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Sustainable Grazing Systems

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EXECUTIVE SUMMARY

The Biodiversity Theme was established to investigate:

1. The impact of using land for grazing on biodiversity,

2. The relationships between biodiversity, productivity and sustainability of grazing systems, &

3. Develop management tools to monitor and manage biodiversity.

These were very broad questions, embracing much more than SGS was able to address with the resources available or within the scale of SGS as SGS focused on small paddocks rather than landscapes. To reduce the scope to something manageable, the main focus across Sites was on plant species biodiversity and productivity in relation to grazing management treatments over time. An initial activity of the *Theme* was to outline the areas of biodiversity that it could contribute to and to foster the debates within SGS on biodiversity and what this could mean within grazing systems.

These debates continue and it is apparent that many in the community still confuse the science of biodiversity and what it is focused on with nature conservation issues. There is some overlap between the two, but a lot of the work in biodiversity is about how ecosystems function, without distinguishing between native and exotic species. The *Biodiversity Theme* examined both total and native species diversity and how that related to the productivity of grasslands.

The *Biodiversity Theme* has drawn upon the primary plant species data sets collected at each Site and some additional data on other components on the grassland ecosystem. Most work focused on the Carcoar Site where treatments were applied to naturalised grassland that contained over 100 plant species. At Carcoar additional studies were done on soil seedbanks & arthropods and a limited survey of microbial diversity. The *Theme* developed procedures for the analysis of biodiversity information that were finally incorporated into the SGS database and which enabled the detailed behaviour of each treatment to be explored and provided some of the monitoring tools required. This report is more concerned with the general results that emerged.

For most SGS Sites there were only two to three years of data available, due to the time initially needed to establish each experiment. Data collection continued through 2001-2 in some cases to obtain a longer series of years. However, no Sites have been through a cycle of good to poor years where the grazing ecosystem was adjusted to each set of conditions. The results presented here are therefore preliminary, but important as this is the first time that a program of grazing experiments in higher rainfall areas of Australia have sought to address biodiversity.

The impact of grazing on biodiversity was considered from two perspectives: first, the general diversity of plant species and second, the diversity of native species. The data obtained from each of the national Sites has tended to show either no change in total plant species or a small reduction with some management practices. Treatments often aimed to increase herbage mass and water use *etc.*, and did not focus on managing species diversity. The species 'lost' from some treatments tended to be minor exotic species that do not make any major contributions to production and were unimportant from a nature conservation perspective.

Carcoar is a Site where native species occur in number and none of the naturalised grassland management treatments lost any native plant species. What changed was the relative abundance of species. Paddocks managed to higher levels of herbage mass (desirable for sustainability reasons) had less of the minor / lower growing / mostly exotic species. The survey of soil arthropod species found a similar range within each treatments and an initial index of soil microbial activity showed no significant differences between treatments. Both the soil arthropods and microorganisms live on organic matter, rather than live plant tissue and may thus be less likely to be influenced by above ground management. These results may reflect a carryover effect from the initial starting conditions and only by continuing these studies over the longer-term will we know if these effects on biodiversity truly reflect the treatments imposed.

Many of the native plant species present in grasslands have now survived under various management regimes for many years. In consequence we should expect them to tolerate reasonable management practices. No SGS Site has identified any rare or threatened species at their Site but these are unlikely to be present in most grazed grasslands because of the history of these areas in southern Australia ie. only the more grazing tolerant species are likely to have survived.

Diversity at complex Sites such as Carcoar is heavily influenced by aspect and slope as well as by treatments. For example, while earthworm numbers responded to treatment effects such as fertiliser, their distribution was also clearly related to moisture level of local microsites, which also influenced plant and arthropod species. Sixteen species of earthworms were found across the SGS Sites with densities up to 18 m earthworms ha^{-1}. Future studies have the challenge of resolving how best to separate these influences so that the full impact of treatments is clearer. The tools to do this have yet to be fully developed.

Above ground diversity is influenced by treatment, but this does not always reflect the below ground diversity and seed banks. This suggests that as management changes the system could respond based upon the species present in ‘storage’ rather than simply on the current above ground species. The survey of the soil seedbank at Carcoar found that annual species were far more common than above ground and hence there could be dramatic changes in plant species composition if the site was disturbed without appropriate management. Soil insects from 18 Orders were found and while these were least in unfertilised continuously grazed plots, like earthworms the insects were clearly influenced by position in the landscape.

The number of plant species and functional groups ie. legumes, perennial grasses *etc.* present, influences the productivity of grasslands. This relationship appears to be asymptotic. At Carcoar it was found, across the naturalised grassland treatments, that productivity was declining as species number increased, probably because that grassland had a super-optimal numbers of species (20+) and many of the additional species were not very productive. Evidence in the literature suggests that around 6-10 species within ‘uniform’ areas are optimal. Often the grasslands are dominated by a few species from one functional group eg. perennial grasses, annual grasses or broadleaf weeds. Diversity of functional groups may be more important than diversity of individual species. Our understanding of how these species groups interact is still rather limited and hence difficult to predict what may limit problems such as weed invasion. The data obtained in SGS has not been sufficiently detailed to decide if eg. broadleaf weeds simply replace other functional groups eg. more palatable forbs or if it is simply a function of the availability of gaps that can be colonised. The data do though support the view that the perennial grasses provide the stable base for the productivity of the ecosystem.

The preliminary work done on microbial activity (measured as microbial carbon) has raised the tentative indication that perennial systems have higher levels of microbial activity than annual and, or fertilised grasslands. This may indicate a general increase in system 'health'.

Fertiliser has had a positive effect on productivity as expected, has increased labile carbon (an estimate of microbial activity) and had few adverse effects on diversity. Where diversity declined the species lost were minor and that may have been a function of insufficient grazing pressure than due simply to fertiliser. Earthworms responded positively to fertiliser and to increasing herbage mass within paddocks.

The preliminary work done within SGS on the relationships between management and biodiversity suggests that provided grazing is optimised to maintain the average herbage mass above 2 t DM ha^{-1} during the year, most plant species will persist and the populations of key indicators such as earthworms will remain high. At this level of herbage mass weed invasion is also likely to be limited and the diversity of soil organisms will remain. The data across Sites also suggests that an upper boundary of 4 t DM ha^{-1} for management may also be appropriate as above that limit productivity and stability in pasture yield declined and minor exotic forbs tended to become more prominent.

Applications of fertiliser do need to be managed carefully to limit the shift towards more annual species and to exotic arthropods such as red-legged earth mite. The management of natural predators for earth mites needs to be more closely studied within the context of more sustainable grazing systems.

The preliminary recommendations from SGS for the management of biodiversity are that herbage mass needs to be carefully managed and over-grazing and under-grazing avoided if species are to be retained and the ecosystem remain fully functional. The initial results provided by SGS suggest that if the average herbage mass on HRZ pastures is < 2 t DM ha^{-1} then over-grazing results and if > 4 t DM ha^{-1} then under-grazing occurs. This supports earlier indicators developed in an MLA project on the *Pasture Management Envelope*. Between these limits plant taxa diversity is optimal for the productivity and stability of the pasture. To achieve these levels of productivity fertiliser often needs to be applied, but care needs to be taken when applying fertiliser that annual and pest species do not become dominant. Producers need to be able to identify the species present in their grasslands to determine if they are native, or exotic and to then monitor their grazing based upon the level of the more desirable components to determine if the grassland is in a desirable *state*. This can be done using tools such as the *Pasture species composition matrix*.

CONTENTS

1. BIODIVERSITY AND GRAZING SYSTEMS: HOW HAVE WE ADDRESSED THIS ISSUE?

Management of grasslands is now much more about harvesting an ecosystem than cropping a paddock with livestock. This is not mere semantics; this is a fundamental shift in paradigm. We need to think of paddocks as grazed ecosystems nested within ecological landscapes. We need to improve our understanding of how these ecosystems function in order to retain and utilise them to our advantage.

Biodiversity is the biological diversity of all lifeforms – the different plants, animals and microorganisms, the genes they contain and the ecosystems of which they form part. The definition developed by the *Biodiversity and Trees & shrubs* (BaTs) *Harvest Team* is:

The diversity of living organisms in grazing systems that sustain and enhance the human and natural environment.

Biodiversity is not a fixed entity but constantly changing and also connotes a way of thinking about the environment and the way we use it. It is a new term that has just been listed in reference Dictionaries eg. the Oxford English Dictionary. Biodiversity reminds us of the need to conserve species and ecosystems. The definitions used do not distinguish between native & exotic organisms. The understanding of biodiversity requires the development and use of techniques that abstract data on the functioning and role of organisms and ecosystems. This is a relatively new area for many involved in more intensive agricultural industries, though it has been a major part of understanding extensive grazing systems.

1.1 Biodiversity Vs sustainability

Biodiversity overlaps but is not synonymous with, sustainability. Biodiversity adds to sustainability the issues of preserving ecosystems and genetic diversity. Unfortunately sustainability is often discussed solely in terms of soil issues, especially physics and chemistry, despite the fact that land degradation probably started with the overuse of plant species. The realisation that biological issues were not being given full consideration has lead to the enlarging interest on biodiversity. Biodiversity studies tend to be done from two related perspectives, conservation and resources. In agriculture we are interested in both, though the emphasis tends towards resources. *We want to know what impact management is having on biodiversity in grasslands and what effect biodiversity has on production and sustainability.*

1.2 Objectives

The *Biodiversity Theme* was established to investigate:

- The impact of using land for grazing on biodiversity,
- The relationships between biodiversity, productivity and sustainability of grazing systems, &
- Develop tools to monitor and manage biodiversity.

These are very broad questions, embracing much more than SGS was able to address with the resources available. SGS was also focused on small paddocks such that effects at a landscape scale could not be addressed, nor could native animals such as birds, reptiles and ants that can readily move between the small paddocks studied. To reduce the scope to something manageable, the main focus across Sites has been on plant species biodiversity and productivity in relation to grazing management treatments plus measurements on some other ecosystem components as explained in following sections.

The strategy adopted by the *Theme* was to concentrate efforts at the Carcoar Site near Orange, with it's strong focus on native pastures, progressively intensified, including have a PhD student do a study of the invertebrates of the soil surface layer, and analyses of the grassland structure in relation to the landscape and the soil seed bank. A limited study was done on microbial diversity. Soil microbial biomass estimates were done at some other Sites.

This work was reinforced with a minimum set of measurements across all Sites:

- Grassland species present and their abundance (sampled every six months)
- Earthworms (sampled in spring 2000)
- Labile carbon (simpler estimate of microbial carbon)

After deciding what could be done within SGS a set of analytical procedures was developed which could be used to routinely analyse the SGS databases.

Biodiversity represented new ground for SGS at the time SGS was being planned and for grazing programs. In this report we:

- expand upon the theory of biodiversity as it relates to grazed ecosystem management in the high-rainfall zone of Australia – to put the work done within context;

- present the findings of the Biodiversity Theme in the National Experiment; &

- outline outcomes for the *harvest year*.

2. DEVELOPING AN ECOSYSTEM APPROACH TO MANAGEMENT

What does biodiversity mean within the context of SGS? To address this issue we considered it was first important to discuss the relationship between biodiversity and grazing ecosystems to identify the components involved and what measurements were taken and why.

Biodiversity encourages an ecosystem approach rather than emphasising individual species in isolation. It accepts the argument that species occupy varying ecological niches ie. different species use different resources and some species need different habitats. The key issue is that species interact in some form and the overall productivity of the system depends upon those interactions. Biodiversity is important in the development of ecologically sustainable management practices for agriculture.

In agriculture we need to optimise the functionality of the ecosystem for both production (derived from utilisation of available resources) and for nature conservation. In grazing systems we want to ensure that all the basic resources are efficiently utilised and the rates of loss from the system are minimised. For example; are the species present maximising productivity and, or stability; are native species surviving in adequate numbers; are weeds, pests and diseases being kept to acceptable levels; are the range and number of species adequate to transpire the rain that falls; & are species adequate to capture soil nitrogen and cycle nutrients? There is evidence that the stability of ecosystems does improve with diversity (eg. Tilman, 1996).

A narrow definition of biodiversity equates it simply with nature conservation. Native species are obviously of increasing importance to society and to SGS, but agricultural environments are disturbed and always involve exotic species, either planned or as volunteers. Biodiversity offers an opportunity to develop ideas on how agricultural ecosystems could be better managed as well as how they can satisfy nature conservation objectives. However, it was considered that it would be a mistake in SGS to simply concentrate upon native species and not consider how they interact with others.

In grazing systems biodiversity can be high, but this can be misleading because, for example many weed species are present. This high diversity doesn't necessarily equate with greater stability or sustainability and we do not know how these species impact on the invertebrate and microflora and microfauna in soils and then how the whole ecosystem is functioning. For instance, is the plant material of exotic species being broken down and nutrients cycled as rapidly as for native species? The study of grassland ecosystems has usually been limited to above ground parts. Very little is known of what goes on below ground in southern Australia (apart from the studies of Hutchinson, King and Greenslade cited in the references).

In SGS we have obtained data on some of the species present at different levels within grazed ecosystems as outlined below. From that we can then start to draw conclusions from conservation and resource perspectives, but we realise that we cannot answer all the questions that can be posed.

2.1 Grassland ecosystems

Grassland ecosystems are built from many trophic layers (Figure 1) from a myriad of soil microorganisms through to a few macroherbivores (sheep or cattle). At each layer in grazing ecosystems it is important that we have desirable species to utilise the available resources, else productivity is limited or undesirable pests, diseases or weeds invade to use those resources. No one species is ever capable of using all the resources available ie. space, nutrients, water *etc.* Resource availability varies for a variety of reasons, including the impact of environmental variation. Annual grasses often remain part of grassland systems because they can exploit that variation and occupy any gaps when and where they are available.

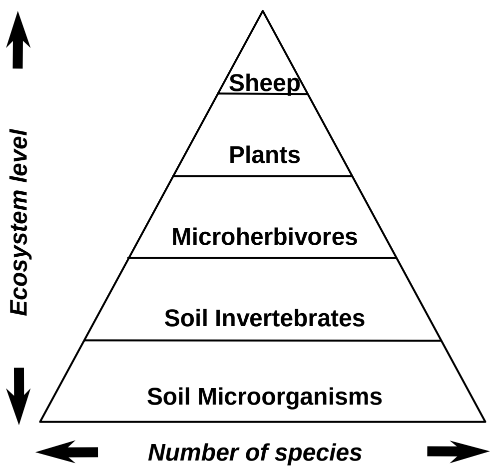


Figure 1: Ecosystem levels & diversity within grassland ecosystems

A consideration of current management practices shows that most effort is commonly focused on the top layers ie. sheep & plants, with almost no attention being paid to the myriad of other organisms. Possibly this is the inverse of what could be done to insure a more functional, productive and stable ecosystem?

Grassland productivity does increase as the number of plant species increases (Figure 2 eg. Tilman *et al.* 1996). Experimental data from North American grasslands shows an increase in annual productivity ie. increasing utilisation of available resources, until the species number is around 10, after that productivity plateaus. Results in support of this view have recently come from New Zealand (Nicolas *et al*, 1997), though that work also showed results were not always consistent. The NZ studies did find that yield was more consistent, with less variation from year-to-year ie. greater stability, as species number increased. More recent data (Tilman *et al*, 1997, Hooper & Vitousek, 1997) has indicated that functional groups eg. perennial grasses Vs annual grasses or legumes are likely to be as important as species diversity (Figure 2), a point most agronomists would support.

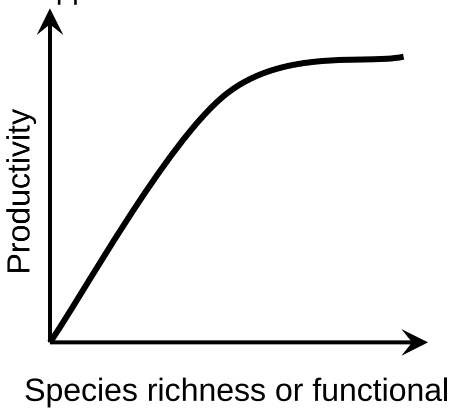


Figure 2: Generalised relationship between species richness or number of

The data discussed here were derived from different combinations of many species, but were in small plots or patches and should be interpreted as an optimum species number within a relatively uniform area. The number of species within a paddock could be considerably more, with different combinations of species occupying the different niches across the landscape. Thus on a paddock scale the optimal range in number of species could be greater than the small plot work suggests.

2.1.1 Macroherbivores

Optimising the utilisation of grasslands by livestock has been the goal of considerable R&D over many decades. Usually that work has been done using one (macroherbivore) species, much less has been done with mixed grazing. A biodiversity perspective would suggest that mixed species grazing would increase the total productivity of that component of the ecosystem.

Cattle, sheep and goats are to some extent complementary grazers – their diets tend to be different. Goats in particular can be very useful at utilising some weeds and fibrous shrubs. The SGS national Sites are not examining this issue but it should be considered in future programs. Each Site has considered how effectively their livestock system utilised the available forage by estimating the percent of available forage used by livestock at each measurement throughout the year. Livestock have an important role in nutrient turnover.

2.1.2 Plants

Plants are the units of primary production in grassland systems. Through photosynthesis they capture energy and produce the basic foods on which other species depend. They are an obvious focus within SGS and the primary ecosystem level monitored across all Sites.

SGS provided an excellent opportunity to test ideas on grassland species richness and resource use and the core plant measurements were used by the *Biodiversity Theme*.

Resource use can be measured by productivity, and productivity can be measured by pasture growth rates (Figure 2). Both above and below ground biomass of individual species are important to get a complete description of biodiversity, but in this case it has only been possible to measure above ground herbage.

Presence Vs frequency Vs abundance. Biodiversity studies often only record the presence or absence of species. But presence is a crude measure – a plant is 'present' if there is just one individual or a whole paddock full. Better measures are yield (abundance) or density (the numbers of plants present). In SGS we measured the contribution of each species to biomass using yield, and frequency (the proportion of samples across the paddock in which the species is present). Frequency data was then related to biomass.

2.1.3 Meso and Microherbivores

Insects, slugs and microorganisms compete with livestock for plant material. They consume both above and below ground plant parts. Typically we consider microherbivores as pests and diseases, but the actual situation is not that simple – they also turn over organic matter and limit the accumulation of litter. However as a minimum at each Site, records were maintained of the incidence of pests and diseases.

2.1.4 Soil invertebrates

Soil invertebrates play a large part in the breakdown of litter and in recycling organic matter. Many are considered to be beneficial for the functioning of ecosystems, especially nutrient turnover. Work by Hutchinson and King (see references) has shown that these species have a large biomass; often five times that of the livestock grazing the pasture. Different species utilise different resources eg. litter, fungi *etc*. Collembola are a major group of soil invertebrates and these have been monitored at the Orange Site in relation to management treatments. This work is discussed in a separate document (Cassis and Hochuli, 1996).

Earthworms are well known and an important part of grasslands. Each Site has sampled the species present and estimated abundance under the main treatments in Spring 2000 ie. at least 18 months after each treatment was established.

2.1.5 Soil microorganisms

Soil microorganisms are important in the breakdown and cycling of organic matter and nutrients within soils. They interact with plants and insects and some cause disease. It would be very difficult and arguably impractical within SGS to monitor all the soil microorganisms and to assess their function. It has often been commented that the number of species of microorganisms within a cubic meter of fertile soils would exceed the number on the barrier reef. Many of these species are likely to be still unknown to science and hence not readily detectable as their characteristics are unknown.

The direct measurement of total microbial biomass (Amato & Ladd, 1988) was done at some Sites. Labile carbon is a possible surrogate for microbial biomass and is relatively easy to measure by non-specialists; measurements were done at all Sites. The value of using the uncertain technique of labile carbon instead of directly measuring microbial biomass was evaluated at Tamworth and further evaluated during the harvest year across other sites.

While it would be impractical to survey all the microorganisms within each Site it may be possible to evaluate the general diversity. An exploratory study at Orange tested the diversity of microorganisms by using the ‘ecolog’ system, which has been derived from ‘biolog’. This system has been developed to speed identification of microorganisms based upon patterns of substrate used. The ‘biolog’ system was developed for use in rapid identification of some bacterial groups using 96 substrates. The ‘ecolog’ system uses some 30 substrates, considered more appropriate for soil organisms.

3. OVERVIEW OF PROGRESS: FINDINGS, OPPORTUNITIES AND UNCERTAINTIES

Progress against the objectives of the *Biodiversity Theme* is outlined below. Emphasis is placed upon data from across the SGS National Experiment Sites and from Carcoar (Orange) and Tamworth, the two Sites that have been most closely involved with the Theme. Data from other Sites is used where appropriate and the outcomes for livestock producers in the higher rainfall zone across southern Australia discussed. The *Harvest Year* enabled the analysis of cross-Site results to be done more expeditiously and the outcomes from those analyses are reported here. These outcomes were then incorporated into the advisory material prepared during that year. The *Biodiversity Theme* was closely involved in the preparation of a special issue of *Prograzier* on biodiversity and a series of *Tips and Tools*.

3.1 An understanding of the impact of using land for grazing on biodiversity

The analysis of results from all Sites within the SGS National Experiment found that:

- More than 200 plant taxa were recorded over the period of the experiment. In some cases sorting plants to a species level was inconclusive and hence a broader taxonomic category had to be used. These estimates are therefore conservative.
- Sites varied in the number of plant taxa present from ~ 25 to > 100.
- The most abundant plant types were grasses, particularly perennial grasses though there were often a high proportion of annual grasses in some treatments.
- The most numerous plant taxa found were broadleaf species – usually minor exotic forbs.
- All treatments had > 10 plant taxa present and some had > 40. This was within the small paddocks used across the National Experiment. Greater numbers could be expected within many farm paddocks eg. the Carcoar 60 ha site had > 100 plant taxa before the experiment commenced. Species number will depend upon the range of micro-environments within a paddock.
- An investigation of various diversity indices, while offering some theoretical advantages did not provide a more useful measure of diversity than species richness ie. the number of species present.

- Future work needs to emphasise functional types of plants more than species number as the productivity of treatments does relate to plant type more than species *per se*.

- About one third of the plant taxa found across all Sites were native (~ 70 taxa). In all cases the native species found remained within the experiment site, though their abundance varied with treatment.

- Native plant species remained within paddocks sown to exotic species.

- Where treatments maintained an average herbage mass > 2 t DM ha^{-1} they retained all the native species within those treatments and many recorded an increase in native species over time (1-2 species yr^{-1}) – presumably arising from the soil seed bank &, or becoming more prominent and hence able to be recorded.

- The main native plant types present were perennial native grass groups; there were very few native annual grasses, forbs or legumes.

At Carcoar studies were done on several trophic levels ie. macrofauna (sheep), vegetation (there were in excess of 100 plant species), mesofauna (soil arthropods and earthworms) and soil microbes. It was found that:

- The ‘active’ management treatment (ie. managed to enhance the proportion of perennial grasses and to a higher mean herbage mass) increased total species number, increased the perennial grasses *Austrodanthonia, Bothriochloa* and *Themeda* but decreased *Microlaena*.

- Fertiliser increased *Microlaena* & *Geranium* and depressed *Epilobium* abundance. Total species richness was depressed (also reflected in Shannon-Weiner, Simpson & Fisher indices) but the species ‘lost’ tended to be minor exotic forbs, which could be ‘redundant’ (ie. their function could be duplicated by other species).

- In general there was a small negative relationship between plant species diversity and total annual production from treatments. However as all treatments had > 20 species this was above the estimates in the literature that 6-10 species were optimal.

- Oversowing with exotic species did depress, but not eliminate the native grasses and increased *Gnaphalium*.

- Some species eg. Echinopogon, Stipa, Poa (Tussock) & *Glycine* were not affected (so far) by any treatments. The general impression to date is that the native species that have persisted in grazed environments are probably well adapted to those conditions – within reasonable limits.

- Aspect has a major influence on plant and arthropod species diversity and productivity and this can override management treatments. Microsite moisture conditions appear to be the main determinant of diversity ie. the wetter the area the more plant and arthropod species present.

- No native plant species have disappeared from any of the naturalised grassland treatments.

- No rare or threatened species were present, which means that SGS will be unable to comment on the impact of management on such species.

- Soil arthropod diversity was similar across a range of management treatments, though abundance varies. Applying fertiliser resulted in a rapid increase in the populations of exotic mites (RLEM) and there are indications that fertiliser may have reduced arthropod species richness. Over 200 morphospecies have been identified from pitfall traps and vacuum sampling. Analysis of the soil and surface-active arthropods for Carcoar took an enormous amount of time, as there were insects from some 18 orders and 200+ morphospecies, which were difficult to identify. Some species have probably never been described.

- Some 68,000 arthropods were collected from the soil and these included representatives from 12 beetle families, 18 wasp families and 15 ant genera. The lowest diversity was in unfertilised, continuously grazed plots.

- There appears to be an association between arthropod species, plant species and plant structure ie. there were different insect communities within tussocks *cf* flat weeds. These relationships were not always definite and possibly reflect that these insects were often feeding on plant residues rather than directly on the plant.

- The plant species found in the soil seedbank and their abundance was different to the above ground measurements. The soil seedbank had more annual species.

- Soil cores taken at the start of the experiment resulted in an average germination of 41,000 plants m^{-2} (maximum of 360,000 plants m^{-2}).

- The apparent diversity of soil microorganisms (assessed using ‘ecolog’ plates) was similar for different pasture systems. This technique was investigated as a means of more rapidly assessing the diversity of microorganisms, but the results were inconclusive as the differences in patterns of substrate use in relation to treatments were not significant. In part this was due to our very poor understanding of the actual diversity of soil microorganisms and of how to sample them.

- Analyses of the earthworm data suggested that the density of earthworms was greatest in ‘actively’ managed treatments, though this was then modified by landscape. Worm numbers reached 18 m ha^{-1}.

- One of the interesting aspects of monitoring plant biodiversity has been a greater appreciation of the role of forbs in pasture systems. The most common broadleaf species is *Hypochaeris* (catsear) yet we do not know much about its productivity, nutritive value (suspected to be high) or ability to prevent invasion by weed species. Our knowledge of these often minor species is very poor apart from those that become weeds. There is the suspicion that the diversity of forbs may relate to the stability of the pasture ecosystems ie. areas with high numbers of forbs are the older and more stable grasslands. The interactions between useful forbs and weed species are poorly understood.

At Tamworth:

- The species list for the 3 SGS Sites on the North-West Slopes, NSW contains > 100 species of which most occur at the two native pastures Sites. Of these 8 were native perennial grasses, 56 forbs, 17 naturalised annual grasses and 11 naturalised annual clovers.

- The pasture species diversity of the sown improved pasture site is narrower than that of the native pastures with less than 20 different species being recorded in the phalaris / subterranean clover pasture.

- Both the sown and native pasture sites are dominated by a few species that have high abundance and contribute to the majority of the herbage mass. ie. some functional groups, especially the perennial grasses, are more productive than others.

- Forbs and naturalised annual grasses and legumes occupy the interplant spaces between perennial grass tussocks ie. they are more typically 'gap' fillers and hence more ephemeral in behaviour.

- Variegated thistles are in highest abundance in fertilised areas.

- Saffron thistle abundance is highest in areas where ground cover, litter and pasture mass are reduced in spring.

- While seedling recruitment of winter and summer growing annuals and some perennial forbs has been observed, no recruitments of perennial grasses have occurred. Across SGS there was limited understanding of the processes whereby perennial grasses recruit.

Other Sites tended to have simpler plant species structures with fewer natives (often only one or two) and treatments did not appear to change the plant species composition within the short-term of SGS.

3.2 An understanding of the relationships between biodiversity, productivity and sustainability of grazing systems

The results from across the SGS National Experiment were that:

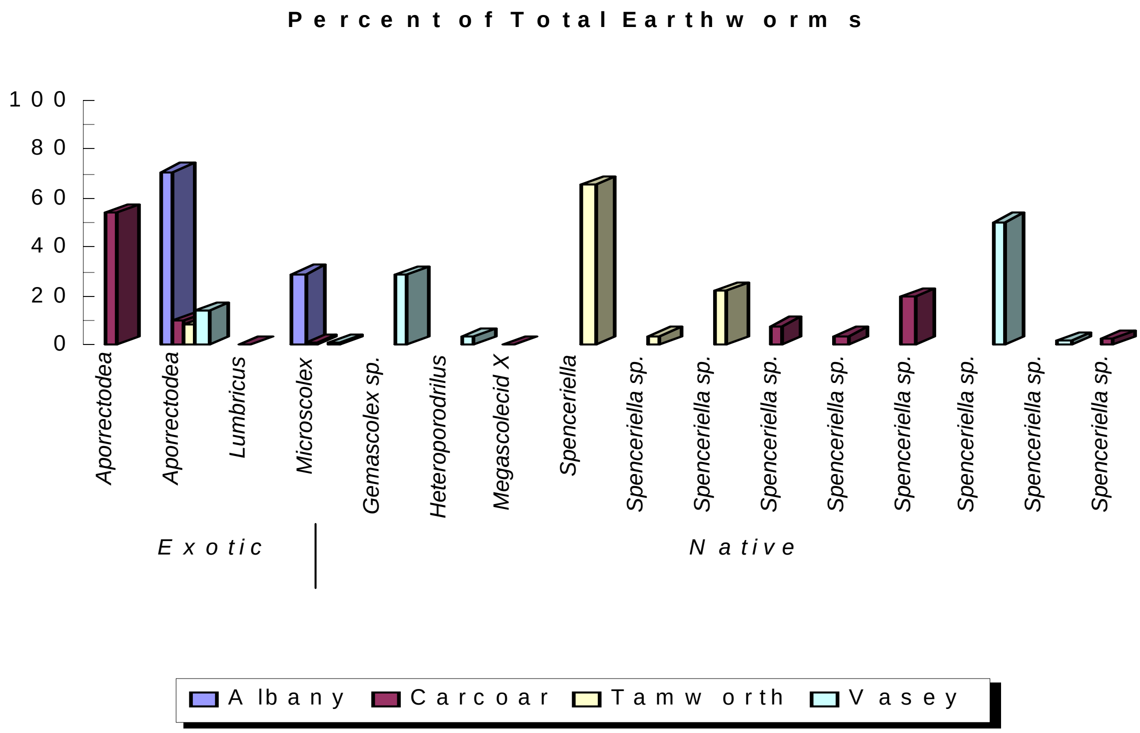
- The productivity of the more diverse treatments (< 40 plant taxa within the paddock) was less in absolute terms and less stable as measured by variation in pasture growth rates throughout the year ie. treatments with fewer species were more productive.

- Lower fertility treatments tended to have more species – usually minor exotic forbs that had low potential growth rates. As fertility increased then more productive species were able to become more competitive and dominate the grasslands. *This suggests that there is an optimal range for plant taxa diversity to sustain productive pastures.*

- The majority of treatments retained the same number of species throughout the short-term of SGS. Where native species loss occurred within a treatment during the experiment this was where the average herbage mass was < 2 t DM ha^{-1}. *This quantifies the condition where over-grazing is probably occurring.*

- Species richness of individual treatments showed variable relationships with mean herbage mass of those treatments. At some Sites all treatments had similar numbers of species and maintaining different levels of herbage mass did not appear to influence species richness. At other Sites the treatments with higher levels of herbage mass tended to have reduced numbers of plant taxa eg. at > 3.5 t DM ha^{-1} (Albany) and > 4 t DM ha^{-1} (Carcoar). *These are probably the first quantifiable estimates where under-grazing may be occurring.*

- Earthworms were sampled on all Sites approximately three years after treatments were applied. There was a considerable range in the 16 species found (12 native) across all Sites (see Figure) and limited overlap between species, native and exotic worms between Sites. Some species were only able to be identified to genus and type.



- The distribution of earthworms within Sites was though probably more dependent upon topography and local moisture conditions than treatments. Mapping the distribution of earthworms at Carcoar found that there were higher numbers in the more moist parts of the landscape. Densities reached 18 m earthworms ha^{-1}.

- The analysis of microbial carbon (an estimate of total microbial activity) found that this tended to increase as the productivity of treatments increased. At Albany microbial carbon was greater under kikuyu pastures than annual systems. At Carcoar the level of microbial activity recorded an 8% increase from the unfertilised naturalised pastures to the fertilised system (where the main species that responded tended to be annuals) and then a further 60% increase to the treatments oversown with productive perennial species.

At Carcoar:

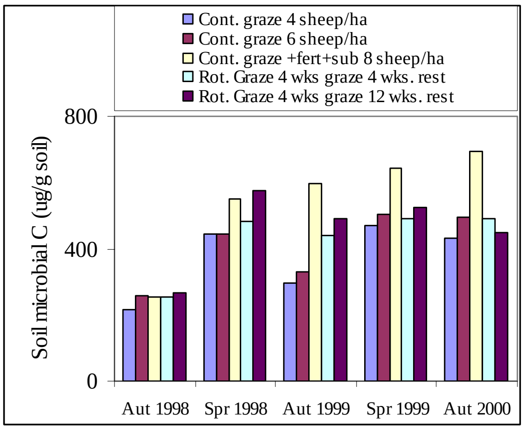
- Litter breakdown increases with fertiliser additions, which then impact on soil arthropod populations. Grazing treatments did not influence litter loss as treatments maintained herbage mass above 2 t DM ha^{-1}.

- The analysis of plant species distribution across the Site at Carcoar at the start of the experiment found that *Vulpia* associates more with the *Austrodanthonia* communities than *Microlaena* or rushes and is found in lower pH and less diverse Sites. An interesting aspect of the *Vulpia* sites is that they were associated with greater cover from perennial grasses, the more common perennial grasses being *Austrodanthonia* spp. In contrast *Hordeum leporinum* was in the more species rich communities on the more fertile soils.

- Neither grazing nor fertiliser treatments had a significant effect on 'evenness'. 'Evenness' evaluates the uniformity in abundance across the species present. This suggests no treatments had imposed sufficient stress to cause any major instabilities ie. in each case several species contributed to most of the productivity of the grassland.

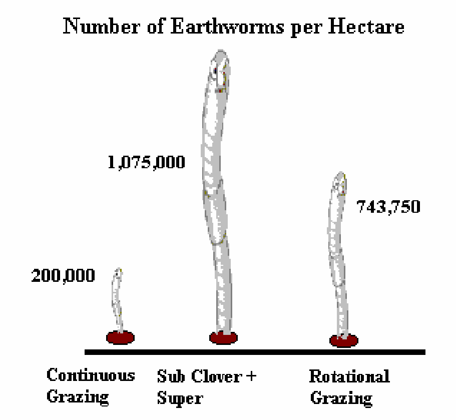
Relationship between soil microbial carbon and treatments (Tamworth)

- Soil microbial carbon levels (0-5 cm) in autumn 1998 were a mean of 250 ug (g dry $soil)^{-1}$. Application of superphosphate and oversowing subterranean clover has resulted in a marked increase in soil microbial carbon in that treatment. By autumn 2000, soil microbial carbon levels in the fertilised treatment were 700 ug (g dry $soil)^{-1}$ compared with an average of 470 ug (g dry $soil)^{-1}$ for the other treatments.



- The effect of the rotations on soil microbial mass in these native pastures, dominated by summer growing native perennial grasses, has been variable and dependent on rainfall. After a relatively wet summer in 1998-99, soil microbial carbon increased as litter accumulated in the rotationally grazed plots. However, in drier summers (1999-00) there has been less of an effect.

Relationship between earthworm numbers and treatments (Tamworth)



Sampling for earthworms (0-10 cm) in a relatively wet period in August-September 2000, found marked differences in numbers in different treatments. Plots continuously grazed at 4 or 6 sheep ha^{-1} since spring 1997 averaged around 200,000 earthworms ha^{-1}, compared with around 1.1 million earthworms ha^{-1} in plots that had been continuously grazed at 8 sheep ha^{-1}, but had received 375 kg ha^{-1} of single superphosphate and been oversown with subterranean clover.

Plots that had been rotationally grazed (4 weeks grazing, 12 weeks rest) at an annual rate of 4 sheep ha^{-1} also had higher numbers of earthworms (around 750,000 ha^{-1}) than the continuously grazed treatments. The significance of these differences needs to be tested.

3.3 Development of management tools to monitor and manage biodiversity

The data obtained were reviewed to discern any general patterns in the relationships between native & total species number and productivity & stability in production that could then be used to provide better management advice for producers. These results were then evaluated against the needs of the other Themes to ascertain if there were any conflicts.

- The literature suggests that within small areas the productivity of pastures increase as plant species number increases to 6-10. Data from the SGS experiments suggested that where small paddocks had 30-40 species, productivity was lower than other treatments. This then suggests that there is an optimum range for species number over which pasture growth is greater. Treatments across SGS where the number of plant species varied from 10-25 within the small paddocks were the more productive suggesting that there is an optimal range in species number and this number of species was sustained when pastures were managed to maintain an average herbage mass of 2-4 t DM/ha.

- This range defines the boundary values for over- and under-grazing as discussed earlier.

- An important point arising from this result is that more productive pastures have more than the 2-3 species typically sown in pasture mixtures. The challenge is to develop management practices to insure that all the species present in a pasture are desirable.

- Higher species numbers were recorded on some treatments outside this range, but the additional species were typically minor exotic forbs and not native species.

- The additional species in more diverse but less productive treatments probably reflects some redundancy in species ie. several that function similarly and hence can replace one another.

- Native plant species that were present on treatments were retained when managed within these boundary values.
- The range in herbage mass proposed for management is also appropriate for the management of many aspects of the water balance ie. runoff, infiltration, optimising green leaf for transpiration *etc.*, for optimising pasture growth, for animal intake, for retaining litter and for resisting the invasion of weeds.

- The main difficulty identified to date with aiming to maintain grasslands within the range of 2-4 t DM ha^{-1} could be a reduced legume content. Further research needs to explore the extent of this problem.

- Tools such as the *Grassland Species Composition Matrix* (developed at Orange) should be developed further to evaluate research results and for technology transfer. The 'matrix' was incorporated in the database for use by the Pastures Theme to provide a common approach to analysing major trends in each pasture system in response to management.

- Data from the Carcoar Site is stored in a geographic information system to enable analyses to be done at a landscape level (see Site Report). These techniques need to be sufficiently developed so that landscape and treatment effects can be separated. That is currently not possible and should form part of future SGS studies.

- There is a need to develop a hierarchy of indicators to capture desirable outcomes more effectively. The primary indicators need to be useful by land managers in day-to-day management (eg. the use of herbage mass as boundary conditions for management) and if satisfied means that the grassland is in a desirable state. If they are not being satisfied then secondary indicators are needed to help identify the problem and potential solutions.

- Future work will need to consider key species or functional groups that could be used to assess the 'health' of a grassland, suitable for routine monitoring. For example; earthworms have often been promoted as a useful primary measure of the 'health' of ecosystems. We need to test that for grasslands as within SGS it was not possible to do any detailed mechanistic studies on the interactions between the soil fauna and above ground flora. A first step is to develop an appropriate working (measurable) definition for 'health'.

One of the difficulties for the *Biodiversity Theme* was to establish a strategy within which we could evaluate the impacts and interactions between biodiversity and grazing systems. That was done and all Sites were then in the position where they can conclude their own analyses of these impacts and interactions. During the *harvest year* the *Theme* was then able to address relevant queries raised by the *Harvest Team*.

The *Biodiversity Theme* was closely involved in delivering advisory material during the *Harvest Year*. This culminated in a special edition of *Prograzier* on biodiversity and an associated series of *Tips and Tools* which, judging from unsolicited feedback, have been well-received by producers and service providers alike.

4. USE OF DATABASE AND MODEL

The Biodiversity Theme has not been central to the development of the SGS model, which has been a major focus of SGS, nor of the database. In consequence the procedures for biodiversity analyses were among the last implemented within the database. Sites were reluctant to extract biodiversity information and in consequence the Theme Leader and Dr King largely did the analyses. A further reason for this was that it was not practical to incorporate all the likely biodiversity analyses into the database, as they were evolving as our understanding progressed. Research cannot be managed as if it were a factory. The database has been an excellent innovation for improving our abilities to collate, organise and do the initial analyses on treatment effects, but it can't be used to automate the whole process of research and delivering outcomes as some members in SGS seemed to expect.

The model has not been designed to analyse biodiversity information and so this Theme had no specific needs from the model. However, some of the general outcomes from the model eg. for water use were used when evaluating the general results from the *Theme*.

5. CHALLENGES AND OPPORTUNITIES

Our work is just the start. Within SGS, the Biodiversity Theme is one of the new directions and a direction that has been among the more exciting parts of the program. However, we do need to acknowledge that we are only scratching the surface. There are many aspects of biodiversity that SGS will not be able to comment upon such as the interrelationships across trophic layers ie. from grazing animals to plants to small animals to microorganisms, fungii and bacteria – Carcoar is the only Site that has attempted to make some inroads on that topic. An important question that will need to be resolved is the wider impact of management treatments eg. as is being done at Carcoar, on soil invertebrates – how adaptable are they? Such questions need to be resolved to provide producers with management advice on sustaining their grassland ecosystems.

Each Site is considering what could be done in future programs and will make those recommendations in their reports. Biodiversity changes can take some time to appear. For example changes in the populations of perennial grasses in response to management would take several years to become apparent and consequent effects on the other species in the system would lag behind that. The short life of SGS has meant that by the harvest year many treatments were well established and at a point where wider effects on the ecosystem could be investigated. Each Site needs to consider those cases and to review the opportunities for future studies that can capitalise on the different grassland systems established. Few Sites have taken the opportunity to record any additional information beyond the minimum required.

Biodiversity interactions take time to develop. The short time frame for SGS does mean that the results obtained cannot be regarded as final. At Carcoar, we will not be able to resolve for how long the soil insect populations reflect previous history (ie., how quickly they adapt to new management systems. That may only be resolvable after some years and major perturbations occur eg. droughts, which could cause significant shifts in species. Projects like SGS should continue through at least one drought to record the impacts of good, bad and recovery periods – or link with targeted monitoring that can capture the key information. We were only able to make preliminary comments about the resilience / stability of grassland ecosystems within the short life of SGS.

The treatment effects within SGS will largely reflect influences upon the vegetative growth of perennial species, whereas in the long run the stability of those species will depend upon the recruitment of new plants. Almost no work was done within SGS on recruitment of perennial species. In the long run such data will be critical for the sustainable management of grasslands.

Biodiversity often requires a landscape perspective. SGS has focused on management at a paddock scale. However, many sustainability and biodiversity issues operate on larger scales. Tools are needed to effectively analyse effects on these larger scales and to help formulate management practices that producers can use on a daily basis to minimise degradation and to sustain production.

Messages need to be integrated and practical. The Biodiversity and other Themes within SGS each developed performance indicators / benchmarks for monitoring and managing grazing systems. We need to explore how these different indices can be integrated – this was a challenge for the Harvest Teams and is reported by them.

Monitoring and management tools need to be developed at several levels: for research, for advisors and for producers, with clear links between each. Biodiversity is a new field of study for many involved in grazing systems research and they are seeking advice on the better ways of understanding their systems. Their need is for both descriptive and analytical tools. Advisors need more general tools that can be used to assess the status of a system and which can also be used to focus messages for producers. The pasture species composition matrix (Kemp et al. 1997) was developed in part for this purpose. Producers need tools that can be used daily in management to insure that they are optimising their systems. Defining rules based upon managing to a minimum value for herbage mass (Kemp 1999) are designed for this need.

Strategic framework and wider issues. SGS has built a strategic framework within which the results are analysed and which can be used to insure that SGS is proactive in public debates. These results need to be analysed within several frameworks to strengthen the messages and to provide the input required eg:

- the use of a 4-D framework for sustainability that attempts to relate the four components; biophysical (ie. ecological & environmental), economic (ie. financial & personal), social factors (ie. the social environment within which we operate) and time. This framework argues that each component needs to be managed within upper and lower boundary conditions (Kemp & Michalk 1993, Kemp *et al* 2001) rather than to fixed points. In the past over-emphasis on eg. net profit often resulted in the degradation of resources. An integrated framework needs to be the focus of future research to investigate better ways of linking key indicators of the performance of grazing systems. New software can help find management pathways that keep within these boundaries.

- the ‘triple bottom line’ is now being promoted for business, but this needs to be extended to a more integrated approach – at present the components of the triple set of accounts operate somewhat independently – the relationships are not clear.

- the National State of Environment Reporting provides a framework for recording industry impacts for the wider community and SGS could use this to provide a checklist. Future work needs to consider these wider contexts when planning SGS future programs.

- in most states and nationally there is, or likely to be, legislation that will require some form of an EIS when farmers seek to change the way they use native species. Future SGS programs need to understand this regulatory framework, the implications for grassland managers and then how we present the results of SGS to best enable the industry to meet these imperatives. As a minimum the various pieces of regulation need to be collated and their implications summarised.

- the QA systems eg. ISO 14000 need to be fully understood so that the outcomes of SGS can be tailored appropriately for markets. QA systems will need a biodiversity component to be acceptable to consumers. It is understood that the MLA has a committee developing suitable proposals, but they had little contact with SGS and hence it is uncertain if the results from SGS have been incorporated into those programs.

6. PUBLICATIONS

The publications in train and proposed by the Biodiversity Theme, are listed below. In general among the planned publications, Site papers are being published first, followed by the overview papers then the papers dealing with specific issues.

6.1 Publications to date

1. Adam, P., Auld, T., Benson, D., Catling, P., Dickman, C., Fleming, M., Gunning, R., Hutchings, P., Kemp, D., and Shields, J. (1997). The New South Wales Threatened Species Conservation Act – a response to Cardew. *Australian Planner*, **34**: 203-6.

2. Dowling, P.M., and Kemp, D.R. (1999). Grazing to manage annual grass weeds in pastures. *Tips & Tools for Sustainable Grazing Systems* No 12/99, pp2.

3. Keen, B.P. (2000). Relationships between plant colonisation in bare-soil gaps, soil nutrient status and the soil microbial community. *B. Land. Man. & Cons. (Hons) Thesis, University of Western Sydney*.

4. Kemp, D.R. (1998). Biodiversity theme protocol. In (Ed. G.M. Lodge) *Themes and experimental protocols for sustainable grazing systems.* Meat and Livestock Australia & Land and Water Resources Research and Development Corporation, Occasional Publication No **13/98**, 55-62.

5. Kemp, D.R. (1999). Managing pasture mass: the minimum threshold concept. *Proceedings of Friends of Grasslands, ACT, Workshop, "Pasture Management for production, Catchment & Biodiversity", Queanbeyan,* August 1999. pp 3. [*Invited Review*].

6. Kemp, D.R. (1999). Managing grassland composition with grazing. *Proceedings of the Bushcare Grassy Landscapes Conference "Balancing Conservation and Production in Grassy Landscapes", Clare South Australia*, 145-152. [*Invited Review*].

7. Kemp, D.R. (1999). Developing options for sustainable pastures. *Prograzier* September 1999, 14.

8. Kemp, D.R. (1999). Biodiversity is a complex issue. *Prograzier* September 1999, 50.

9. Kemp, D.R. (2001). Managing pastures during drought. *Prograzier, Spring 2001, Meat & Livestock Australia*, p10.

10. Kemp, D.R. (2001). Rest our pastures to keep them healthy. *Prograzier, Spring 2001, Meat & Livestock Australia*, p27.

11. Kemp, D.R. (2002). (Ed.) Biodiversity. *Prograzier*, Winter 2002, pp 28.

12. Kemp, D.R. (2002). Managing for dollars and diversity. *Prograzier*, Winter 2002, 3.

13. Kemp, D.R. (2002). Sustainability means working closely with Nature. *Prograzier*, Winter 2002, 28.

14. Kemp, D.R., and Dowling, P.M. (1999). Taking a long term view. *Prograzier* **3(1)**, 7.

15. Kemp, D.R., Dowling, P.M., King, W.McG., and Jones, R.E. (1999). The assessment of weed status, trends and management in pastures and grasslands. *Proceedings 11th European Weed Research Society Symposium, Basel*, paper 59. [*Invited Presentation*]

16. Kemp, D.R., and Junor, K. (2002). Looking after your pastures in drought. *Tips & Tools for making change, Feedbase and Resource Management*, *Meat & Livestock Australia*, FRM.12.02, pp 2.

17. Kemp, D.R., and King, W.McG. (2002). Sustainable grazing systems and biodiversity. *Prospects for Biodiversity and Rivers in Salinising Landscapes, WA October 2002* (in press).

18. Kemp, D.R., King, W.McG., Crosthwaite, J., and Andrew, M. (2002). Encouraging biodiversity benefits. *Tips & Tools for making change, Feedbase and Resource Management*, *Meat & Livestock Australia*, FRM.01.02, pp 2.

19. Kemp, D.R., King, W.McG., Michalk, D.L., and Alemseged, Y. (1999). Weed-proofing pastures: How can we go about it? *Proceedings 12th Australian Weeds Conference, Hobart*, 138-143. [*Invited Review*].

20. Kemp, D.R., and Michalk, D.L. (1999). Weed management in pastures without magic bullets. *Proceedings 40th Conference Grassland Society of Victoria, Geelong*, 107-114. [*Invited Review*].

21. Kemp, D.R., Michalk, D.L., and Charry, A.A. (2001). The development of performance indicators for sustainable systems. *Proceedings 10th Australian Agronomy Conference, Hobart*. 4c, 202.

22. Kemp, D.R., Michalk, D.L., and Dowling, P.M. (2001). Managing permanent temperate naturalised grasslands in Australia for sustainable forage production. *Proceedings International Conference on Grassland Science and Industry, China*. 27-36. [*Invited review*].

23. Kemp, D.R., Michalk, D.L., Dowling, P.M., and Klein, T.A. (1997). Analysis of pasture management tactics using a pasture composition matrix. *Proceedings 18th International Grassland Congress*, 1090.

24. King, W.McG., and Kemp, D.R. (1999). Diversity in pastures. *Proceedings Pacific Science Congress, Sydney, July 1999*.

25. King, W.McG., and Kemp, D.R. (2001). The effects of grazing management and fertilisation on grassland diversity and productivity. *Proceedings XIXth International Grassland Congress, Brazil*. 904-5.

26. Reid, A. (2000). Pasture management and arthropod diversity: implications for sustainability. *National Postgraduate Conference in Ecology, Evolution and Systematics, Australian National University, Canberra*.

27. Reid, A., Hochuli, D., and Cassis, G. (2000). Pasture management, litter decomposition and arthropod diversity: implications for sustainable practices. *Ecological Society of Australia Conference* 2000, La Trobe University, Melbourne.

Seminars on the biodiversity theme have been given by various members (Kemp, King, Reid) to groups including Sydney University, CSU and NSW Agriculture.

6.2 Planned Publications

Title	**Senior author**	**Description**
SGS Overview		
SGS Biodiversity Theme: impact of plant biodiversity on the productivity and stability of grazing systems across southern Australia. *Aust J Exp Agric*	David Kemp	Outline reasons for study, the methodology chosen and Site comparisons [see Appendix]
Earthworms in response to management	Geoff Baker	Across Site data on the density and composition of earthworms from survey
Soil invertebrates – several papers	Adele Reid	Results from her analyses of the impact of management on soil invertebrates
Survey of soil microbe composition in response to management [still being discussed and may be incorporated in a 'soil health' paper] *Aust J Exp Agric*	Brad Keen	Results of survey in 1999 of soil microbiology in contrasting management treatments
Carcoar Tablelands Site – relevant to the Biodiversity Theme		
Vegetation and environment relationships in naturalised pasture in Central NSW: Implications for management *Aust J Exp Agric*	Warren King	Include relationships between landscape, soil, vegetation and climate based on the Site initialisation data-
Sustainable grazing systems for the Central Tablelands of NSW 8. Relationship between plant species diversity and productivity. *Aust J Exp Agric*	David Kemp	Impacts of management and pasture type on plant diversity and productivity; impact of site characteristics (pH, water regimes, slope) on species diversity.
Sustainable grazing systems for the Central Tablelands of NSW 9. Seedbank diversity in	Warren King	Analysis and discussion of implications of all seedbank studies.

relation to above ground plant diversity. *Aust J Exp Agric*		
NW NSW Slopes – relevant to the Biodiversity Theme		
Relationship between microbial and labile carbon in grazed, temperate pastures	Greg Lodge	Analysis and discussion of these alternative procedures for estimating microbial activity.

7. BIODIVERSITY THEME: FINANCIAL STATEMENT

The Biodiversity Theme was designed to largely use the resources provided through Sites and themes eg. Pastures to collate and analyse the data required. In the last year funds were provided through the University of Sydney, in other years they were part of the Site budget for the Carcoar Site managed by NSW Agriculture.

Year	Funds ($)
1997-98	7,500
1998-99	7,500
1999-00	7,500
2000-01	7,500
2001-02	25,500
Total	55,500

Notes:

- All funds have been acquitted on Theme business.
- Funds in the early years were largely used to facilitate communication & travel among Sites, supporting the employment of consultant taxonomists to identify species, sampling for earthworms and to support workshops.
- In the final year funds supported the statistical analysis of data (requiring additional software and consultancies), travel to visit sites to extract data, to work with the database consultant and to conferences to present Theme results, additional analyses of microbial carbon to compare with the labile carbon estimates done at all Sites and for identification of earthworms.

8. THE HARVEST YEAR

8.1 Value adding to the Theme through the Harvest Year

The *Harvest Year* was a most innovative component of SGS; it was of great value for consolidating the primary outcomes of SGS and it delivered material to producers and the first series of papers in record time.

The *Biodiversity and Trees & shrubs (BaTs) Team* was formed to cover a much wider range of issues than the *Biodiversity Theme* was charged to consider. Biodiversity has not previously been part of grazing systems research in the Higher Rainfall Zone of southern Australia. Within SGS the *Biodiversity Theme* was probably the poorer cousin, and the work was necessarily limited to the pasture data that was being collected for other purposes eg. in the *Pasture Theme* to provide some insight into the relationships between management and biodiversity, and some additional key measurements and studies on other aspects of the biodiversity. At a biodiversity workshop held early in the life of SGS to scope the work of this Theme, it was agreed that the budget would constrain the biodiversity studies to this, and it was acknowledged that the *Theme* would be unable to thoroughly explore how the grassland ecosystems functioned in relation to management treatments. However despite these limitations the *Theme* was able to deliver some useful outcomes, framed within the context of the sustainability goals of SGS, and to be a pioneering study.

The limited work done on biodiversity within SGS though meant that for the *Harvest Year* the *Theme* could only deliver appropriate material on some of the issues of concern to the *Harvest Team* eg. there was limited data at a landscape scale, sampling of soil organisms was restricted, no studies were done on sustaining species over the longer-term and no studies were done on larger fauna (birds, reptiles *etc.*). The *Harvest Team* did though deliver appropriate material and its products obviously benefited from the work done by the *Theme* – bringing the practical experience of working on biodiversity within grazing systems to those with different backgrounds. In a complementary way the *Harvest Team* then helped the *Biodiversity Theme* to better frame the context for their work, even though that wasn't a specific goal of *BaTs*. This arose because in *BaTs* there was a renewed focus on parts of the ecosystem beyond that being studied in SGS – parts that do need to be considered in framing solutions for producers.

The *Harvest Year* provided an excellent opportunity to keep focused on the outcomes of the *Theme* and to insure that the conclusions drawn stand up to scrutiny, as there was a body of people still focused on SGS and not being distracted by having to deliver on new projects. We would estimate that the *Harvest Year* sped up the delivery of SGS products by 4-5 years compared with previous practice.

The *Theme* findings did change in some detail through the *Harvest Year*. This occurred often through being able to analyse data from all the National Experiment Sites such that conclusions for one Site could then be tested against other Sites – often resulting in some modification to Site conclusions. In the end this gave greater confidence in the findings. A key aspect of this was being able to explore ideas on the boundary conditions eg. as t DM ha^{-1} within which pastures should be managed to optimise biodiversity and the other goals of SGS eg. water, nutrients, pastures, animals *etc.*

8.2 Post-doctoral Fellows

The *Biodiversity Theme* had limited involvement with the post-doctoral fellows. The *Pasture / Animal Fellow* did though help with some REML analyses and we exchanged data base outputs to enable analyses to be done on a common basis. This proved useful in developing the *Theme* paper (see Appendix). Had the *Biodiversity Theme* been a larger component in SGS then a post-doctoral fellow probably would have been needed to insure that the *Theme* was able to deliver on time.

8.3 Improving effectiveness of the Harvest Year

The *Harvest Year* was an innovation that people were unfamiliar with and in consequence they were uncertain how to get the most from it. It probably then took some time for participants to get up to speed. There was a greater focus on the *Harvest Teams* than on the *Themes* and in consequence those *Theme* members involved in a *Harvest Team* had less time to devote to the *Theme.* That is almost unavoidable, but does need to be acknowledged in the time that outcomes can be delivered. The *Theme* probably spent more time during the *Harvest Year* preparing extension material than writing the research papers, when a more equal distribution of time would have been more effective. After all the *Theme* was charged with doing research and the outcome of that research needs to be in journal papers to have credibility.

SGS became a short-term program for the actual experimental work, which meant that some Sites needed part of the *Harvest Year* to conclude at least three years of measurements. This arose because of the slow start to SGS and other factors eg. drought at establishment. Some clash is probably inevitable, but the problems that arise from overlap need to be considered positively in planning the year and in budgets. The start-up phase needs to be well planned to minimise problems late in a program. Future projects should seriously look at using established sites such as Carcoar to speed up implementation.

9. THE THEME PROCESS

The development of *Themes* within SGS provided the glue that structured the National Experiment and gave a common purpose to the participants. In the end *Themes* became more important in many ways than the Sites. That point had probably been reached before the *Harvest Year*, but got stronger during that year. A *Theme* approach is an excellent vehicle for uniting disparate groups and extracting more from national programs than has often been the case. These comments are included here to help support future projects that may use this approach.

Overall the *Biodiversity Theme* worked reasonably well, though the main contributors to the development and outcomes of the *Theme* were David Kemp and Warren King. Others did collect data and provided us with copies of that information, but did little else. That may reflect the fact that others considered the philosophy developed and implemented in the Theme appropriate and hence they felt little need to intervene. That limited involvement continued when papers were being written.

A continuing challenge that the *Biodiversity Theme* had to deal with was the limited appreciation of what the science of biodiversity is about. The *Theme* developed a position about what it was going to do, but many in SGS either didn’t read that or had other views as to what biodiversity meant (often without reading the scientific literature and without providing any alternative approach) and that lead to some confusion / tension at times as to what the *Theme* was doing and why. Allied to this was the attitude that biodiversity is just a ‘fad’ and not really relevant, when in fact a major aspect of biodiversity studies is to investigate how ecosystems actually function – a very core issue for SGS and the only *Theme* attempting to address that issue! Many in Australia also think biodiversity is simply about nature conservation and while that is part of such studies it doesn’t feature as the dominant issue in the world literature. Others seemed to have an even more limited view and regard biodiversity as solely about rare and endangered species and when none such species were found at SGS Sites were even more uncertain as to the need for the *Theme*. These issues were an undercurrent that probably meant at some Sites the personnel involved did not fully appreciate the need, timeliness *etc.* for some measurements. We raise these points here as in the future when 'new' areas for investigation are introduced into R&D programs; some internal education programs may be needed to obtain a common understanding and ownership of innovative *Themes*. Grazing systems research is clearly being done within ecosystems, but many agriculturalists don't fully acknowledge that. The limited biodiversity studies also meant that no Site was able to develop an integrated statement on how their grazing ecosystems were functioning.

Problems occurred with the *Themes* in that they were added after the Sites were established and had limited power to insure a consistent approach across Sites. Most of the measurements really depended upon the goodwill of the Sites, who were the primary recipients of funds. It could have been better to fund the *Themes* and *Sites* equally or sufficiently, so that the *Themes* could then provide the specific funding to do the measurements required, when required and to provide that additional focus on developing principles.

The *Biodiversity Theme* was the last in the queue in many instances eg. in terms of being established, in incorporating components within the database and it had little involvement with the SGS model. That probably arose from the newness of such a *Theme* and the limited resources provided. Also the initial discussions about incorporating biodiversity within SGS did not include key personnel with a scientific understanding of biodiversity and grassland ecology. These factors meant that the *Biodiversity Theme* was thought of last and not emphasised as much as other groups. There is arguably more concern about biodiversity in the wider community than *for example* soil degradation? Biodiversity does need to be supported as well as other *Themes* in future work to retain faith with the wider community.

10. ACKNOWLEDGMENTS

We thank the members of SGS for their tolerant interactions with us as we have formulated our ideas in a field that is new to most SGS participants. In constructing the data analysis protocols Dr Warren King has been invaluable. Other members of the Theme team have all contributed important components. Dr King was funded by the CRC for Weed Management Systems, who also provided an Honours Scholarship for Mr Brad Keen to investigate soil microbial diversity. SGS proved to be an innovative program that melded a group of disparate individuals into a team working for a common goal. The Leadership provided by Dr Warren Mason in doing this is to be commended.

11. REFERENCES

Amato, M., and Ladd, J.N. (1988). Assay for microbial biomass based on ninhydrin-reactive nitrogen in extracts of fumigated soils. *Soil Biology and Biochemistry* **20**, 107-114.

Brussard, L., Bakker, J.P., and Olff, H. (1996). Biodiversity of soil biota and plants in abandoned arable fields and grasslands under restoration management. *Biodiversity and Conservation* **5**: 211-21.

Burnside, D., and Rasmussen, A. (1997). Ecosystem management: Can it succeed? *Rangelands* **19**: 20-24.

Cassis, G., and Hochuli, D. (1996). Sustainable grazing and soil biodiversity: a comparison of low and high input pasture systems. *Submission to MLA*.

Chapin, F.S., *et al.* (1998). Ecosystem consequences of changing biodiversity. *Bioscience* **48**: 45-52.

Elton, C.S. (1958). *The ecology of invasions by animals and plants*. Methuen, London, England.

Giller, P.S. (1996). The diversity of soil communities, the ‘poor man's tropical rainforest’. *Biodiversity and Conservation* **5**: 135-168.

Grime, J.P. (1979). *Plant strategies and vegetation processes*. (Wiley: Chichester, UK).

Grime, J.P. (1997). Biodiversity and ecosystem function: the debate deepens. *Science* **277**: 1260-1261.

Hooper, D.U., and Vitousek, P.M. (1997). The effects of plant composition and diversity on ecosystem processes. *Science* **277**: 1302-1305.

Hutchinson, K.J., and King, K.L. (1976). The effects of sheep stocking intensity on the abundance and distribution of mesofauna in pastures. *Journal of Applied Ecology* **13**: 41-55.

Hutchinson, K.J., and King, K.L. (1980). The effects of sheep stocking levels on invertebrate abundance, biomass and energy utilisation in a temperate, sown grassland. *Journal of Applied Ecology* **17**: 369-87.

Hutchinson, K.J., and King, K.L. (1981). Invertebrates and nutrient cycling. *Proceedings 3rd Australasian Conference Grassland Invertebrate Ecology*: 331-338.

Hutchinson, K.J., and King, K.L., (1984). Biological aspects of nutrient cycling in grazed pastures the underground movement. *Animal Production in Australia* **15**: 133-136.

Jones, C.G., Lawton, J.H., and Shachak, M. (1994). Organisms as ecosystem engineers. *Oikos* **69**: 373-386.

Kemp, D.R. (1999). Managing pasture mass: the minimum threshold concept. *Proceedings of Friends of Grasslands, ACT, Workshop, “Pasture Management for production, Catchment & Biodiversity”, Queanbeyan,* August 1999. pp 3.

Kemp, D.R., and Michalk, D.L. (1993) (Eds.). *Pasture Management: Technology for the 21st Century*. (Eds. D.R. Kemp and D.L. Michalk), (pp 177) (CSIRO: Melbourne).

Kemp, D.R., and Michalk, D.L. (1993) Pasture Management: Introduction. In *Pasture Management: Technology for the 21st Century*. (Eds. D.R. Kemp and D.L. Michalk) (CSIRO: Melbourne).

Kemp, D.R., and Michalk, D.L. (1997). Assessing the status and trend in grasslands. *ESA97 - Ecological Society of Australia Conference*.

Kemp, D.R., Michalk, D.L., Dowling, P.M., and Klein, T.A. (1996). Improving pasture composition by grazing management in relation to a management envelope. *Proceedings 8th Australian Agronomy Conference*, 345-348.

Kemp, D.R., Michalk, D.L., Dowling, P.M., and Klein, T.A. (1996). *Development of the Pasture Management Envelope*. Report on DAN.078 to the Meat Research Corporation. pp 65.

Kemp, D.R., Michalk, D.L., Dowling, P.M., and Klein, T.A. (1997). Analysis of pasture management tactics using a pasture composition matrix. *Proceedings 18th International Grassland Congress*, 1090.

King, K.L. (1989). *The role of microarthropods in decomposition and nutrient cycling in temperate pastures*. PhD Thesis, University of New England.

King, K.L., Greenslade, P., and Hutchinson, K.J. (1985). Collembolan associations in natural versus improved pastures of the New England Tablelands, NSW: Distribution of native and introduced species. *Australian Journal Ecology* **10**: 421-427.

King, K.L., and Hutchinson, K.J. (1980). Effects of superphosphate and stocking intensity on grassland microarthropods. *Journal of Applied Ecology* **17**: 1-11.

King, K.L., and Hutchinson, K.J. (1981). Effects of fertilisers and improved pastures on invertebrates. *Proceedings 3rd Australasian Conference Grassland Invertebrate Ecology*.

King, K.L., and Hutchinson, K.J. (1983). The effects of sheep grazing on invertebrate numbers and biomass in unfertilised natural pastures of the New England Tablelands (NSW). *Australian Journal of Ecology* **8**: 245-255.

Lamont, B.R. (1995). Testing the effect of ecosystem composition / structure on its functioning. *Oikos* **74**: 283-295.

Lawton, J.H. (1994). What do species do in ecosystems? *Oikos* **71**: 367-374.

Lawton, J.H., *et al.* (1998). Biodiversity inventories, indicator taxa and effects of habitat modification in tropical rainforest. *Nature* **391**: 72-76.

Lee, K.E. and Pankhurst, C.E. (1992). Soil organisms and sustainable productivity. *Australian Journal of Soil Research* **30**: 855-92.

May, R.M. (1973). *Stability and complexity in model ecosystems*. Princeton University Press, Princeton, New Jersey, USA.

McGrady-Steed, J., Harris, P.M., and Morin, P.J. (1997). Biodiversity regulates ecosystem predictability. *Nature* **390**: 162-165.

Michalk, D.L., and Kemp, D.R. (1993). Pasture management, sustainability and ecosystems theory: Where to from here? In *Pasture Management: Technology for the 21st Century*. (Eds. D.R. Kemp and D.L. Michalk) (CSIRO: Melbourne).

Nicholas, P.K., Kemp, P.D., Barker. D.J., Brock, J.L., and Grant, D.A. (1997). Production, stability and biodiversity of North Island New Zealand hill pastures. *Proceedings 18th International Grassland Congress*.

Pankhurst, C.E., Ophel-Keller, K., Doube, B.M., and Gupta, V.V.S.R. (1996). Biodiversity of soil microbial communities in agricultural systems. *Biodiversity and Conservation* **5**: 197-209.

Siepel, H. (1996). Biodiversity of soil microarthropods: the filtering of species. *Biodiversity and Conservation* 5: 251-60.

Tilman, D. (1996). Biodiversity: Population versus ecosystem stability. *Ecology* **77**: 350-363.

Tilman, D., Knops, J., Wedin, D., Reich, P., Ritchie, M., and Siemann, E. (1997). The influence of functional diversity and composition on ecosystem processes. *Science* **277**: 1300-1302.

Tilman, D., Wedin, D., and Knops, J. (1996). Productivity and sustainability influenced by biodiversity in grassland ecosystems. *Nature* **379**: 718-720.

Wardle, D.A., and Giller, K.E. (1996). The quest for a contemporary ecological dimension to soil biology. *Soil Biology and Biochemistry* **28**: 1549-1554.

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