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Grain & Graze™

Profit through knowledge

Aligning on-farm biodiversity with regional plans and targets through the national Grain & Graze program

(BIODIVERSITY IN GRAIN & GRAZE)

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UTAS

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GRDC Grains Research & Development Corporation

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Executive Summary

Grain & Graze is a national program aimed at boosting farm profitability across the mixed farming zone of southern Australia, while minimising impact on the environment. The program is collaboration between four leading Research and Development Corporations – Land & Water Australia, Grains Research and Development Corporation, Meat and Livestock Australia and Australian Wool Innovation Limited. Over 60 industry and land care groups, research providers and regional catchment management authorities are involved in research focusing on cropping, pastures, livestock, profitability, feedbase management, whole-farm economics, biodiversity, social issues, soil and water.

There are nine participating regions, each with its own research program. In addition there are four national projects, whole-farm economics, feedbase management, social and biodiversity. The national biodiversity project was instigated after the realisation that many regions did not have the capacity to develop regional biodiversity projects.

The role of mixed farming systems in maintaining and actively managing biodiversity has received very little attention compared to previous research studying single enterprises such as grazing (LWW, SGSL) or crop production (Mason et al. 2004). In addition much of the existing biodiversity literature concentrates on the role that native or semi-native vegetation provides as habitat in farming landscapes. The Biodiversity in Grain & Graze (BiGG) project was initiated to provide information on the relationship between biodiversity and a range of land uses across mixed farming landscapes.

Four land use types on 47 mixed farms across the nine Grain & Graze regions were surveyed in autumn and spring 2006 and 2007. Biodiversity surveys for birds, surface invertebrates (beetles, ants, spiders), vegetation and soil fungi were undertaken in four land classes on each farm; crop, ‘rotation’ (break crop/pasture phase), perennial pasture and remnant vegetation. Data were collected by regional Grain & Graze project officers and were sent to the University of Tasmania for collation, analysis and interpretation.

Farmer awareness and regional capacity to understand and undertake biodiversity projects was greatly enhanced by the Biodiversity in Grain & Graze (BiGG) project. Stakeholders now have clear idea of what ‘biodiversity’ might look like and how some components, such as beneficial predator species (beetles, spiders, birds) offer production benefits. Farmers also increased their awareness of the impact of land management practices on biodiversity, and the role of their farm in contributing to the national conservation estate.

The project commenced in November 2005 and finished in June 2008 (ie 2 years and 7 months including 2 years data collection).

Recommendations

Many of the statements highlighted in blue throughout this document have important implications for the future management of biodiversity and for future biodiversity research. Some also have policy implications.

There are three key audiences for the messages coming out of BiGG – farmers, policy makers and researchers. Messages for each are summarised below.

For mixed farmers;

1. What mixed farming can do for biodiversity?

- Birds. Remnant vegetation on mixed farms provides important habitat for birds. In this first national bird survey carried out specifically on mixed crop and livestock farms, a total of 181 bird species were recorded on the 47 farms. Thirty three of these were priority or threatened species and 23 were recognised as nationally declining species. The number of species recorded on a farm was positively correlated with the proportion of remnant vegetation on a farm and the condition of vegetation as measured by its structural complexity (the number of vegetation layers). The significance of vegetation condition for bird species diversity reinforces the importance of managing those forms of disturbance that reduce vegetation complexity, such as grazing and fertiliser application.

- Beetles. Mixed farms provide habitat for a great diversity of beetles, with 504 different taxa identified to the level of genus or species including several rare weevils not seen for decades (Peter McQuillan pers. comm.). Similar numbers of species found on all land use types indicating the extent to which beetles have adapted to farming landscapes. Functional groups of beetles vary with land use type, reflecting variability between regions and land management practices. Carabid beetles may be useful indicators of environmental stress as their body size and relative mobility differs between disturbed (farmed) and relatively undisturbed (remnant) land use classes.

- Ants. Over 850 different ant taxa were found, with a clear distinction between eastern and western Australia in term of habitat preference. Little difference was observed between the number of ant species in each land use type in Western Australia and South Australia compared to the eastern states. In the east, ant species richness was closely followed level of disturbance with most found in remnant vegetation, least in crop, and intermediate numbers in pasture and rotation. The dominance of particular functional groups varies between regions and land use types.

- Spiders. Three hundred and thirty species of spider were found. Most were ground-dwelling spiders, common in two-dimensional habitats. They were found to respond to the mix of land uses on a farm, with higher numbers of individuals found on farms with a higher proportion of land under crop and rotation. However, the higher the crop yield (wheat t/ha), the fewer numbers of different species recorded.

2. What biodiversity can do for mixed farming

- Birds. Sixty four percent of the bird species observed were known to eat insects, suggesting that further study might help to identify which birds species are predators of particular crop and pasture pests, providing production benefits (ecosystem service)

- Beetles. The data from this study suggests there is potential to develop a national IPM program on mixed farms on the basis that predatory beetles were found to occur in every region surveyed.

- Ants. In water limiting environments typical of Australia's mixed farming zone, ants and termites are known to play an important role in soil aeration and nutrient cycling, the equivalent role that earthworms play in more humid environments. The high diversity of ant species found and their preference for least disturbed areas suggests their role as ecosystem engineers could be enhanced through a better understanding of the interactions between ants, tillage practices, fertilizer use and pesticides.

- Spiders. The relationships between land use types and crop yield observed above suggest spiders are preferentially targeting crop pests. Further study is needed to confirm this tentative observation and identify particular predator pest relations that could be fostered through the adoption of IPM.

3. Management that benefits biodiversity and mixed farming.

Adoption of the guidelines below should provide enhanced biodiversity and long-term production benefits through the protection of beneficial predators (birds, invertebrates) and healthy soils (microbial diversity):

- Careful management of existing remnant vegetation to enhance structural complexity (i.e. number of vegetation layers; trees, shrubs, ground cover including litter) will provide more habitats for a range of plants and animals.
- Maintaining ground cover, particularly with perennial species, will increase biodiversity.
- Decreasing soil disturbance across land use types will maintain habitat for ground-dwelling species such as spiders, beetles and ants.
- Reduction of chemical inputs across the farm will increase biodiversity.

For policy makers

1. Biodiversity does not start and end in national parks and reserves Data collected in the project clearly show that. Data collected through BiGG showed that considerable biodiversity exists on agricultural land and is affected by the management decisions and farming practices of farmers. This suggests that biodiversity considerations should be an important factor in the development of agricultural policy as well as environmental policy.

2. Biodiversity does not start and end in the remnant vegetation patches on farms. The data from this project also shows that biodiversity in the agricultural

components of farms can be significant as well as beneficial. It can vary from land-use to land-use, and so in mixed farms it is important that biodiversity across the entire farm be considered in farm planning and in the extension messages of agricultural, NRM and catchment management field staff. This on-ground action can be enhanced by recognition of the value of biodiversity in agricultural production at higher policy levels.

3. Although biodiversity can be significant in the agricultural component of farms, it remains most significant, and possibly most vulnerable, in remnant vegetation. This reinforces the need for policies that provide targeted and ecologically-based incentives for the effective protection of remnant vegetation and rewards for practices that go beyond duty of care.
4. Understanding of what constitutes native and remnant vegetation and 'good condition' varies markedly across Australia and suggests the need for closer links between catchment-based organisations and industry extension programs to improve the capacity of farmers to more accurately read their farming landscapes.
5. Large biodiversity gains can be made by making changes to existing land management practices: improving the condition (structure) of vegetation across all land use types (including the retention of regeneration of paddock trees); minimising soil disturbance; reducing reliance on chemical inputs.
6. Regional biodiversity planning at a landscape level will help to maximise public good investments into on-farm actions supporting biodiversity.
7. Remnant vegetation covers an extremely small proportion of the landscape in some regions. In addition, patches of remnant vegetation on twenty of the 47 farms are less than the recommended 5 ha considered necessary for their on-going survival. It is possible that at an extinction debt exists at a landscape scale. These results suggest that the long term functionality of ecosystems within regions is unclear. While it is easier to retain existing patches of native vegetation, revegetation is an important land management action in many regions, used to redress the functional imbalance across the landscape.

For researchers

This project suggests that the following areas of research and specific research questions would contribute to better integration of conservation and production and identify specific aspects of biodiversity that can contribute directly to the productivity of mixed farming

What can biodiversity contribute to productivity on mixed farms? These questions would require new and detailed life history studies of selected crops and pasture systems and associated native plants and animals.

- What is the relationship between particular functional groups of plants and animals recorded in the BiGG data set to agricultural productivity (eg pest-predator relationships, soil microbial activity and productivity)?
- What ecosystem services do selected functional groups of invertebrates contribute to farm production and sustainability?
- What are the economic and production benefits of adopting integrated pest management in crop and pasture management?
- What contribution do birds make to agricultural production through pest management? (If positive, which ones, how and how much do they contribute?)
- Does the diversity of soil micro-organisms benefit agricultural production across a range of soil types? If so, how can farmers manage soils to increase below-ground biodiversity?

Does the presence of ground cover enhance soil microbial activity? How does this impact on nutrient cycling, carbon storage and soil biodiversity?

How can management of mixed farms contribute to biodiversity without compromising long-term production? These questions would require experiments that examined the biodiversity implications of a range of crop and pasture management practices.

- How does grazing management (intensity, seasonality, inputs, native, perennial, annual pastures) impact on soil invertebrates (macro-invertebrate indicator species such as worms and mites and microbiological diversity), and what is the role of these invertebrates in influencing soil structure, nutrient recycling and infiltration?
- To what extent do planted woody perennials (e.g. fodder shrubs, carbon and biomass plantings) support biodiversity?
- Can field margins, remnant and planted, be used to provide habitat for native beneficial species in crop and annual pasture paddocks?
- How do beneficial invertebrate species respond to continuous cropping compared to crop-pasture phase rotation?
- Do no-till systems support more biodiversity in the soil and at the soil surface than conventional tillage?
- What is the impact of raised bed systems on soil and surface biodiversity?
- How do chemical (pesticides, herbicides, fertiliser) and ‘natural’ (biosolids, ‘recycled’ waste water) inputs impact on soil health (e.g. soil macro-invertebrates)?
- What opportunities exist for remnant native vegetation to contribute to farm viability (e.g. habitat for beneficial species, future opportunities, environmental stewardship, and environmental credibility)?
- Which on-farm management actions provide multiple benefits to biodiversity?

Characterising interactions between biodiversity and agriculture at the landscape scale

- Which aspects of biodiversity are likely to confer greater resilience of mixed farming to climate variability?
- Are remnants in agricultural landscapes suffering from an extinction debt?
- Do the thresholds (maintain 30% tree cover, have no more than 30% intensive farming) proposed by McIvor and McIntyre (2002) hold for mixed farming landscapes?
- What impact does increasing the intensity of production have on biodiversity at the landscape scale?
- How are mixed farmers likely to respond to changes in commodities markets and new technology, and how will these impact on regional biodiversity? (e.g. increased returns from grain production, GM crops, biofuels, 'environmentally friendly' farm products)

Characterising socio-economic elements of biodiversity in agricultural landscapes

- Which mixed farming systems are both profitable and maintain and enhance biodiversity?
- Is it possible to profile producers undertaking natural resource management and biodiversity enhancement in social, economic or other terms?
- Is it possible to identify 'trigger points' to attitude and behavioural change towards biodiversity on farm?
- How significant are stewardship payments to mixed farmers in terms of providing encouragement and compensating for opportunity costs?
- What impact do stewardship payments have on the long-term maintenance and enhancement of biodiversity in agricultural landscapes?

1. *Background – Why did we do the project?*

In recent years the Australian federal government has increased funds for the improvement of natural resource management (NRM) on farms (Hajkowicz and Collins 2008). A large component of these funds is allocated to the protection of natural values, through habitat provision in patches of native vegetation. This trend in increasing funds for stewardship payments mirrors international spending on NRM to private land holders (OECD 2003). The focus on NRM, and biodiversity in particular, is becoming an increasingly important issue in agriculture, at regional, national and international scales. A major impetus for the formal incorporation of biodiversity conservation into national environmental policies was the United Nations Conference on the Environment held in Rio de Janeiro in 1992. Signatories to the Convention on Biological Diversity (CBD) (UNEP 1992) agreed at subsequent conferences to develop biodiversity strategies based on regional goals and targets. In Australia, a parallel process has led to the devolution of responsibility for biodiversity goals to catchment management authorities and boards. The concept of biodiversity is now being introduced to land holders who are being asked to incorporate biodiversity goals into their land management activities.

The role of mixed farming systems in maintaining and actively managing biodiversity in has received very little attention (Mason et al. 2004, Appendix 1) compared to previous research studying single enterprises such as grazing (LWW, SGSL) or crop production. In addition much of the existing biodiversity literature concentrates on the role that native or semi-native vegetation provides as habitat in farming landscapes. The Biodiversity in Grain & Graze (BiGG) project was initiated to provide information on the relationship between biodiversity and a range of land uses across mixed farming landscapes.

The original Grain & Graze program model developed a vision to include a biodiversity component which was to focus on regionally relevant investigations into the role of biodiversity in mixed farming systems. However, in reality, many regions did not have the capacity to develop a biodiversity research, resulting in most regions not implementing a biodiversity project one year after the program started. It was at this time that Prof. Ted Lefroy (then with CSIRO) was invited to develop a national biodiversity project that included participation across all nine Grain & Graze regions. Prof. Lefroy (now with the University of Tasmania) and Warren Mason (as a representative for Meat and Livestock Australia) developed a proposal that linked regional biodiversity research to catchment management targets: *Aligning on-farm biodiversity with regional plans and targets through the national Grain & Graze program* (Appendix 1). Jann Williams (Native Vegetation and Biodiversity Subprogram Manager for Land, Water & Wool) became a third author after she was invited to review the original proposal. At stage, the broad approach identified for the Grain & Graze biodiversity proposal had already been endorsed by the Operations Committee of the overall Grain & Graze program.

Mason et al. (2004) considered the term biodiversity not to be a useful or ‘user-friendly’ concept at a farm level because it could be interpreted as “*often ambiguous, complex, often contested, value laden, frequently science-driven*” (Mason et al. 2004, p. 1). They also noted that biodiversity studies often focused on native vegetation components of the landscape, with the aboveground vegetation being used as a surrogate for other groups of plants and animals. They suggested that Grain & Graze could advance farmers' knowledge on the subject of on-farm components of biodiversity by assessing selected taxa across the major land use types common to mixed farming systems. They also recognised that given the limited data available, project funds should be invested in surveying biodiversity across the range of land use classes on mixed farms, with the information being used to develop a dialogue between catchment management authorities (CMAs), farmers and research staff, to develop regionally meaningful hypotheses (or hunches) from which to test relationships between components of biodiversity and land management in production landscapes.

The original proposal by Mason et al. (2004) suggested that the biodiversity project be undertaken on the existing Grain & Graze case study farms. In this way the project would facilitate serious local engagement around the issues associated with mixed farming and biodiversity, while collectively contributing to a very broad scale understanding of how to balance the needs of mixed farming businesses and biodiversity at farm and catchment scale.

Their document focused on the core question of 'how do we get the best outcome for biodiversity (composition, structure and function) on mixed farms that consist largely of crops and pastures and relative small areas of remnant vegetation?'

The resulting project took into account the fact that for many farmers and other land managers, biodiversity is possibly more important for social/aesthetic reasons than for production benefits. Therefore management options to maintain or enhance biodiversity on farms need to take farming systems and social factors into consideration. The approach provided an opportunity to link paddock, farm and regional outcomes on a national scale.

Data were collected at paddock, farm, and regional scales to provide insights into the current status and potential role of biodiversity on mixed farms. Key to the project's success was engagement of all stakeholders, making the social component as important as the biophysical.

In summary the project aimed to:

a) provide a 'snap-shot' of biodiversity across land use types to provide a benchmark for mixed farms;
b) use the data in conjunction with dialogue between farmers and regions to establish relationships between biodiversity, productivity and geographic features, to be tested in the future; and
c) use the relationships as a basis for management advice where they are well supported by evidence, and as hypotheses for future work where they are speculative.

The project was accepted by the funding bodies (MLA, GRDC, LWA, AWI) with additional funds provided by the Natural Heritage Trust. The project was structured under a private consultancy to Kiri-gainai Research, who sub-contracted the project to the University of Tasmania. BiGG commenced in October 2005, nearly two years after other Grain & Graze research activities.

Definitions

Biodiversity

The definition used in the 'biodiversity in Grain & Graze' (BiGG) project is:

Biodiversity is the variety of life, its ***composition, structure and function****, at a range of scales*' (Freudenberger and Harvey 2003). This in turn is based on Noss (1990), who proposed that biodiversity be considered as three inter-related components - compositional diversity (how many), structural diversity (how arranged) and functional diversity (what they do).

1. Compositional diversity – what native and exotic species are present on mixed farms, and in what numbers?
2. Structural diversity - how is the diversity of species and ecosystems arranged on mixed farms, both within remnant vegetation, and in the broader agricultural landscape?
3. Functional diversity – what functional groups are present and what is their relationship to the management of mixed farms?

This definition includes all species, not just native species, to reflect the interest of farmers in the diversity of organisms that are found on their farm and contribute to the services it provides.

Composition was assessed through measures of species richness and abundance as these are the simplest measure to calculate and the most easily communicated to a wide audience. Structural elements were addressed in terms of vegetation condition and habitat provision at the paddock and farm scale and at a regional scale through the use of landscape metrics. Functional diversity was assessed for invertebrates (guilds) and bird species by classification on the basis of food preference.

Species abundance
Throughout this document, species abundance refers to the total number of individuals counted. Abundance measures were calculated at the paddock, farm and regional scale.

Species richness
Species richness (or species diversity) refers to the number of different individuals (species) found at a paddock or farm scale.

2. What did we intend to achieve?

The contract with the NHT lists the following expected outputs and outcomes for the project:

1) Engagement of landholders in 8 regions across Australia on the issue of biodiversity and its relationship to mixed farming.
2) A national database containing information on the status of biodiversity on 40 farms across Australia.
3) Answer three key questions on the relationship between agriculture and biodiversity in the mixed farming zone:
    a) The extent to which farm scale measures of biodiversity (in the form of plant functional group diversity, bird species diversity, soil biological activity, vegetation condition score and species abundance for selected invertebrate taxa) are related to agricultural production.
    b) The influence of the type and intensity of agricultural management on native biodiversity on farms (as measured by surveys of birds, soil surface invertebrate species diversity, and the area and condition of native vegetation).
    c) The relative influence of site (climate, soils, topography and proximity and distribution of remnant vegetation in the landscape) and system features (cropping intensity, grazing management and native vegetation management) on selected measures of biodiversity (plant functional group diversity, bird species diversity, soil biological activity, vegetation condition score and species abundance for selected invertebrate taxa).
4) Recommendations on farming practices and landscape management likely to improve the status of natural diversity in Australian agricultural landscapes.

In order to achieve these outputs and outcomes an holistic approach to biodiversity surveys on mixed farms was adopted from the outset, taking into account social and production drivers of land use. A participatory research model was used in order to engage farmers and CMAs in the project to ensure useful outcomes for all stakeholders. An additional outcome was added, that of raising the profile of biodiversity beyond remnant vegetation and to have biodiversity seen as a core component of the farm business and management, not an optional extra to be addressed during periods of relative prosperity.

The three key research questions (3a,b,c) have been adapted from the original project proposal (Mason et al. 2004). A decision was made to attempt as many components as possible, focusing on data collection on farms, given the available time and funds. Data were collected at a range of scales and in a variety of formats.

The project proposal put forward by Mason et al. (2004) stated that the approach to the project should be *'to explore the relationships between site and system characteristics of mixed farms (climate, geography and management) and selected measures of farm performance and biodiversity. It's about starting at square one, and trying to quantify and understand the role biodiversity plays in supporting production on mixed farms and the role that farm management can play in supporting the viability of the native biota and ecosystem processes.*

The data → dialogue → hypothesis approach will involve collecting information on the composition, structure and function of biodiversity on mixed farms as the basis for dialogue between landholders, scientists and natural resource managers, allowing them to jointly develop hypotheses that can be tested in greater detail. To jump to hypotheses without the participation of landholders will result in 'more of the same'. In addition, developing hypotheses (with or without farmers) up front, requires a level of information about biodiversity and mixed farms that is currently only available for remnant vegetation and not for the other land uses on mixed farms. The dataset described below will allow the Grain & Graze Program to not only engage in a dialogue with farmers about biodiversity, but also provide sufficient data to tentatively explore relationships of interest to both farmers and those with responsibility for nature conservation at larger scales.' (p. 6).

A model of data collection is provided in Figure 1. This figure shows a stylised mixed farm with four land use classes (two in crop rotation, one permanent pasture and one remnant vegetation). One paddock considered typical of each land use type is selected as representative of that land use. The vegetation layer is depicted as the central element of the paddock sampling as agriculture focuses on manipulating the vegetation layer – crops, pastures and remnant vegetation. The approach focuses on exploring relationships between measures of site and system characteristics of mixed farms (i.e. climate, geographical features and management regime) and selected measurements of biodiversity (species and functional group diversity within plants, birds and invertebrates) and farm physical and economic performance. Further details are given in Appendix 2.

Success factors include:

1) Engage landholders in exploration of biodiversity on their farms and in doing so empower them to take more part in debates on the role of biodiversity on mixed farms;
2) Establish a database as a benchmark from which to draw hypotheses;
3) Instill a greater understanding of components of biodiversity and management impacts on them in mixed farming systems; and,
4) Recognise the contribution that mixed farmers make to the national conservation estate.

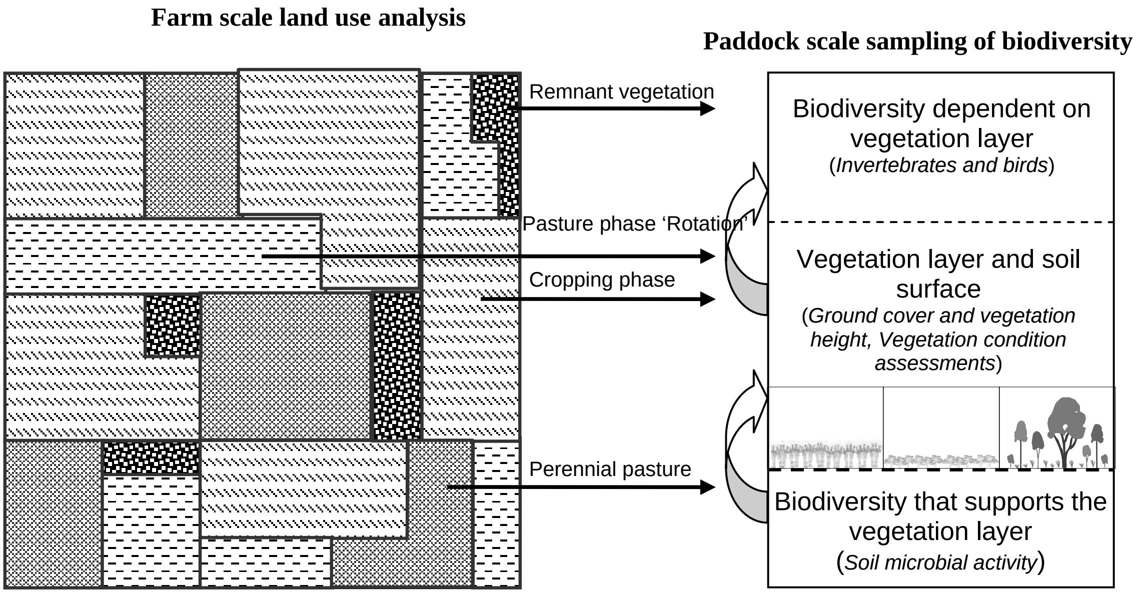

Figure 1. Stylised mixed farm with four land uses and four paddock based sampling sites. Adapted from Mason et al. (2004).

The approaches taken to successfully achieving stated objectives include:

1) Use of workshops, face to face meetings, field trips, development and dissemination of extension material;
2) Create standard data collection protocols with the data being sent to one central location for collation and analysis in order to maximise consistency and quality control in the dataset. Methods to be adjusted when and where appropriate e.g. data sheets were reviewed and revised after the first season of sampling, cotton strips buried wet during 2007 due to the extremely dry conditions ;
3) Liaise with regional project officers regularly via telephone and email and at least one face to face meeting per year, provide assistance with interpretation of regional data sets; and,
4) Reach out to a wider audience via conference papers, extension material and input into regional extension material.

The national program team organised two forums each year; a research forum and a national forum. Farmers, regional project staff and national project teams were invited to these forums which were held in different regions around the country. These events provided opportunities for all stakeholders to engage with each other across a range of topics, providing additional communication opportunities for the projects.

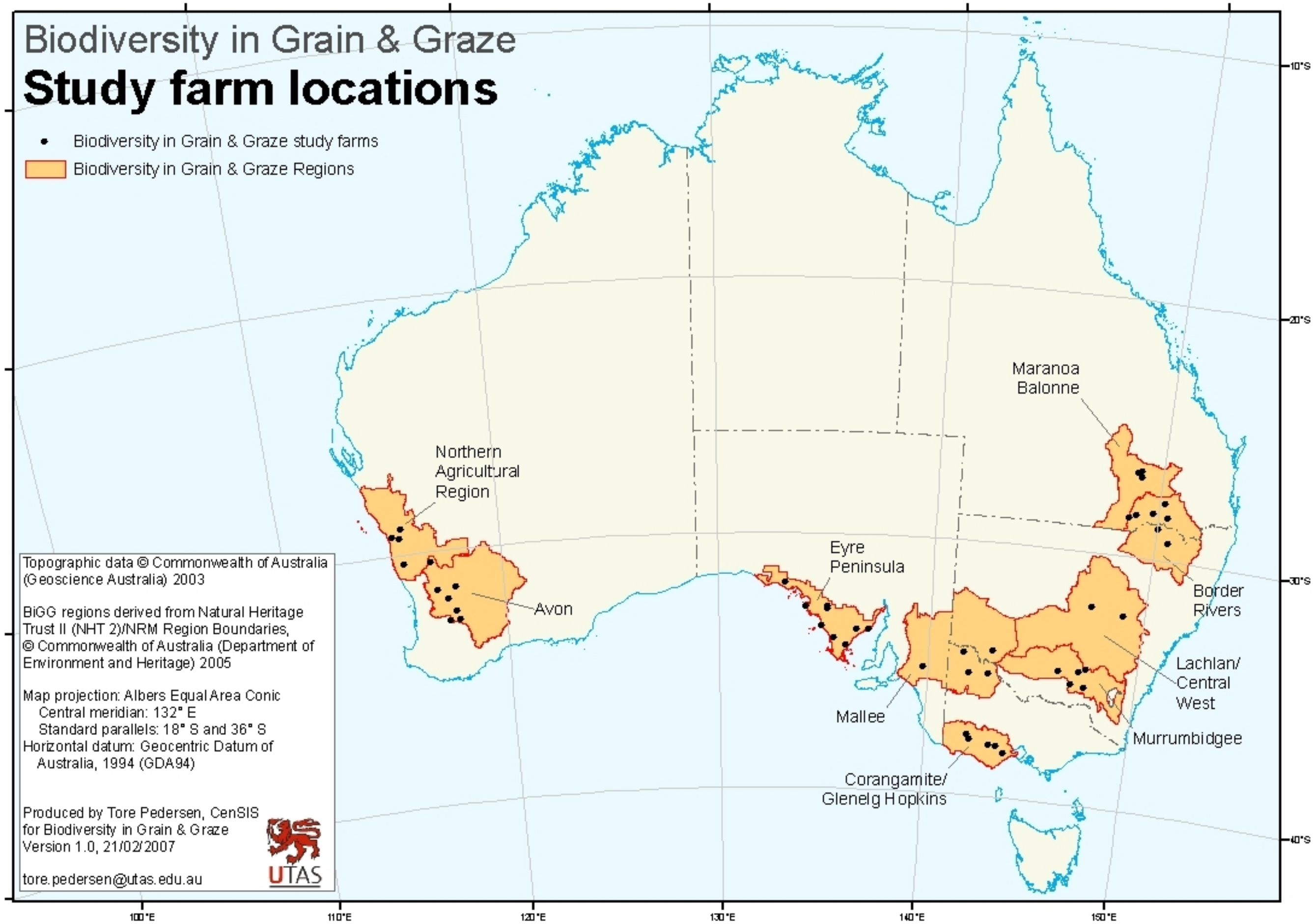

Figure 2. Location of BiGG farms across the nine regions. Abbreviations throughout the document for regions are;
NAR=Northern Agricultural Region, Avon=Avon, EP=Eyre Peninsula, Mall=Mallee, CGH=Corangamite/Glenelg-Hopkins, Murr=Murrumbidgee, LCW=Lachlan/Central West, BR=Border Rivers, MB=Maranoa-Balonne

Methodology

Initially eight of the nine Grain & Graze regions were approached by the national program manager to participate in the project. Each region was asked to enlist the help of five farms on which to collect the necessary information. Farms were chosen to represent the range of mixed farming enterprises. Regional officers were asked to choose one farm with a high proportion of cropping, one with a low proportion of cropping, one close to a large remnant, one isolated from a large remnant and one other mixed farm. Farm locations are given in Figure 2.

Each farmer nominated four land use classes where the biodiversity data would be collected during autumn and spring 2006 and 2007: crop paddock (preferably wheat); a 'rotation' paddock i.e. under pasture phase – the aim was for this to be under annual pasture but for some regions with longer rotations included perennial species (e.g. lucerne); a perennial pasture (native and/or exotic grasses, lucerne, tree lucerne, salt bush) and 'remnant' vegetation (included a wide range of remnants from excellent to very poor condition).

A field data collection manual was written and trialed with the regional project officers in January 2006. The project officers then undertook field surveys for vegetation (plant species, presence and cover, functional group, height, habitat provision), surface invertebrates (pitfall traps were used to collect ground dwelling spiders, beetles and ants), soil samples (for soil nutrient analyses) and microbial activity (using cotton strips, buried for 2 weeks). Bird surveys were undertaken in the same locations by Birds Australia atlasers. These were organised by regional project officers. Farmers were interviewed on their knowledge and approach to biodiversity management on farm and were also asked to provide information on production (t/ha wheat, number of bales of wool, number and type of stock sold) and land management practices, particularly with respect to inputs and outputs on the four 'target' paddocks. They were also asked to provide information on the layout of their farms including number of paddocks, land use and whether remnants were fenced or unfenced.

The subset of beetles, ants and spiders were targeted for the invertebrate surveys as they have been shown to respond to land use changes, both in Australia (Anderson 1995) and overseas (Weibull et al. 2003). They also provide 'ecosystem services' on farm in the form of pest management (beetles and spiders) and nutrient turnover (ants). An additional advantage is that many are large and may be identified by farmers, potentially as indicators of land use impacts.

The research team, including the project coordinator, was based in Hobart at the University of Tasmania (UTAS). All invertebrate samples were sent to UTAS for sorting and identification. All cotton strip samples were frozen and sent to UTAS by airfreight for analysis. Bird surveys were completed on Birds Australia survey forms and were sent to Birds Australia and to UTAS. Vegetation data were recorded on field data recording sheets and sent to UTAS either in hard copy or electronically. GIS data were compiled by the GIS team.

Not all organisms were identified to species level (e.g. invertebrates). However the terms species abundance and species (morphospecies) richness relate to the level of identification relevant to each group (birds, plants, beetles, ants, spiders).

3. *Results – What were they and what do they mean?*

1) Engagement of landholders in 8 regions…

Engagement of landholders was driven by the regional project officers, with the national project team focusing on engaging and training the project officers.

Initially eight regions were approached to take part in the project. Many regions were able to offer five farms as requested while others offered more (Eyre Peninsula – 10 which was reduced to 9, Avon – 6) and one provided two properties due to a large commitment to a regional biodiversity project. Six months into the project, Maranoa-Balonne region asked if they could be involved in the project, adding another five properties to the dataset.

This project was funded to allow stakeholders to convene at least once a year. Most farmer engagement was undertaken on the farm, through regional project officers. The national project coordinator was able to visit all regions at least twice over the two year data collection period. She visited 32 of the 47 participating farms and assisted with field data collection in six of the nine regions. This experience was invaluable in coming to terms with the range of systems, natural and agricultural, in operation, which provided additional insights into data interpretation during the analysis phase of the project.

Additional opportunities for farmers, regional project officers, and national team members to meet were provided at the annual research and national forums, and the farmer forum in Hobart. The research and national forums, in addition to regional field days, allowed for the engagement of farmers not directly involved with BiGG.

Engagement of regional officers required development of a standardised field data collection manual (Appendix 2). This was introduced to regional project officers through a field trial with all project officers attending. Sheila de Lange, the BiGG regional officer for Murrumbidgee CMA, organised the trial sites on one of the participating farms in January 2006. Three days were spent learning about the diversity of mixed farming systems across the regions, trialing the field techniques and receiving advice on how to conduct farmer interviews from Nigel McGuckian from the national social project. This workshop provided momentum within the team and led to increased engagement with the project.

A second meeting was held in Hobart in January 2007. This meeting provided the regional project officers with additional insights into how their invertebrate and cotton strip samples, vegetation and bird surveys, farm data and other information was being processed. There had been some concern over the delay between sending samples in and results being sent out. The delays were caused by a range of factors, including some problems with data collection within regions and 'bottlenecks' occurring at UTAS, particularly with relation to sorting invertebrates. Once regional officers could see first hand how the data were being processed, they became much more accepting of the project and had a greater understanding of the potential outcomes. Regional project officers were contacted regularly through email and telephone and requests for data were met as often as was practical, usually in the form of posters for regional displays and field days (Appendix 3a,b,c,d,e).

Regional officers provided advice to the national team, particularly with respect to communicating the expectations of all involved in the project.

Biodiversity results were presented at the research and national forums, in conjunction with regional project officers involved with BiGG and other regional biodiversity projects. This format was used to highlight the interaction and links between the research projects operating at different scales. It was at these events that engagement with non-BiGG farmers could take place.

The third BiGG forum for farmers in Hobart in Jan 08 provided an excellent opportunity for BiGG researchers to interact directly with farmers and with regional project officers. This forum was funded by LWA and was a great success in terms of the development of 'hunches' that could be developed into research hypotheses (Appendix 4). Discussions facilitated by Nigel McGuckian covered topics such as the definition of biodiversity and its relevance to production. Informal interaction between farmers provided valuable insights into the possibilities arising from the appropriate management of natural resources on farms. The opportunity for farmers to explore the various components of biodiversity, collected from their own properties extended many of their perceptions about biodiversity and the roles they play in managing biodiversity across a range of land use types on their properties. Their perception of biodiversity existing outside remnant vegetation was developed during this forum and captured in the publication 'Thinking BiGG' (in press).

Communication activities included providing regions with graphs and posters of preliminary results for their region. Bird Fact sheets were also created enabling each farmer to see their relative contribution within their region (Appendix 3c). Farmers were given a folder of results at the forum in addition to a display box of beetles and ants, identified from their properties. Additional information included the function of the animal on the farm in relation to ecosystem service provision and potential production benefits.

Other more general communications activities included presentations at a range of conferences, some research oriented (Spatial Science Conference, Hobart, May 2007, see Appendix 5, Ecological Society of Australia, Perth, December 2008), and others with a mixed audience, including farmers, extension officers and researchers (Tamar NRM Biodiversity and Production Conference, Launceston, July 2007, Stipa, Mudgee, October 2007, see Appendix 6).

Products developed by Sefton & Associates in collaboration with Kiri-gani Research and BiGG include 'Thinking BiGG' and 'Talking BiGG', producer interviews based on their perception of biodiversity and how they manage their properties to enhance biodiversity outcomes on farm (in press). Both of these came out of the farmer forum held in Hobart.

Landholder engagement in the biodiversity component was central to the success of the project. A total of 47 landholders from 9 regions were successfully and actively engaged with the project. Initially this engagement was channelled through the regional project officers. Response by regional project officers varied between regions. Less positive responses were strongly linked to the late starting date of the project, the sense that it had been imposed on regions when they had already committed their resources (staff and funds) to other regional Grain & Graze projects and that four of the eight regions had actually invested in regional biodiversity projects.

The project exceeded its objective in terms of engagement of number of farms and number of regions. This was a result of enthusiasm at the regional level in some regions (e.g. EP where two school groups were involved), and enthusiasm at the farm level (e.g. Avon where one farmer contacted the regional field officer to ask if he could be involved, even though five farms had already been chosen. This resulted in Avon collecting data on six farms).

Many of the issues relating to early engagement of regional project officers may have been averted had the project been better aligned from the start with other national and regional projects. However, multiple visits to each region by the national biodiversity coordinator to assist in field data collection and to liaise with regional project officers with respect to issues and the integration of their interpretation of regional results **led to a very high level of engagement over the two year data collection period**. Initially regional project officers were impatient with the length of time taken before results of the surveys were sent out. Once they had seen the process of data collation/sorting/analysis, they were much more accepting of the time lag between collection time and receipt of results. For example, the sheer number of invertebrates in samples meant that sorting and identification took up to 6 months for each season.

Time taken to sort invertebrate samples was grossly underestimated. The value in having research staff and field officers meeting regularly (at least once a year), sometimes together with the participating farmers, cannot be underestimated, and this paid enormous dividends in maintaining the energy levels of all involved.

Additional funds were provided by Land & Water, Australia on behalf of the Grain & Graze partners at the request of Dr Richard Price to run a farmer forum in Hobart. This event provided research staff, regional project officers and farmers with an opportunity to interpret results and develop hypotheses requiring further testing. Twenty-seven farming families, including partners and children, took part in the BiGG Farmer Forum in Hobart in January 2008. General attitudes towards biodiversity were captured in the farmer interviews at the start of the project. Most farming families had a much deeper understanding of biodiversity on their farm after the workshop. However one producer commented that his management across all land uses must be satisfactory because there was little difference in biodiversity measures between them. In actual fact, the remnant chosen for this property was in very poor condition. **This highlighted the regional differences at a national scale of what constitutes 'remnant vegetation' and what**

constitutes 'good condition'. There is an important policy and communication issue here about the capacity of landholders to meaningfully read their farming landscapes.

Farmers developed 'hunches' with respect to what they thought the data were telling them, and whether the findings were conclusive or whether more information needed to be collected. They were much more accepting of the time delays with respect to obtaining results than the regional project officers and seemed to have a better understanding that the data collection and interpretation would take some time. Two products 'Thinking BiGG' (a booklet of BiGG case studies) and 'Talking BiGG' (a CD of BiGG interviews) are based on farmers' insights about the management of biodiversity on their farms.

The farmer forum was an expensive exercise in terms of financial investment, but the returns in engagement, team-building and co-ownership of the present and potentially future projects cannot be underestimated.

2) National database

Summary biodiversity data for birds, invertebrates, cotton strips and vegetation have been sent to the Grain & Graze national database at the University of New England (managed by Professor Jim Scott). GIS data are currently held on a 15 gigabyte external hard drive. These data are bound by licensing agreements to the BiGG national team for the life of the project. A catalogued invertebrate database is held at the School of Geography and Environmental Studies, UTAS and is continually being updated as taxa are identified. Bird survey data have been forwarded to Birds Australia, to be added to their database. Spreadsheets for each region are kept with the national biodiversity project co-ordinator in TIAR, UTAS.

Developing the various databases was labour intensive, particularly the GIS databases and it was difficult to engage participants when they were unsure of what the information would be used for. The data are in a variety of formats making it difficult to combine all in one database. **The BiGG database contains valuable benchmarking data for the future use of taxa (e.g. beetles, ants) as regional indicators of sustainable land use.** There is much more information available in the database than has currently been analysed and so the full value of the data has not been realised. The database can be used to build on the initial engagement with farmers to test hypotheses developed in BiGG.

Most datasets are relatively complete. Data were assessed when they arrived to ensure that datasets were relatively consistent. Some cotton strip samples were discarded if they took longer than 24 hours to reach UTAS or if they were obviously not frozen on arrival. Data collection for birds was relatively reliable due to the use of Birds Australia registered atlasers to undertake the surveys.

Regional capacity was overestimated in some cases, limiting the use and value of the biodiversity dataset for the region. Some regions did not engage easily with ecologists necessary to undertake some of the field components, for example bird surveys, or identification of unknown plant species. This limited capacity most affected the vegetation data set. As a result no analyses could be confidently undertaken on the composition of plant species across land use types on farms in all regions. Some regions employed ecologists providing relatively reliable vegetation data.

Collating GIS information for farms and for state native vegetation layers took more time than anticipated. Capacity for GIS data collection was not available in many regions. In future it would be preferable for a GIS officer to have direct links with farmers and regional GIS support staff when collecting the spatial data in order to better communicate project needs. Standard GIS terms were often seen as 'jargon' by regional project officers and farmers, with the result that farm paddock maps took a long time to produce (Appendix 7).

The GIS database is an excellent resource for future work and can contribute to the development of regional biodiversity catchment targets. The automation of spatial metrics was a key output for the GIS component. In addition adding finer scale digital elevation models and other environmental variables such as soil, geology and rainfall data to the dataset would enable greater application of the terrain analyses. The value of the farm maps showing their relative contribution to native vegetation cover within the farm and in the surrounding area makes them a powerful communication tool.

Addressing the three key research questions

The results section can be delivered in a variety of ways based on the questions asked (Key Questions 3a,b,c), the type of data analysis (descriptive, exploratory statistics) and scale (paddock, farm, region). What is presented here is a subset of the potential suite of data analyses from the BiGG datasets. Methods for data collection are given in the Field data manual (Appendix 2). Due to the unbalanced design of the data (e.g. different number of farms in different regions, missing variables, different scales of data collection), non-parametric statistics were preferred for the preliminary analyses.

One-to-one relationships were explored between one of the measures of biodiversity (e.g. ant species richness) and one site or system feature or one measure of productivity. These are presented as scatter-plots and correlations in sections 3a and 3b.

Single measures of biodiversity (e.g. bird species composition) were analysed with multiple measures of site, system and productivity. These multivariate analyses are displayed in the ordination plots in sections 3b and 3c. These data exploration approaches were undertaken to see if it was possible to identify major drivers, trends or patterns, influencing biodiversity, across the full suite of 47 farms. A more complex level of analysis is between groups of biodiversity measures and groups of site, system and productivity measures using canonical correlation analyses. These were carried out to answer the question '*Do site or system features have greater influence over biodiversity',* i.e. how much of the variation in biodiversity measures is a function of farming practice (system features) and therefore open to human influence, and how much is determined by topography, off-farm vegetation and other geographic features outside the immediate influence of the land manager?

Addressing key research question

3a) *Is there a relationship between farm scale measures of biodiversity and agricultural production?*

Yes

It was difficult to collect data on on-farm production as there was no planned overlap with other Grain & Graze national projects, particularly the economics and the social projects which were established almost a year later. In many regions, field officers were uncomfortable asking farmers personal questions with respect to profit. Therefore production questions were asked in terms of t/ha wheat produced, number and type of stock carried/sold, number of bales of wool produced. For these figures to be comparable across the country, they needed to be averaged within the region. However much of this information was missing from the interview data. **A more targeted approach involving economists and ecologists would be able to provide more detail to this question.**

The selected farms covered a wide range of cropping/livestock production mixed enterprises (Figure 3a,b). Farm level analyses indicated several correlations between variables collated, and coded where necessary, from the farmer interview data (see Appendix 2 for interview questions). For example, properties that had been owned or managed for a long time were more likely to have a greater proportion of their land under perennial pasture, and less under crop/rotation (Table 1).

Properties with a large proportion of perennial pasture ran more livestock, with a preference for either cattle or sheep, which is likely to be reflected in regional differences in landscape suitability. The choice of cattle or sheep is likely to be related to regional preferences, with properties in Queensland recording high numbers of cattle, while those in southern Australia had high numbers of sheep.

The data suggest that sheep livestock production can be further broken down into farms focusing on wool or meat sheep. Smaller farms (<3000 ha) produced more wool than larger farms (Figure 3b). Farms recording higher production of wool per year produced finer wool, whereas sheep meat producers produced coarser wool. Meat sheep production generally relied on more pasture inputs, such as fertiliser, due to the increased nutritional requirements of cross-bred prime lambs compared to merinos used for wool production.

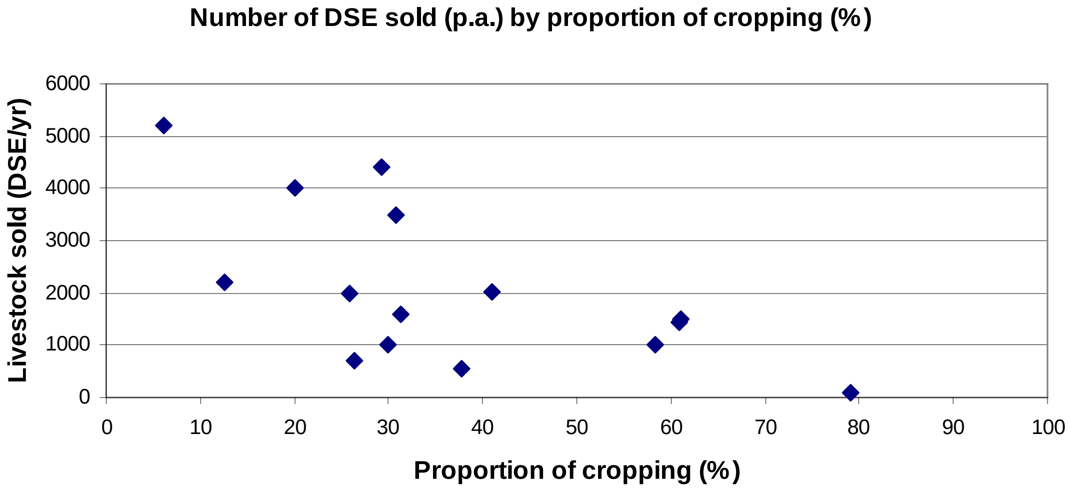

Figure 3a. Number of livestock sold per annum is lower on properties with strong focus on cropping.

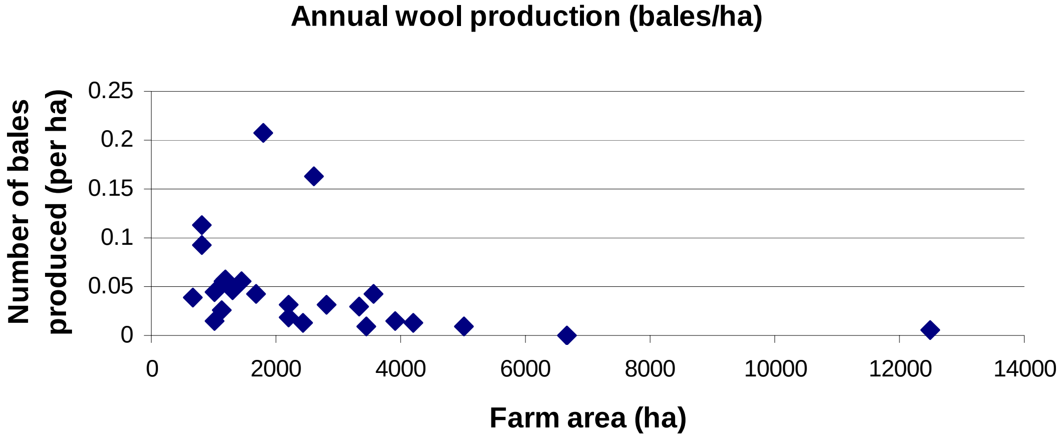

Figure 3b. Annual wool production (bales/ha) decreases with increasing farm area.

Differences between enterprise mix are important because they impact on selected measures of biodiversity found on mixed farms, through the inputs used. Herbicides were more likely to be used on properties with large areas of perennial pastures, while pesticide use was positively correlated with percentage of arable land and negatively correlated with percentage of remnant vegetation. Microbial activity was positively correlated with fertiliser use on pastures, and is also correlated with a range of soil nutrient variables (Hon 2007, Appendix 8). Therefore, this project uses the results from the cotton strip analyses as surrogates for agricultural inputs and soil disturbance.

These selected measures of production impact on biodiversity at a farm scale in many ways. More species of beetles were found in pastures recording higher microbial activity (a surrogate measure of nutrient inputs) in perennial pastures (Table 1). However the converse is true for ant species richness. The total number (biomass) of beetles was higher in pastures and remnants with high levels of microbial activity. Large properties were less likely to report that they grazed remnant vegetation. However, farmers that produce large quantities of wool reported that they were more likely to graze remnant vegetation. Grazing will impact on vegetation structure, height, litter availability, all of which can impact on habitat for fauna such as ants and spiders. Other possible explanations for these relationships are given in section 3b,c and section 4.

Farms with high grain production (wheat t/ha) had fewer different species of spiders and birds than farms with lower grain production (Figure 4a,b), however this was more likely to be influenced by the fact that farms with higher wheat production (t/ha) also had a lower proportion of remnant vegetation (Table 1).

These results could also reflect regional differences such as time since settlement and proximity to large areas of native vegetation on and off farm, all of which warrant further attention.

Table 1. Significant relationships between production data collated from farmer interviews and selected measures of biodiversity.
(Test statistic Spearman's rank correlation coefficient, r_s >±0.4, n=number of samples, *P<0.05, **P<0.01, ***P<0.001. TSR= total species richness, TA= total abundance)

	Tensile strength (microbial activity on cotton strips)			Sheep		Proportion – sheep %		Grain
Bird TSR	Remnant	Pasture	Rotation	Bales/yr/arable/ha	Micron	Meat	Wool	Wheat t/ha/yr
Bird TSR								-0.539** (n=27)
Spider TSR								-0.447* (n = 27)
Beetle TSR		-0.427** (n=46)	-0.489*** (n=46)					
Ant TSR		0.418** (n=46)						
Beetle TA	-0.429** (n=46)	-0.498*** (n=46)				-0.446* (n=29)	0.412* (n=29)	
# Cattle sold (pa)				-0.434* (n=33)				
# Bales/yr/arable/ha					-0.445* (n=24)			
Micron						0.425* (n=25)	-0.425* (n=25)	

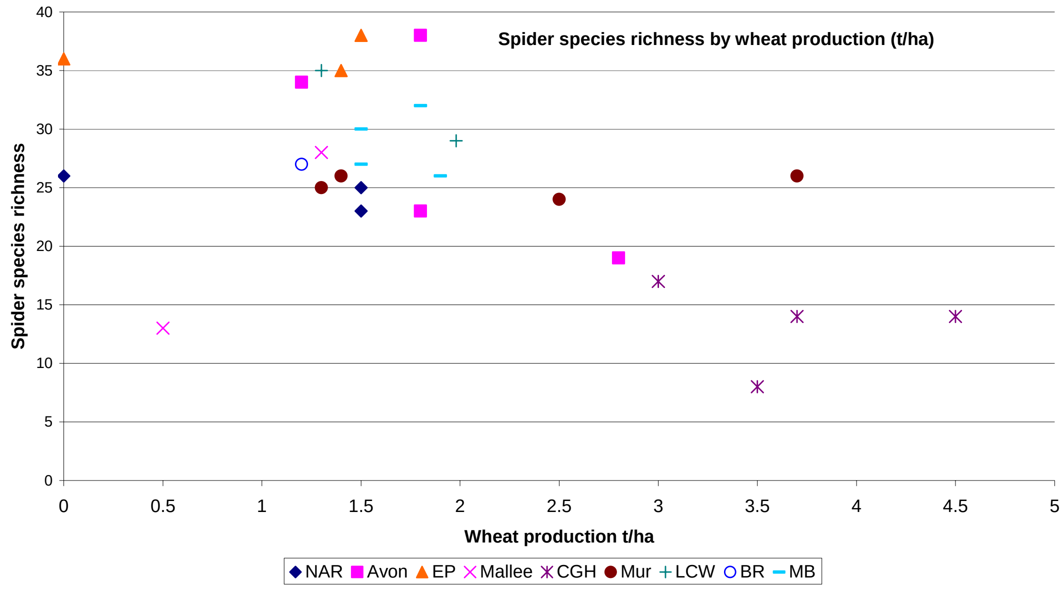

Figure 4a. The relationship between spider species richness and wheat production (t/ha)

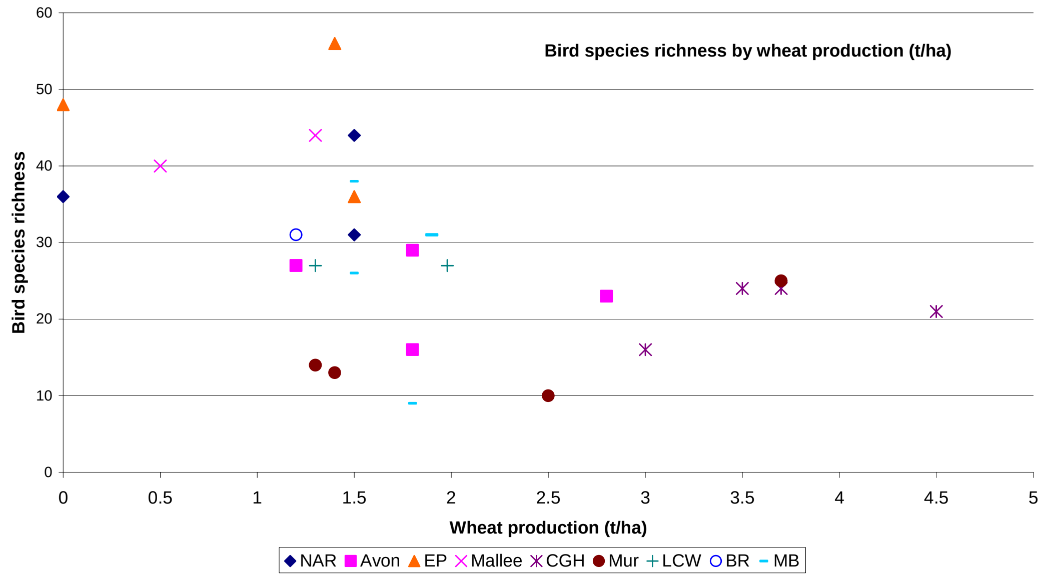

Figure 4b The relationship between bird species richness and wheat production (t/ha)

Addressing key research question:

3b) *Does the type and intensity of agricultural management influence native biodiversity on farms?*

Yes

Remnant vegetation provides diverse habitat for a variety of taxa. Birds and ants (Figure 5,6,7) recorded higher species richness in remnant vegetation than in other land use types. Perennial pastures recorded high species richness for some taxa (birds, ants) compared to crop and rotation paddocks. **Crop and rotation paddocks were the least diverse across a range of taxa.** Management of remnant vegetation e.g. grazing, nutrient inputs affects native biodiversity by impacting on the condition or habitat value of the vegetation.

Birds, spiders and ants were correlated with similar environmental variables, in many cases indicating some overlap between habitat preferences or resource requirements. Interestingly, **the presence of threatened bird species was significantly higher in regions where exotic bird species were in low numbers or absent**.

There was considerable overlap between the land use classes. This was unavoidable in many instances due to the scale at which data were collected. Rotations (break-crop/pasture-phase) in some regions allowed for the establishment of lucerne whereas in other regions annual pastures and legumes dominated rotations. Perennial pastures included lucerne, tree lucerne, salt bush, and native and sown pasture species. Remnant vegetation varied in extent, vegetation type and quality/condition, and usually included trees. Standard definitions of different land use types were given in the field data manual but were not broad enough to incorporate the range found in different regions. However **strong differences were found for biodiversity measures between different land use classes. These differences related to soil disturbance regimes where crop and rotation are more heavily disturbed than pasture or remnant.** Tillage practices are likely to impact on ground dwelling invertebrates, but this could not be explored using the current data set. Investigations into 'field margins' around crop paddocks e,g. salt bush alleyways could increase biodiversity around intensive land use classes.

Birds

Type of agricultural production

A total of 181 bird species from 45 families were recorded on the 47 farms over the two year survey period over 2006 and 2007 (autumn and spring surveys only). Of these, eight are introduced species, 28 are listed species (listed priority or threatened species under state or federal legislation) with 17 of these listed species sighted in paddock types outside remnant vegetation. Listed species were found on 39/47 farms (see an example of the bird fact sheets in Appendix 3). Twenty-three birds are listed as nationally declining species (Barrett et al. 2003) and 51 are listed as nationally increasing species, i.e. those that are able to adapt to fragmented, agricultural landscapes. Sixty-four per cent of the birds are known to predate on insects. No exotic species were recorded in Maranoa-Balonnne.

Bird species richness was highest in remnant vegetation over any other land use type (all data, all seasons, Kruskal-Wallis H=195.6, d.f. = 3, P<0.001, Dunn's Method, P<0.05, Figure 5).

Birds were classified into functional groups according to their diet and habitat preference. Significantly more bird species from all food preference groups were recorded in remnant vegetation (Figure 6, Kruskal-Wallis, all groups d.f. = 3, P<0.001, Dunn's Method, P<0.05). This was also the case for the woodland reliant species. All bird groups were represented in all other land use types.

Intensity of agricultural production
At the farm scale, bird species richness was higher on properties that had a greater proportion of remnant vegetation (r_s =0.46, n = 42, P<0.005) and was lower where microbial activity was high (r_s =-0.412, n=40, P<0.01) and where fertiliser had been added to pasture paddocks (r_s =-0.412, n=37, P<0.05).

Significantly more birds species were recorded in sites that had two or three shrub/tree layers (H=75.3, P<0.0001), compared with those with just one overstorey layer, highlighting the role that vegetation structure plays in providing habitat for birds.

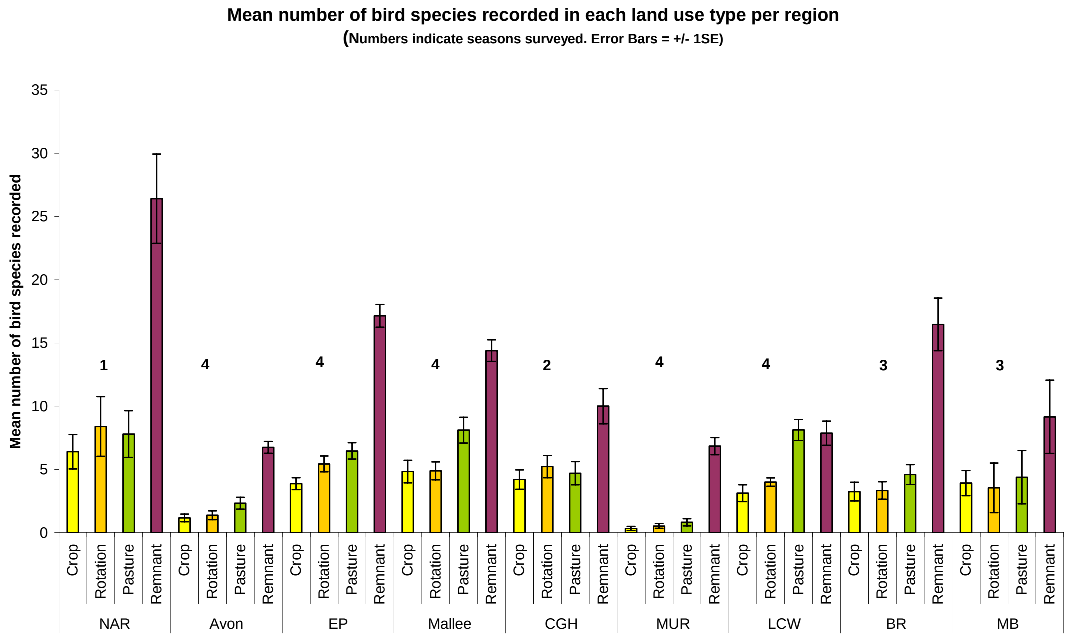

Figure 5. Distribution of mean bird species richness in each land use type for each region

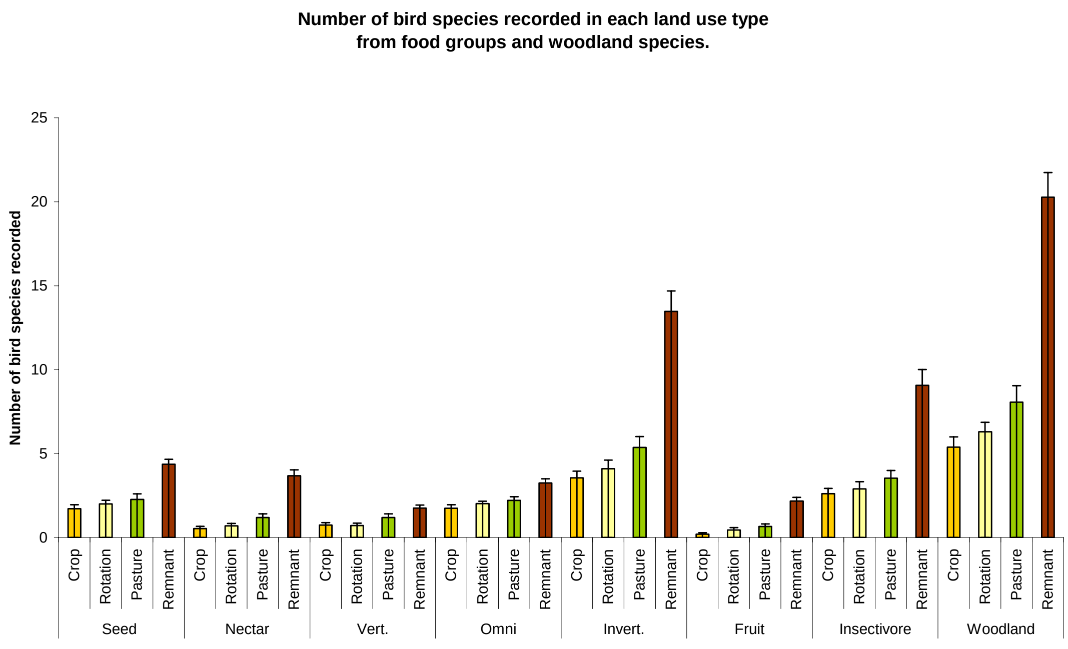

Figure 6. Distribution of mean bird species richness in each land use type by food and habitat preference

Invertebrates
This invertebrate collection represents the most comprehensive ever collected in Australia over a range of land use classes common to mixed farming systems. A total of 4933 samples were collected for three seasons (autumn and spring 2006 and autumn 2007), amounting to 233 902 individuals being sorted and identified, comprising of 330 spider groups (sorted to sub-family), 504 beetles (sorted to genus or species) and 858 ants (sorted to genus). Due to the large number of invertebrates collected, sorting and analysis is taking longer than anticipated meaning that only three of the four seasons' data are available for analysis. The data set includes species that have not been recorded for decades, highlighting the lack of investment in nation wide invertebrate surveys.

Type of agricultural production - ants
Across the whole data set ant species richness was highest in remnant vegetation and lowest in crop and rotation paddocks (H=60.4, d.f. = 3, $P<0.001$, Dunn's Method $P<0.05$). The difference between land use types was noticeably greater in eastern states than in western states (NAR, Avon, EP, Figure 7). The reason for this difference could be due to productivity gradients (e.g. higher productivity in the east compared to the west) or the presence of more diverse soil types in the east.

The difference in crop and rotation paddocks is more noticeable in eastern regions and may be related to the types of crops grown and the frequency of pesticide use. These hypotheses require further attention.

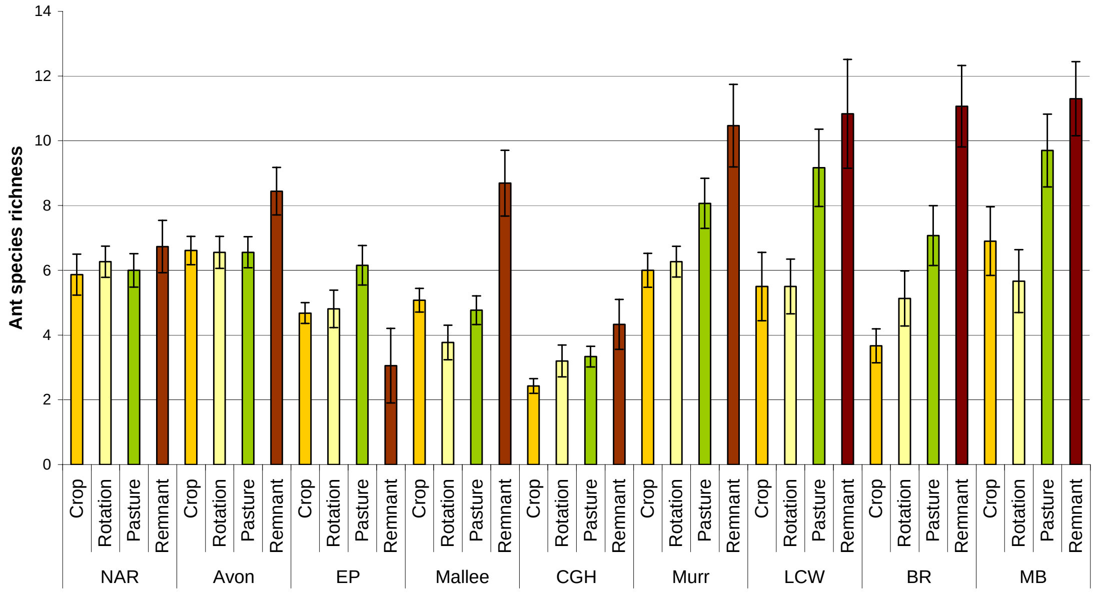

Figure 7. Variability in mean ant species richness (genus) across land use types for each region.
(Standard error bars shown)

An ordination of ant data illustrates the difference in ant genera between different land use classes (Figure 8). The remnant vegetation for Corangamite/Glenelg-Hopkins (CGH) is located with the crop and rotation paddocks of other regions, indicating the poor quality of the remnants in that region.

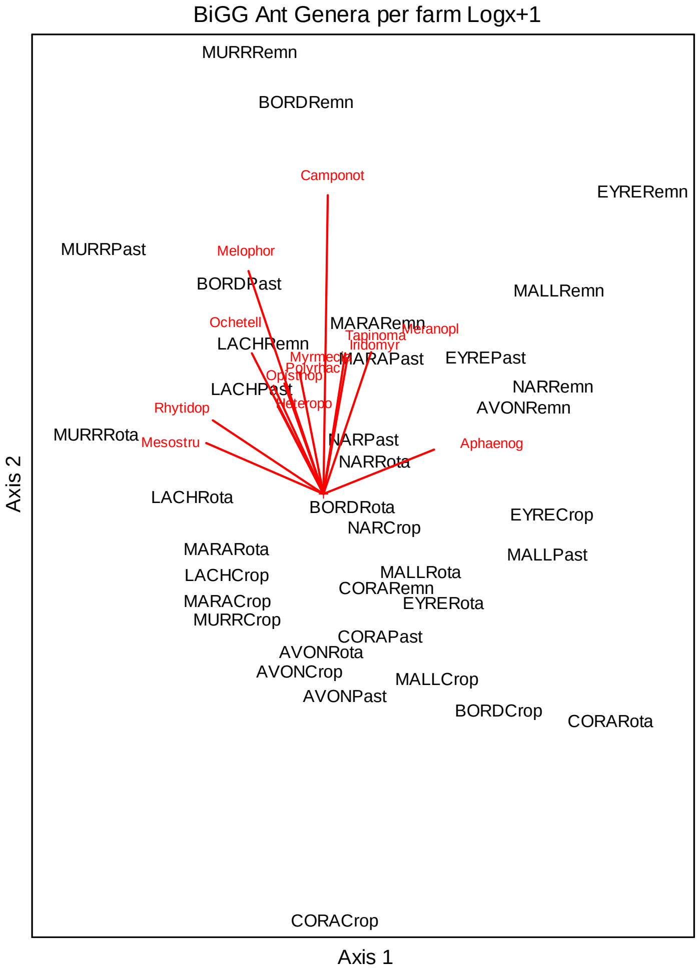

Figure 8. NMDS ordination of ant genera across all land use types.

Land use had a dramatic effect on ant numbers (Figure 9) and the profile of ant genera present in the regions (Figure 10). Rotations and crops had less than one-third the ant activity recorded in pastures and remnants. Remnants typically yielded the largest number of ants and the largest diversity of genera. Pasture was also high to very high in ant numbers but the diversity of genera was lower than in the remnants.

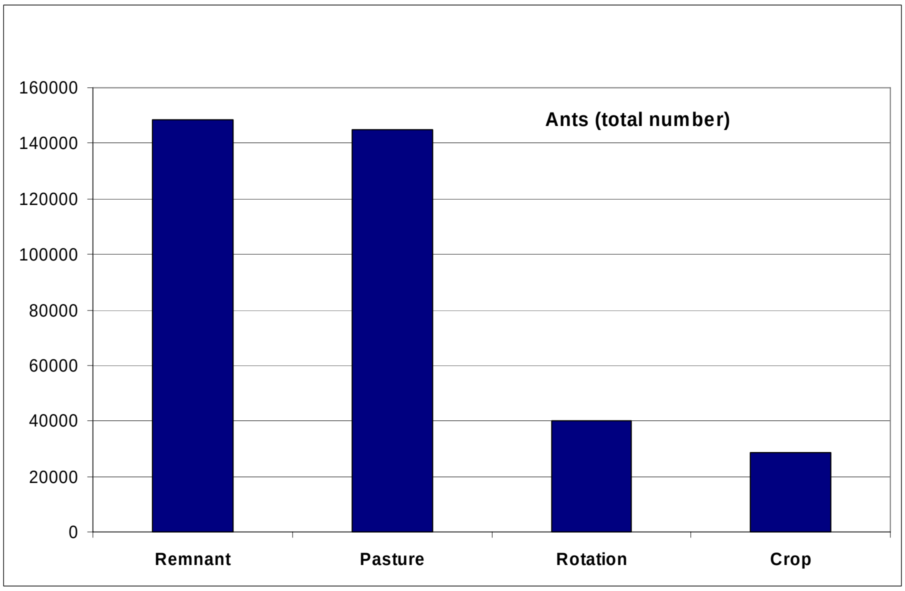

Figure 9. Differences in ant abundance across land use classes

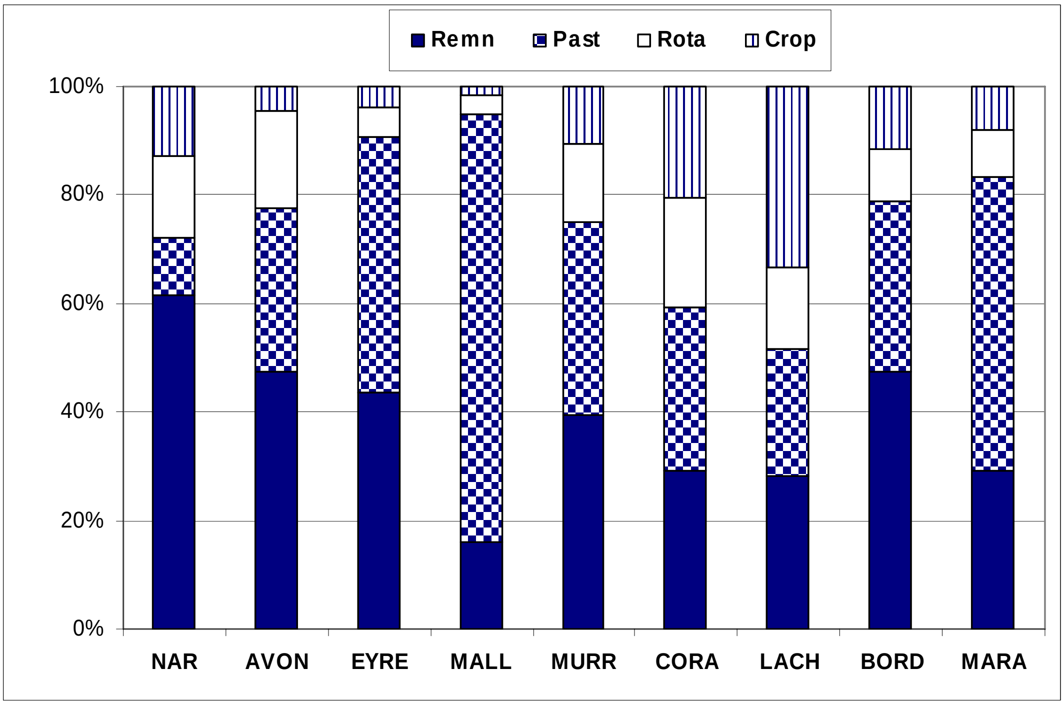

Figure 10. Relative abundance of ants in each land use type for each region. (NAR = Northern Agricultural Region, Eyre = Eyre Peninsula, Mall = Mallee, Murr = Murrumbidgee, Cora= Corangamite/Glenelg-Hopkins, Lach = Lachlan/Central West, Bord = Border Rivers, Mara = Maranoa-Balonne)

The CGH (Cora in Fig. 10) region was unusual because it had a rather even proportion of ant numbers in each land use class. This result may reflect the poor condition of the remnants chosen in this region (see section 4 for more discussion on the impact of remnant condition on biodiversity). Mallee had the highest proportion of ants in pasture but the lowest in crops and remnants compared to other regions (Figure 10).

Intensity of agricultural production - ants
The farm level analyses show fewer ant species in land uses recording high microbial activity (a surrogate measure of inputs). However in remnant vegetation, ant species richness was lower on properties that had a high proportion of sheep used for wool production. This is likely to relate to the increased likelihood of the remnant being grazed in mixed farming systems that focus on wool production, therefore altering habitat availability. This hypothesis is supported by data on remnant vegetation condition, where ant diversity is positively correlated with the presence of woody vegetation, trees and shrubs (r_s =0.499, P<0.001, n=178) and small shrubs 0.5-2m tall (r_s =0.44, P<0.001, n=177).

Type of agricultural production - beetles
Analysis of the beetle data showed similar species richness across all land use types but with higher species richness in pasture paddocks than in remnant vegetation (*H*=10.1, d.f.=3, P<0.05), largely driven by results from three regions (Border Rivers, Mallee and EP, Figure 11). All Border Rivers properties and many of EP properties had a large component of native pastures in the perennial pasture land use types. Native pastures support a diversity of beetles and other fauna which depend on grass, herbs, root material, and soil organic matter.

The method of collection can also affect the results and need to be addressed when interpreting the data. Pitfall traps are generally more efficient in a two-dimensional pasture than in structurally complex vegetation such as remnants. Pitfall traps are appropriate for collecting ground-dwelling species but not those that feed on foliage well above ground. Remnants will support a wide range of beetles, many of which are not ground-dwelling and therefore will be under-represented in the BiGG samples. The samples did reveal a difference in the dominance of particular functional groups of beetles between land use types and between regions (Appendix 9).

Wingless (less mobile) beetles were more common in remnant vegetation than in crop or rotation paddocks (Figure 12). A larger proportion of winged beetles in more disturbed land use classes reflects their ability to more readily reinvade these areas after disturbance.

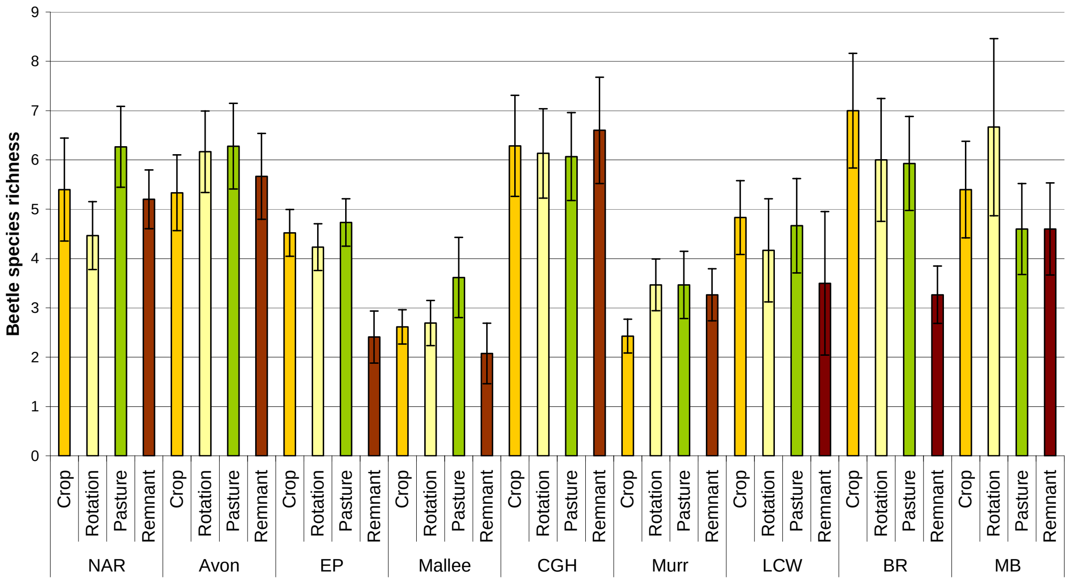

Figure 11. Mean beetle species richness for land use types within regions. (Standard error bars shown)

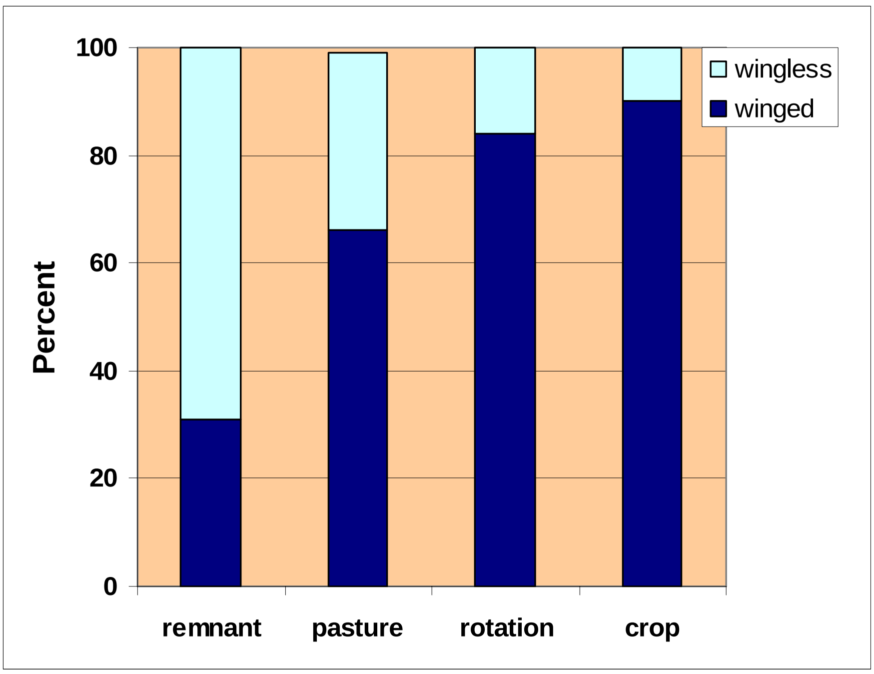

Figure12. Proportion of winged to wingless beetles across land use types (all data combined)

Larger body size in beetles is known to reflect environmental quality and is negatively related to environmental stress, making this a potentially useful measure of the habitat value of farming systems. Body size was found to be significantly larger in remnant vegetation compared to farmed land in four of six sites where this was measured (Table 2).

Table 2. Measure of mean body length (mm) of carabid beetles in remnant and farmed land use classes.

Region	Species richness	Remnant	Non-remnant	P
NAR	12	13.7 (1.1)	9.4 (0.9)	*
Avon	17	11.1 (1.0)	9.2 (0.7)	ns
EP	10	12.0 (1.4)	9.6 (0.5)	*
CGH	13	13.1 (0.9)	11.0 (0.7)	*
Murrumbidgee	9	12.4 (1.9)	10.6 (0.7)	*
Border Rivers	16	15.5 (1.9)	13.9 (2.8)	ns

Intensity of agricultural production - beetles

Beetle species richness was positively correlated with microbial activity in pastures at the farm level. High microbial activity is correlated with rainfall (Appendix 8) and soil moisture, and soil carbon levels, all of which will favour beetle diversity. Beetle abundance was negatively correlated with the presence of meat sheep but positively correlated with the presence of wool sheep. Higher beetle abundance in improved/fertilised pastures is largely driven by a handful of small species (e.g. aphodiine scarabs, some tenebrionids) which attack the roots of grasses and can become pests. Greater fertility generates greater plant biomass which will impact on herbivorous and detritivorous beetle numbers and richness. A proportion of the productivity increases in herbage which follows application of fertilisers or moisture is simply channelled through these particular beetle species.

Table 3 illustrates the difference in beetle species in different land use classes for two farms in the LCW region.

Table 3. Variability in beetle presence across land use classes for two farms in the LCW region.

		Farm 1				Farm 2			
Coleoptera morphospecies	**Guild**	Crop	Rotation	Pasture	Remnant	Crop	Rotation	Pasture	Remnant
Carabidae: ***Scopodes 2***	Predator	x	x						
Tenebrionidae: ***Adelium 1***	Detritivore		x	x					
Curculionidae: ***Naupactus leucoloma***	Herbivore			x					
Curculionidae: Adelognatha 1	Herbivore							x	
Elateridae: ***Agrypnus 1***	Herbivore	x							
Scarabaeidae: ***Liparetus*** 3	Herbivore			x					
Anthicidae: ***Formicomus 1***	Predator			x					
Byrrhidae: ***Microchaetes 1***	Herbivore			x					
Coccinellidae: ***Diomus 1***	Predator	x	x						
Carabidae: Harpalinae: ***Phorticosomus 5***	Predator					x			
Latridiidae: ***Corticaria 2***	Fungus feeder			x	x				
Anthicidae: brown tiny 2	Predator					x	x		
Staphylinidae: ***Eulissus***	Predator		x						
Staphylinidae: Xantholinini 1	Predator		x						
Undet Cucujoid	Fungus Feeder						x		

Type of agricultural production - spiders

There was no significant difference in the richness of spiders between the different land use classes (H= 2.99, d.f. = 3, P>0.05, Figure 13). However, pitfall traps favour the capture of ground dwelling spiders over other functional groups and do not efficiently sample spiders which live on vegetation. If other collection methods had been used, more differences between land use classes may have been observed.

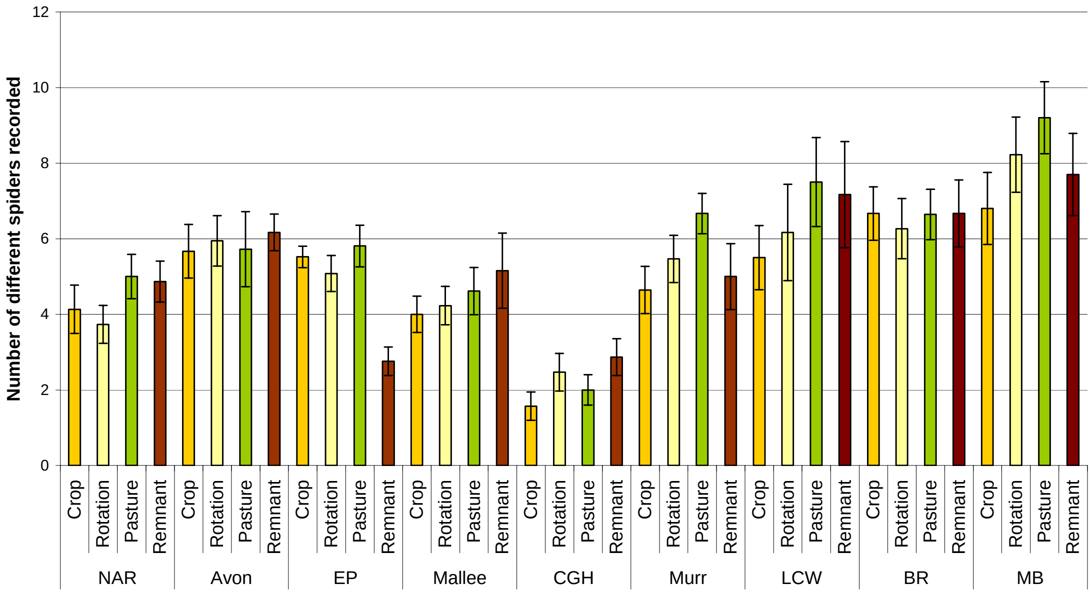

Figure 13. Mean spider species richness across land use types for each region

Intensity of agricultural production - spiders

At the farm level, spider abundance and diversity were positively correlated with ant abundance and diversity. One possible reason is that ground-dwelling zodariid spiders are very common on the farms and these may eat some ants as prey. In addition, sites with high ant diversity suggest an abundance of other insects as potential food for ants and therefore for spiders. Fewer different species of spiders were found in highly productive cropping paddocks (wheat production in t/ha), but the total number of individuals (biomass) was greater on properties with a high proportion of crop/rotation land use classes. This suggests that spiders target pests of crops, but are depleted in diversity on farms with high yielding crops. Within land use classes they appear to favour improved perennial pastures and cropped paddocks where stubble is retained. Increased structural complexity of habitat was correlated with increased spider diversity. However there were no significant correlations between the diversity of spiders and vegetation structure for any land use type.

In fragmented landscapes, dispersal mechanisms can greatly influence spider numbers. Long-lived sedentary mygalomorphs (also ground dwellers) were found in remnants (Figure 14). Aerially mobile linyphiids were most abundant in rotation and pasture paddocks and least abundant in remnants (Figure 15) where niches may already be occupied. The most common linyphiids in Australia (and in this study) are introduced species from Europe. They probably prey on springtails, tiny insects which mostly eat fungi, although a few are pests of seedlings.

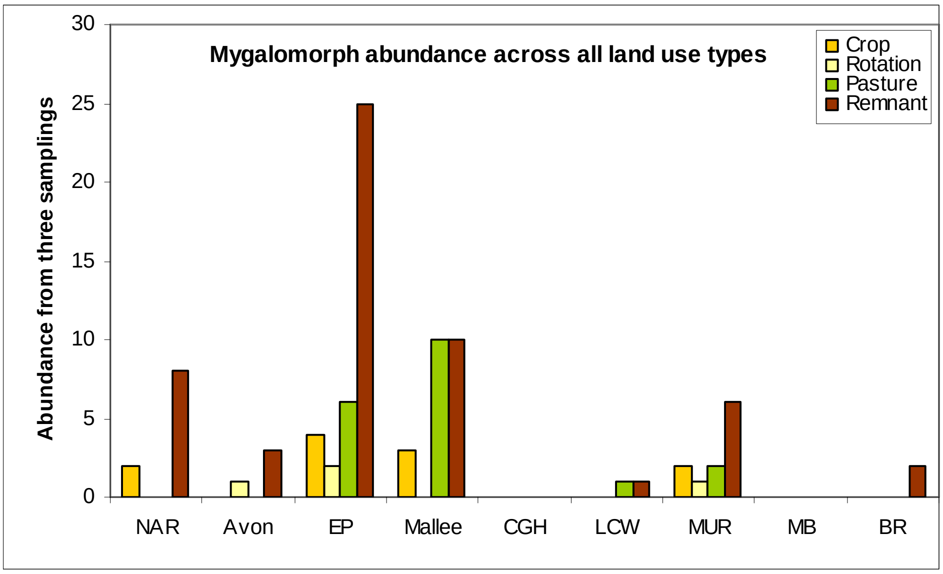

Figure 14. Abundance of ground dwelling mygalomorphic spiders in different land use types for all regions

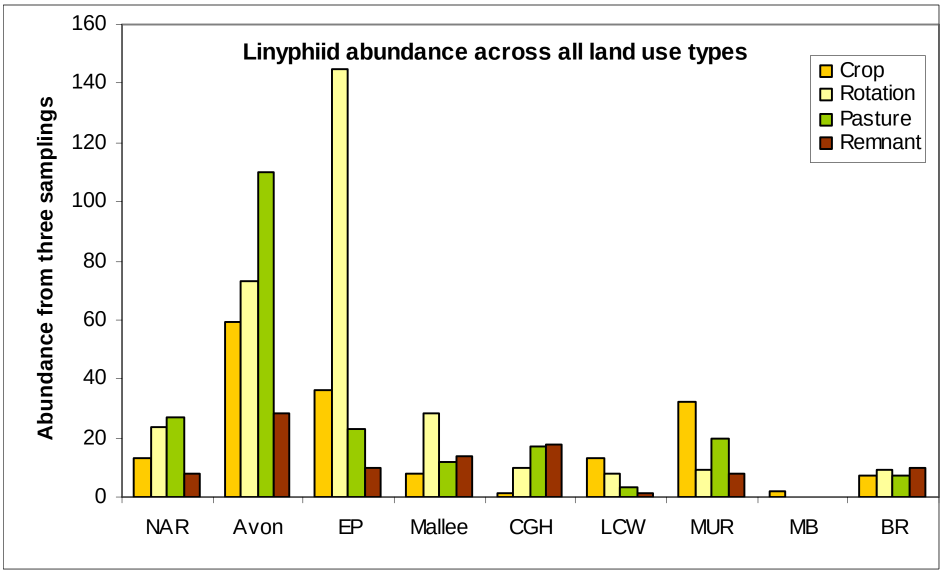

Figure 15. Abundance of ground dwelling linyphiid spiders in different land use types for all regions

Type and intensity of agricultural production - vegetation characteristics
Farm management practices affect a range of habitat variables such as vegetation height, litter availability and ground cover. Percentage bare ground was greater in crop and rotation land use classes than in perennial pasture or remnant vegetation (H=62, d.f. = 3,

P<0.001, Dunn's Method, P<0.05), and was inversely related to plant species richness (r_s =-0.42, P<0.001, n=188).

Detached litter and bare ground tended to be inversely correlated with each other. Detached litter was higher in remnant vegetation than in other land use classes.

Mean maximum vegetation height was higher in remnant vegetation, denoting the presence of shrubs in the 1 x 1 m quadrats, than in any other land use type. Presence of crop stubble was responsible for the significant difference in vegetation height between cropped paddocks and pastures.

Mean plant species richness (measured in 10, 1 x 1 m quadrats) was significantly higher in perennial pastures than in crops and rotation land use classes. However values were low reflecting such variables as vegetation type, the method of data collection and the degraded nature of some of the land use classes, particularly patches of native vegetation.

Type and Intensity of agricultural production - fungal diversity and microbial activity
Fungal diversity was generally low across all regions and land use types (Figure 16). This was potentially a result of a number of factors: lack of rainfall, use of the plate method to detect fungi and the presence of two relatively aggressive species. However, unusual species were recorded from two remnants from the Northern Agricultural Region and from the Border Rivers Region. More work would need to be undertaken to understand the ecology of these species.

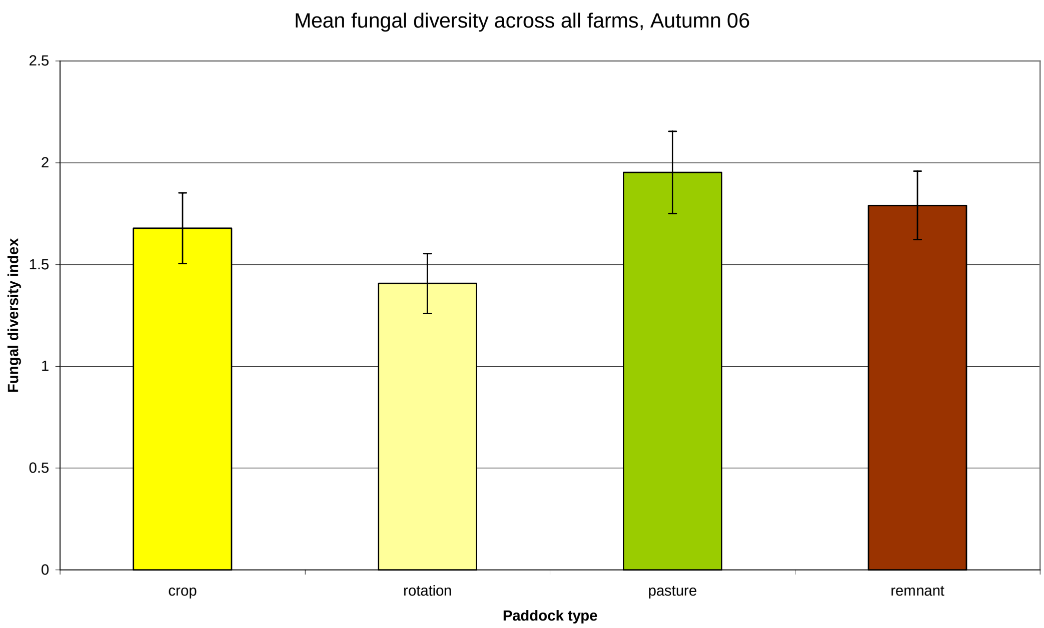

Figure 16. Fungal diversity (plate count method) by land use type, Autumn 2006. Source: Hon 2007

Across all land use types, for the whole data set, fungal **diversity** was higher in perennial pasture paddocks and the remnant vegetation, and was lowest in 'rotation' (Figure 16). However, values were generally low and the differences between land use types were not statistically significant.

Between regions, there was no consistent pattern in fungal diversity across land use types. For example diversity was significantly higher in remnant vegetation in the Avon region than in the crop or rotation paddocks, but this was not the case in the Northern Agricultural Region where rotation paddocks recorded the highest value and were significantly higher than remnant vegetation (Figure 17a). Differences between farms within regions were also apparent (Figure 17a,b).

A correlation analysis indicated that fungal diversity did not relate to any of the measured soil nutrient variables other than pH, to which it was inversely related (Hon 2007, Appendix 8).

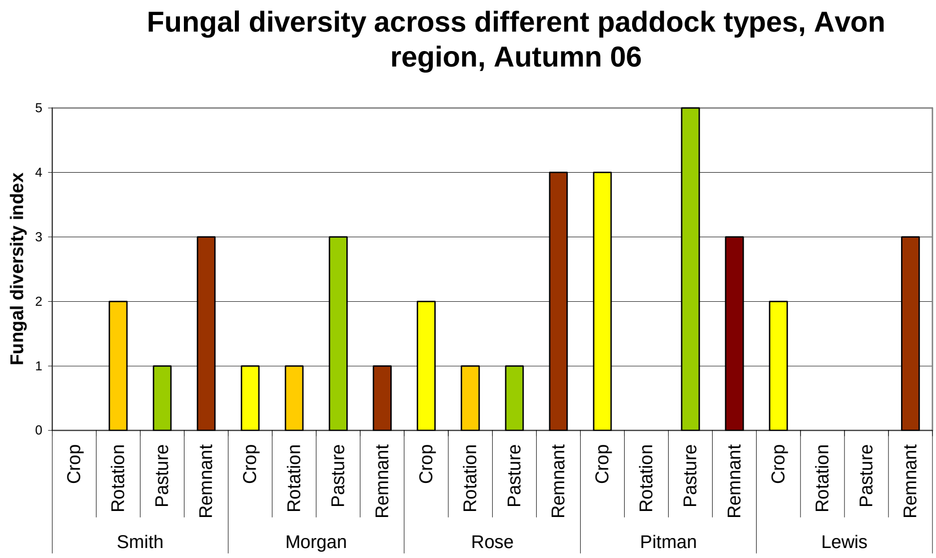

Figure 17a. Fungal diversity for four land use types, across six farms in the Avon region, Autumn 2006. Source: Hon 2007

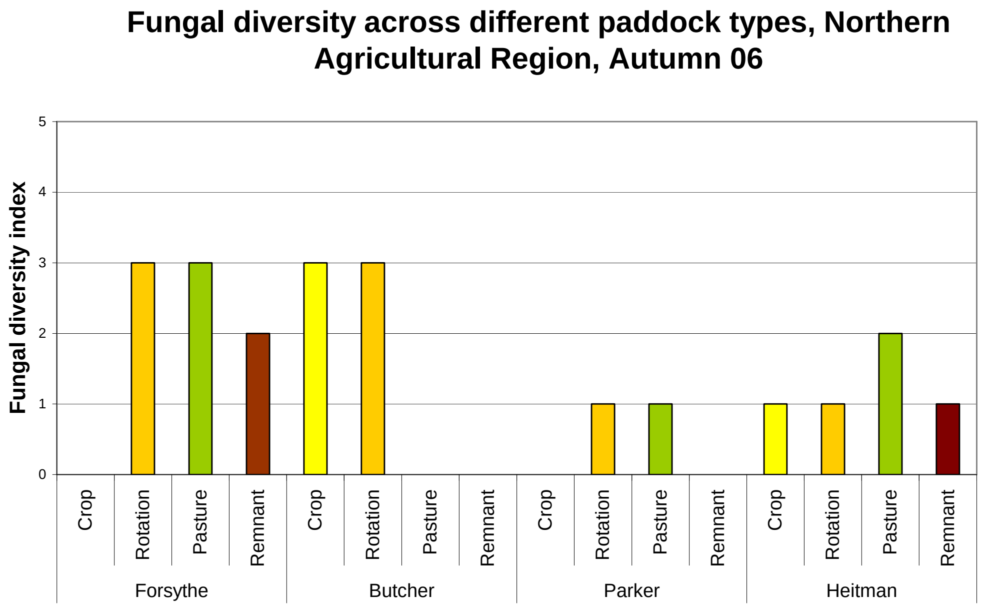

Figure 17b. Fungal diversity for four land use types, across four farms in the Northern Agricultural region, Autumn 2006. Source: Hon 2007

Microbial activity

Microbial activity, as measured in the laboratory, was correlated with a range of soil nutrient measures and rainfall i.e. the more nutrients available, particularly N and P, the higher the microbial activity recorded (Hon 2007, Appendix 8).

The force (measured in Newtons) taken to break cotton strips is used as a measure of the amount of microbial activity present in the soil; the higher the tensile strength, the lower the microbial activity. In contrast to fungal diversity, microbial activity was significantly higher in cropped paddocks than in remnant vegetation or in perennial pasture paddocks (Figure 18, H=58.8, d.f.=3, $P<0.001$). The laboratory cellulase measurements support the data from the tensile strength measurements of the cotton strip assays (Appendix 8). Despite the lack of rainfall over the two year period (Appendix 10), the cotton strips were a very useful and economical indicator of the responsiveness of microbes to cellulase based substrates. The results tend to reflect the level of inputs and disturbance into cropping soils.

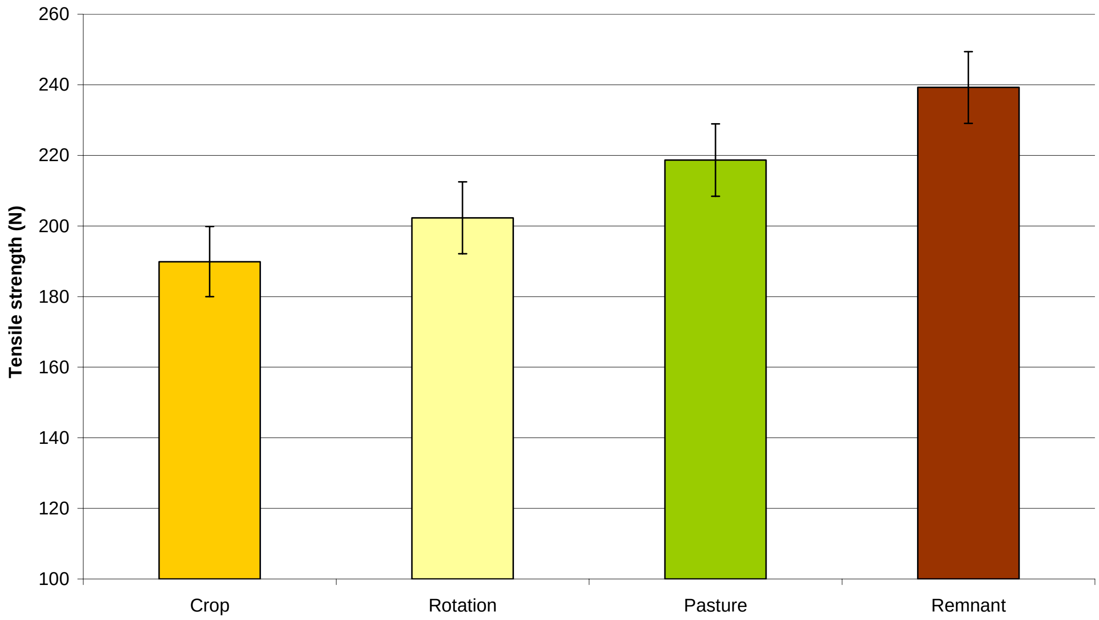

Figure 18. Force taken (N) to tear cotton strips for the four land use types, all seasons, all farms combined. N.B. Microbial activity is highest in the crop paddock (less force taken to tear cotton strips, standard error bars shown). Values greater than 200N indicate little activity.

Degradation of cotton strips in cropped paddocks was significantly but weakly correlated with rainfall (r_s = -0.42, P <0.001, n = 150, Figure 19).

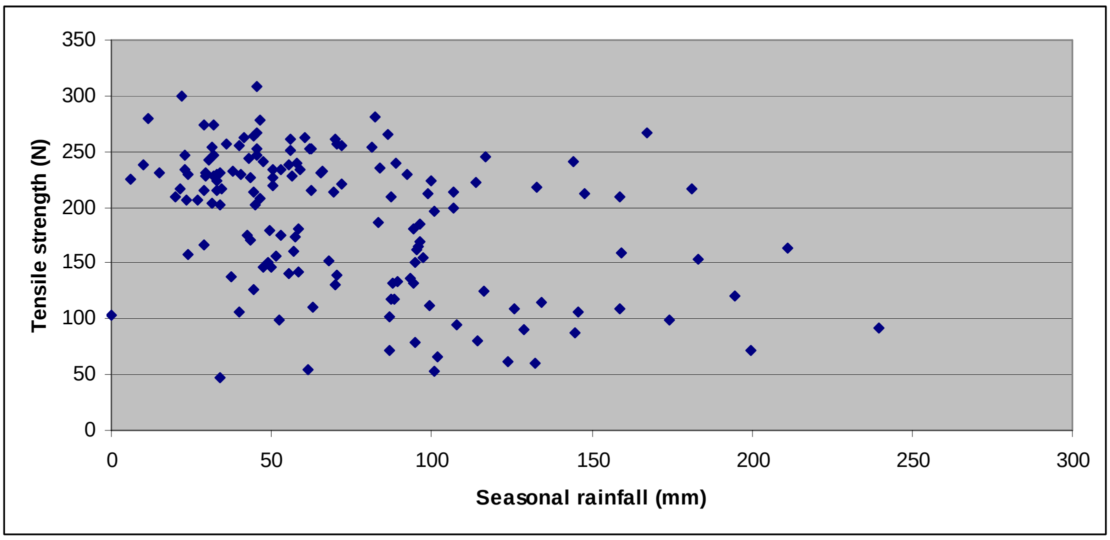

Figure 19. Graph demonstrating an inverse relationship between microbial activity (measured by tensile strength in Newtons) and seasonal rainfall totals over the survey periods (autumn and spring 2006, 2007)

Detailed soil biodiversity measurements were taken on two BiGG Mallee farms by Gupta Vadakattu of CSIRO (unpublished data). While microbial activity relating to the breakdown of cellulase is greater in high input/high disturbance systems, catabolic diversity has been shown to be significantly higher under remnant vegetation than in crops. The results showed that catabolic microbial diversity (using the Shannon Index) was highest for soils under remnant vegetation, followed by permanent pasture and was lowest under crops (Figure 20).

Catabolic diversity is influenced by the composition of bacteria and fungi. The composition of soil fungi (which is driven by the quality of crop residues and disturbance) greatly contributes to the illustrated differences in catabolic diversity. Cultivated systems in general show higher levels of activity compared to undisturbed systems unless cultivation resulted in severe degradation of the system. Further work at a finer scale is needed to address questions relating to the role of microbial diversity in supporting paddock productivity.

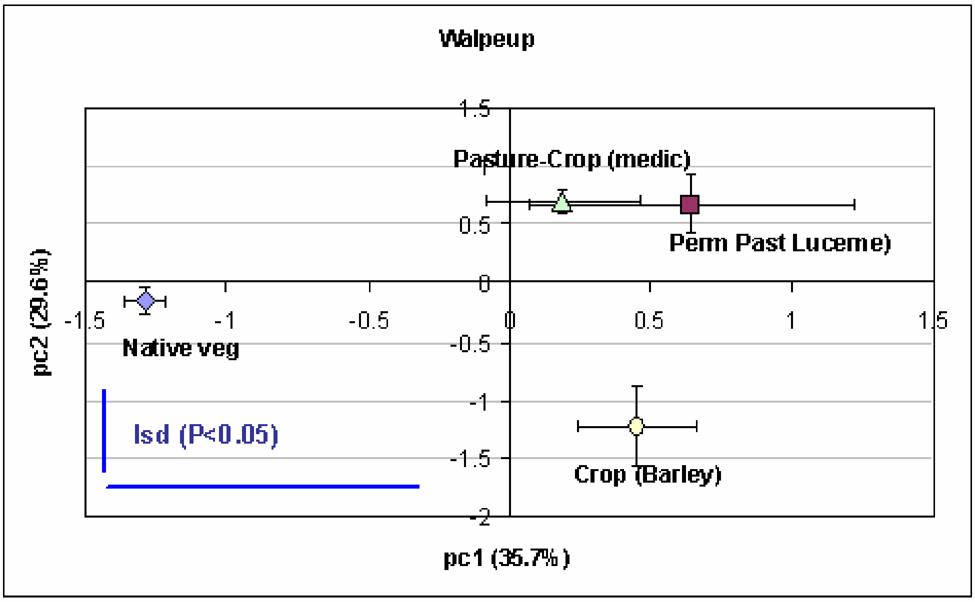

Figure 20. Catabolic diversity profiles for surface soils from four land use types on a mixed farm, Walpeup, Victoria.
PCA indicates that soil microbial communities under Native vegetation, cropping (Barley) and pasture (Medic and Lucerne) systems are significantly different from each other. * indicates significant differences with other treatments at P<0.05. Source: Vadakattu unpublished data.

Addressing key research question:

3c) *Which is more important site (landscape context) or system (land management) on biodiversity?*

Both are important. They operate at different scales for different taxa.

Landscape metrics are best suited towards large, mobile animals and are of limited use in determining the relative impact of farm scale management practices on biodiversity. Birds respond to site and system features. As large, extremely mobile animals, they utilise much greater areas than other taxa studied. They were the only taxa to show strong correlations to landscape metrics. Habitat condition is also important for birds. **Bird species are more abundant in remnants with structural diversity than those with one understorey layer and the more remnant on a farm, the more birds are found.**

Other taxa operate on smaller scales and are more likely to depend on habitat requirements at a local (within farm) scale. Habitat condition is important within patches. Habitat condition is influenced by farm management practices such as the grazing of remnant vegetation, the type of pasture available (annual v. perennial), the proportion of ground cover, vegetation height, number of structural layers. All of these variables can be manipulated through land management.

Responses to this question rely on the scale at which the analysis is undertaken. Canonical correlations analysis pointed to site features, i.e. where a farm is geographically located, being more important than system (land management) features in impacting on biodiversity values (Corkrey 2008, Appendix 11). The two analyses of all farm data showing correlation coefficients greater than two were the vegetation fragments (VEG) analysis and the class mosaic (CLS) analysis (Figure 21). Within these analyses, the most important determinants of biodiversity values were:
VEG – the patch area weighted mean patch perimeter-area ratio and the percentage of like adjacencies, i.e. the area, shape and proximity of native vegetation patches;
CLS – low values for the mean area of individual patches combined with high values of 'mesh' (a surrogate for connectivity).
Values for these variables within analyses combined to give relatively high biodiversity scores.

Bird species richness was the only biodiversity measure that had a high degree of correlation ($r>0.5$) with any of the axes developed from the site/system data (Corkrey 2008). Other taxa (ants, spiders) were significantly correlated with the second axis in many of the correlation analyses (Appendix 11). These results have not been fully investigated, however the data demonstrate that birds respond to landscape or site features while other organisms respond to local or site features only.

Land use classes of crop, rotation, pasture contain lower values for selected biodiversity measures than remnants, with biodiversity increasing with decreasing disturbance (Figure 21).

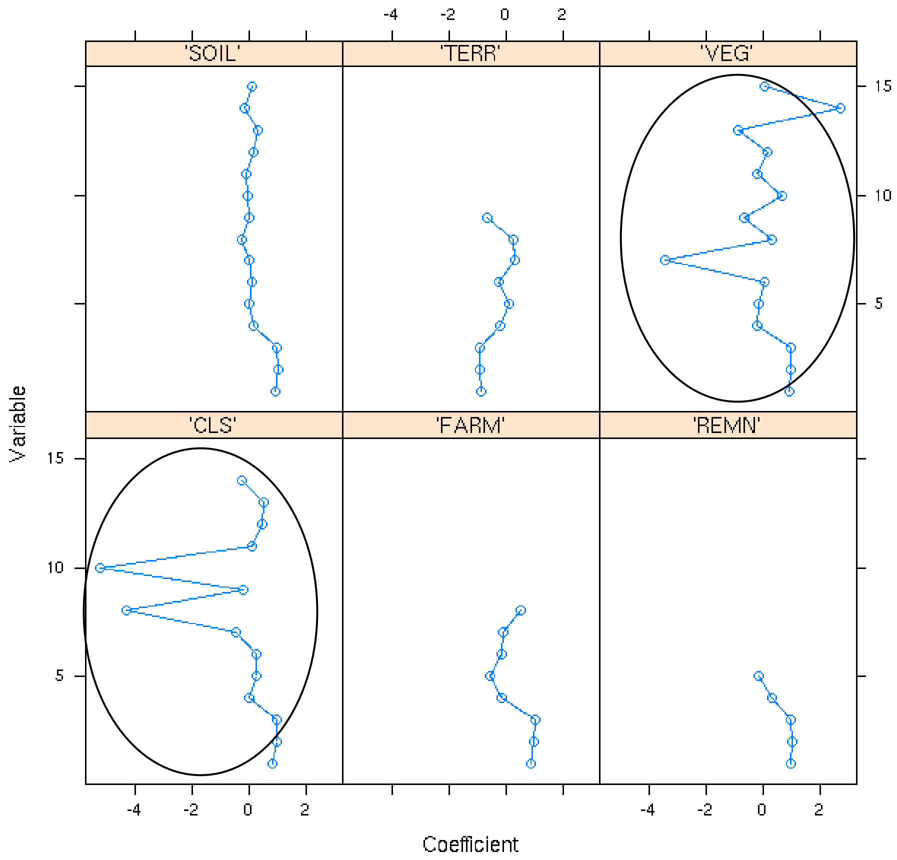

Figure 21. First System-Site coefficients for the 'veg' Biodiversity group for each System-Site analysis. *System-Site variables are, , in numerical order:*
(SOIL: paddcrop, paddrota, paddpast, TEXTURE, GRAVEL, NITRATEN, AMMONIUM, P, K, S, OC, Fe, CONDUCTY, PH_CACL2, TOTALN);
(TERR: paddcrop, paddrota, paddpast, MEAN_DEM, STD_DEM, MEAN_Slope, MEAN_solar, MEAN_Wet_In, Ratio_2D_3D);
(VEG: paddcrop, paddrota, paddpast, PD, LPI, ED, AREA_AM, GYRATE_AM, SHAPE_AM, FRAC_AM, CIRCLE_AM, PROX_AM, DIVISION, MESH, SPLIT);
(CLS: paddcrop, paddrota, paddpast, PD, LPI, AREA_AM, SHAPE_AM, PARA_AM, CLUMPY, PLADJ, IJI, COHESION, AI, CAz);
(FARM: paddcrop, paddrota, paddpast, CONTAG, PLADJ, IJI, SHDI, AI);
(REMN: paddcrop, paddrota, paddpast, TAIB_farm_p, TAIB_patche);

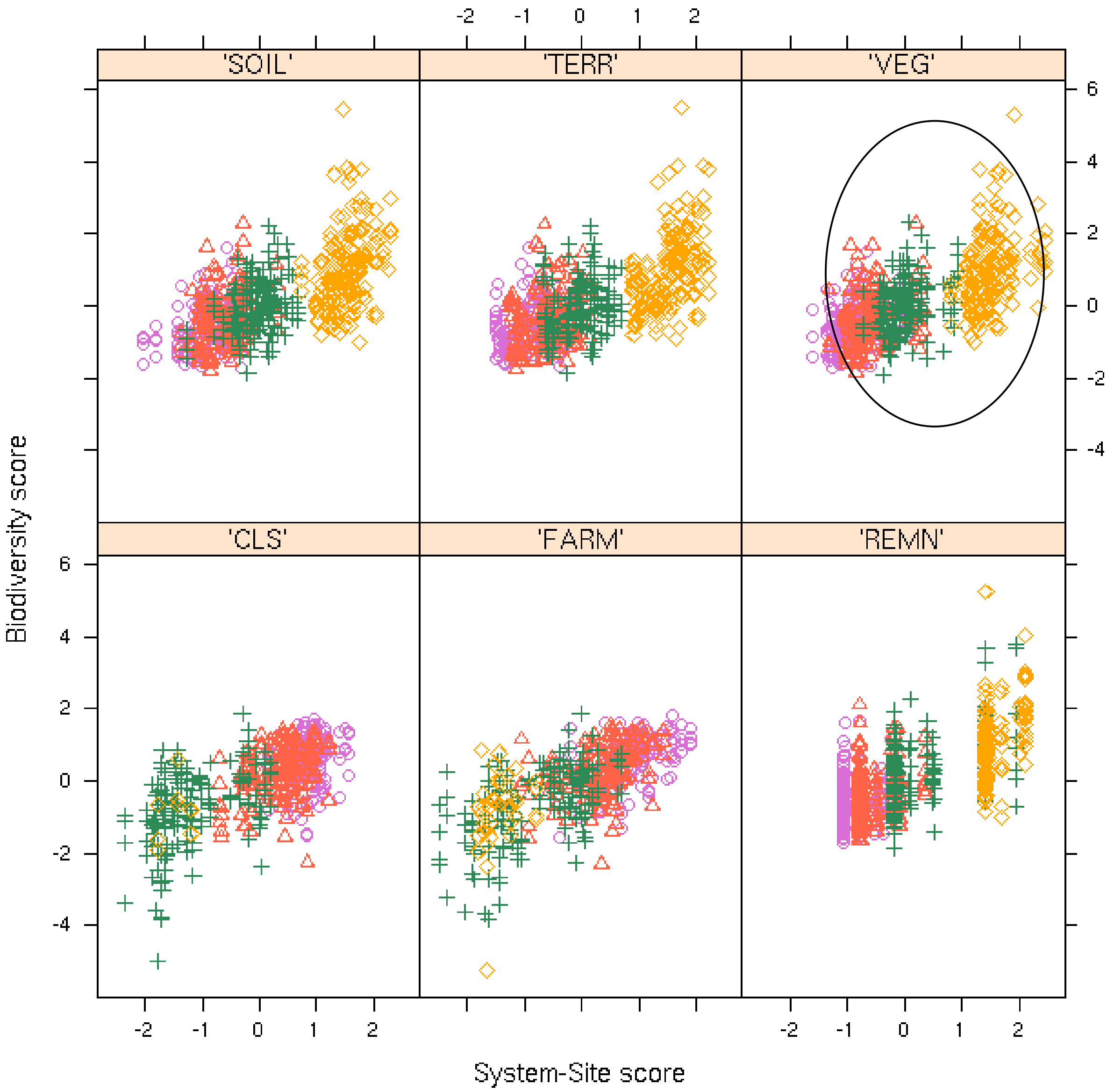

Figure 22. Biodiversity scores plotted against the System-Sites scores by analysis for the 'ex veg' Biodiversity variables. Paddocks are shown as crop(circles), rotation (triangles), pasture (crosses), remnant(diamonds).

Figure 22 illustrates the differentiation of land use types along axis one (system-site score) while biodiversity measures are aligned with axis two (biodiversity score). There are clear differences between crop paddocks and remnant vegetation in the CLS and VEG analyses. The quality of the remnant is likely to be differentiating remnant patches in the VEG analysis. For example, birds respond to landscape (site) and system (management) features. An example of landscape metrics taken from three regions shows that there is a significant difference in bird species richness which can be attributable to site and system features.

Table 4. Comparison of remnant condition and landscape context for three regions. Values followed by the same letter are not significantly different at $p<0.05$; ns = not significant.

	P	Avon	EP	Murr
Mean bird species richness in remnants	**	16.2a	31.0b	13.6a
Number of vegetation layers in remnants	***	2.5a	2.9a	1.4b
Available P	*	4.3a	19.8b	28.0 b
Mean farm area (ha)	ns	1757a	2683a	1609a
Total area of remnants (ha) on farm	ns	64.7a	343.9a	49.0a
Area of remnants (>10 ha) within 5 km of farm	*	880a	4738b	1079a
Proportion of remnant 'edges' on farm (total length of remnant patch/total area of remnants)	**	861a	347b	1393c
Fragmentation index of remnants on farm	**	6462a	794b	6235a

Bird species richness was lower in Avon and Murrumbidgee than all other regions. Mean bird species richness was relatively high in EP. Both Avon and Murrumbidgee are highly fragmented, significantly more than EP (Table 4). Vegetation condition, measured here by the number of structural layers and the amount of available P in the soil, is of a higher quality in EP and Avon than in Murrumbidgee. Therefore vegetation condition characteristics separate Avon from Murrumbidgee. Murrumbidgee remnants have a high edge to area ratio which will also impact on vegetation condition as the remnants are more exposed to management of adjacent land uses. Thus Avon and Murrumbidgee record low bird species richness but for different reasons; fragmentation and remnant quality.

The condition of the remnant is closely linked to management and production value. Grazed remnants are generally less species rich than those that have little or no grazing value.

Figure 23 demonstrates that species richness of birds in remnants is influenced by remnant condition (soil available P) along the x axis and potentially a grazing gradient along the y axis. Farms with high bird species richness are located in the lower half of the plot in the centre. A third vector relating to the size and extent of remnants on and off-farm is also evident.

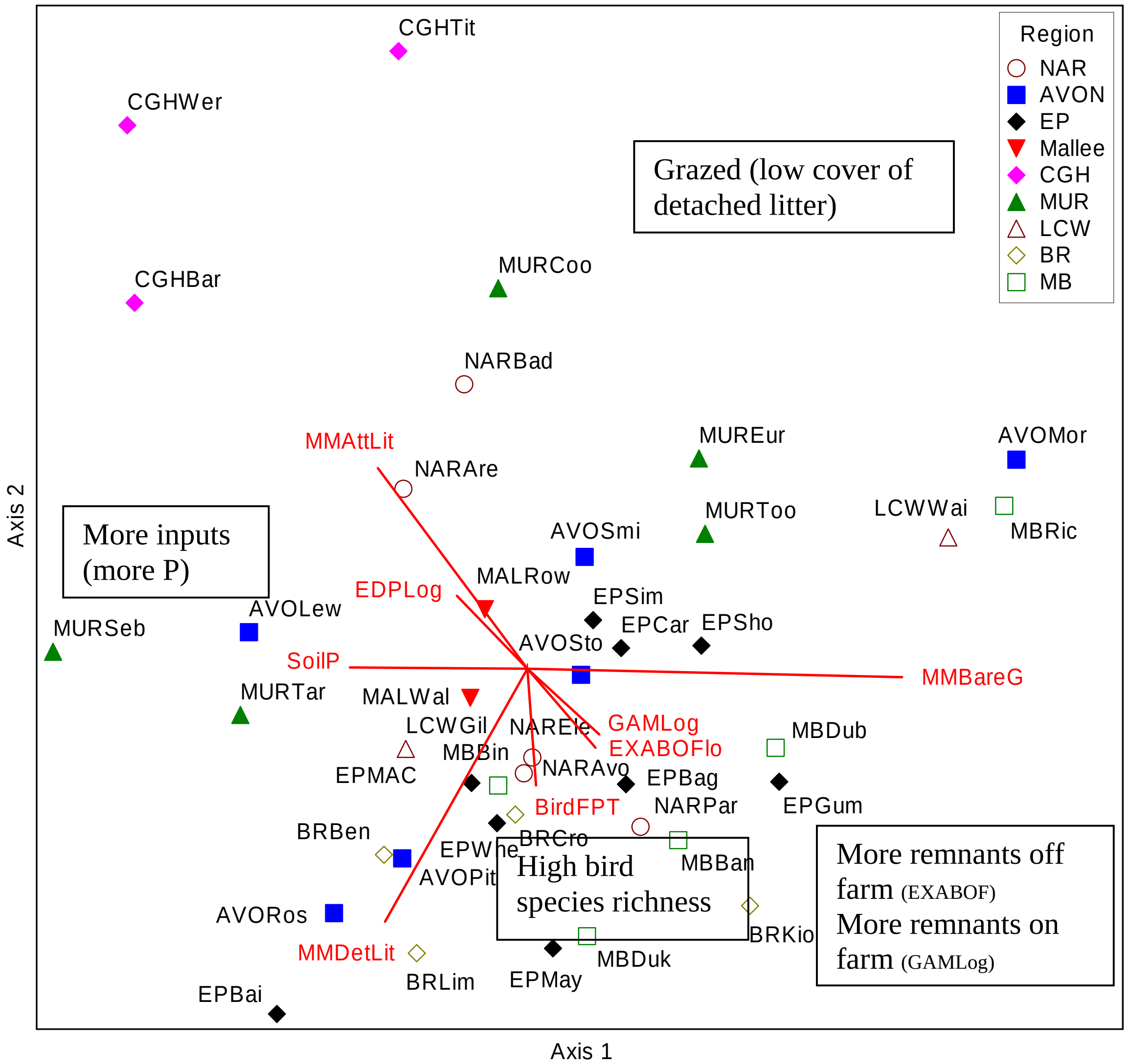

Figure 23. NMS ordination of bird species richness data in remnant vegetation for 41 farms. Environmental variables include farm scale data (ground cover and soil P levels) and landscape metrics (number of remnants on and within 5km of the farm boundary). Stress for 3D = 12.21

4. *What do the results mean for how we manage mixed farms?*

Motivations for managing biodiversity on farms relate to the intrinsic value of the organisms or ecosystem or their resource value. This section will address both and provide 'hunches' relating to the drivers of biodiversity management, the individual taxa studied and potential links to production.

The project relied on comparisons between native vegetation ('remnant') and other land use types in mixed farming systems. The role of native vegetation was to provide a relatively undisturbed, low input comparison to land uses under more intensive production. The difference in availability, quality and individuals' perceptions of 'remnant' vegetation was highly variable across the regions.

Consequently, some high quality remnant vegetation was chosen in some areas and very low quality remnant vegetation was chosen in other areas. This was mainly a result of the availability of remnants but also a result of the perception of the local field project officer and the landholder of what constituted a remnant. This emphasises the importance of having clear definitions of what is included in a remnant, as well as the need to have input from native vegetation experts when selecting remnants.

Most remnants contained trees, and many, particularly in southeastern Australia had an understorey dominated by exotic species. Only one of the selected remnants from 47 farms was native grassland (Maranoa-Balonne) with no trees present. In one region, four of the five remnants contained no native species in the understorey. Poor quality remnants were less likely to be differentiated from other land use types in terms of biodiversity values. This led to the misconception by a farmer at the forum in Hobart that his management over the whole farm was good because there was no difference in species richness for a range of taxa between the remnant and the other land use classes. However, the remnant was in very poor condition (Plate 1).

Plate 1. The poor quality remnant (absence of understory species, grazed by sheep, unfenced, elevated nutrients) that was used as an 'undisturbed' comparison to other land uses on the farm.

Table 5 details the variability in the recognition of ‘remnant’ vegetation from three sources: interview data; aerial photographic interpretation by farmers and the GIS team (Appendix 7) and from state level native vegetation maps. Native vegetation comprises a small proportion of the area of the majority of farms. More than half of the properties had less than 15% native vegetation of any description on farm.

Landscape metrics (aerial photographic interpretation of farm maps) and interview data give higher estimates of native vegetation than the state vegetation layer. This may be due to the coarse scale at which native vegetation is mapped at a state level. It may also be due to the inclusion of revegetation areas on the maps or poor quality ‘remnants’ in regions where remnant vegetation has been largely cleared. The range of regional benchmarks of native vegetation in ‘good condition’ is evident in the vegetation survey data and the choice of sites. These regional differences cannot be underestimated when developing management recommendations within regions.

Table 5. The proportion of native vegetation on farms from three data sources.

Landscape metrics				Interview data			State vegetation mapping		
	Mean %	Range %	n	Mean %	Range %	n	Mean %	Range %	n
NAR	20	9-33	5	21	10-34	5	13	4-30	5
Avon	10	6-18	6	16	4-34	6	4	2-7	6
EP	18	5-37	8	17	0.1-30%	6	14	4-36	9
Mallee		29-72	2	25	1-78	5	26	4-72	4
CGH	6	1-14	5	4	3-5	5	1	0-2	5
Mur	4	3-6	4	3	2-4	4	3	1-4	5
LCW		4	1		4-18	2		4-19	2
BR		5	1	14	2-25	4	13	0-31	5
MB	22	2-52	5	18	5-30	5	12	1-27	5

Every patch of native vegetation counts, no matter what the condition. Native vegetation in better condition will have more species in it, across a wide range of groups, than native vegetation in poor condition. These remnant patches can be seen as ‘banks’ for beneficial (and pest) species.

Regional implications

McIvor and McIntyre (2002) suggests that functioning landscapes that were formerly grassy woodlands require a minimum of 30% woodland or forest cover on properties, and that woodland patches need to be a minimum of 5-10 ha to remain viable. In addition, no more than 30% of the property area should be under intensive agriculture, including grain and forage cropping and sown pastures. Many of the 47 farms involved in BiGG, particularly in southeastern Australia, are located in regions where grassy woodlands were once widespread. However most of the BiGG farms do not meet these suggested thresholds. Twenty of the 45 farms we have data for have a mean patch size of less than 5 ha (Figure 24).

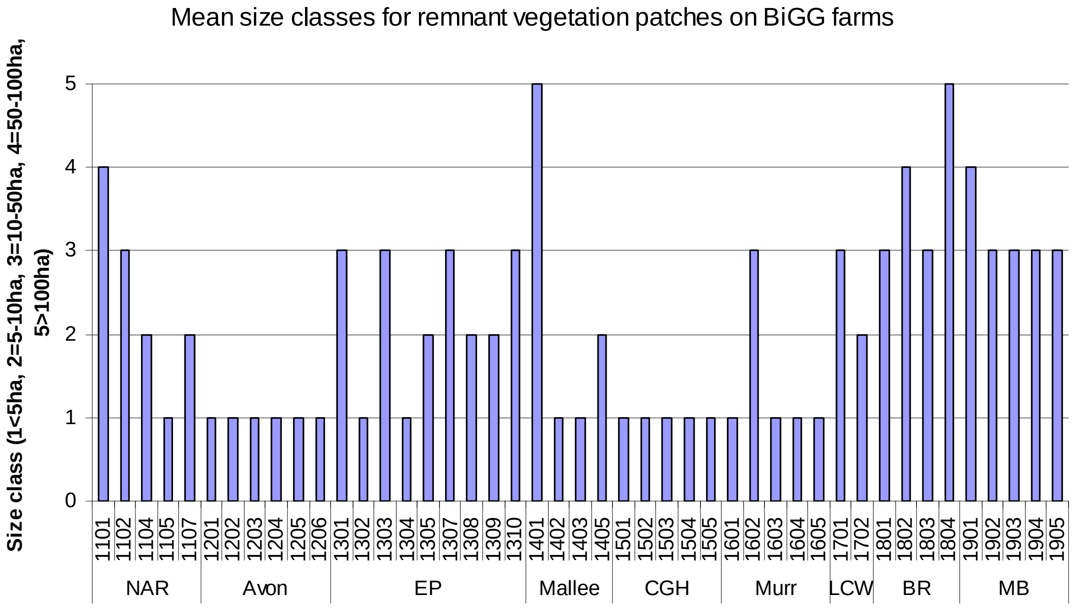

Figure 24. Mean patch size of remnant vegetation (defined using state vegetation layers) for 42 farms with available data. 1 = 0-5 ha, 2 = 5-10 ha, 3 = 10-50 ha, 4 = 50-100 ha, 5 = >100 ha).

These results suggest that the long term functionality of ecosystems within regions is unclear. While it is easier to retain existing patches of native vegetation, revegetation is an important land management action in many regions, used to redress the functional imbalance across the landscape.

Many of the Grain & Graze regions have very low levels of remnant vegetation retained but within this context invertebrate biodiversity can be locally high. As much of the land development has happened in the last 50-100 years it is possible that there is a significant unrealized extinction debt. However, ants may be relatively resilient to environmental change, in contrast to particular groups of beetles who show evidence of environmental stress in farmed landscapes compared to remnant vegetation. The BiGG database is a valuable tool that can be used to address these hypotheses.

Farm management practices that promote biodiversity

The BiGG database contains valuable benchmarking data for the future use of ants and beetles as regional indicators or sustainable land use.

Ants

Ants are sensitive to high levels of soil surface disturbance, whether from erosion, stock movements or tillage. Thus there was higher species richness and abundance in remnants followed by perennial pastures, with lower values in crop paddocks. The full set of functional ant groups was encountered in the study (Appendix 9). An important function of ants in Australian ecosystems is soil surface aeration and as ecosystem engineers through burrowing and nest building. This has important implications for soil structure and soil water infiltration. While the maintenance of this role by ants has limited compatibility with cropping, the abundance and species richness of ants could be used as indicators of ecosystem health in pastures and remnant vegetation. They have been used as indicators of ecosystem health (Anderson 1995) for pastoral lands and rehabilitated mine sites.

Native ants are a very important component of the biodiversity of mixed enterprise farms but their distribution is variable. The large differences in ant numbers and profiles between land uses may reflect the relative degree of surface disturbance and resource availability. Any tillage associated with cropping is likely to disrupt the soil nests of many species, especially those which construct large permanent nests. Where no-till options prevail, the passage of machinery used for planting and harvesting and applying fertilisers and pesticides, cause soil compaction which can be detrimental to ants.

The range and availability of food is also likely to influence ant diversity and numbers. Remnants offer a more comprehensive range of food than the other land uses, including access to carbohydrate resources from extra-floral nectaries (on *Acacia* especially), psyllids, leafhoppers and scale insects on trees. In addition, a greater variety of physical resources such as rocks, roots, logs and stumps offer desirable nesting sites.

Most pastures were dominated by seed-harvesters. Pastures, and rotations at certain times, generate high quantities of small seeds which ants may collect, especially ants of the genera *Pheidole* and *Aphenogaster*. A positive correlation was recorded for ants and improved pastures at the paddock scale.

Beetles

Of all the selected measures of biodiversity, beetles were the only group where similar numbers of species were found in all land use types, reflecting their important and widespread role in both agricultural and natural ecosystems. All functional groups, from predators to detritivores, were represented in all land use types. Beetles respond to environmental stress, making them potentially very valuable as indicators of environmental condition (see section 3 ‘Results’ for the impact of land use on functional groups of beetles). The Integrated Pest Management project in the Corangamite/Glenelg-Hopkins region has already highlighted the important role of carabid beetles as predators of crop pests (Day et al. 2008). Horne (pers. comm.) noted that beneficial beetles and spiders occurred in the BiGG dataset for all regions. This highlights the fact that production benefits may be delivered on all BiGG farms with the appropriate management of invertebrate populations.

Birds
Figure 25 demonstrates that high bird species richness increases on farms where the proportion of remnant vegetation is greater than 20%. However, this relationship is not linear. Individual farms can have relatively high diversity at lower proportions of remnant vegetation. Many farms have less than 10% native vegetation but may record high or low numbers of different birds. This may reflect the extent of native vegetation adjacent to the farm.

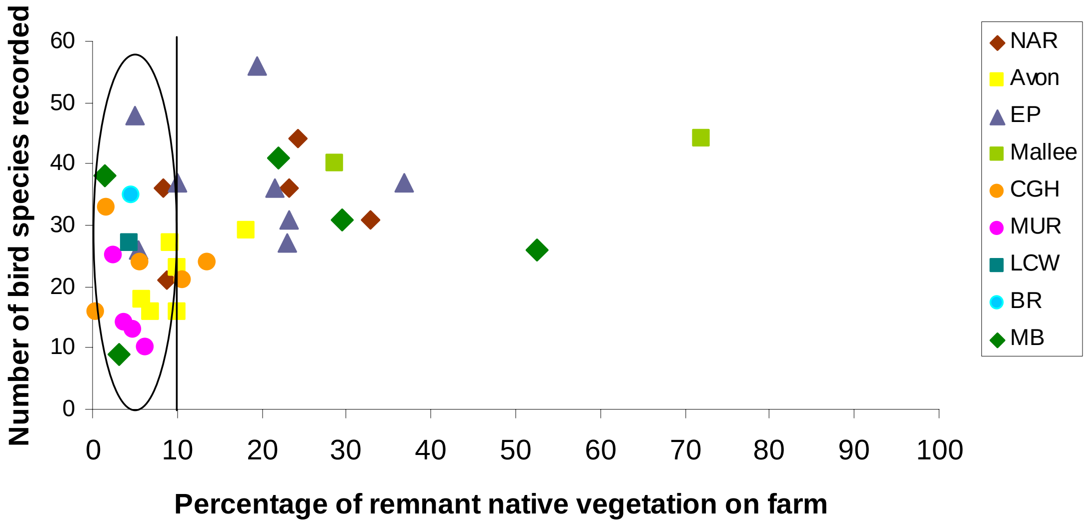

Figure 25. The relationship between the proportion of native vegetation on farm and bird species richness

Figure 23 suggests that these remnants are likely to be in close proximity to off-farm remnants or are in very good condition, providing adequate habitat for birds. The fact that high bird species richness can be obtained on farms with relatively small proportions of remnant vegetation implies that land managers can impact on bird species richness by addressing particular management issues that affect habitat for birds. Inappropriate grazing regimes and nutrient additions negatively impact on remnant condition, the latter through promoting weeds and poisoning some native plants.

Recommendations on farming practices and landscape management…

Table 6 provides potential management responses to the following question, as posed in the original project proposal (Mason et al. 2004)*:*

> *"How can landholders with mixed farming operations manage for profit and deliver the biodiversity improvements required by regional biodiversity goals and targets?"*

Remnant vegetation provides valuable habitat for a variety of regionally and nationally listed species of birds, plants and rare invertebrates. Other land use types on the farm can provide valuable habitat for native plants and animals. Perennial pasture paddocks on many farms contained native plant species, rare birds and a variety of invertebrate species, some known or suspected to provide ecosystem services by the removal of pest species.

Management options are divided into management for intrinsic value (what producers can do to enhance biodiversity) and for resource use (what biodiversity can do for production). It is important to note that each farm is unique through a combination of farming system (relative focus on cropping and livestock), the biodiversity resources available within and around the farm and the ability and opportunity for farmers to manage their biodiversity assets. This is an important message when trying to use such information to inform land managers as the information needs to be relevant to farmers in the context of their current situation.

Most biodiversity (species richness, structure) exists in native vegetation but all land use types have biodiversity in them (it may be below ground). Every land use type has potential for more biodiversity and benefits may be wide-ranging. They may not be obvious eg land clearance and salinity.

Some components of biodiversity may have direct links to production. For example the Corangamite/Glenelg-Hopkins regional biodiversity project focuses on Integrated Pest Management (IPM), where populations of beneficial predator beetles and spiders are promoted through promoting appropriate land management practices such as the targeted use of pesticides. **Native beneficial predators were found in all nine Grain & Graze regions indicating that all regions had the ability to adopt IPM on their existing invertebrate populations.**

The Mallee regional biodiversity project has linked microbial diversity below ground to increased crop and pasture production. **On-going and further studies will strengthen these production-biodiversity links, allowing biodiversity assets to be valued, utilized and promoted in production landscapes.**

General messages support other data i.e. that most biodiversity will be found in remnant vegetation. The quality or condition of the remnant determines how much habitat is available for a wide range of species, which can be easily manipulated by land management decisions. Many other studies have noted the value of remnant vegetation, even when in poor condition. This finding is not new, but its relevance may be 'new' to many of the 47 farmers involved in this study. It has meant that work done elsewhere may be directly relevant to their farm. **Clearly there is a need to maintain a focus on supporting the retention, expansion and appropriate management of native vegetation as habitat provision for a wide range of other species.**

This project has improved landholder understanding of some of the components of biodiversity that exist on their farms. In addition to the engagement and communication opportunities, this dataset provides an important benchmark of the impact of agricultural land use at a national scale on selected measures of biodiversity. The project is the first to use standardized methods of data collection across the country. Longitudinal studies at this scale are currently non-existent; therefore the dataset provides an opportunity to measure the long term sustainability of Australia's mixed farming systems.

The data set also allows us to address important ecological questions such as the relative proportion of intensive, extensive and conservation areas at a landscape scale (McIvor and McIntyre 2002), the ecological redundancy debate (i.e. how much biodiversity do we need?) and investigating potential extinction debts.

There are three key audiences for the messages coming out of BiGG – farmers, policy makers and researchers. Messages for each are summarised below.

For mixed farmers;

1. What mixed farming can do for biodiversity?

- Birds. Remnant vegetation on mixed farms provides important habitat for birds. In this first national bird survey carried out specifically on mixed crop and livestock farms, a total of 181 bird species were recorded on the 47 farms. Thirty three of these were priority or threatened species and 23 were recognised as nationally declining species. The number of species recorded on a farm was positively correlated with the proportion of remnant vegetation on a farm (Figure 25) and the condition of vegetation as measured by its structural complexity (the number of vegetation layers, Figure 23). The significance of vegetation condition for bird species diversity reinforces the importance of managing those forms of disturbance that reduce vegetation complexity, such as grazing and fertiliser application.

- Beetles. Mixed farms provide habitat for a great diversity of beetles, with 504 different taxa identified to the level of genus or species including several rare weevils not seen for decades. Similar numbers of species found on all land use types indicating the extent to which beetles have adapted to farming landscapes (Figure 11). Functional groups of beetles vary with land use type, reflecting variability between regions and land management practices (Appendix 9a). Carabid beetles may be useful indicators of environmental stress as their body size (Table 2) and relative mobility (Figure 12) differs between disturbed (farmed) and relatively undisturbed (remnant) land use classes.

- Ants. Over 850 different ant taxa were found, with a clear distinction between eastern and western Australia in term of habitat preference. Little difference was observed between the number of ant species in each land use type in Western Australia and South Australia compared to the eastern states (Figure 7). In the east, ant species richness was closely followed level of disturbance with most found in remnant vegetation, least in crop, and intermediate numbers in pasture and rotation. The dominance of particular functional groups varies between regions and land use types (Appendix 9c).

- Spiders. Three hundred and thirty species of spider were found. Most were ground-dwelling spiders (Appendix 9b), common in two-dimensional habitats. They were found to respond to the mix of land uses on a farm, with higher numbers of individuals found on farms with a higher proportion of land under crop and rotation. However, the higher the crop yield (wheat t/ha), the fewer numbers of different species recorded (Figure 4a).

2. What biodiversity can do for mixed farming

- Birds. Sixty four percent of the bird species observed were known to eat insects, suggesting that further study might help to identify which birds species are predators of particular crop and pasture pests, providing production benefits (ecosystem service)

- Beetles. The data from this study suggests there is potential to develop a national IPM program on mixed farms on the basis that predatory beetles were found to occur in every region surveyed.

- Ants. In water limiting environments typical of Australia's mixed farming zone, ants and termites are known to play an important role in soil aeration and nutrient cycling, the equivalent role that earthworms play in more humid environments. The high diversity of ant species found and their preference for least disturbed areas suggests their role as ecosystem engineers could be enhanced through a better understanding of the interactions between ants, tillage practices, fertilizer use and pesticides.

- Spiders. The relationships between land use types and crop yield observed above suggests spiders are preferentially targeting crop pests. Further study is needed to confirm this tentative observation and identify particular predator pest relations that could be fostered through the adoption of IPM.

3. Management that benefits biodiversity and mixed farming.
Adoption of the guidelines below should provide enhanced biodiversity and long-term production benefits through the protection of beneficial predators (birds, invertebrates) and healthy soils (microbial diversity):

- Careful management of existing remnant vegetation to enhance structural complexity (i.e. number of vegetation layers; trees, shrubs, ground cover including litter) will provide more habitats for a range of plants and animals.
- Maintaining ground cover, particularly with perennial species, will increase biodiversity.
- Decreasing soil disturbance across land use types will maintain habitat for ground-dwelling species such as spiders, beetles and ants.
- Reduction of chemical inputs across the farm will increase biodiversity.

For policy makers

- Biodiversity does not start and end in national parks and reserves Data collected in the project clearly show that. Data collected through BiGG showed that considerable biodiversity exists on agricultural land and is affected by the management decisions and farming practices of farmers. This suggests that biodiversity considerations should be an important factor in the development of agricultural policy as well as environmental policy.

- Biodiversity does not start and end in the remnant vegetation patches on farms. The data from this project also shows that biodiversity in the agricultural components of farms can be significant as well as beneficial. It can vary from land-use to land-use, and so in mixed farms it is important that biodiversity across the entire farm be considered in farm planning and in the extension messages of agricultural, NRM and catchment management field staff. This on-ground action can be enhanced by recognition of the value of biodiversity in agricultural production at higher policy levels.

- Although biodiversity can be significant in the agricultural component of farms, it remains most significant, and possibly most vulnerable, in remnant vegetation. This reinforces the need for policies that provide targeted and ecologically-based incentives for the effective protection of remnant vegetation and rewards for practices that go beyond duty of care.

- Understanding of what constitutes native and remnant vegetation and 'good condition' varies markedly across Australia and suggests the need for closer links between catchment-based organisations and industry extension programs to improve the capacity of farmers to more accurately read their farming landscapes

For researchers

This project suggests that the following areas of research and specific research questions would contribute to better integration of conservation and production and identify specific aspects of biodiversity that can contribute directly to the productivity of mixed farming

What can biodiversity contribute to productivity on mixed farms? These questions would require new and detailed life history studies of selected crops and pasture systems and associated native plants and animals.

- What is the relationship between particular functional groups of plants and animals recorded in the BiGG data set to agricultural productivity (eg pest-predator relationships, soil microbial activity and productivity)?
- What ecosystem services do selected functional groups of invertebrates contribute to farm production and sustainability?
- What are the economic and production benefits of adopting integrated pest management in crop and pasture management?
- What contribution do birds make to agricultural production through pest management? (If positive, which ones, how and how much do they contribute?)
- Does the diversity of soil micro-organisms benefit agricultural production across a range of soil types? If so, how can farmers manage soils to increase below-ground biodiversity?

Does the presence of ground cover enhance soil microbial activity? How does this impact on nutrient cycling, carbon storage and soil biodiversity?

How can management of mixed farms contribute to biodiversity without compromising long-term production? These questions would require experiments that examined the biodiversity implications of a range of crop and pasture management practices.

- How does grazing management (intensity, seasonality, inputs, native, perennial, annual pastures) impact on soil invertebrates (macro-invertebrate indicator species such as worms and mites and microbiological diversity), and what is the role of these invertebrates in influencing soil structure, nutrient recycling and infiltration?
- To what extent do planted woody perennials (e.g. fodder shrubs, carbon and biomass plantings) support biodiversity?
- Can field margins, remnant and planted, be used to provide habitat for native beneficial species in crop and annual pasture paddocks?
- How do beneficial invertebrate species respond to continuous cropping compared to crop-pasture phase rotation?
- Do no-till systems support more biodiversity in the soil and at the soil surface than conventional tillage?
- What is the impact of raised bed systems on soil and surface biodiversity?
- How do chemical (pesticides, herbicides, fertiliser) and ‘natural’ (biosolids, ‘recycled’ waste water) inputs impact on soil health (e.g. soil macro-invertebrates)?
- What opportunities exist for remnant native vegetation to contribute to farm viability (e.g. habitat for beneficial species, future opportunities, environmental stewardship, and environmental credibility)?
- Which on-farm management actions provide multiple benefits to biodiversity?

Characterising interactions between biodiversity and agriculture at the landscape scale

- Which aspects of biodiversity are likely to confer greater resilience of mixed farming to climate variability?
- Are remnants in agricultural landscapes suffering from an extinction debt?
- Do the thresholds (maintain 30% tree cover, have no more than 30% intensive farming) proposed by McIvor and McIntyre (2002) hold for mixed farming landscapes?
- What impact does increasing the intensity of production have on biodiversity at the landscape scale?
- How are mixed farmers likely to respond to changes in commodities markets and new technology, and how will these impact on regional biodiversity? (e.g. increased returns from grain production, GM crops, biofuels, 'environmentally friendly' farm products)

Characterising socio-economic elements of biodiversity in agricultural landscapes

- Which mixed farming systems are both profitable and maintain and enhance biodiversity?
- Is it possible to profile producers undertaking natural resource management and biodiversity enhancement in social, economic or other terms?
- Is it possible to identify 'trigger points' to attitude and behavioural change towards biodiversity on farm?
- How significant are stewardship payments to mixed farmers in terms of providing encouragement and compensating for opportunity costs?
- What impact do stewardship payments have on the long-term maintenance and enhancement of biodiversity in agricultural landscapes?

	Vegetation	Birds	Soil microbes	Ants	Beetles	Spiders
Resource value *WHAT BIODIVERSITY CAN DO FOR PRODUCTION ON MIXED FARMS*	***Functional role***: • Stock shelter • Water table management • Habitat for beneficial species* ***Land use types:*** ***Management:*** • Maintain existing native vegetation* Encourage understorey, groundcover, litter and woody debris through judicious management e.g. grazing* & nutrient inputs* as these are correlated with species richness and abundance of beneficial birds and invertebrates.	***Functional role***: • Predation of crop and pasture pests ***Land use types:*** All ***Management:*** • Improve the condition of remnant vegetation by promoting natural regeneration and structural complexity*. • Increase structural complexity of perennial pastures*	***Functional role***: • Increased crop and pasture productivity through nutrient turnover • Symbionts • Mycorrhizal fungi ***Land use types:*** All ***Management:*** • Maintain organic carbon* • Minimise soil surface disturbance • Minimise compaction • Minimise erosion & salinisation	***Functional role***: • Nutrient cycling • Soil aeration • Water infiltration • Seed dispersers • Ecosystem enginerrs • Food source for birds* and lizards • ***Land use types:*** Crop and pasture ***Management:*** • Minimise soil disturbance* • Target pesticide use* • Use appropriate grazing management*	***Functional role***: Predation of crop and pasture pests ***Management:*** • Adoption of IPM • Target pesticide use in crop paddocks* • Maintain ground cover in pastures*	***Functional role***: Predation of crop pests ***Management:*** • Retain stubble* • Maintain height and structural complexity* • Maintain groundcover* • Target pesticide use* • Minimise soil disturbance*
Intrinsic, aesthetic and psychological values *WHAT MIXED FARMERS CAN DO FOR BIODIVERSITY*	• Maintain existing native vegetation* • Improve the condition of remnant vegetation* by promoting natural regeneration and structural complexity*. • Increase structural complexity of perennial pastures*	• Improve the condition of existing remnant vegetation (structure, complexity, reduced nutrient and pesticide impacts)* • Eliminate feral predators • Increase the 'mesh' or distribution of vegetation across the farm* • Increase the area of remnant vegetation on farm*	• Maintain organic carbon* • Minimise soil surface disturbance • Minimise compaction • Minimise erosion and salinisation	Minimise soil surface disturbance* Provide suitable habitat (remnant vegetation)*	• Increase overall herbaceous ground cover (some beetles more prevalent in pastures)* • Improve condition (complexity) of remnant vegetation*	• Increase complexity of vertical habitat in all land use types*

Table 6. Management recommendations to enhance biodiversity in mixed farming systems.
Statements supported by BiGG data are marked with *.

What have we learnt as participants in a highly complex project/program?

Management

The foresight of having good resources (funds) to allow the coordinator to travel to each region at least twice to meet with regional field officers and farmers. The two regional workshops were also very important to the success of the project as the engagement of regional officers under sometimes very difficult conditions created some momentum for the project and guaranteed a certain level of compliance driven by interest in the project and the results. The second workshop in particular allowed regional officers to see first hand how their data were being processed and analysed with the result that they had a greater understanding of the slow nature of the turn-around for some of the data sets (particularly the invertebrates).

The additional funds gained for the producer forum, again with inputs from regional staff, while expensive, was money well spent. This process 'sealed' the engagement of the farmers but is really only the beginning of their involvement with data from the BiGG project and the management implications that may flow from the results.

Support for extension activities included sponsorship of a one day symposium 'Embedding an ecological approach in agricultural landscapes: a way forward' at the Ecological Society of Australia's annual conference in Perth, WA, in December 2007. The project also funded a one day field trip to visit three farmers involved in the biodiversity project in the Avon region.

The project co-ordinator has had strong collegial support from the Steering Committee, from team members at UTAS and from within the regions and from the farming community.

Co-ordination

Team building within UTAS and across BiGG was an extremely important activity. Much good will was generated and called upon to help the project reach completion. The project achieved a great deal in a very short space of time. **Running the project through a University provided considerable added value through access to students projects and staff who had expertise they were prepared to 'donate' to the project because of the value they saw in it.** Justice has not been done to the dataset within the 2.5 year lifespan of the project. There is a large resource of information in the various datasets that cannot be explored during the life of the project. Ideally this project would need 8-12 months to fully explore the data set. The final data collection occurred in Spring 2007 and some samples did not arrive at UTAS until Jan 08. Given that the invertebrate samples take a minimum of 4 months to sort, the original timelines were unrealistic.

Data management was a big issue for the project, with hundreds of thousands of data points collected. Data could not always be entered into data bases because labels did not exist for the samples. In future, a locally based database manager would be able to provide assistance on the development of a data base and more streamlined methods of inputting data e.g. scanning data sheets; a method used by Birds Australia. The national database manager raised the possibility of having regional staff upload their data into the national database. However this idea was rejected because the data needed to be sighted in a relatively raw format to assess its quality. In future, a combined approach would be beneficial but assessment of the raw data is essential.

Institutional structures, partnerships and collaboration

BiGG started on the back foot in that the national project was not an integrated component at the start of the Grain & Graze program. It was developed in response to the lack of regional uptake of local research into biodiversity on mixed farms. The project was introduced two years into the program when most regions had committed time and funds to other projects. Therefore there was some level of resentment for those regions that had actually instigated regional biodiversity research projects. Engagement through the initial BiGG research workshop helped to overcome some of the unease that regions felt, and **an effort was made to try and link BiGG to existing regional projects to ensure that the BiGG data set could, where possible, add value to regional data sets and that more detailed regional data sets might be used to validate the BiGG data set.** This was achieved for the three of the four regions that collected additional biodiversity data (Border Rivers, Corangamite/Glenelg-Hopkins, Mallee). The LCW biodiversity project operated at a landscape scale. Our preliminary results support their research findings (Figure 24).

Regional capacity was limited with respect to links to other organisations who had expertise useful to the regional project officers. In most regions, the project officer was not an ecologist or may not have had NRM training. **However, the 'best' regional data sets were those that had been collected by ecologists or NRM trained specialists.**

Having all of the data sent to UTAS allowed the various research teams to integrate on a regular basis. The whole team met at least four times a year with smaller meetings between component groups at more regular intervals (every 2-3 months). Issues with data anomalies could be easily identified and rectified. All correspondence was sent/received through the project co-ordinator to ensure that conflicting messages were minimised. The development of an all encompassing database would be beneficial but is unlikely given the format of the different datasets and the data licencing requirements placed on the State or Catchment Management Authority GIS layers. **An all-encompassing agreement with the Grain & Graze program and all collaborating partners may have alleviated licencing (and access) issues.**

Given the time lag placed on sorting and then identifying invertebrates, it was difficult to populate the national data base until one year after the project started. Even then only preliminary data were sent and were revised at least three times as individual datasets were updated. The regions were not engaged with the national database and many did not attempt to use it until a week before their final reports were due. Many contacted the national project for assistance with interpretation of the data. Time was limited as the BiGG final report was also due at the same time.

Integrating R D & E disciplines

The integration of research, development and extension was done through cooperation with the regions and with other national projects and through research and producer forums. When requested, the national team would create interpretive material (posters, fact sheets) for regional project officers. Information was delivered and discussed at Grain & Graze forums with the highlight being the farmer forum in Hobart. Given the tight timelines for the project, much more could be done in interpreting and communicating the results, particularly to the regions and on farm. For example **over 200 photographs have been taken of different beetles which could form the basis of a web based identification key, emphasizing beneficial predators and pest species.** Several journal articles will be written in 2008, presenting the results to ecological and agricultural audiences.

Communicating results

Given the short space of time to complete the project after the final data collection period, there has been little opportunity to communicate results. The direct link the farming community was strongest after the farmer forum in Hobart. Here farmers were able to interpret the data from their own farming context and could provide insights into how data differed across the nine regions. **A key message for the research team is that the workshop increased farmers' understanding of what biodiversity is, what it looks like and how they can alter management to promote biodiversity, particularly beneficial species.** This encouraging forum felt like it was the start of biodiversity focused dialogue on farms despite it being held five months before the project finished. Before this farmer forum, most communication was done through the regional project officers or at the research and national forum events organised by Grain & Graze, or when the national project coordinator visited regions. **The advantage of having regional officers communicating directly with farmers was that they were best able to transfer results using local terminology and context.** BiGG had to apply terminology that made sense nationally but didn't necessarily make sense regionally. Not all regional project officers were engaged to the degree that was envisaged with constraints such as time, limiting their ability to spend additional time on the farm. With hindsight, two components of the data collection on farm would have best been undertaken by one or two individuals across all farms, these were the farmer interviews and the collation of farm paddock maps for GIS mapping. **Ideally each region would have had access to a dedicated BiGG project officer with an appropriate time allocation and budget and access to vegetation survey staff if necessary**. Each regional project officer needed to visit each farm three times per season. This was more than was originally anticipated and for most, available funds barely covered their travel expenses.

Integration of the results in a regional context was left very much to regional project staff to deliver. The national project provided summaries of results, usually in the form of posters, fact sheets and tables. Integration with other national projects could have created a much stronger communications message with regional significance.

The alignment of final reports for regional and national projects was unfortunate. Many regions required some assistance in interpreting their data sets. As all reports were due at the same time, it was difficult to allocate time to assist them. Assistance was given in the form of proof-reading and additional data sets. If regional reports were due after the national reports, then the regions would be able to make use of the national reports to help them interpret the results.

Final reports from the regions (Appendix 12) suggest that regions now have the capacity to develop and undertake biodiversity research within the region. They too have a greater understanding of what biodiversity looks like, and the potential benefits to production.

Interpretation of their regional subset of the national BiGG data set was varied due to the small number of farms surveyed in each region, resulting in a high degree of variability in management and subsequent impact on biodiversity between farms. The BiGG data set is a national data set and needs to be analysed as a national data set. Hypotheses that have been created from the project have been developed in alignment with regional research focus areas.

More results are expected over the next six months as research papers are written for publication in scientific journals. Interpretations of these results will be provided to regional project staff, who have identified this as a primary need, both verbally to the national project coordinator and through the GG program evaluation. Financial support for these activities would ensure the best possible outcomes in terms of information delivery to a range of audiences in a variety of formats.

National project interaction

Ideally some overlap between 'case study' farms and the four national projects could have provided greater insights into the impact of enterprise mix, economic and social decisions and impacts on natural resource management and biodiversity. The relationship between biodiversity and production could not be explored in any great detail within the biodiversity project, but could have been addressed with the assistance of the other national projects. The BiGG project officers were not comfortable asking questions relating to the economic performance of farms. Links with the economics project on case study farms could have been beneficial.

The original intent was that the BiGG project be carried out on the same 40 farms that were being used as case studies within regions. This did not happen. The unfortunate delay in the project, and the relatively tight deadlines to start the field data collection program meant that it was not possible to directly align BiGG with the other three national projects.

Recommendations for future projects

Funding of research projects should allow for appropriate time after the data collection phase to maximise messages and recommendations based on the results. Ideally 8-12 months would be adequate to fully analyse the data set. Final data collections did not arrive at UTAS until late Jan 2008 and complete GIS data were not available until April 2008. This left one month to analyse the data and write up the report. The project was under some pressure to present results for documents when analyses hadn't taken place, and when data collection had not been completed.

The experimental design did not allow specific detailed questions on the impact of land management practices on biodiversity to be addressed. Having five farms in each region, combined with regional differentiation and variable land management between farms within regions, meant that questions relating to tillage practices and herbicide/pesticide use could not be easily addressed as statistical power was low. However the results provide support to develop hypotheses to address specific relationships on the impact of land management practices on biodiversity.

The data from BiGG clearly show differences in enterprise mixes and how these mixes impact on biodiversity values, i.e. farms with a relatively large grazing enterprise have higher biodiversity values than those that have more of a cropping focus. Further exploration of these results, using a triple bottom line approach would provide greater insights into the triple bottom line profile of the variability that exists in mixed farming systems.

The participatory approach provides benefits, particularly in terms of engagement and hopefully on-ground adoption of results. Insights from regional project officers and farmers enhanced the project and provided increased capacity within regions. While this approach requires a large amount of funding, to allow stakeholders to engage with each other, there are trade-offs with data collection, with some data quality issues. Data quality can be addressed by altering data collection techniques and by ensuring that regions have the capacity to collect the information needed.

The dataset forms the basis of further research into management recommendations at the farm scale and for the protection and enhancement of native vegetation at the catchment scale. These management recommendations can address regional issues and may include how to enhance crop/rotation land use systems to improve biodiversity outcomes.

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Appendicies

1. Biodiversity and Mixed Farming Systems: Warren Mason, Ted Lefroy and Jann Williams (30/11/04)
2. BiGG field data collection manual
3. (a-e) Examples of communications to regions (BiGG posters and fact sheets)
4. Farmer interpretations of the BiGG data, Hobart, January 2008
5. BiGG GIS research article: Mount, RE, Lacey, MJ, Pederson, TK. (2007) A spatial (Landscape ecology) metrics tool for assessing the biodiversity of agricultural land. *Proceedings of the Spatial Science Institute Biennial International Conference.* Hobart, Tasmania, Australia, 14-18 May 2007, pp. 1-13
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10. Rainfall data for the period 2005-2007
11. Corkrey, R. (2008) 'Canonical Correlations Analysis relating biodiversity and system-site variables. Unpublished report to BiGG, TIAR, April 2008.
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