individual specimens from urban areas in Canberra. No populations are known. "Intensive collecting has failed to yield any specimens outside the Australian Capital Territory" (Rentz and John 1990).

Habitat

C. canberrae probably lives under bark and litter associated with grasslands and woodlands. It has been found in suburban gardens (Dr. D. Rentz, CSIRO, pers. comm.).

Life history/ ecology

The only ecological information available is the time that specimens were collected. Adults have been collected from December to March. One nymph was collected in May, and it matured in December.

Reasons for listing

This species appears to have a very restricted distribution, and it appears to have declined in abundance in the 10 years since the holotype was collected, in 1981 (Dr. D Rentz, CSIRO, pers. comm.).

Existing conservation measures

None.

Research strategy

Virtually nothing is known about this large wood cricket. Of immediate importance is determining if it is still extant, where it occurs and how extensive the populations are. Dr. David Rentz (CSIRO Entomology, Canberra) is unable to identify potential sites and so the best approach may be to search near areas where specimens have been collected. If the species is extant, research should be directed into determining:

1) Habitat requirements
2) Threats to existing populations
3) Optimal management techniques

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