A COMPARISON OF THE EFFECTS OF GRAZING AND MINING ON VEGETATION OF SELECTED PARTS OF NORTHERN SOUTH AUSTRALIA

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TABLE OF CONTENTS

APPENDICES (on CD inside back cover).

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

This study examines the effects on vegetation at selected sites in northern South Australia of excluding various herbivores over a four and a half year period and of two intense but controlled grazing pulses over a six month period followed by an 18 month recovery period in a dune-swale land system. These changes are compared with changes recorded over an 11-year period at the Olympic Dam mine site.

Seven sets of exclosures were constructed on pastoral country, with all but one in cattle country north of the Dog Fence. Each set of exclosures consisted of a rabbit and stock-proof area, a stock-proof area that gave access to rabbits, and a control area that allowed unrestricted grazing. The grazing experiment site and Olympic Dam are south of the Dog Fence.

Data on vegetation composition at exclosure sites were collected biannually. Monitoring at Olympic Dam was also carried out at six-monthly intervals. Monitoring at the grazing experiment site was carried out before and after each grazing pulse and following heavy rainfall two years after the initial grazing. A range of edaphic and topographic information was collected for all sites.

All data were analysed using the classification and ordination modules of the CSIRO PATN computer package. Classification of exclosure data showed few differences between grazed and ungrazed sites. Major rapid shifts between classification groups correlated with heavy rainfall events, while slower shifts correlated with the drying-off of vegetation. Four exclosure sites had four years with less than 100 mm of annual rainfall, although above average rainfall preceded the first monitoring. Heavy rainfall prior to the final monitoring correlated with the majority of shifts between classification groups. There were no shifts between groups at other exclosure sites, where annual rainfall was more consistent.

Data from the grazing experiment showed a distinct and rapid shift between classification groups at grazed sites after both grazing pulses. A partial recovery occurred at swale sites following light rainfall after both pulses, with recovery to a better condition than at the start of the experiment following heavy rainfall preceding the final monitoring. There was less recovery on dunes than on swales between grazing pulses, or following the major rainfall event. A generally unpalatable grass species that was largely removed by grazing did not fully recover during the monitoring period. A relatively high cover of cryptogams remained after the two grazing events.

The Olympic Dam data showed no correlations between classification groups and different land uses. Rapid shifts between groups correlated with major rainfall events, while slower shifts followed attrition of annual species as conditions became drier. One group based on an introduced species was not recorded following heavy rainfall that allowed establishment of native species. Another poor-condition group appeared at a time when most vegetation was moving towards a better condition following heavy rainfall. This may have been because of emissions from the tailings ponds or processing plant and was restricted to within 500 m of the emission source. Although massive germination was recorded at many sites, recruitment of perennials, even at fenced sites, was sufficient only to maintain populations at their baseline level.

Species richness on the mine lease was only about half of that for the exclosure sites, possibly as a result of high kangaroo numbers on the mine lease, or of higher kangaroo numbers south of the Dog Fence than to the north.

The main finding of these studies is that short-term changes in vegetation revealed by ordination of periodical cover, density and species richness, are attributable to the periodicity of rainfall and that, under present grazing regimes, rainfall effects override grazing effects.

Differences between the effects of sheep and cattle hoof damage are worthy of further investigation, as is the impact of kangaroo grazing. These two factors may have important implications for the management of Australian rangelands.

DECLARATION

This work contains no material that has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

I give consent to this copy of my thesis, when deposited in the University Library, being available for loan and photocopying.

F.J. Badman

Date 17 September 2002

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Greg Campbell and David Oag obtained the data on sheep hoof sizes and animal weights and Greg Campbell the equivalent data for cattle.

Lindsay Owler prepared the location map.

CHAPTER 1 GENERAL INTRODUCTION

1.1 SCOPE OF THIS STUDY

This study investigates whether periodical data on cover, density and diversity, from discrete samples collected to assess vegetation status of rangelands in parts of the South Australian arid zone, can be subjected to analysis using ordination to discover whether seasonal moisture availability has a greater effect than apparent grazing intensity on short-term patterns of change in vegetation. These changes are then compared to different grazing regimes and to changes caused by underground mining and an associated processing plant and township development. Three main quantitative data sets are analysed.

All study sites (Figure 1.1), including the Olympic Dam mine lease prior to fencing in 1987, have long histories of grazing by domestic stock (Richardson 1925, Bowes 1968, Kinhill-Stearns Roger 1982, Litchfield 1983, Badman 1995a) and continue to be grazed by kangaroos and by rabbits.

1.2 THE EXPERIMENTAL SITES

1.2.1 THE EXCLOSURE SITES

The exclosure dataset recorded changes to vegetation from 1993 to 1997 at exclosure sites constructed by the Kingoonya and Marree soil conservation boards. Grazing was by both domestic livestock at normal paddock stocking rates and by rabbits. Exclosure sites were located on Billa Kalina Station in the Kingoonya Soil Conservation District and at Wilpoorinna, Dulkaninna and Cowarie Stations in the Marree Soil Conservation District. Billa Kalina, Dulkaninna and Cowarie stations run cattle, while Wilpoorinna runs sheep and cattle.

Reports on the preliminary examination of data from the soil board exclosures have been prepared for the two boards (Badman 1998a, 1998b). These did not include any statistical analysis.

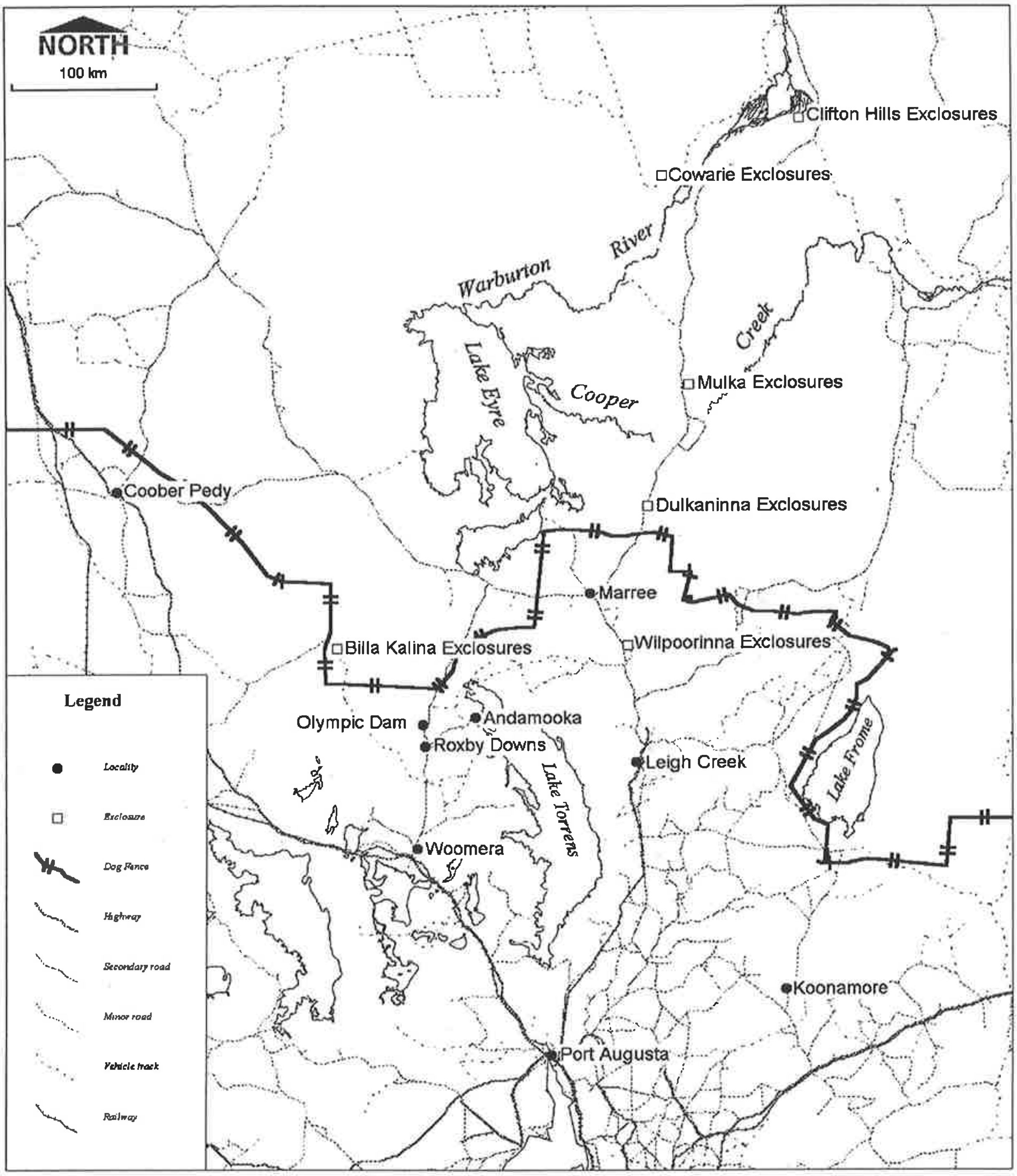

Figure 1.1: The General Study Area and Location of the monitoring sites.

1.2.2 The Grazing Experiment

The grazing experiment dataset recorded changes to the vegetation brought about by an intensive grazing experiment on Andamooka Station adjacent to the Olympic Dam Special Mine Lease. Two grazing pulses occurred, with monitoring carried out before and after each pulse. The pulse grazing was far heavier than any grazing normally experienced on a well managed pastoral station in this district. The final monitoring was carried out two years after the first grazing pulse.

1.2.3 The Olympic Dam Dataset

The largest dataset was collected on behalf of Olympic Dam Corporation, mainly by Dr Tim Fatchen and Deborah Fatchen but with input from other workers including myself, between 1981 and 1996. This dataset recorded quantitative information on the vegetation of the Olympic Dam area since the start of mining, mineral processing and town development.

Exploration activities at Olympic Dam began in 1975 and the mine and metallurgical plant were officially opened in 1988. The first environmental studies at the mine site were carried out in 1981 and regular vegetation monitoring began in 1986. As part of an on-going review of the environmental work carried out at Olympic Dam, environmental studies have progressed from a monitoring phase to a management phase (Badman *et al.* 1996). Although the year-to-year changes in vegetation have been well documented (e.g. Fatchen Environmental 1997, ODO 1997), there has been no previous analysis of trends over periods longer than one year using the whole data set. This study, in part, continues the long-term analysis of data collected during vegetation monitoring of the mine site and surrounding areas that was begun by Badman in 1995 (Badman 1995a).

The period covered by the Olympic Dam data set, 1981 to 1997, extends from the baseline vegetation studies (Fatchen 1981, Kinhill-Stearns Roger 1982) and covers exploration, and construction of the mine and processing plant and the town of Roxby Downs. It also covers the first nine years of production, several expansion phases, the initial fencing of the mine and municipal leases from Roxby Downs Station, the removal of domestic stock, and the erection of the rabbit-proof fence and control of rabbits around the town.

1.3 FRAMEWORK OF THE THESIS

This study examines changes in the composition and abundance of the vegetation at several sites with different land uses in northern South Australia. This is done in four ways:

1. By literature search (Chapter 2);
2. By analysing quantitative data collected during five years of monitoring at the exclosure sites (Chapter 4);
3. By analysing quantitative data collected over two years at a pulse-grazing site (Chapter 5);
4. By analysing quantitative data collected during 18 years of vegetation monitoring at permanent quadrats by consultants on behalf of Olympic Dam Operations (Chapter 6).

1.4 AIMS

Aims of the study were to:

1. Identify any changes to native vegetation caused by domestic or feral herbivores within the time-frames of the datasets;
2. Compare the effects on native vegetation by means of purpose-built exclosures that excluded various domestic and feral herbivores;
3. Compare the effects of normal present-day light stocking practices and heavy but short-term pulse grazing;
4. Investigate whether classification and ordination techniques can detect any different effects on native vegetation caused by grazing and mining activities, or by town development and occupation.

1.5 PLANT NOMENCLATURE

Plant nomenclature mainly follows Jessop (1993), but includes later taxonomic changes in families such as Compositae[1].

Early work at Olympic Dam used Jessop (1981) as the authority for plant names. Many of these names have now been reduced to synonymy and, as was done by Badman (1995a), where taxonomic revision has involved simple name changes all Olympic Dam databases were updated to use the nomenclature of Jessop (1993) or subsequent revisions. This is the case within genera such as

[1] Author citations for all plants mentioned in the text are given in Appendix A.

Helipterum and for species such as *Urochloa praetervisa* and *Alectryon oleifolius*. However, where one species has been split into two or more different species, as has happened with *Boerhavia diffusa* and *Zygophyllum ammophilum* (the two main species that affect this thesis), it was often impossible to determine which species had been recorded in the past, especially in the case of ephemeral species. *Boerhavia diffusa* is now represented in the study areas by *Boerhavia dominii*, *Boerhavia coccinea* and *Boerhavia schomburgkiana*, while *Zygophyllum ammophilum* has been split to include *Zygophyllum emarginatum* and *Zygophyllum simile* (Eichler 1990), both of which occur in the study areas. In these and similar cases the original name has been retained.

A reference collection of all plant species identified at the exclosure sites was compiled and given to each station manager for use by future observers. Duplicates were lodged with the State Herbarium of South Australia. No plants were collected from within the quadrats or exclosures. Voucher specimens of all plants from Olympic Dam are housed in the Olympic Dam reference collection, with duplicates lodged with the State Herbarium of South Australia. Most determinations have been verified by taxonomists from the State Herbarium of South Australia.

A list of all plant species mentioned in this thesis, together with families and author citations, is given in Appendix A.

CHAPTER 2 LITERATURE REVIEW

2.1 THE SOUTH AUSTRALIAN ARID ZONE FLORA

2.1.1 INTRODUCTION

Three main vegetation associations occur in the general study area: gibber plains with chenopod low shrubland vegetation; sandridges with hummock grassland vegetation; and watercourses with fringing woodland and tall shrubland vegetation and floodplains with shrubland or grassland vegetation. A fourth association, sandplains with woodland vegetation, is common in the north-west of South Australia, but is poorly represented in the present study areas.

The history of botanical studies in the study areas has been covered in very general terms by Willis (1981), Kraehenbuehl (1986) and Badman (1995a, 1999: Chapter 2). Apart from the results of the State Government's rangeland monitoring programme and the brief report of Badman (1998b), nothing appears to have been written about the vegetation of Billa Kalina Station. One of the first publications to mention the plants of the Olympic Dam region was that of Cleland (1930) who travelled from Chances Swamp (Roxby Downs HS) to Andamooka, probably passing just to the south of Olympic Dam. Murray (1931) provided a more comprehensive report on the vegetation of an area extending as far north as Arcoona (near Woomera) for the period 1927-1930. She recorded 387 plant species in the Lake Torrens region, but provided no species list.

The earliest botanical collections from the Marree area were made by the Babbage Expedition in 1858. Joseph Herrgott was the expedition botanist and his collections were described by Mueller (1859). P.H. Warburton replaced Babbage, but apparently made few collections near the present study areas, concentrating more on areas to the south-east, including the Flinders Ranges (Willis 1981). Other plant collections were made by the John McDouall Stuart expeditions of 1858-1862, but particularly by the 1858-59 expeditions (Stuart 1864). Because of imprecise locality details in Stuart's report it is impossible to say exactly which collections were actually made in South Australia (Kraehenbuehl 1986) or whether any were made in the present study areas. A summary of these early botanical collections was given by Tate (1889).

2.1.2 FOCUS OF VEGETATION STUDIES

Lange and Fatchen (1990) described the change in focus of botanical research, from a "search for the new" approach by the explorers of the mid-19th Century, often to the exclusion of the common species, to the more analytical approach that is widely used today. The early taxonomic focus had begun to change to an ecological one dealing with vegetation associations by the time of the Horn Expedition of 1894, with a more analytical focus since the late 1960s. This has led to the present management-based approach to vegetation studies, often focussing on species that have economic significance to the pastoral industry, particularly *Atriplex vesicaria, Maireana astrotricha, Acacia aneura* and *Astrebla pectinata* (e.g. Jessup 1951, Lay 1979, Lay *et al.* 1993) or on the rare and endangered elements of the flora (e.g. Davies 1995).

2.1.3 THE STUDY AREAS

2.1.3.1 The General Area

A major paper by Lange and Fatchen (1990) gave an overview of the vegetation of the north-east deserts of South Australia, an area that includes all of the present study sites (Tyler *et al.* 1990). Several other studies have dealt with the vegetation of areas to the north and south of the study areas, particularly of the wetlands associated with Cooper Creek and the Diamantina and Warburton rivers. The most comprehensive early study of vegetation close to the Billa Kalina and Olympic Dam sites was that of Jessup (1951), who worked in the North-west Pastoral Area. He listed the plants recorded in various vegetation associations and was the first worker to adopt a vegetation association based approach in this region. Jessup's surveys were later repeated by Lay (1979) and Maconochie (Maconochie and Lay 1996).

Several surveys have concentrated on the north-eastern part of the State, including the Nature Conservation Society's biological survey of the North-East of South Australia (Jessop 1975). Major studies have been carried out during the last 15 years on the vegetation associated with the Cooper and Diamantina wetlands (e.g. Mollemans *et al.* 1984, Gillen and Reid 1988, Gillen and Drewien 1993). Other work in this area has been carried out by or on behalf of Santos in relation to the Moomba oil and gas fields (e.g. Santos 1981, 1983, SEA 1997).

There have been three major foci for vegetation studies in the present study areas. These have been the Olympic Dam mine in the south, rangeland assessment surveys carried out on pastoral leases, and the Stony Deserts Biological Survey (Brandle 1998). The former research was carried out by or on behalf of industry, while the others were State Government initiatives. The study areas have also been covered in whole or in part by other studies (e.g. Lange and Fatchen 1990, ODO 1992a, 1992b, Badman 1995b, 1999, Kinhill 1995a). Brandle's study (Brandle 1998) is the only one to have analysed large amounts of quantitative data.

The Pastoral Program of the South Australian Department of Environment and Heritage has recently conducted an assessment programme on pastoral leases in South Australia. Dulkaninna Station was also the subject of an earlier assessment (Faithful 1986).

2.1.3.2 The Olympic Dam Environmental Studies

The Olympic Dam Mine is the most southerly of the present study areas. Preparation of the Environmental Impact Statement for the Olympic Dam Mine (Kinhill-Stearns Roger 1982) led to a major focus on the biological values of the area. A study of the regional vegetation was carried out during the early 1980s, although the field work occurred during severe drought conditions and few annual or ephemeral species were recorded. The survey plant list included only 138 taxa (Kinhill-Stearns Roger 1982). A supplementary study of the vegetation of service corridors for the mine and town (Fatchen and Associates 1982) listed 79 taxa. This regional list has subsequently grown to 748 taxa (ODO 1996a) and new species are occasionally still recorded from the area. Over 1000 taxa are known to occur in the nearby Lake Eyre South catchment (Badman 1999: Chapter 9).

Botanical studies carried out by or on behalf of Olympic Dam Operations have also focussed on the vegetation of mound springs and the development of Borefield B (Kinhill 1995a), pipeline corridors (ODO 1992a, 1992b), powerline corridors (Badman 1992b, 1997a) and the Lake Eyre South catchment (Badman 1999). Other botanical studies by Olympic Dam environmental scientists have included those of Read (1995) and Badman (1995a, 1995b).

2.1.4 Current and Ongoing Research

Current research by the Pastoral Program of the Department of Environment and Heritage (DEH) is concentrated on rangeland condition, particularly of palatable perennial shrubs (e.g. PMB 1991). This research, although based on quantitative data from photopoint quadrats, is to be repeated at intervals of 7-14 years and therefore lacks the intensity of the on-going Olympic Dam

Operations vegetation monitoring programme or the Stony Deserts Survey (Brandle 1998), or the regularity of the twice-yearly Olympic Dam monitoring programmes.

2.2 THE EFFECTS OF NATIVE HERBIVORES ON ARID ZONE VEGETATION

As recently as 40 000 years ago, arid Australia was inhabited by diprotodontid herbivores that weighed as much as two tonnes (Flannery 1994). The skeletons of these wombat-like animals have been found at Lake Callabonna, just to the east of the present study areas (Flannery 1994). The effect of these animals on the local vegetation is not known, but they were more than double the size of any modern domestic herbivores and their impact on vegetation and watering points must have been considerable if they were present in even moderate numbers. The ecological niche formerly occupied by the grass-eating diprotodons remained empty for more than 35 000 years until European settlers introduced their large domestic herbivores (Flannery 1994).

Immediately prior to European settlement, it is unlikely that native herbivores had a significant impact on the land (Williams 1977). However, any herbivore can damage its environment if it is present in inappropriate numbers. Since construction of the Dog Fence (Figure 1.1) and the installation of artificial watering points, red kangaroos in particular have dramatically increased in numbers inside the fence to the point where they can do considerable damage to the vegetation (Box and Perry 1971, Wilson 1991, Bennett 1997, James *et al.* 1998). The increased availability of water has enabled kangaroos to extend their range into areas that would previously have been inaccessible to them in all but the wettest years. Kangaroos were probably almost non-existent in the study areas prior to European settlement (Badman 1999: Chapter 10). The removal of their major predator, the dingo, has further allowed numbers to build up to unsustainable levels (cf. Caughley *et al.* 1980). Caughley *et al.* (1980) found that kangaroo numbers inside the Dog Fence can be as much as 166 times higher than they are outside. They also showed that emus can be up to 26 times higher inside the fence where dingoes are controlled. Newsome *et al.* (1996) considered that the creation by cattle of "marsupial lawns" around artificial watering points on open grassy plains, where dry perennial grasses have been removed so allowing the growth of green tillers that are attractive to kangaroos, has also benefited kangaroos and led to an increase in their numbers in central Australia.

Kangaroos may be more selective in the areas they graze, with a preference for grasslands (Leigh et al. 1989) and therefore have the potential to cause greater degradation in their preferred habitat than herbivores that are less selective (Landsberg and Stol 1986). However, their soft feet cause less physical damage to the soils and vegetation than the hard hooves of domestic stock.

Large amounts of vegetation can also be removed by large numbers of grasshoppers, locusts or insect larvae (Reid 1993, Shaw 1993), or by native rodents (Predavec 1994). Rodent numbers can fluctuate dramatically over time, with up to 40-fold differences between periods of highest and lowest abundance (Predavec 1994). North American prairie dogs were found to cause an increase in species richness and diversity within their colonies (Archer *et al.* 1987), with significant decreases in the height of the grasses on which they feed. Most changes occurred within the first two years of establishing a new colony, with conditions stabilising in subsequent years. Rangeland management must consider total grazing pressure, not just the impact of domestic stock (Parker and Graham 1971, Ssemakula 1983, Grice and Barchia 1992).

2.3 THE EFFECTS OF DOMESTIC GRAZING ON ARID ZONE VEGETATION

2.3.1 AN OVERVIEW

There is no evidence in the literature of any significant grazing pressure being exerted on the landscape by native herbivores at the time of European settlement (Williams 1977) and vegetation communities are believed to have been in some kind of equilibrium (Williams and Roe 1975). Aboriginal people did not have an economy based on domestic grazing animals, as is the case in similar climates and topography in other parts of the world (Galaty and Johnson 1990). Although many plants have developed defences against herbivory (Coley *et al.* 1985), the Australian arid zone flora has not yet had sufficient time to adapt to hard-hoofed herbivores as has occurred in other parts of the world (Box and Perry 1971, Plumptre 1993).

Kimber (1976) suggested that there are similarities between some Aboriginal hunting practices in central Australia and conventional pastoral activity. He suggested that the central Australian Aboriginal practice of maintaining a kangaroo or emu population in a given area and culling from it just sufficient animals to meet their immediate needs is similar to what is done by pastoralists. This may have been the case in the early days of Australian arid zone pastoralism, but is probably not the case today. Early grazing of beef cattle virtually meant the harvesting of animals from a nomadic and sometimes largely feral herd (Box and Perry 1971, Coughenour 1991) that was unmanaged for most of the year. Animals could be moved to particular areas, but, without fences, they did not always stay there. Similarly, prior to the erection of fences and before construction of the Dog Fence, sheep flocks of about 1500 animals had to be constantly shepherded during the day and yarded at night. This meant that large flocks were held around the same watering point for long periods. Shepherding gave the sheep less chance to spread out over large areas and take advantage of feed produced by small falls of rain because shepherds would want to get back to their huts on most nights. Today's pastoral management is more sophisticated: pastoralists now have better technology that allows greater utilisation of much more of the country than was possible by Aboriginal people or the early settlers. This new technology includes fences, permanent artificial watering points and greater mobility through road, rail and air transport.

Early European settlers of the Australian arid zone had no experience of its climate, erratic rainfall, low water availability and poor quality, infertile soils. Because of this, they often had unrealistic expectations of how many stock the country could carry. Although the process of land degradation can be a natural event (Pickup 1989), it was often accelerated by the pastoralists' inability to quickly remove stock during a drought and by the subsequent arrival of the rabbit. Expectations of the early explorers and settlers were heightened when their first sight of the country was in a good season (e.g. Stuart 1864, and see remarks by Horn 1896). Initial lease sizes were often too small to be viable, leading to overstocking and land degradation (Young 1979, Passmore and Brown 1992). Further subdivision of leases led to social problems and increased environmental degradation (Pickard 1990), while the terms of tenure, particularly the short duration of leases, were often blamed for land degradation (Pick 1944). Inappropriate Government regulations, requiring a minimum stocking rate rather than a maximum, also contributed (Purvis 1986). The dreams of the legislators often became the nightmares of the settlers (Pickard 1990). Decisions were often made on economic and administrative grounds rather than for ecological reasons (Buckley 1985).

Despite all of the above, not all early pastoralists were unaware of the damage that was being done to the country and the vegetation (e.g. Ross 1882, Dixon 1892, Hamilton 1892). Numerous contemporary publications demonstrated an understanding of marginal environments (Quinn 1997). Kimber (1994) pointed to the growing trend in contemporary literature to portray pastoralists as the villains and destroyers of the rangelands, while Mitchell (1991) warned of the dangers of repeating folklore and myths.

The repeated use of the generally accepted view that the early settlers "did not know any better" may now be hindering the management of some of the land degradation problems (Mitchell 1991). Quinn (1997) saw the current trend to attribute past failures to a lack of knowledge or to ignorance as a convenient and simplistic excuse for past management deficiencies. Even in the early days of European pastoral settlement there was a wide understanding, as there is today, that the maintenance of the environment was essential (Quinn 1997). However, this did not preclude bad judgement, just as more sophisticated contemporary knowledge does not (Quinn 1997).

Overstocking of leases often followed increased debt in an attempt to remain solvent. Re-occupation of abandoned lands was encouraged in the belief that if left unstocked they would degrade, harbour pests and threaten the viability of neighbouring properties (Quinn 1997). This belief is still held by some modern graziers (Shaw 1993). Despite this, Curry and Hacker (1990) considered that there was no empirical basis to the popular conception that formal conservation objectives could not be met on pastoral land without the complete removal of domestic stock. Conservation-orientated pastoralism as a legitimate land-use is now being prejudiced by these old preconceptions (Curry and Hacker 1990).

One of the big ecological disadvantages of running stock, particularly cattle, on unfenced rangelands was that they tended to congregate on the best country and eventually render it useless (Dawson *et al.* 1975, Friedel *et al.* 1990, Fleischner 1994, Rolf *et al.* 1997). These same areas also provided the best habitat and refuge areas for wildlife (Newsome 1980, Morton 1990, Foran *et al.* 1990, Recher and Lim 1990, Tunbridge 1991) and formerly for Aboriginal people (Meggitt 1962, Tindale 1974, Badman 1999: Chapter 10). These best areas of vegetation act as indicator landscapes for the rest of the country. If they are still in good condition, despite domestic and feral grazing, then the rest of the country will be too (Friedel *et al.* 1990).

The importance of rangeland research and the need for a coordinated approach was recognised more than three decades ago (Perry 1966). However, there has been little research into the effects of grazing domestic livestock, particularly cattle, in the present study areas, and little into the effects of cattle grazing in similar landforms in other parts of Australia. Cattle-grazing has been extensively studied in the Alice Springs district of the Northern Territory and these studies are relevant to the sand ridge country of the present study areas, particularly in the northern parts. South Australian studies of sheep grazing at Middleback Station near Whyalla (e.g. Lange *et al.* 1984) and at the

T.G.B. Osborne Reserve on Koonamore Station (e.g. Hall *et al.* 1964, Carrodus *et al.* 1965, Crisp 1975, Noble 1977) have some relevance to the chenopod shrublands that occur over much of the present study areas, especially in the south. There are few references in the literature concerned with the effects of cattle grazing in this habitat (Fatchen 1975, 1978, Read 1999), and even less outside the Dog Fence. Studies in New South Wales (e.g. Wilson *et al.* 1969, Graetz 1978, Wilson 1991a, Hodgkinson *et al.* 1995, Landsberg and Stoll 1996), western Queensland (e.g. Griffiths *et al.* 1974, Orr and Evenson 1991) and in Western Australia (e.g. Collett 1961, Yan *et al.* 1996), are again concerned entirely or mainly with the effects of sheep rather than cattle grazing. Studies of cattle grazing in south-west Queensland are generally concerned with landforms that do not occur in the present study areas. Most of these studies were also carried out in areas with higher rainfall than occurs in northern South Australia.

The drilling of artesian bores into the Great Artesian Basin aquifer has allowed greater utilisation of the district by domestic and feral herbivores. These bores allow grazing of outlying areas when no natural surface water was present, thus expanding the area available for pastoral use (Landsberg *et al.* 1997).

Friedel *et al.* (1990) pointed out that current stocking rates in the Alice Springs district are now one quarter of those proposed for the area in 1887. Purvis (1986) cited the case of one paddock where present stocking rates are only 4% of a previous stocking rate. Even today, land managers must deal with a plethora of different Government Departments, who do not always liaise with each other and sometimes give conflicting advice (Friedel *et al.* 1990).

Similar, or sometimes even greater, degradation and reductions in carrying capacity have occurred during the 1800s or early 1900s in rangelands in other parts of the world (e.g. Box and Perry 1971, Ares 1974, Harris 1983, Gilles and Gefu 1990, Mitchell 1991, Earl and Jones 1996) and in some temperate Australian pastures (Lawrence 1995). However, in some developing countries, where the traditional lifestyle has always involved the grazing of domestic livestock, degradation has occurred more recently because of increasing population pressure (Le Houerou 1989, Kumar and Bhandari 1992) and poverty (Pearce and Turner 1990). The problems involving the positioning of artificial watering points and resultant increased utilisation of the country also occur in other countries (Hitchcock 1990, Bennett 1997), with some areas able to be grazed only because of these waters (Perkins and Thomas 1993).

Australian rangelands have been degraded less than those in some other countries because of the shorter period of domestic grazing and lower human population pressures (Box and Perry 1971, Harrington 1983). In western New South Wales, Pickard (1990) reported the early decline in carrying capacity and a subsequent increase in carrying capacity during the 1970s and 1980s that was mirrored by a broad increase in district rainfall and an improvement in rangeland condition.

Even in more the recent times of heightened environmental awareness, economists such as Davidson (1987) argued that these environmental costs have been minimal and were essential to the development of Australia. Williams (1977) took the view that the elimination of some long-lived plants by domestic and feral herbivores was the European contribution to natural selection pressures.

The traditional attitude that the Australian rangelands were suitable only for the grazing of cattle and sheep are now being challenged (Box and Perry 1971, Buckley 1982b, Morton 1993, Fitzhardinge 1994, Heathcote 1994, Holmes 1994, 1997, Wilcox and Burnside 1994, Holmes and Day 1995). This is particularly so in light of the potential threat posed by grazing to biodiversity (Morton 1990, Leigh and Briggs 1992, Reid and Fleming 1992).

New roles are evolving for parts of the rangelands, including those with biological, cultural and amenity values. These roles may become even more diverse in the future and include such things as an increased role for the harvesting of common kangaroo species (Grigg 1991). The role of primary production from the rangelands is also changing. The production of basic agricultural commodities is no longer seen as providing the future economic wealth of Australia (Chudleigh 1993). The pastoral industry must now be viewed in the light of its sustainability (Heitschmidt and Walker 1996).

As Tiver (1992) pointed out, lack of adequate enforcement of legislation may be due to a lack of resources. The onus is obviously on governments to ensure that adequate resources are available to provide assistance to land managers who are aiming towards ecologically sustainable land management practices and to control those who are not.

It is sometimes difficult to ascribe changes in rangeland vegetation communities to any single factor. Buffington and Herbel (1965) described vegetational changes over a 105-year period in a semi-desert rangeland in New Mexico, but while they were able to describe gross changes in the ratio of grassland to shrubland, they were unable to ascribe this to any single factor. They were able to say that the changes were not directly brought about by over-grazing: changes in fire regimes, spread of seed by horses and local Indian populations, and other Indian subsistence practices were all thought to have contributed.

2.3.2 The Early Effects of Pastoralism

Early pastoral impacts on the Australian landscape were sometimes devastating (Dixon 1892, Ratcliffe 1936, Pick 1944, Williams 1974), with stock numbers in some areas far beyond what could be sustained by the country (Trumble and Woodroffe 1954). Carrying capacity of the best areas was sometimes extrapolated over the whole lease (Purvis 1986). The worst degradation of arid ecosystems always coincided with lengthy drought conditions (Bernus 1990, Morton 1990, Hodgkinson and Cook 1995, Rapport and Whitford 1999), when large numbers of stock often concentrated around a single watering point (Newman and Condon 1969). Pastoral management practices often prolonged the effects of droughts (Purvis 1986).

Some chenopod shrublands were deliberately degraded in the belief that this would increase the growth of grasses and palatable forbs (Newman and Condon 1969, Lange *et al.* 1984). This approach has some support from the research of Noble (1977), who found that biomass of short-lived species decreased when shrub density increased. However, reliance on short-lived forage species removes the drought-resisting qualities of the pasture, with little for the stock to fall back on once the short-lived vegetation has gone. The belief that removal of the shrubs would increase carrying capacity was supported by government administration of the time (Lange *et al.* 1984) but proved to be false, leading to serious soil erosion (Lange *et al.* 1984, Fatchen 1978). Although pastoral production was increased by ephemeral growth following rainfall, this growth ceased once scalds developed and there was no subsequent pastoral production in dry years (Newman and Condon 1969). The widespread death of saltbush shrubs reported from southern parts of South Australia and from Western New South Wales following the first few years of European settlement (Friedel *et al.* 1990) does not appear to have occurred to the same extent within the present study areas, or if it did the subsequent recovery has been better. Grazing of some *Eragrostis setifolia* grasslands was managed so that these relatively unpalatable perennial grasses were replaced by shorter-lived grasses that were more palatable (Newman and Condon 1969), perhaps *Enneapogon* spp..

This early degradation of the land, mainly through ignorance of the function of local ecosystems or through trying to make more money from the same amount of country, usually commenced towards the end of the 19th Century but was not restricted to the present study areas. It also occurred in other parts of South Australia (e.g. Ratcliffe 1936), Australia (e.g. Dixon 1892, Friedel *et al.* 1990, Ash and Stafford Smith 1996) and the world (e.g. Buffington and Herbel 1965, Ares 1974).

Early pastoralists generally considered that it was necessary to increase livestock numbers in order to increase production. Although there were some early warnings and exceptions (e.g. Dixon 1892), the realisation that greater production could be accomplished by lower numbers of better managed, higher quality livestock, of better temperament and grazing better pastures, generally came later, both in Australia and overseas (Ares 1974, Purvis 1986, Foran *et al.* 1990). Subdivision of large paddocks, giving the capability to spell large areas, also featured in improved management programmes. Previously, spelling of certain areas was possible only when a bore could be turned off, or when only ephemeral waters were present. Stock would move on to temporary waters and allow the country around permanent waters to recover during the growing season following heavy rainfall. These "best practice" techniques also allow approximately the same number of stock to be run in both wet and dry years (Lange *et al.* 1984, Purvis 1986).

Quinn (1997) suggested that the continuation of the theme of a "vandalistic past" has been used in some circles because it allows a refuge for a society that is proficient in accruing environmental information and knowledge, but is much less well equipped to execute their successful application.

The earliest impacts of pastoral grazing in the study areas were caused by large numbers of sheep and smaller numbers of horses. Large numbers of camels were kept around Marree and regularly travelled through much of the study areas until the 1920s (Stevens 1989). Cattle have replaced sheep throughout most of the western and northern parts of the study areas since the 1930s. This is the opposite to the situation in some other areas such as western New South Wales, where sheep have now replaced cattle (Mitchell 1991). Sheep remain within the study areas on Roxby Downs and Wilpoorinna Stations. Horse numbers have decreased in the last 30 years as they have been replaced by motor vehicles and light aircraft.

2.3.3 Ongoing Effects of Grazing

Although Friedel *et al.* (1988) considered that *"desertification continues unabated or is accelerating in much of the world's rangelands"*, this view is not shared by all Australian or overseas workers. Impacts around watering points, e.g. removal of vegetation and lessening of biodiversity caused by both grazing and by trampling both the soil and individual plants, have been lessened by increasing the number of watering points and reducing the number of stock that drink at each point.

Pickard (1990) considered that the original five kilometre diameter "sacrifice zone" around each watering point has now shrunk to less than one kilometre. He also attributed similar benefits to the increased number of stock yards now used on each property (usually one per watering point in the present study areas). However, the reduction in area of the sacrifice zone will occur only if the overall carrying capacity of a paddock is not increased because of additional watering points. Extra watering points can allow utilisation of a larger proportion of a paddock. Unless overall grazing pressure is kept at or below previous levels, this can lead to greater degradation of larger areas of land than occurred previously.

Hanan *et al.* (1991), reporting on desertification around deep wells in the African Sahel, cited cases of "desert patches" (areas of exposed soil) around the wells commonly extending for up to 30 km and occasionally to 50 km. Both distances are beyond the normal foraging range of cattle, the main domestic animal involved, so other factors such as linking of the areas around two wells are likely to be involved. Hanan *et al.* (1991) used satellite imagery to assess the spread of desertification from new wells, but were unable to detect any consistent relationship between primary production and proximity to a well. Van Rooyen *et al.* (1994) studied vegetational gradients around artificial watering points in the Kalahari Gemsbok National Park, but were also unable to establish a significant relationship between distance from the watering point and plant species composition. They found plant species composition was related to selective grazing, but not to watering points. In the Chihuahuan desert, Fusco *et al.* (1995) were able to establish an association between the amount of standing crop and distance from water for conservatively stocked rangelands, but found that no such relationship existed for heavily stocked rangelands. In the otherwise waterless Kalahari Desert of Botswana, Perkins and Thomas (1993) concluded that not all effects of artificial watering points had a negative impact on vegetation, with at least one plant species actually benefiting from grazing.

Land degradation in some arid parts of the world has been blamed on the increasing demands of the local population (cf. Le Houerou 1989), particularly where this has led to the grazing of more marginal areas (Gilles and Gefu 1990). Improved technology has allowed the sinking of deeper wells and has made more water available for domestic livestock. Better veterinary health has allowed more of these livestock to survive between droughts (Hanan *et al.* 1991).

Although not in a strictly arid area, but in an area where annual rainfall could be as low as 214mm, Thurow and Hussein (1989) found that heavy continuous grazing in coastal southern

Somalia eventually formed a herbaceous vegetation community dominated by short-lived annual forbs of low palatability. Removal of all grazing resulted in the formation of a palatable vine mat that overtopped other herbaceous species, but died off soon after the end of the rainy season. Moderately stocked short-duration grazing opened up the vine mat and allowed the establishment of other plants, especially grasses, that were a source of forage during the dry season.

Recent work by John Maconochie in the KSCD area has shown that the situation in this area is improving (Maconochie and Lay 1996). His work was a continuation of work started by Jessup during the 1940s (Jessup 1951) and continued by Lay in the early 1970s (Lay 1979). Maconochie found that contrary to the opinion that degradation of the rangelands has yet to be reversed (e.g. Reid and Fleming 1992), the density of chenopod shrubs in this area had actually increased in the 46 years since Jessup's survey. In Western Australia, Yan *et al.* (1996) also found that major perennial species, including dominant species, remained stable or increased during an eight year sheep grazing study. They found that 38-74% of the variation in mortality and recruitment was caused by seasonal conditions rather than by grazing.

An even more recent study into the condition of pastoral land in the North East Soil Conservation District of South Australia (Barnes 1997) showed that the condition of country to the south-east of the present study areas deteriorated dramatically during the period 1880-1900, with little real improvement until the 1950s. She recorded the first increase in the best condition country (rather than a decrease in the worst condition) during the 1960s and particularly the 1970s. Conditions in the 1980s showed a reversal of the improvement, with a slight decrease in sites rated as being in best condition and an increase in poorer condition sites, but not in those in the worst condition. This reversal was only temporary, with a return to greater numbers of best condition sites in the early 1990s. Barnes (1997) attempted to use the same methods in the MSCD, but found that lack of suitable data and a greater diversity of landforms and habitats precluded this.

2.3.4 Effects on the Microbiotic Soil Crust

Microbiotic or cryptogamic soil crusts cover much of the soil surface in semi-arid regions. They are usually seen as a desirable component of healthy ecosystems (Eldridge 1996), although this view is not shared by some Soviet and South African rangeland ecologists (West 1990) and increases in cryptogams have sometimes been associated with a decline in perennial grasses (Kleiner 1983). Cryptogamic crusts are most common on clay soils, but they occasionally occur on sandy soils

(Danin 1996). Cryptogams are largely restricted to those parts of South Australia with a predominantly winter rainfall (Rogers and Lange 1972) and are most susceptible to damage during dry periods (Marble and Harper 1989, Eldridge 1996).

Microbiotic soil crusts include brown and green algae, bacteria, cyanobacteria, lichens, mosses, liverworts and fungi (Heshmatti 1997). These play an important role in stabilising soil surfaces and in water infiltration processes through changes to soil physio-chemical properties and through their influence on soil surface roughness (Eldridge and Green 1994). Microbiotic crusts are therefore useful indicators of soil surface condition. They also fix nitrogen (Rogers *et al.* 1966) which can then be utilised by developing vascular plant seedlings (Eldridge and Green 1994). These soil crusts also inhibit the growth of some exotic annual species (Kaltenecker *et al.* 1999). Rogers *et al.* (1966) considered that about 40 species of lichens occur in the southern central arid zone in Australia, slightly more than the 34 taxa recorded by Hodgins and Rogers (1997) from a sub-tropical grassland in south-west Queensland. Rogers and Lange (1971) found that none of the soil crust lichen vegetation was stimulated to greater population development by grazing and that the destruction of the original lichen crust left the soil bare.

Cryptogamic crusts are important in nutrient recycling (West 1990) and in preventing erosion (Marble and Harper 1989, West 1990), especially during droughts when the soil surface is not protected by vascular plants (Eldridge 1993). They also enhance infiltration at ungrazed sites (Marble and Harper 1989, West 1990), but do not significantly increase infiltration at sites grazed by sheep (Eldridge 1993). These crusts also help to reduce evaporation by sealing the surface and may help to protect seeds in the soil (West 1990).

These organisms are susceptible to natural disturbance, usually through being covered by sand from which they recover rapidly following rain (Danin 1996), but are more susceptible to disturbance by ungulates (St Clair *et al.* 1993, Danin 1996, Hodgins and Rogers 1996). They are less likely to be affected by soft-footed animals such as rabbits and kangaroos. Natural differences in cryptogamic cover are exaggerated by grazing (Kleiner and Harper 1977), while Anderson *et al.* (1982) considered that any domestic grazing may be incompatible with cryptogamic crusts. Recovery following trampling may be very slow (Belnap 1993, Danin 1996), although it is quicker if the grazing has been light (Belnap 1993), particularly if hoof marks are few and do not touch each other (Danin 1996). Light grazing may even assist the spread of cryptogams (Eldridge 1996).

Hodgins and Rogers (1997) found that even moderate hoof impact had a significant effect on the cryptogamic community which correlated with distance from water. Similar effects were recorded by Andrew and Lange (1986a) and Heshmatti (1997). Crisp (1975) found that this resulted in a disruption of nitrogen fixation by the cryptogams, and also a loosening of the soil which allowed wind and water erosion of surface layers.

2.3.5 Grazing Preferences of Livestock

Domestic herbivores, kangaroos and rabbits generally prefer to graze the short new growth of palatable species. They leave older perennial growth, particularly of grasses, and less palatable species until this new growth has been removed. Cattle and kangaroos prefer grasses, while sheep prefer forbs and low shrubs (Griffiths *et al.* 1974). This has the effect of leaving the perennial grasses as a drought reserve (Hacker and Tunbridge 1991). However, the collapse of many perennial grasslands in arid areas has occurred rapidly under drought conditions when plants have been grazed below 10 cm in height (Ares 1974, Hodgkinson and Cook 1995). Kumar and Bhandari (1990) found that even low grazing pressure resulted in heavy mortality of the palatable vegetation during drought. Perennial grasses that grow in run-on areas appear to be the most susceptible to overgrazing, particularly where they are directly competing with trees for water (Hodgkinson and Cook 1995). The presence of trees in areas with good grass cover, such as along watercourses, also provides shade for grazing animals and encourages them to stay longer in these areas, thus further increasing the grazing pressure on these grasses. This also increases the local return of nutrients from these animals to the soil. Continuation of heavy grazing pressure on perennial grasslands may eventually lead to their replacement by annual species with highly erratic yields, a condition which is often difficult to reverse (Westoby *et al.* 1989).

Williams (1982) suggested that some species that are important food plants for introduced herbivores are now represented in many areas mainly by old individuals, with little recruitment from seedling populations since the introduction of domestic stock. However, grazing favours those species which possess mechanisms that discourage grazing of their seeds. These include early initiation of flowering, synchronisation of flowering times within a community, delaying flowering until close to maximum plant growth has been attained and production of seeds close to the ground where they are relatively safe from cattle, but probably not from close-grazing animals like rabbits and sheep (Williams 1982). Other species have seeds or seed heads that are unpalatable to grazing animals, or the plant or some of its parts are toxic to herbivores. However, under extreme circumstances grazing can still preclude flowering and eliminate seed set (Williams 1977).

2.3.6 Effects of the Pastoral Industry

The direct impacts of the pastoral industry, besides the consumption of vegetation, are generally recognised as being soil compaction and surface pulverisation, increased erosion, trampling of vegetation, selective grazing of certain species and plants, reduction of plant density, reduction of the litter layer, relocation of nutrients through meat and wool exports, concentration of egesta, fouling of natural water sources and depletion of ground water resources through bores (Buckley 1985, Noble and Tongway 1986, McFarland 1992). Indirect impacts include increased access for third parties, provision of artificial water sources (Bennett 1997, Landsberg *et al.* 1997) and altered fire regimes. Fleischner (1994) also added loss of biodiversity, lowered population densities for a wide variety of native taxa, disruption of ecosystem functions including nutrient recycling and succession, change in community organisation, and change in the physical characteristics of terrestrial and aquatic habitats. Increases in ammonia (NH_3) and nitrite (NO_2) caused by cattle have been reported as affecting local fish populations (Taylor *et al.* 1989).

It is widely acknowledged that any grazing causes changes to the vegetation and that heavy grazing does considerable long-term damage. Degradation of some landscapes of the dry eastern Mediterranean has been largely due to uncontrolled grazing and fuel gathering by people. Whether such damage is reversible in the long-term is debatable. There are several documented cases where this damage was not reversible (e.g. Pick 1944), or where recovery of the vegetation was towards a different vegetation community, or involved increased cover of the remaining species, but no establishment of new species (cf. Westoby *et al.* 1989). Species most at risk are those that are in a minority in the community, take a long time to produce their first seed crop, flower at irregular intervals, and are preferred grazing species during extended dry periods. Williams (1977) considered seedlings of annual species to be more at risk from natural desiccation than from direct grazing by herbivores. Recovery of annual species may be most rapid immediately following the removal of cattle, as long as there is a nearby seed source and may, as in a study carried out by Waser and Price (1981), consist mainly of the less common species. Williams (1977) considered that in the long-term and in the face of continued heavy grazing pressure, many minority perennial species of value to domestic livestock are likely to be eliminated from the rangelands through selective grazing.

The relationship between grazing and annual plant cover is not necessarily consistent between years (Waser and Price 1981). Some species may flower more profusely following grazing (Williams 1977, Orr 1991), while the reverse is true for other species and some may die if the grazing is heavy or at the wrong period of their growth cycle (Williams 1977). Grazing may lead to an increase in the diversity of annual plants (Gibson and Brown 1991) by removing competitive dominants and thereby creating niches for colonisation by other species (Harper 1969). However, this is not always the case and in some cases it may be necessary to limit the grazing episodes (Waser and Price 1981). There is documented evidence of long-term exclusion of grazing animals causing a decrease in species diversity (e.g. Curry and Hacker 1990), while Smith (1940) found that some species, particularly those that are unpalatable or benefit from the removal of dominant species, actually increased in abundance under light grazing. Edroma (1981a, 1981b) found that a combination of burning and grazing removed a dominant invasive weed and allowed the establishment and co-existence of numerous species in its place.

Some patchiness (i.e. areas of bare ground between patches of vegetation) of the soil surface, beyond natural patchiness (Specht 1972, Williams 1982, Stafford Smith and Morton 1990), can be attributed to the differential compaction and erosion of the soil by cattle and sheep (Williams 1982). This effect is most marked in the piosphere around stock watering points (Osborn *et al.* 1932, Lange 1969, Barker and Lange 1969, 1970, Barker 1979, Andrew and Lange 1986a, 1986b), although these effects are not necessarily symmetrical (Graetz 1978, Heshmatti 1997). Patchiness can also be influenced by the fodder preference of herbivores or by more natural events such as uneven rainfall across the landscape or soil types, or the occurrence of bushfires. Noble *et al.* (1999) considered that depletion of fossorial vertebrates since European pastoral settlement has been a neglected facet of changes in the maintenance of surface heterogeneity.

There is also some selective grazing of certain plants amongst individual species. Graetz (1978) and Maywald (1998) both found that sheep selectively grazed female *Atriplex vesicaria* shrubs, causing up to a five-fold change in the sex ratio (Graetz 1978) due to a chemical deterrent in male plants (Maywald 1998). Grazed female plants were found to be smaller and less vigorous than male plants in the same area, with long-term grazing affecting the viability of populations (Maywald 1998). Williams (1972 cited in Maywald 1998) considered that a ratio of male to female plants greater than 2:1 in a grazed population may be indicative of poor recruitment potential. She found such ratios at several of her paddock sites, including one site where only 32% of male plants showed evidence of grazing, compared to 77% of female plants.

Heavy grazing, leading to removal of the majority of the vegetation, results in an increase in the amount and rate of run-off and sediment removal following heavy rainfall (Eldridge and Koen 1993, Lawrence 1995, Scanlan *et al.* 1996). This in turn can lead to an increase in erosion. Although erosion is a natural feature of the landscape, it is accelerated to unnatural levels when protective vegetation cover is removed. Therefore, the role of vegetation in preventing erosion becomes even more important as degradation of the soil surface increases (Eldridge and Koen 1993).

Friedel (1994) linked an increase in shrubbiness of watercourses in central Australia to grazing. She found that the weight of woody trees and shrubs in grazed watercourses was approximately 30% higher than for ungrazed areas. Most of the additional weight was made up of shorter-lived woody shrubs. She also found that the peak biomass of herbs along grazed watercourses was double that of ungrazed sites. Increased disturbances in the form of run-off and deposition were found to benefit the shorter-lived species.

Major changes in vegetation structure caused by grazing appear to relate mainly to changes in abundance of species, although this is difficult to quantify because of a lack of adequate baseline information and its dependence on temporal considerations. Many changes will not be detected by short-term monitoring or research programmes. Major changes that have been recorded in the abundance of woody shrubs in other states (e.g. Stafford Smith and Morton 1990, Booth *et al.* 1996) have not occurred to the same extent in the present study areas. These changes are considered to be indicative of over grazing of fragile ecosystems (Tueller 1973), often following the collapse of perennial native grasslands (Hodgkinson *et al.* 1995), overgrazing of savannas (Walker *et al.* 1981), flooding (Tueller 1973), or under-utilisation of fire (Griffin and Friedel 1985).

Large gaps in the regional distribution over the study areas of the palatable perennial grasses *Eragrostis eriopoda, Monachather paradoxa* and *Thyridolepis mitchelliana* do not appear to be connected to domestic grazing. *Monachather paradoxa* is prone to grazing induced mortality (Grice and Barchia 1992) but is still very common in pastoral country to the north-west, west and south of the study areas, particularly west of the Stuart Highway, and further to the east in New South Wales, while *Thyridolepis mitchelliana* is common to the north-west of the study areas, with a few herbarium collections from further south. There are no collections of either species in the State Herbarium of

South Australia from the study areas or from the eastern part of the Lake Eyre botanical region in South Australia, so it is likely that they may never have occurred there. *Eragrostis eriopoda* is uncommon in the Olympic Dam area, but is even less common further north and east in the present study areas. It is common to abundant further to the west in landforms similar to the sandhills of the study areas. If these species had been removed from northern parts of the present study areas by grazing it would be reasonable to assume that there would either be early herbarium collections or records from the area, or that occasional plants would remain in areas that have rarely been subject to grazing. This is not the case (Badman 1999: Chapter 6).

As Pickard (1990) pointed out, it is impossible to restore an ecosystem to its former condition when it is not known exactly what that condition was. Mason (1963) discussed this problem in some detail and urged greater examination of historical records such as journals and diaries of explorers and early settlers to obtain details of vegetation distribution prior to domestic grazing.

Some individual land systems or vegetation communities are more at risk from grazing, or from trampling and pugging by the hooves of large herbivores, such as cattle and horses, than others. For instance, mound springs have suffered from severe trampling and pugging, as well as removal of much of their vegetation by grazing. This was once widely thought to be causing serious degradation to the springs and their biota (e.g. Ponder 1985, 1986, Harris 1989, 1992, Badman 1991b), but it is now known that, at least as far as the vegetation is concerned, the aesthetic damage has in many cases been worse than the environmental damage (Fatchen and Fatchen 1993). Some plant species and communities require some form of biotic or abiotic disturbance, including that provided by grazing animals, in order to attain their full potential growth or species diversity (Collins and Barber 1985). It is also now known that mound spring vegetation reaches its greatest species diversity when it is changing from dominance by one species to dominance by another (Fatchen and Fatchen 1993, Section 2.6 of this thesis). This change in dominance happens only following disturbance such as that caused by grazing, fire or mechanical intervention.

The lack of regeneration of some tree and shrub species is well documented for the semi-arid and arid zones of Australia (e.g. Lange and Graham 1983, Chesterfield and Parsons 1985, Auld 1990, 1995). The rabbit has been blamed for much of this, through the elimination of seedlings before they become established (Lange and Graham 1983, Friedel 1985, Ireland 1997a, 1997b). Sheep also have the same effect on *Atriplex vesicaria* shrubs, but by a different means: whereas rabbits allow shrubs to flower, but eat the seedlings, sheep eat the shoots before they flower but generally leave seedlings (Lange *et al.* 1992). The end result is the same. Pick (1944) considered that while sheep-grazing of young shoots would eventually kill the plant, cropping of mature stems had no long-term effects and plants would recover after rain. Although Pick considered that pruning of young saltbush was advantageous, he also stated that saltbush shrublands could not stand continuous grazing and that one third of the country should be ungrazed at any one time. Crisp and Lange (1976) found that the combined grazing efforts of rabbits and sheep totally prevented recruitment of three arid zone shrub species. Pick (1944) considered that the overall damage to vegetation was no greater on stocked pastoral country than it was on unstocked "outside" country and blamed this entirely on the rabbit. Auld (1995) found little regeneration of four arid zone tree species even when there was no grazing pressure from any domestic livestock, with rabbits and kangaroos responsible for elimination of both suckers and seedlings. Although kangaroos have evolved with the native rangeland vegetation, because of their present unnaturally high numbers in many areas (Section 2.2) and contrary to the suggestion of Tiver (1998), this animal is not necessarily in equilibrium with its habitat (Badman 1999: Chapter 6). Auld (1995) and Read (1995) both found that desiccation contributed to the death of seedlings. Tree seedlings may initially also face fierce competition from grasses, whose roots often dominate the upper soil horizon (Seghieri 1995).

Earl and Jones (1996) suggested that while grazing animals are one of the major contributors to land degradation, when managed in a different way they may be one of the most valuable tools for the restoration of grassland communities. Dagget (1997) reported on the successful use of cattle in rehabilitating mine tailings dumps. Cattle were fed hay on the dumps, which was their only food source. Cattle enriched the basic building block, soil provided by the dumps, by trampling in some of the hay and also through their excrement. Eventually the soil was enriched and grass seeds from the hay germinated and covered the dump. This method was successful even where more traditional methods had failed. The floristic composition of vegetation established in this way can presumably be controlled by the floristic content of the hay that is used.

2.4 PASTORAL MANAGEMENT

2.4.1 MANAGEMENT OF GRAZING

The most effective tool available to the station manager is the ability to vary the stocking rate (Westoby *et al.* 1989). This does not mean that stock numbers must necessarily be constantly fluctuating, although this is one management option (Foran *et al.* 1990), but may mean that a sustainable lower stocking rate is adopted (Purvis 1986). Artificial watering points and fencing, discussed below in Sections 2.4.2 and 2.4.3, allow far greater control of livestock than was previously achievable on unfenced rangelands.

2.4.2 STOCK WATERING POINTS

Damage to the vegetation, and to the ecosystem as a whole, caused by domestic livestock is generally greatest in the piosphere surrounding a watering place (Section 2.3.6), with the disturbance and soil compaction halo gradually diminishes with distance from water. This eventually has implications for the seed bank. Initial disturbance may increase the density of the seed bank (Thompson 1978, Navie *et al.* 1996), but prolonged disturbance will eventually cause the density to drop (Navie *et al.* 1996). Many seeds are eaten by herbivores and a variable proportion retain their viability and are spread to new areas through the animals' digestive tracts (Williams 1977). Grazing can also increase the level of recruitment of perennial shrubs by removing competition from older plants (Tiver 1992), although total grazing pressure would need to be kept at low to moderate levels for recruitment to succeed in arid areas.

One of the major changes brought about by the establishment of artificial watering points is the ability to maintain stocking rates well beyond the point that would have been possible with natural, mostly ephemeral, waters. This can allow heavy stocking to continue well into a drought, the time when most environmental damage occurs. This in turn allows faster utilisation of areas around ephemeral waters when rain does fall. Conservative management practices are essential to ensure that this does not occur and that vegetation has time to recover after a drought.

Unless the pastoral industry becomes self regulatory on this point, the case for a network of small conservation reserves, as proposed by Stafford Smith and Morton (1992), may become overwhelming. However, the cooperation of viable pastoralists is also fundamental to their success (Pickard 1993). There have already been problems in other parts of the world where conservation has been forced on a population dependent on a traditional natural resource that has been taken from them through dedication of formal conservation areas (Neumann 1992).

2.4.3 Fencing

In the early days of pastoral settlement there were no fences in inland parts of Australia. Sheep were generally shepherded to protect them from dingoes, while cattle were mostly left to range at will between annual musters. This meant that they congregated on the best areas of feed and water, often removing all vegetation soon after rain fell from what should have been the drought refuge areas. They were then forced back on to these same areas when conditions became dry. If these best areas were not grazed by the cattle belonging to that particular lease, they were often grazed by the neighbour's cattle. Heavy grazing of these areas was sometimes seen as the only sure way of keeping out neighbouring cattle (Ares 1974). Fencing of pastoral leases eventually ensured that stock were mostly contained on the property where they belonged. This became a crucial factor in the elimination of Brucellosis and Tuberculosis from herds in the study areas during the 1970s and 1980s and led to the completion of boundary fencing and to the erection of many internal sub-division fences. These allowed, for the first time, property managers to have a greater measure of control over the areas where their cattle grazed. It also placed an onus on managers to actually manage their stock, rather than let them roam at will.

Ideally, paddocks would separate different land units so that each could be managed in the most sustainable way, but this is seldom the case (Graetz 1978). It is unlikely to happen in the study areas for economic reasons. Although grazing is focussed on watering points (Graetz 1978), different land units are included in the same paddock and are grazed in different ways. This leads to over-utilisation of some land units and under-utilisation of others.

2.5 THE EFFECTS OF RABBITS ON ARID ZONE VEGETATION

2.5.1 Spread of the Rabbit and its Effects on Vegetation

The rabbit was introduced into Australia by early European settlers and had spread across northern South Australia before the end of the 19th Century (Bonython 1971, Tolcher 1986, Tiver 1992). Its arrival was closely followed by severe droughts between 1890 and 1902. The combination of these two factors had a devastating effect on the arid and semi-arid rangelands of Australia (Noble and Tongway 1986). Bonython (1971) cited the case of sheep flocks at the Killalpaninna Mission, on the eastern side of Lake Eyre, having to be reduced by half when the rabbit arrived in that area. Rabbit numbers fluctuate wildly and major plagues were expected every 5-7 years (Bromel 1984). The rabbit was described by Pickard (1991), together with the sheep, as a "biological chainsaw", but while sheep can be easily managed, rabbits cannot. It is this fact, that the rabbit has not yet been permanently and economically managed in the arid zone, that makes it the greatest threat to arid zone ecosystems (Graetz 1990, Morton 1990, Morton and Pickup 1992). Arguments against this have been proposed by Reid (1992, 1993) and Tiver (1992), although Tiver's study area was in higher rainfall country on the southern edge of the rangelands and has few similarities to the present study areas. Rabbit grazing is most severe in sandy country that is suitable for construction of warrens and on plains within about a kilometre of such areas (Badman 1999: Chapter 6).

Rabbit plagues usually occur following significant rainfall events that produce large numbers of palatable annual and ephemeral plants. Badman (1995a) showed that maximum rabbit numbers coincided with major rainfall events at Olympic Dam, while kangaroo numbers peaked in the following year. The main impacts of the rabbit are the early removal of ephemeral vegetation; disturbance of microphytic soil crusts through scratching and digging; destabilisation of sand dunes leading to erosion; modifications to the vegetation, especially through the reduction of numbers and frequency of perennial plant species; opening of the vegetation to invasive species; and competition with native herbivores. The heaviest grazing pressure is often within 50 m of a warren (Leigh *et al.* 1989), but in arid areas it usually extends much further than this. Warrens often have sparse vegetation cover, dominated by low quality Mediterranean weeds, and are more susceptible to wind erosion than surrounding areas (Eldridge and Myers 1999).

The area over which the majority of extinctions of medium sized mammals has occurred corresponds with the present or former distribution of the rabbit (Morton 1990). These native mammals were placed under most stress when very heavy grazing pressure was associated with drought (Morton 1990, Stafford Smith and Morton 1990). The threat posed by the rabbit to the recruitment of some perennial plant species in inland Australia is well known (e.g. Crisp and Lange 1976, Lange and Graham 1983, ESD 1991, Auld 1993). Reduction of rabbit numbers on an off-shore island led to stabilisation of formerly eroded areas, which were then recolonised by plants, and expansion of wildlife populations (Norman 1970).

Even when rainfall is sufficient to ensure regular germination of seedlings, these are usually quickly removed by rabbits (Lange and Graham 1983, Auld 1990, Pickard 1991, Robertshaw 1995). However, during very wet seasons, green annual herbs, the preferred food of the rabbit, provide a buffer around perennial shrub and tree seedlings and allow their establishment (Lange and Graham 1983, Tiver 1992). Dramatic reductions in rabbit numbers in the study areas followed the spread of Rabbit Calicivirus Disease (RCD) in 1996. With very few rabbits present, there was excellent growth of plants following well above average rainfall in February 1997. The unusual aspect of this was that the majority of the herbaceous layer, even of ephemeral species, was still standing at the beginning of the following summer.

The effects or RCD are considered by local pastoralists as being the same as those brought about by the spread of myxomatosis during the 1950s. The spread of myxomatosis also coincided with several wet years and resulted in recruitment of many species of perennial plants, as well as an increase in cover of annual and ephemeral species. This situation lasted for several years until the effects of myxomatosis began to wane and rabbit numbers built up again.

The long-term effect of rabbits is to potentially prevent the establishment of long-lived species (Auld 1990) and to change the species composition to one dominated by annuals (Dixon 1892) and therefore more susceptible to drought (Robertshaw 1995). This means that when current aging perennial populations eventually die they may not be replaced (Lange and Purdie 1976, Lange and Wilcocks 1980). Even some species that are apparently unpalatable to stock may have recruitment suppressed by rabbit grazing (Chesterfield and Parsons 1985). Reid (1992, 1993), Baker (1992) and Tiver (1998) have all placed the effects of rabbit grazing on arid zone ecosystems below that of stock grazing. Their main argument is that rabbits quickly die off once the best feed has been eaten, while domestic stock can be maintained at artificially high numbers by pastoralists. This argument apparently assumes that all rabbits die at such times. If this were the case there would be no rabbit problem in inland Australia: droughts would have wiped them out long ago. Unfortunately, a few rabbits always survive even the longest drought, long after the last domestic stock have died or been removed from the area. Hayes (1987) described how rabbits were almost wiped out by the central Australian droughts of the 1920s, but were back in plague proportions by 1932. Even very low rabbit numbers are enough to limit recruitment of many nutritious perennial species to below the level required for replacement of senescent plants (Robertshaw 1995) and are able to selectively eliminate seedling populations (Lange and Graham 1983).

The greatest damage by rabbits, as with other herbivores, is undoubtedly done during droughts. Rabbits cannot be easily controlled at any time, domestic livestock can. Continued grazing at such times can prolong the effects of drought and larger falls of rain are necessary to promote the growth of vegetation than would otherwise have been the case (Purvis 1986).

The most recent weapon against the rabbit is RCD, but this alone will not provide long-term rabbit control. To be most effective, other control methods must be used as part of an integrated control programme (Cohen 1997, Williams 1997). The most successful non-biological control method is warren ripping, followed by fumigation (Parer and Milkovits 1994) and explosives. The latter is the only practical method in some steep hilly country. Even though some warrens are re-opened (Parer and Milkovits 1994), warren ripping can have long-term benefits for the environment in many areas (Mutze 1991), but is usually too costly to be feasible, on purely economic terms, in extremely arid areas such as those covered by the present study areas (Badman 1999: Chapter 6).

Unlike the rabbit problem, most other major threats to arid ecosystems, particularly those produced by the pastoral and mining industries (e.g. Reid 1992), can be managed and legislation is in place to enforce good management practices. If these are not being enforced it is because somebody is not doing their job properly or because governments lack the political will to enforce appropriate regulations (Tiver 1992).

2.5.2 Ecological And Social Effects Of Rabbit Removal

The most obvious visual effects following the spread of RCD through the study areas in 1996 and the above average rainfall of February 1997 were the gradual disappearance of the browse-line on tall shrubs and the amount of dry vegetation that remained standing at the end of 1997 compared to previous years. Lower foliage of *Acacia ligulata* in particular has always been subject to heavy grazing by rabbits. This and other palatable tall shrubs in the study areas had previously exhibited a distinct browse line about 70 cm above ground level.

It takes from 12 (Linton and Cooke 1997) to 16 (Short 1985, Pickard 1990) rabbits to eat as much as one sheep (1 dse), while 160 rabbits eat as much as one cow (Pickard 1990). Linton and Cooke (1997) calculated that even at the relatively low density of 1.5 per hectare, rabbits consumed more than half of the dry vegetation that was available to sheep stocked at the rate of 12 per square kilometre. Rabbits have been recorded at densities of 3-4 per hectare in the Olympic Dam area (Badman 1995a) and at densities of 6-7 per hectare at the Billa Kalina exclosure sites (Chapter 4).

In central Australia, Foran *et al.* (1985) came to the conclusion that even though there were ecological and economic benefits, in the form of increased forage available for cattle, rabbit control was not economically viable in central Australia. They reached this conclusion after a two year study and considered that most of the changes they recorded were due mainly to seasonal changes rather than rabbit control. However, they did record standing biomass levels of *Enneapogon* spp. that were 300 kg ha^{-1} lower at sites grazed by rabbits than within exclosure sites. Cattle grazing further decreased biomass by 150 kg ha^{-1}. Foran *et al.* (1985) considered that substantial improvement in vegetation condition over the longer term might alter their conclusion on the benefits of rabbit control.

The social issues of rabbit control were discussed by Williams *et al.* (1995). They concluded that the problem is complicated by images of "likeable" rabbits from children's literature, the use of rabbits as an economic resource, animal welfare issues and ignorance of the environmental damage caused by rabbits. The use by some Aboriginal groups of the rabbit as a major part of their diet and their perception that this animal is an integral part of the land also poses problems for its control.

Cooke (1991) put forward compelling arguments against the use of rabbits as an economic resource. He estimated that rabbit shooters would need to take about 50 times more rabbits than the 3 million that were harvested in 1989 (Ramsay 1991) before they began to reduce the size of the rabbit population. Overseas markets could not handle this number of rabbits (Cooke 1991), with commercial harvesting of wild rabbits in Australia having peaked at 50 million in 1948/49 (Ramsay 1991). Shooting as a control measure is only commercially viable when rabbit numbers are high (Cooke 1991). It is even less viable since rabbit populations were reduced by RCD.

2.6 THE EFFECTS OF RELEASE FROM DOMESTIC GRAZING

There are several published reports on the response by vegetation to release from domestic grazing in Australia. The T.G.B. Osborn Vegetation Reserve (formerly the Koonamore Vegetation Reserve) on Koonamore Station in South Australia, was fenced-off from grazing in the 1920s (Hall *et al.* 1964, Crisp 1975, Noble 1977). Quantitative data have been collected from permanent quadrats and transects at this site for more than half a century. This area had a history of heavy grazing over a period of 52 years and was chosen as a research site because it contained a variety of plant communities and was in the "worst eaten-out portion" of a large paddock (Hall *et al.* 1964). The effects of sheep grazing were exacerbated because:

- this area was in the southern part of the paddock (sheep tend to feed into the prevailing wind, which is from the south in this area);
- sheep tended to camp under the trees in this part of the paddock;
- sheep could smell the water in the next paddock to the south which encouraged them to "hang" in this part of the paddock (Osborn *et al.* 1935).

The area was fenced to exclude sheep and rabbits in 1925, although this fencing did not initially achieve its desired effect (Hall *et al.* 1964).

By 1962, 37 years after release from grazing, there was little or no regeneration of tree and shrub species in areas where rabbits and kangaroos were still present, with many stands showing obvious signs of senescence and many trees dying (Hall *et al.* 1964). However, some areas showed good regeneration of the low shrub *Atriplex vesicaria,* mainly in close proximity to mature plants that provided a seed source (Hall *et al.* 1964). Of the tree species, there was no regeneration of *Casuarina pauper,* although it was not certain whether this may have been occurring through new suckers, and *Alectryon oleifolius,* and only one seedling of *Myoporum platycarpum* was recorded (Hall *et al.* 1964). Stands of *Casuarina pauper* were found to be flourishing, despite the lack of regeneration, but *Alectryon oleifolius* was mostly senescent and dying and even root suckers, its most common form of reproduction, had not survived. There was some germination from seed of the only other tree in the area, *Santalum acuminatum,* although all but one of the young plants eventually died. This plant survived to set seed that in turn produced further seedlings, which died in later droughts. Hall *et al.* (1964) considered one of the reasons for this to be competition for available moisture by the root systems of nearby mature trees, although lack of a sufficiently vigorous host for this parasitic species may also have been a factor.

Regeneration of tall shrubs of *Senna* spp. was also spectacular in some places (Hall *et al.* 1964), but *Eremophila sturtii* and *Eremophila scoparia* were less successful, again possibly due to competition by mature bushes nearby. Successful recruitment of *Eremophila longifolia* followed a reduction in rabbit numbers in 1954, with numerous seedlings surviving. There was also good recruitment of *Acacia burkittii*, a species that is amongst the first perennial colonisers of disturbed areas in this region (Badman 1997b).

The regeneration of *Atriplex vesicaria* at Koonamore was mentioned above, but *Atriplex stipitata* also showed good recruitment in some areas and continued to spread into nearby areas as new plants produced a fresh seed source (Hall *et al.* 1964). There was some germination of the very long-lived low shrub *Maireana sedifolia,* but most seedlings were found in mulch around old bushes, where they eventually died because of competition from these established plants (Hall *et al.* 1964).

Crisp (1975) made cross-fence comparisons between grazed and protected (ungrazed) areas. He found significant differences between the vegetation structure on the reserve and on the surrounding sheep station. Differences were found in the soil cryptogams, ephemeral species and low shrubs. The abundance of the native grass *Stipa nitida*, as measured by biomass, density of plants and density of seeds in the soil, was greater in the protected area, while the abundance of the alien grass *Schismus barbatus*, measured on the same criteria, was greater on the grazed area. Soils in the protected area were found to be more fertile, less compacted, higher in organic matter content and had a better developed lichen crust than the grazed area. The greatest difference was in the lichen crust, with the other differences being slight. Some of the differences were attributed to further deterioration of the vegetation in the grazed areas, rather than an improvement on the protected area. Crisp found that although 19 taxa that had not been recorded on the reserve occurred in the adjoining grazed paddock, there were 56 taxa on the reserve that were not found in the grazed paddock. A total 175 species was recorded on the reserve, but only 139 species in similar landforms in the adjoining paddock (Crisp 1975).

Noble (1977) found that all growth pulses of short-lived plants at Koonamore were triggered by heavy summer rainfall of at least 85 mm in a month. He found that summer rainfall of 75-85 mm was insufficient to cause a growth burst in short-lived species except in run-on areas. Major peaks coincided with summer rainfall of greater than 100 mm. However, one high intensity summer storm produced 109 mm of rain and caused considerable erosion, but produced no growth response. The initial increase in biomass following release from grazing was followed by a decrease corresponding to the increase of shrub densities.

At a central Australian site, the removal of cattle for 11 years was found to have less influence on vegetation than that attributed to seasonal conditions (Foran *et al.* 1982), a finding supported by the work of Leigh *et al.* (1989) in central New South Wales. Although some plant species and species groups were affected by grazing, the overall density and cover of plants was not affected.

However, these workers did concede that the run of wet years in the mid-1970s may have masked some effects of grazing treatments. Leigh *et al.* (1989) found that changes in non-grass species due to grazing were generally insignificant, but changes in species composition due to seasonal conditions were highly significant. No new species appeared on plots exclosed from grazing for 10 years.

There are even more published accounts of the effects of long-term release from grazing from overseas countries (Gardner 1950, Robertson 1971, Turner 1971, Kleiner 1983, Hatton and Smart 1984, Brady *et al.* 1989, Putman *et al.* 1989, Omar 1991), with five of these sites in the USA. Two of these (Gardner 1950, Robertson 1971) dealt with areas where cattle had been excluded for 30 years. Old cultivated lands may take even longer to return to something resembling their natural state (Dean and Milton 1995).

Gardner (1950) reported grass density on the ungrazed land at a site in New Mexico as being 110% higher than on the nearby grazed land, but little difference in species composition between the two areas. Drought conditions at the site resulted in gullies eroding on the grazed land, while old erosion gullies on the ungrazed land continuing to improve 30 years after release from grazing. Gardner (1950) considered that the process in these gullies still had a long way to go.

Robertson (1971), reporting on a site in northern Nevada 30 years after stock were removed following a grazing history spanning about 50 years, found that perennial forbs had increased by 85% and there was a 60% increase in vegetation cover. Only annual forbs decreased in cover. Some desirable pasture grasses were beginning to colonise parts of the ungrazed area, although it is not known from the data when this process began. There was also a slight reduction in the height of sagebrush, which was attributed to either the demise of taller plants without replacement, or an increase in density with younger age classes present and suppressed by competition. Faster results, as far as recruitment of desirable pasture species was concerned, were obtained in a nearby experimental plot where the brush was cleared and the ground seeded with pasture grasses.

In a study in part of the Canyonlands National Park in the United States, 10 years after release from grazing, Kleiner (1983) also found that the cryptogamic cover, particularly of a species of moss, was one of the first things to recover (cf. Crisp 1975). Prevalence of perennial grasses declined, but the increase in cover of cryptogams was less than the decrease in grass cover. After 10 years, the area's vegetation was approaching the condition of an adjoining part of the National Park that was regarded as being in pristine condition, although Kleiner (1983) conceded that it would take much longer than one decade to reach this condition.

Not all changes at sites released from grazing could be ascribed with certainty to the removal of herbivores. Although there was an increase in vegetation cover and species diversity at an experimental site in Arizona 16 years after release from grazing, long-term seasonal factors were thought to have played a part in this, as well as short-term factors brought about by elimination of grazing (Brady *et al.* 1989).

Turner (1971) recorded only small changes to the vegetation following 10 years without grazing at a site in western Colorado. Changes were ascribed mainly to lack of rainfall rather than removal of grazing. Omar (1991), reporting on a 10 year study in Kuwait, found that vegetation cover continued to decline after release from grazing. The decline was correlated to the amount of rainfall in the 10 years preceding each survey. Drought, erosion and sand encroachment slowly continued to contribute to land degradation, irrespective of the degree of protection from grazing.

Facelli (1988) studied the reintroduction of cattle to an area that had been ungrazed for nine years. He found that after two years, a newly grazed site was more similar to the ungrazed site than to nearby sites that had been continually grazed. This comparison was made on the parameters of total cover, cover of grasses and dicotyledons, cover of creeping grasses, floristic composition and dissimilarity between sites. The newly grazed site had a very low cover of dicotyledons, with different species composition to the continuously grazed area. One year later the two areas were more similar, but it was not until five years after re-introduction of grazing that the exotic dicotyledons that were dominant in the continuously grazed site were recorded at the re-opened site.

Five years after release from grazing of a site in Kenya, Oba (1992) found that despite an initial increase in plant cover, vegetation on the site remained similar to that of nearby grazed areas. Weather was an important determining factor. One species that thrived on grazed areas died following six years of protection.

One of the best documented effects of release from domestic grazing near the present study areas, although not in a typical rangeland situation, has occurred at mound springs on the former Finniss Springs Station. The effects on mound spring vegetation were documented by Fatchen and Fatchen (1993). They reported a general trend of initial increase in mean species richness and diversity, followed by a period of stability and subsequent decreases. Maximum diversity was reached during a change from domination by the sedge *Cyperus laevigatus* to the tall grasses *Phragmites australis* (Fatchen and Fatchen 1993), about two or three years after release from grazing. Domestic stock had less impact on long-term mean species richness and diversity than might have been expected.

2.7 THE EFFECTS OF MINING ON ARID ZONE VEGETATION

2.7.1 INTRODUCTION

Mining of ochre and quarrying of stone were practiced by Aboriginal people for at least several thousands of years and were an important part of their culture (McBryde 1982, Jones and Sutton 1986). Mining continues to be an integral part of modern society. Nothing that is used in modern everyday life is untouched by mining: those things that are not made from minerals have been grown or processed using implements made from minerals. In 1991, mining and minerals processing accounted for almost a tenth of Australia's Gross Domestic Product and half of merchandise exports (Gould 1991). Despite this, mining activities had directly affected only 0.02% of Australia's land mass by 1991 (Gould 1991, Farrell and Kratzing 1996).

Most of the worst examples of visible mining impacts are from operations which took place many years ago (Farrell and Kratzing 1996). During the last two decades in particular, the mining industry has become very aware of its environmental responsibilities and is covered by strict State and Federal Government regulations, as well as by self-regulation. Industry bodies have produced numerous handbooks and guidelines to promote minimal environmental disturbance (e.g. AMIC 1986, 1987, 1989, DME 1995). All large mines now employ environmental professionals to advise on minimisation of disturbance during exploration and construction, to monitor the effects of operations on the environment and to rehabilitate disturbed areas.

In order to share knowledge and to keep environmental professionals abreast of latest developments, environmental workshops are regularly held around Australia (e.g. Lawrie 1985, GRG 1992) and by individual companies (e.g. WMC 1992). The mining industry is also represented at some regional conferences and workshops designed primarily to cover general rangeland issues (e.g. annual conferences arranged by the Australian Rangelands Society, Badman 1993, Odermatt 1993), and at international conferences (e.g. Tongway and Murphy 1999).

Although there is a large literature on the effects of open cut mining and rehabilitation (e.g. Odermatt (1992) in South Australia; Osborne *et al.* (1993), Fletcher (1996), Howard (1996), Osborne and Fox (1991) and Tongway and Murphy (1999) in Western Australia; Hannan and Gordon (1996) in New South Wales; Lawrie (1985) and Roe *et al.* (1996) in Queensland; McNally *et al.* (1996) in the Northern Territory; Mulligan (1996) for Australia; Rethman *et al.* (1999) in South Africa; Giurgevich (1999) in the USA), much less has been published on the effects of underground mining on the vegetation of an arid area. The low impact of the Olympic Dam Mine on the vegetation and landforms of the surrounding area was mentioned by Badman (1992a, 1995a) and by Badman *et al.* (1996). This is discussed in Chapter 6 of this thesis.

2.7.2 Local Mining Ventures

The earliest mining ventures in the vicinity of the present study areas involved mining by Aboriginal people of stone slabs for the manufacture of grindstones (Badman 1999: Chapter 10). There are several major grindstone quarries in or near the study areas (McBryde 1982, Hercus and Sutton 1985) and these were often associated with mythological stories. Ochre was mined at several sites in the region. All of these quarry sites still have great cultural significance to Aboriginal people and form important links with the past.

The first local European mines were associated with the extraction of copper ore. The most notable of these are the Wheal St Dora Mine on the former Finniss Springs Station and a collection of mines in the Tarlton Knob area of the Willouran Ranges on Witchelina Station. These mines were abandoned in the early part of the 20th Century, but several shafts and mullock heaps and some old machinery can still be seen at both sites. No rehabilitation has been carried out at the Wheal St Dora Mine. There has been no revegetation of the site because, until recently, material from mullock heaps was used for road construction, particularly at floodways, by the Department of Transport. Any native vegetation that had colonised these heaps has since been destroyed. Tarlton Knob has had far less recent disturbance and although the area was not actively rehabilitated, native vegetation has established on much of the previously disturbed ground.

Various other old mines are located in the Willouran Ranges, but these are generally quite small, often with only a single shaft. Many of the mullock heaps at these sites remain as small mounds on the hillsides that have naturally revegetated over time and often blend in with the surrounding countryside.

Opal was discovered at Andamooka in the 1930s and the area was proclaimed a Precious Stones Field. Mining at Andamooka, and at the Stuart Creek Opal Field located 40 km to the north-north-east, has proceeded with no environmental input or management and no rehabilitation of old mine sites. A similar situation exists at the much larger Coober Pedy opal field, to the north-west of Andamooka. Rehabilitation of old opal mines is hindered by the nature of the industry and the lack of will on the part of all Governments to enforce regulations. Most mines are owned by individuals or small companies who do not have the benefit of professional environmental advice. Mines frequently change hands and new owners are reluctant to spend time and money rehabilitating disturbance caused by their predecessors. The mullock heaps are also seen as a major tourist attraction, with appeal to many Australian and international tourists for their historical and cultural values. Similar arguments for not rehabilitating degraded landscapes were proposed by Quinn (1992) for the Appalachian copper basin in Tennessee.

More recently, mineral exploration activities were carried out over a large part of the Willouran Ranges during the 1980s. This work involved the bulldozing of tracks, often with little thought to their erosion potential, and the drilling of numerous exploratory drill holes. Whilst this work was unsightly and little rehabilitation was attempted, it affected only a small area, was largely centred on existing tracks and had little overall effect on the regional vegetation.

The underground Olympic Dam copper-uranium-silver-gold mine remains the largest mining operation to have been undertaken in or near the present study areas. Exploration work began in 1975 and production in 1988. The mine has a predicted life of between 63 and 240 years, depending on whether calculations are made on proven reserves or probable resources, and any future expansions in production. Despite the world-class scale of this mine, all exploration, construction, mining and process activities had disturbed only 4% of the mine lease area in 1996 (Kinhill 1997b). The ground disturbance caused by underground mining is therefore small when compared with pastoralism, which has the potential to disturb all of the ground surface.

2.7.3 Exploration

In the case of underground mines, exploration often disturbs larger areas than the subsequent mining operation. The first and most obvious evidence of mineral exploration is the formation of a network of new tracks. The next phase includes the construction of pads that support drilling rigs to take core samples from geological anomalies that may be indicative of underlying mineralisation. In hard country, e.g. on heavy clay soils or on stony country, drill pads may require no further preparation other than clearing trees and shrubs, although current best practice is to avoid trees wherever possible. In softer country, especially in sand or mud, preparation of a hardstand area is usually required to allow the stable and safe operation of the drilling rig. The typical size of such pads does not exceed $1000m^2$ (Badman 1992a). Initial exploratory drilling is usually based on a widely spaced grid pattern, with closer-spaced drilling if mineralisation is discovered (Stevens 1991).

Dust is often the biggest problem associated with exploration drilling in arid areas, particularly in the early stages when no proper roads have been constructed. This problem can often be reduced by careful planning (White *et al.* 1996). Once mineralisation is discovered, a network of formed roads is usually constructed and this reduces the overall dust problem, especially when these tracks are watered regularly. Lack of formed tracks also results in people driving on formerly undisturbed areas when conditions deteriorate on a particular stretch of track. This can lead to a disturbed corridor many times wider than the original track. Dust deposition can result in widespread tree and shrub deaths up to 200 m from the source (Fatchen Environmental 1995) if it is not quickly removed by heavy rainfall.

A recent innovation in arid areas has been the use of rolling rather than grading in the preparation of seismic lines on gibber plains during oil and gas exploration (Bleys *et al.* 1990, White *et al.* 1996). In shrubby country, the practice of grading with the blade below ground level is also becoming less widely used. Best practice now involves keeping the grader blade above ground level so that only high spots are cut off and the herb layer and roots of shrubs are left largely intact. This has the advantage of minimising soil disturbance, the seed bank is left intact and many shrubs quickly resprout from the old rootstock. During construction of the WMC Port Augusta to Olympic Dam 275Kv power transmission line in 1997 and following suitable winter rainfall, shrubs such as *Atriplex vesicaria* were observed to regrow and set seed within six months of being completely flattened by heavy vehicle tyres. Another advantage of this method is that no windrows are left to disrupt natural water flows and fauna movements. When trees cannot be avoided and have to be cleared, the visual impact is now taken into account and long straight cleared lines through woodlands are generally avoided (White *et al.* 1996).

Exploration companies are now well aware of their environmental and social responsibilities and take steps to minimise disturbance to the environment, especially in highly sensitive areas (Bleys *et* *al.* 1990, Warris *et al.* 1990, AIG 1991, Elliot and Kemp 1991, Ringwood 1991, Tacey 1991, SEA 1997), and disruption to people' lives and culture (Nayton 1991, Smyth 1991, Syme *et al.* 1991, Williams 1991). However, the changes in work methods required to attain this level of minimal disturbance come at a cost which will eventually be passed on to the consumer. In cases reported by Bleys *et al.* (1990) and SEA (1997) the methods used included exclusion of vehicles from some areas and carrying equipment by hand or in backpacks,. However, while the adoption of these minimum impact measures in arid zone situations may be socially desirable, they are unlikely to be economically acceptable other than in very special circumstances.

2.7.4 ENVIRONMENTAL MANAGEMENT

Recent local activities, including those at Olympic Dam, have included a high environmental management component (Kinhill-Stearns Roger 1982, ODO 1990b, 1993, 1996b, Kinhill 1997b, SEA 1997). This covers minimisation of disturbance and rehabilitation of disturbed areas, as well as environmental impact studies before any work begins. The latter ensure that no important biological communities are affected and that disturbance to other communities is minimised. The emphasis is now on prevention or minimisation of damage rather than full scale restoration at the end of the project (e.g. ODO 1994, 1996c, SEA 1997), although restoration work is still carried out as required.

This minimal disturbance approach was adopted by WMC (Olympic Dam Operations) Pty Ltd (WMC) during construction of its Borefield B Stage 1 pipeline in 1996. Both the new borefield, whose development was discussed in the original Olympic Dam EIS (Kinhill-Stearns Roger 1982) and the pipeline route were subject to detailed environmental field investigation to determine the most appropriate locations. This appraisal considered the effect on riparian woodland and other important vegetation communities (ODO 1992b) with the final route planned to avoid the most sensitive areas. Construction was preceded by further detailed environmental investigations that took into account all new information gathered since the original studies (Kinhill 1995a).

Prior to construction of the Borefield B pipeline, an environmental code of practice was developed (Kinhill 1995b) which anticipated environmental problems and suggested ways in which disturbance could be minimised. This document was issued to the constructor and adherence to its conditions formed a part of the contract. All workers on the project were given a copy as part of their induction process. Each worker was obliged to sign a tear-out page at the back of the book to say that he or she had read and understood its contents and would abide by them. This, together with regular liaison between environmental staff and project engineers, restricted all disturbance to a 22 metre corridor which was successfully rehabilitated on completion of construction. Independent audits during and after construction discovered only a few minor breaches of the code of practice. Stage 2 of the Borefield B pipeline project used similar methods, had its own environmental code of practice (Kinhill 1997c) and achieved a similar low impact outcome (Kinhill 1998).

Introduction of weeds has always been a potential problem associated with exploration and mining activities (Keighery 1991), although this is less of an issue in arid areas than in more mesic ones (Badman 1995a). Introduction of weeds was minimised by WMC during construction of the two stages of the Borefield B pipeline and the 275 kV Port Augusta to Olympic Dam powerline, by insisting that all plant and equipment was cleaned before it entered the area. Management of this issue was covered in the relevant environmental code of practice (Kinhill 1995b, 1997a, 1997c) and compliance was checked by way of signed declarations from the constructor as well as by random visual checks by WMC staff and independent auditors. Despite these precautions, there was some local spreading of *Xanthium spinosum* just north of Port Augusta. This was promptly controlled by WMC environmental officers working in conjunction with the local PIRSA weed control officer.

Humphrey (1994) proposed a biological monitoring programme that would subject baseline data to a vigorous and powerful statistical analysis to provide early detection of possible adverse effects and assessment of their ecological significance. This proposal suggested that monitoring programmes should be designed to establish future impacts of all new ventures in Australia. These programmes would be designed so that any impact on the ecosystem greater than a prescribed amount and to a high degree of probability would be detected. Such a precautionary approach represents a shifting of the "burden of proof" from the present one of allowing development to continue as long as there was no "proof" that it was impacting on the environment. Humphrey (1994) suggested that 2-5 years data would be required to give analysis the desired level of statistical power.

2.7.5 REHABILITATION

Although the total area of land disturbed by mining in Australia is very small compared with other forms of land use, the potential for local disturbance can be high (Bell 1996). The mining industry has prepared guidelines for the rehabilitation of mined areas (MCA 1998) that augment those prepared by government (EPA 1995) and by industry (Bell 1996). The potential for disturbance can be reduced by careful planning in the initial stages of exploration (White *et al.* 1996, Bell 1996, MCA 1998).

It is unrealistic to expect post-mining land managers to continue with control measures that were used during the life of the mine. The practical alternative is for mining companies to restore the land to a stable condition that is compatible with the planned future land use (Bell 1996, MCA 1998). The objectives of rehabilitation are therefore to create a landscape that is stable against the effects of wind and rain and that is able to be used in a productive manner (Bell 1996). Old waste dumps should blend in with the surrounding landforms (MCA 1998, Tongway and Murphy 1999). In the present study areas the future land use is likely to be pastoralism using native vegetation, but conservation is also a possibility (Turner 1992). The post-mining land use should be established early in the exploration phase (Bell 1996).

In order to allow the establishment of native vegetation on disturbed areas, it is necessary to re-create a suitable substrate or root zone. This must be capable of supplying adequate plant nutrients, be free from excessive salinity, acidity and alkalinity, have an adequate available water capacity, have adequate aeration, and not restrict root growth through mechanical impedance (Bell 1996). The natural effects of fire, wind and water are being used to accelerate the natural process of rehabilitation in the Great Sandy Desert of Western Australia (Burrows *et al.* 1994).

Mine dumps require special consideration, especially if they contain sulfide material that may leach out as acid drainage or radioactive materials such as at Olympic Dam. Coverings of clay to prevent leakage and rock to give long-term stability may be required beneath the topsoil or root zone layer (Bell 1996, MCA 1998). However, long-term (>10 years) changes in the chemical and physical nature of overburden material are still largely unknown (Sharma and Gough 1999). The use of local native species in rehabilitation is now being widely accepted by the mining industry (Redente and Keammerer 1999). Colonisation by summer growing native perennial grasses reduces the possibility of creating an arid zone vegetation community dominated by alien species (Badman 1995a).

Some rehabilitation practices used in other (wetter) parts of Australia, especially the planting of tube stock (Foster 1985) are often not feasible in the arid zone (Badman 1992a).

2.8 THE EFFECTS OF URBAN DEVELOPMENT ON ARID ZONE VEGETATION

2.8.1 URBAN DEVELOPMENT

Arid zone urban development affects native vegetation in three ways. Firstly there is the removal of vegetation during actual town construction; secondly there is removal of vegetation during construction of town infrastructure such as power transmission lines, water pipelines and sewage treatment plants; and thirdly there is the disturbance caused by the activities of the town population. A fourth affect, air pollution (O'Leary and Westman 1988), is unlikely to affect the vegetation surrounding Roxby Downs and similar small country towns. Urban development of opal mining communities has in the past been largely unregulated and little attempt has generally been made to protect native vegetation. Fragmentation of natural ecosystems was also given by Saunder *et al.* (1991) as an outcome of development. Again this is unlikely to play a major role at Roxby Downs and similar mining towns, but is probably more relevant to towns like Coober Pedy, Andamooka and Leigh Creek where mine development surrounds the town and extends over a large area.

The majority of new towns established in the arid zone of Australia during the last 50 years, and possibly during the last 100 years, have been as a result of mining operations. Roxby Downs, Andamooka, Coober Pedy and Leigh Creek all fall into this category. Woomera, constructed during the late 1940s as the base and support centre for long-range rocket testing facilities, is an exception,.

At Roxby Downs, the town site was chosen from a short list of six sites (Kinhill-Stearns Roger 1982) and was preferred because of the amount of land available for urban development, the lesser impact of this site on surrounding pastoral properties, its proximity to existing service corridors, the ease of construction of urban facilities, its elevation which removes the likelihood of flooding, the presence of trees and its horticultural aspects. The site did not overlay any mineralisation and this was also taken into account. The town of Leigh Creek had to be moved in the mid 1980s because it overlay the best remaining coal reserves (Zwar *et al.* 1992). The fact that the Roxby Downs site was situated within a native woodland was seen as a benefit to the town rather than as a disadvantage to the native vegetation. Despite this, particular care was taken during the initial planning stage to maximise the retention of large trees such as *Acacia papyrocarpa* and *Callitris glaucophylla* (Kinhill-Stearns Roger 1982), as was also the case at Leigh Creek when the town was relocated in 1985 (Zwar *et al.* 1992). A similar policy was adopted prior to the construction of new subdivisions at

Roxby Downs in 1997 (Kinhill 1997b). Many of the principles used in developing Roxby Downs had previously been used successfully by the same company at Leinster in Western Australia.

The Roxby Downs infrastructure corridors were also covered by the same vegetation retention policy as the town (Kinhill-Stearns Roger 1982, Kinhill 1997b), with further protection given to the vegetation during construction by the use of environmental codes of practice (Kinhill 1995b, 1997a, 1997c). Compliance with the environmental codes of practice was monitored by the WMC project environmental adviser and an independent auditor. Non-compliance could lead to dismissal of offending workers.

In practice, the infrastructure corridors presented less of a problem than the town area. The ongoing problem of off-road driving has been exacerbated by the young age of the population (Kinhill 1997b) and became a major concern for the ODO Environmental Department, particularly in regard to the off-road use of trail bikes. This problem was largely avoided at Moomba in far north-eastern South Australia by having a camp rather than a town. The fly in-fly out workforce spend the majority of their leisure time away from the region (Santos 1981). Very few private vehicles are kept on site at Moomba. Off-road driving using company vehicles during working hours is much easier to control than it is in private vehicles during leisure hours. A similar fly in-fly out approach has been taken by many mining companies, including the Beverley uranium mine in South Australia (Heathgate Resources 1998) and the Phosphate Hill mine in north Queensland (Kinhill 1996).

Although WMC recommended small lawn areas and the planting of native species with low water requirements (Zwar *et al.* 1992), many residents, as is the case in other towns, preferred larger lawn areas and non-native species with high water requirements. There was no legal requirement for residents to retain the large trees that were saved during construction and some of these were later removed by householders or the local council.

The Andamooka township gradually developed following the discovery of opal in 1930 (Zwar *et al.* 1992). Decisions on town management are made by members of the Andamooka Progress and Opal Miners Association. There are few trees in the Andamooka area, with the town located on an undulating gibber plain. Amenity plantings are limited by the scarcity and high cost of water, much of which has to be carted in by truck. Woomera is also located on a similar plain with chenopod low-shrubland vegetation, but amenity plantings are common here because water is cheaper and more readily available through a pipeline from the River Murray.

2.8.2 TOURISM

Tourism is a relatively new industry within the study areas, yet it is already having an impact on natural ecosystems and landforms. Tourism in inland Australia is certain to increase, not only because of the natural features of the area and the different lifestyle of its inhabitants compared to that of most urban dwellers, but also because this area represents one of the last sparsely inhabited areas of the world where native vegetation can be seen almost in its natural state (Morton 1993). Increasing visitor pressure has led to the dedication of the Wabma Kadarbu Mound Springs Conservation Park, to the west of Lake Eyre South, to protect the Bubbler, Blanche Cup and Coward mound springs. Fences have been erected to control animals and vehicle access, while board walks have been required in some areas to minimise the impacts of pedestrians. Pedestrian traffic also causes compaction at camping areas that can lead to the death of seedlings and established vegetation, prevention of water infiltration and increased water run-off and erosion. Money raised from visitor permits is used to assist with conservation of this and other conservation areas.

The other main impacts of tourism are in the form of off-road driving and the use of firewood. Off-road driving leads to damage to vegetation as mentioned above, but also to the formation of new tracks that are often not in the most appropriate location to prevent soil erosion. Tracks at right angle to the contour on steep hills are especially prone to water erosion and this damage, usually in the form of deep gullies, is evident for many years and can be difficult to repair.

There is a major shortage of natural timber for firewood throughout much of the study areas, but particularly in the Marree area. Removal of this resource by tourists causes loss of nutrients and habitat for small fauna as well as aiding water run-off and accelerating erosion processes.

2.9 THE SPREAD OF ALIEN PLANT SPECIES

The mining industry and other resource users are often accused of allowing the intrusion of alien species into pristine or near pristine areas along access tracks which they have created (Buckley 1981a, Keighery 1991, Burton *et al.* 1994). This topic was the subject of a previous investigation by Badman (1995a) and the findings did not support the previous statement as far as the South Australian arid zone is concerned. The main findings of the study, centred on the Olympic Dam area but extending from Port Augusta to Muloorina Station near Lake Eyre and with general comments on the spread and establishment of alien species in northern South Australia, were:

- The first alien species to reach an arid area will not necessarily be the ones that will become established;
- The majority of alien species occurring in the area are winter growing annuals;
- There has been an increase in the distribution of alien species during the last 20 years (to 1994), but this may be partially due to increased collecting and recording effort on the part of biologists;
- There was evidence to suggest that the increased occurrence of alien species may now be levelling off or decreasing following the adoption of more conservative land management practices;
- The alien flora of the Olympic Dam area can be divided into two distinct suites; those that were present before mining exploration activities began and those restricted to damp habitats around the town of Roxby Downs;
- All the common alien species were already present in the area before the commencement of exploration and mining activities;
- The "town area" species were not spreading out into the surrounding countryside, despite two very wet years during the study period which should have made this possible if it were going to happen. None of these "town weeds" were recorded at any of the monitoring sites set up to record such events and they appeared not to be persisting in rehabilitated areas such as old rubbish dumps;
- The same patterns in the incidence of alien plant species occurred on all areas, irrespective of current land use;
- Alien species were out-competed by native species, particularly grasses, following the exceptional rainfall events of the first half of 1989 and in 1992. There was an actual decrease in the incidence of alien species in both years;
- Summer rainfall is important in the establishment and growth of native grasses, which then prevent the establishment of alien species by occupying niches which the aliens might otherwise have occupied following subsequent winter rainfall;
- A high incidence of alien species occurs following fire in this area, but this is not maintained once the relatively high nutrient levels left by the fire are exhausted, especially if summer rainfall allows the establishment of native grasses;

- A decrease in the incidence of alien species following control of rabbits inside the town rabbit-proof fence coincided with an increase in total vegetation cover;
- The recording of several alien species in the area for the first time may have been the result of more intensive monitoring, including the presence in the area for the first time of on-site biologists, rather than Roxby Downs being different from other towns in the area;
- Physical control of short-lived alien species such as *Brassica tournefortii, Citrullus* spp. and grasses is not economically practicable at present. Control of the single perennial species, *Nicotiana glauca*, was already carried out and would continue.

2.10 OTHER IMPACTS ON VEGETATION

Another cause of environmental disturbance in the study areas is road construction. Its main environmental impact, apart from the obvious one of the road itself, is the excavation of borrow pits to obtain construction material. Despite their name, material is permanently removed from these pits, rather than borrowed, and no rehabilitation work has been carried out at many of the older ones. Unless properly located, constructed and rehabilitated, these pits are prone to erosion, especially when they have steep batters or are located on a steep slope. They are also more prone to weed invasion than the usually less disturbed areas that surround them, although this problem is not as severe as it is in more mesic areas to the south (Badman 1995a).

Other environmental impacts of road construction include clearing of vegetation along roadsides in scrubby country to improve visibility; clearing of shrubland along watercourses to improve the flow of floodwaters from the roadway; and grading of cut-off and diversion drains. These latter practices sometimes cause erosion that would not have occurred if the original vegetation had been left in place (Badman 1999: Chapter 6).

Campsites used by mobile road construction gangs require some clearing of native vegetation and present a potential rubbish problem. Both can be minimised by good management practices. Carting hardstand material to a campsite usually keeps vehicular movement to the sheeted area and the same site is then likely to be re-used on subsequent visits, rather than disturbing a new area.

2.11 COMPARISONS WITH OTHER ARID AREAS WITH SIMILAR LAND USES

There appear to be many similarities between the problems caused by grazing in the present study areas with those in similar areas in other countries (e.g. Box and Perry 1971, Ares 1974, Le

Houerou 1989, Galaty and Johnson 1990), although sometimes the reason for the problem is different. This was discussed in Section 2.3. A good example is the degradation caused by early pastoralism in the study areas compared to similar degradation in the African Sahel. The former was caused largely by ignorance and personal economic necessity (see Section 2.3) and the latter mainly by community social and economic need as a result of population pressure. Problems associated with the construction of artificial watering points are also found in other countries (Hitchcock 1990, Section 2.3), with some areas totally dependent on this source of water (Perkins and Thomas 1993).

2.12 THE THEORY OF VEGETATION ECOLOGY

2.12.1 Introduction

Two different approaches were used initially to tackle the problems of ecological research: the holistic ("physiological" or "holological") and reductionist ("demographic" or "merological") perspectives (Wiegert 1988, Hagen 1989). In the latter, the emphasis is on the process for determining community structure. Communities and their deterministic processes, particularly competition and predation, are considered to be sufficiently strong to allow the community to be a group of closely interacting populations sharing the same geographic locality (Hagen 1989). The species composition of a community is largely dependent on which species establish first (Connell and Slatyer 1977), which may then inhibit the growth of other, often slower growing, species (Drury and Nisbet 1973). Wiegert (1988) considered that at the purely descriptive level the difference between the holistic and reductionist approaches did not really matter because there is still so much to be learned that almost any facts are useful.

2.12.2 The Clementsian Succession Theory

Clements (1916) believed a plant community to be a "complex organism" with a well-defined life cycle. All components were considered to be functionally integrated through food chains, food webs and nutrient cycling (Odum 1969) and the community was considered to be in equilibrium. Clements (1916) advocated a series of regular, continuous and reversible changes along an ecological gradient involving several different states until the final stable climax condition was reached. This theory was initially developed to explain variations in vegetation communities, but became the basis of ecological thinking in the English speaking world for the first half of the 20th Century (Mueller-Dombois and Ellenberg 1974). The "climax" vegetation community was considered to be resilient, with any deviation from the climax, brought about by grazing or other forms of disturbance, being reversible by way of successional change along a linear gradient once the disturbance stopped (Hart and Norton 1988, Smith 1988). The particular kind of climax community that was reached as an end point was considered to be influenced mainly by climate and other environmental factors. A climax community could be thought of as a pattern of overlapping populations and trends, fluctuating about some average structure and productivity (Whittaker 1956, 1960, Heshmatti and Squires 1997). This endpoint, the climax, was used as a standard for measuring conditions of the rangelands, while ecosystems that did not meet the climax criteria, perhaps because of grazing, were considered to be disclimax, an equilibrium state somewhere below climax (Smith 1988). While this approach proved to be successful in native grassland communities, it was less successful when disturbed communities were invaded by shrubs and exotic species and the situation was not readily reversible (Smith 1988).

The opposing viewpoint is that communities are made up of sets of species rather than sets of individuals and that vegetation is a continuum where each species responds independently to varying factors in space and time (Goodall 1966, McIntosh 1967, Moravec 1989). The distribution of species forms a continuum along an environmental gradient (Austin and Smith 1989). This concept suggests that each combination of species at any point in time or space is unique and cannot be repeated. Vegetation communities can be regarded as abstractions to account for continuously varying vegetation (Auerbach and Shmida 1993). Although Goodall (1966) attributed this concept to Gleason (1926), it was in fact first proposed by the Russian botanist Ramensky (1910), but his work was overlooked by most workers because it was not available in Western languages (Sobolev and Utekhin 1978). Ramensky proposed the arrangement of plant communities into gradient series as the best method of systematising data on continuous vegetation (Sobolev and Utekhin 1978), although he gave less importance than Gleason to the dynamic nature of communities.

The Clementsian theory and the underlying successional model of vegetation change now have little support (Drury and Nisbet 1973, Connell and Slatyer 1977, Smith 1988, Walker 1988, Friedel 1990). Smith (1988) considered this approach to be untenable in the light of modern ecological theory which stresses the importance of disturbance and the chance occurrence of rare events as they interact with the life histories of plants and animals. It is possible for vegetation change to take multiple pathways and enter multiple steady states (Connell and Slatyer 1977, Smith 1988, Westoby *et al.* 1989). Changes in structural and functional properties are not consistently associated with species composition and later stages in succession are not consistently unidirectional (Drury and Nisbet 1973). The species that first colonise open spaces usually inhibit the establishment of other species, especially slower growing ones (Drury and Nisbet 1973), until at least the end of their natural lifespan or until they are removed by some major disturbance (Connell and Slatyer 1977).

2.12.3 The State and Transition Model

The state and transition model was proposed by Westoby *et al.* (1989) in order to provide a practical and workable alternative that would overcome problems encountered by the Clementsian model. In this model, the "states" represent relatively stable vegetation assemblies that include combinations of dominant plants and the "transitions" represent movements between the states.

Plant community dynamics have three components; plant demography, plant resources use and resources availability (Wedin 1999). Transitions involve changes to one or more of these factors. These may be caused by either natural or artificial events. These events can cause the vegetation community to cross a threshold (Friedel 1990, Rapport and Whitford 1999, Wedin 1999) and move to a different state. Transitions can be either desirable, if the vegetation shifts to a more favourable state, or undesirable if the new state represents a worse condition than the original, with either fewer species or dominance by less desirable species. Transitions may also involve changes in soil processes (Allsopp 1999). Transitions may be brought about by natural events such as fire or drought, or by management actions such as altered grazing regimes, burning, destruction or introduction of plant populations, or by combinations of these events (Westoby *et al.* 1989). Following fire, the transition from one state to another can happen very quickly, but with events such as drought in the absence of grazing the change may be very gradual.

Whatever the cause, the transition will not stop half-way and may not be reversible on a time scale that is relevant to management (Westoby *et al.* 1989), even following release from grazing (Allsopp 1999). Transitions caused by intense competition during times of drought may reshape plant communities for decades thereafter (O'Connor 1999). Some transitions, such as burning woody weeds following a rainfall event that produced an ephemeral understorey, can be manipulated to the advantage of the land manager. Conversely, if the opportunity is not taken when presented, the opportunity for a transition to a different and more desirable state may be lost (Westoby *et al.* 1989). Transitions may also result in positive interactions between different plants that have been largely overlooked in the past (Callaway and Tyler 1999).

2.12.4 The Modern Development of Quantitative Ecology

Anderson (1971) argued that it is only when an accurate qualitative model of an ecological system has been formulated that quantification is likely to provide a significant additional input. The modern development of quantitative ecology mirrors, although on a shorter time span, the development of mathematics (Anderson 1971). Mathematical synthesis of data has led to a more objective presentation of results (Mueller-Dombois and Ellenberg 1974). This in turn has further developed the intellectual thrust in ecology (Anderson 1971), although Kent and Coker (1992) warned that the processes of analysis should not become ends in themselves. Although experimental science provides the most direct and convincing results (Noy-Meir 1971), it presupposes the fact that the community is subject to experimental manipulation and can be divided into replicate portions on which various treatments and controls can be imposed (Ludwig and Reynolds 1988). It also requires the formation of well-informed hypotheses that can be experimentally tested (Ludwig and Reynolds 1988), which in turn requires good quality quantitative data. Quantitative analysis is not possible in cases where only brief descriptions of the vegetation are available, or even completely lacking (Kent and Coker 1971, van der Maarel 1989).

2.12.5 Pattern, Classification and Ordination in Ecology

Pattern is central to the concept of vegetation science (Wiegleb 1989). The theories concerning succession and ecosystems underlie all methods of classification (Mueller-Dombois and Ellenberg 1974) because it is impossible to classify a completely homogenous environment. Classification is possible in vegetation ecology only because there is no ultimate "true" classification (Hagen 1989), so that there are several possible outcomes from the classification of a data matrix (Whittaker 1978).

Classification is a specifically European concept whose relative power was originally overlooked by American ecologists, while the Europeans tended to overlook its limitations (Hagen 1989). Although many early models dealt with forest systems (Curtis and McIntosh 1951, Whittaker, 1956, 1960, Drury and Nisbet 1973, van der Maarel 1989) this form of analysis has now gained widespread acceptance (Urban *et al.* 1987, Herrera 1992). The mathematical approach to grouping and ordering vegetation data allows an objective and repeatable approach to vegetation survey and data analysis (Mueller-Dombois and Ellenberg 1974, Poore 1955).

Ordination, together with classification, provides a fundamental tool for the exploratory analysis of vegetation data. In fact, one school of thought considers ordination to be the only appropriate method for the investigation of vegetation (Moravec 1989). Ordination was regarded by Belbin and Cam (1993) as being a more powerful tool than classification when used for pattern analysis (Faith 1991), although they stressed that care must be taken not to allow outliers to influence the result.

The Russian botanist Ramensky was amongst the first to describe ordination techniques in relation to vegetation analysis (Sobolev and Utekhin 1978), although, according to Bray and Curtis (1957) the actual term "ordination", from the German word *ordnung* "to set in order", was not widely used until the 1950s. The use of this method was stimulated at that time by more efficient sampling techniques and the collection of stand data on a large scale. The mathematical computations necessary to perform this type of data analysis are realistically possible only with the use of computers. The development of personal computers and increased user-friendliness of programs is very important and has made them accessible to a wider range of ecologists (Kent and Coker 1992).

CHAPTER 3 STUDY AREAS AND METHODS

3.1. LOCATION OF THE STUDY SITES

3.1.1 EXCLOSURE SITES

3.1.1.1 Billa Kalina

Billa Kalina station homestead is located about 170 km north-west of Woomera and 110 km north-west of Olympic Dam. Latitudes and longitudes of the exclosure sites are given in Appendix B. Four sets of exclosures, each including an unfenced control area, were constructed about 13 km SSE of the Billa Kalina homestead. Their location is shown in Figure 1.1 and their layout in Figure 3.1. The control sites were all located on similar country and close to the exclosures, but were not connected to them so that the fences would not channel stock through the control area.

3.1.1.2 Marree Soil Conservation Board

One set of exclosures was constructed at each of three sites, at Wilpoorinna Station (Site 1), Dulkaninna Station (Site 2) and Cowarie Station (Site 3). Each set of exclosures included an unfenced control area. The Wilpoorinna exclosure is located about 40 km south of Marree and about 4 km west of the Wilpoorinna homestead. The Dulkaninna exclosure is located about 72 km north-east of Marree and about 8km SSW of the Dulkaninna homestead. The Cowarie exclosure is located about 60 km NNE of the Cowarie homestead, about 40 km by road from the Birdsville Track, and 300 km north of Marree. The location of these exclosures is shown in Figure 1.1. Control sites were located in a similar fashion to those at Billa Kalina. Latitudes and longitudes of the exclosure sites are given in Appendix B. Their layout was identical to that of the Billa Kalina exclosures (Figure 3.1).

3.1.2 ANDAMOOKA STATION GRAZING EXPERIMENT

The Andamooka Station grazing experiment was carried out on the western side of Andamooka Station and immediately east of the Olympic Dam Special Mining Lease boundary (Figure 3.2). A control area for this experiment was located inside the mine lease boundary, just to the west of the two experimental paddocks. This area was not fenced, but was protected from grazing by domestic stock by the mine lease boundary fence.

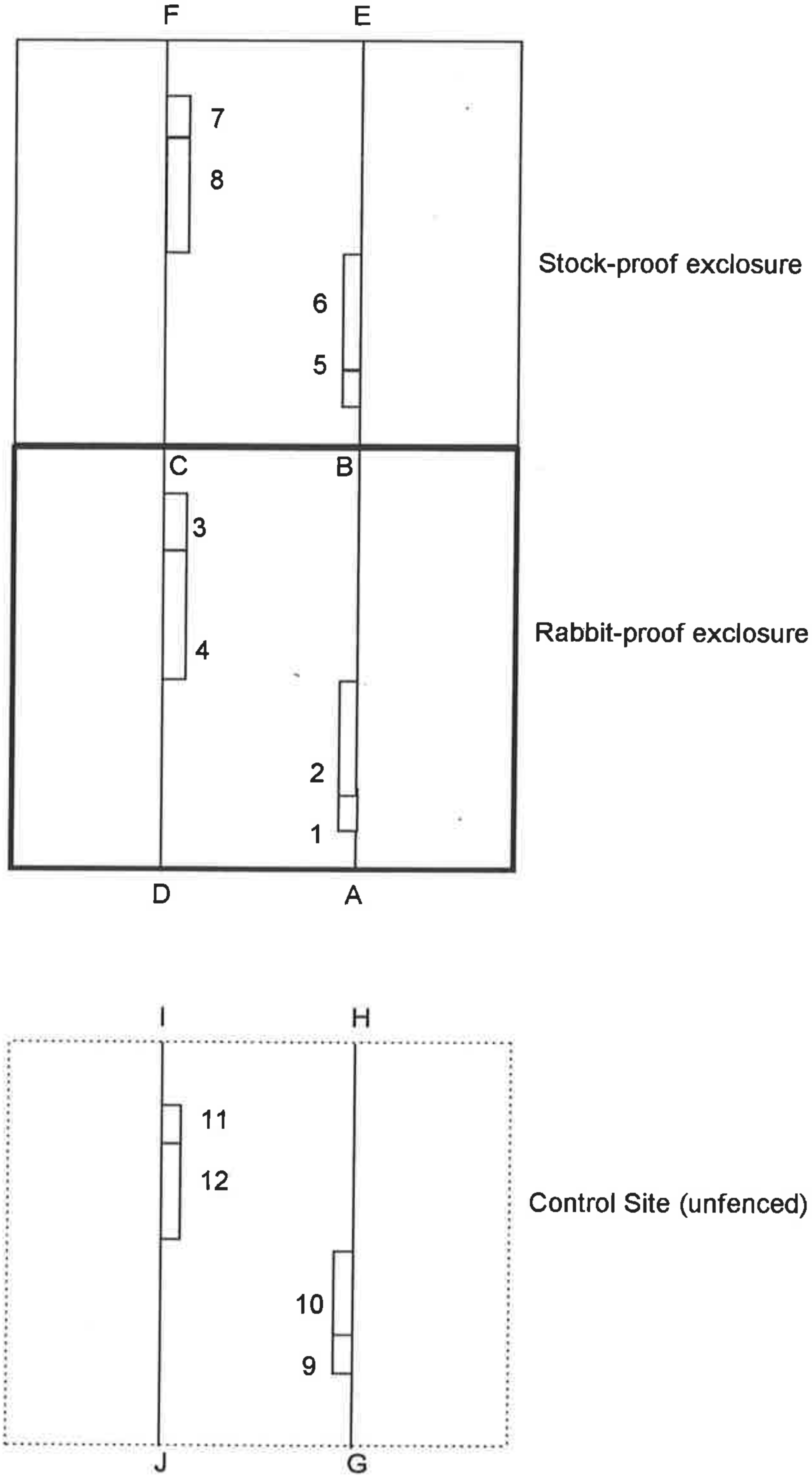

Figure 3.1: Layout of exclosures and quadrats.

Each exclosure is 50 x 50 m.

Odd numbers inside the exclosures indicate the 2 x 5 m quadrats; even numbers indicate the 2 x 20 m quadrats, which include the 2 x 5 m quadrats. Data from the two pairs of quadrats in each exclosure are averaged to obtain the final data values for each exclosure.

Shrub count transects (1 x 50 m) run from A to B and from C to D, from B to E and C to F, and from G to H and from I to J on the inside of the line (on the same side as the quadrats). Results from the two 50 m transects are added together to give the number of shrubs per 100 m^2 for each exclosure or control site.

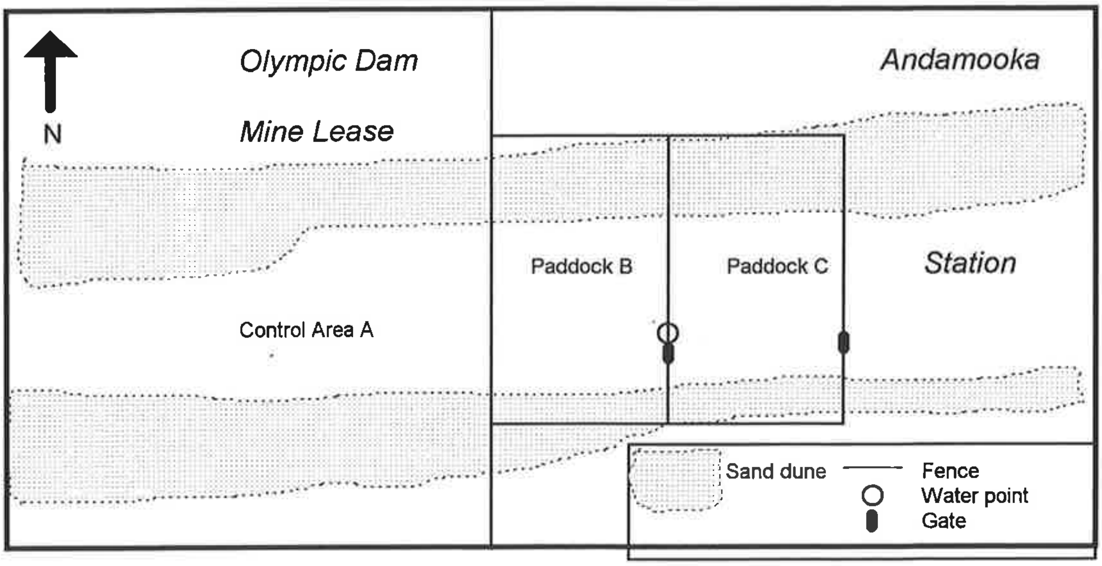

Figure 3.2: Layout of the Andamooka grazing experiment paddocks (not to scale).

3.1.3 Olympic Dam

Monitoring sites are located around, and at varying distances from, the Olympic Dam mine and processing plant, the town of Roxby Downs and on surrounding pastoral land on Andamooka and Roxby Downs stations. Their latitudes and longitudes are given in Appendix B. Olympic Dam is located about 520 km NNW of Adelaide (Figure 1.1). The layout of sites is shown in Figure 3.3.

3.2 LANDFORM, GEOLOGY AND SOILS

3.2.1 Exclosure Sites

Soils at the Billa Kalina sites are either siliceous or gypsiferous yellow sands of low dunes, or saline alluvial sands and calcareous clays of swales (KSCB 1996). Soils become more saline and more alluvial close to small salt lakes. The Wilpoorinna site has Cretaceous clays and silts overlain by a thin veneer of fine-grained gypsiferous sands (Krieg *et al.* 1992). The soils at the Dulkaninna site consist of crusty red duplex and calcareous brown earths (Faithfull 1986). There are also small areas of shallow sand veneer with siliceous red sands overlying the clays. Soils at the Cowarie site are cracking grey clays of the Warburton floodplain (MSCB 1997b).

3.2.2 Olympic Dam

Because of the numerous environmental studies carried out during preparation of two Draft Environmental Impact Statements (Kinhill-Stearns Roger 1982, Kinhill 1997b) there is a considerable literature covering the geology and geomorphology of the Olympic Dam area. This is far greater than that of the exclosure areas.

Two distinct landforms occur in the Olympic Dam study areas. These are parallel longitudinal dunes and swales. The swales vary in width from a few metres near the township of Roxby Downs to more than a kilometre in areas to the north of the Olympic Dam mine. The average height of the east-west trending dunes is about six metres above the underlying plain, with individual dunes reaching heights of up to 10 m. Dunes are composed of red quartz soils (Kinhill-Stearns Roger 1982). Soils of swales are sandy where dunes are close together, but the original gibber-covered tableland surface with its more silty and clayey sandy soils is exposed where dunes are widely spaced.

This area forms the Roxby land system (McDonald 1992, KSCB 1996). An extensive gibber plain, the Arcoona Tableland, occupies pastoral country to the south and east of Olympic Dam and forms the Arcoona land system (McDonald 1992, KSCB 1996). These land systems are described in more detail in Section 3.7.

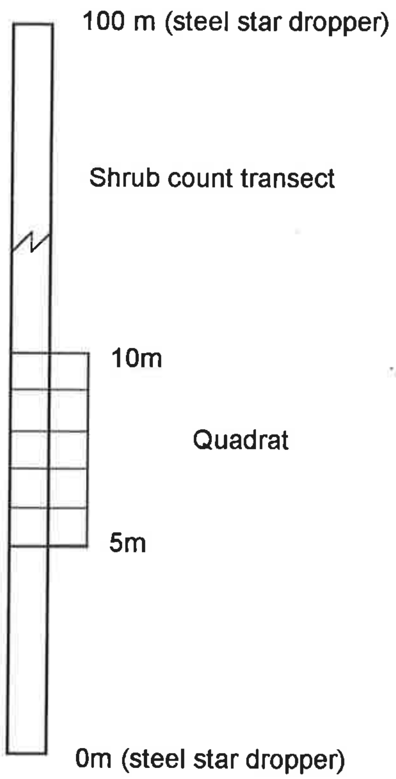

Figure 3.3: Layout of the Olympic Dam transect and monitoring quadrat.

Landforms are generally related to two main factors: the weathering of the underlying rocks of Cambrian to Cretaceous age and the superimposition of more recent windblown sand over the extensive tableland (Woodburn 1981). The area is underlain by three types of rock; Arcoona quartzite, Andamooka limestone and Cretaceous kaolinitic siltstone (Woodburn 1981).

Six terrain features were identified in the area by Kinhill-Stearns Roger (1982) in relation to susceptibility to erosion. These are the stony tablelands, sand dune ridges, interdune corridors (swales), drainage depressions, low stony rises and dunefields. Sand dune ridges and dunefields are of Quaternary origin and are the landforms most susceptible to erosion during periods of high winds. The stony tablelands are particularly resilient as long as the protective gibber mantle is intact, but are susceptible to water erosion once this is removed (Kinhill-Stearns Roger 1982, MSCB 1997a).

Andamooka limestone underlies much of the area around the Olympic Dam mine lease. It is covered by up to 10 m of Quaternary sediments, although in some areas the soil is very shallow and outcrops of limestone occur (Kinhill-Stearns Roger 1982). More recent work by Olympic Dam Operations has shown that in a few places as much as 25 m of clay overlies the limestone. The tableland surface is generally undulating with sandy textured calcareous soils and extensive occurrence of gibber in the interdune corridors. Drainage is into claypans, small vegetated depressions or dolines, with no river systems flowing through the area. A series of low north-south trending stony rises divide the area into a number of discrete catchments and probably represent silicified strandlines associated with an old Tertiary lake system (Ambrose and Flint 1981).

3.3 LAND USE

3.3.1 Aboriginal Use Of The Study Areas

Although Aboriginal occupation of some parts of Australia may date back more than 50 000 years (Kohen 1995) and of some sites in the central Australian ranges to 30 000 years (Smith 1991, Thorley 1998), occupation of the present study areas is thought to be restricted to the late Holocene period, i.e. the last 5000 years (Kinhill-Stearns Roger 1982). Radiocarbon dates obtained by Florek (1993) were all within the last 1000 years.

Numerous archaeological sites are scattered throughout the study areas (Kinhill-Stearns Roger 1982, Kinhill 1997b), but there is no natural permanent water near any of the present study sites. In very wet years, many claypans hold water for several months and a few for several years. This general lack of surface water means that there could have been no permanent occupation of this area unless the climate was considerably wetter than it is at present. This is thought unlikely during the period of known Aboriginal occupation (see Badman (1999: Chapter 10) for detailed discussion on this topic). Permanent water is available from mound springs in the Marree area, but none of these springs is close to any of the exclosure sites.

Many Aboriginal people worked on local pastoral runs until at least the 1960s. Their numbers, and station work-forces in general, have diminished in recent years as motor transport has replaced horses. Most Aboriginal people who still have links with the study areas now live or spend much of their time elsewhere.

3.3.2 European Use Of The Study Areas

Pastoralism is now the main land use of the country surrounding the exclosure sites, with beef cattle run on Billa Kalina, Dulkaninna and Cowarie stations and merino sheep for wool production and beef cattle on Wilpoorinna Station. In the Olympic Dam area, land use is divided between mining and processing of ore (Olympic Dam Special Mining Lease), town living, recreation and industrial use (Roxby Downs Municipal Lease), sheep and cattle grazing (Roxby Downs Station) and cattle grazing (Andamooka Station).

The Olympic Dam Mine is an underground copper-uranium-gold-silver operation. It takes its name from a local pastoral watering point. The mine and associated metallurgical plant is owned by WMC Limited and is managed by WMC (Olympic Dam Operations) Pty Ltd. Roxby Downs, a modern town of 4000 people, was built 15 km south of the mine to house workers and provide support facilities. The 180 km^2 mine lease and 100 km^2 municipal lease were formerly part of Roxby Downs Station, from which the township takes its name.

As a general rule, station properties south of, or “inside”, the dingo proof fence (the Dog Fence) run sheep, while those to the north of, or “outside”, the fence run cattle. However, the recent downturn in the wool industry has resulted in increased numbers of cattle being run south of the Dog Fence. Billa Kalina, Cowarie and Dulkaninna stations are situated to the north of the fence, while Andamooka, Roxby Downs and Wilpoorinna stations and Olympic Dam and Roxby Downs township are located to the south.

Sheep and possibly cattle grazing on the area now covered by the mine and municipal leases has always been light because of a general lack of water except in very wet years. The original Olympic Dam has provided stock water since 1956, but since 1988 it was observed to be dry as often as it contained water.

Early pastoral settlement of the north-west of South Australia, including the Billa Kalina and Olympic Dam areas, was documented by Richardson (1925) and for the Marree area by Litchfield (1983). Billa Kalina initially ran sheep, but has run cattle since the 1930s. It has been owned and managed by the present owners, the Greenfield family, since the late 1930s. Wilpoorinna Station was originally part of Sir Sidney Kidman's large Mundowdna lease, but was handed over to a relative named Wills in the early 1900s and became a separate run in 1926. Ownership of the lease was taken up by the present owners, the Litchfield family, in 1971. It has run mainly sheep, with some cattle and horses, since that time. Dulkaninna Station was also once part of the large Mundowdna lease which ran sheep and then camels (Litchfield 1983). Dulkaninna became a lease in its own right in 1896 but was abandoned during the 1920s (Litchfield 1983). The station has been managed by the present lessees, the Bell family, since 1932. The Birdsville Track passes through Dulkaninna Station and this led to often severe degradation of vegetation by large mobs of travelling cattle. Anecdotal evidence suggests that the condition of the country has improved since road transport replaced the drover in the 1960s (Badman 1991a, Barnes 1997, MSCB 1997b). Cowarie Station has run cattle since 1875 (Litchfield 1983) and is owned by the Oldfield family.

Andamooka Station was taken up in the late 1860s and the present Roxby Downs lease was established in 1932 (Kinhill-Stearns Roger 1982). However, the latter was previously part of Andamooka Station (Richardson 1925, Kinhill-Stearns Roger 1982). During the last few years Andamooka Station has changed from sheep to cattle, partly as a result of the presence of an increasing number of dingoes inside the Dog Fence.

Gold is reported to have been discovered near Andamooka in 1862 (Jensen and Wilson 1980) but the finder is said to have died before he could report the exact location (Richardson 1925). Opal was discovered at Charlie Swamp, north of the present Andamooka Opal Field, in 1904. The Andamooka Opal Field was discovered in 1930 (Kinhill-Stearns Roger 1982). Opals have also been mined at Stuart Creek Opal Field and Yarra Wurta Cliff to the north of Andamooka.

The Woomera Rocket Range, to the south of Roxby Downs, was developed from 1947 onwards. Maximum use of the range occurring during the 1960s (Kinhill-Stearns Roger 1982), but this has had little impact on the present study areas.

Exploration work associated with the Olympic Dam mine began in 1975 and the mine and metallurgical plant were officially opened in 1988. Several expansion phases have since been undertaken, with annual refined copper production increasing from 45 000 tonnes in the first year to 85 000 tonnes in the mid-1990s. The most recent expansion increased annual production of refined copper to over 220 000 tonnes.

3.4 CLIMATE

3.4.1 SUMMARY

The study areas lies within the Australian arid zone. They have warm to hot summers and mild to cool winters. Winter temperatures often fall below freezing point. Rainfall is low and unreliable and evaporation exceeds rainfall in almost all months. Winds are generally lighter and predominantly from the north during autumn and winter, with stronger south-west and southerly winds during spring and summer (ODO 1995).

These are areas where the zones of winter rainfall from the south-west and summer rainfall from the north-west meet and sometimes overlap. Although rain may come from either of these sources, in many years rainfall is insufficient to produce recruitment of the flora (Badman 1999: Chapter 1). Much of the study areas experience a mean annual rainfall around 160 mm, making them some of the driest areas in Australia. The study areas generally experiences more wet days during winter, which is reflected in the slight peak in the median rainfall figure for these months (Figure 3.4) but individual rainfall events are of greater intensity during summer, resulting in higher mean monthly totals at this time.

The ratio of precipitation to evaporation generally falls within the range of 1: 10 in wet years to 1: 40 in very dry years, with a mean ratio of about 1: 20 (Section 3.4.4). Very occasionally there is even greater variability. However, as Anderson (1982) has pointed out, the term "arid" extends beyond low rainfall. It also implies highly irregular rainfall, a frequently aperiodic oscillation between drought and plenty, high seasonal and diurnal radiation loads and poor quality soils that are often saline and lacking in essential nutrients.

Although the study areas currently experience slightly more rainfall from the north, the vegetation still reflects a strong winter rainfall influence in the form of chenopod low shrublands. Grasslands relying on summer rainfall become progressively more common to the north of the study areas. Carolin (1982) considered the original arid zone flora to be adapted to a temperate climate with winter rainfall and Singh (1981) suggested that summer rainfall was greater prior to 4000 years ago than it has been since that time. There has been an upward trend in the mean annual rainfall over a large area of central Australia, including the present study areas, during the last 100 years (Newsome *et al.* 1996).

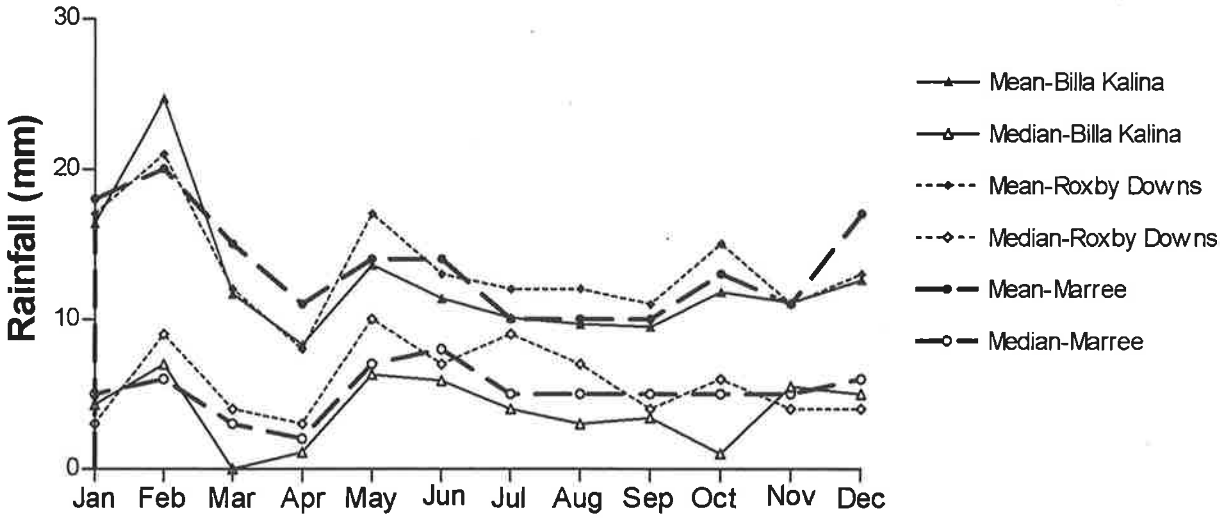

Figure 3.4: Mean and median monthly rainfall for Billa Kalina, Roxby Downs and Marree.
(sources: Billa Kalina and Roxby Downs station rainfall records; Bureau of Meteorology).

The arid zone in general, including the present study areas, is probably subject to seasonal cycles that extend beyond European knowledge of such areas (Baker and Mutitjulu Community 1992) while manifestations of natural environmental perturbations may be evident in as little as 50 years (Emanuel *et al.* 1978). The similar-age populations of mature trees that are not being replaced by juvenile plants (Lange and Purdie 1976, Fatchen 1978, Lange and Wilcocks 1980) may be a result of such cycles. Whether the next series of events that have in the past proved suitable for recruitment of these species will produce the same results, given the changes brought about by European settlement and pastoralism in particular (Badman 1999: Chapter 5), remains to be seen. However, the situation is further complicated by the effects of global warming and it would seem unlikely that such events would have the same effects as they have in the past.

3.4.2 Rainfall

3.4.2.1 Long-term Trends

Rain may fall in the study areas following summer monsoonal depressions from the north-west, or from cold fronts from the south-west during winter. Occasionally rain may come from both quarters in the same year, while in other years no worthwhile rainfall events occur. Significant rainfall events may occur in any month, but extended dry periods are a common occurrence. Heaviest rainfall events occur during summer, but winter rainfall is often more effective in producing plant growth (Buckley 1981b).

The longest sequence of rainfall records from near the southern part of the district is from Arcoona Station, east of Woomera and about 90 km from the southern part of the study areas. Records kept there since 1882 show a mean annual rainfall of 160 mm and a median of 141 mm. The annual variability ranges from 35 mm to 446 mm in a single year. The most complete long-term rainfall records from the northern part of the study areas are those from Marree. The long-term mean for Marree is 164 mm and the median is 145 mm, with a range from 39 mm to 409 mm per year. Data from Marree from 1885 to 1996 were used to compile this section and for long-term comparisons for the northern part of the study areas.

At Roxby Downs Station, where records from 1931 to 1988 were examined, the mean annual rainfall is 162 mm and the median is 136 mm. In contrast, the mean annual rainfall at Olympic Dam from the time recording began in August 1980 until December 1997 was 189.8 mm (Olympic Dam rainfall data, Table 3.1). Mean annual rainfall for Olympic Dam has been skewed by exceptional rainfall events in 1989, 1992 and 1997, although the mean is decreasing and was over 200 mm in 1995 (ODO 1995). This difference is likely to be the result of long-term seasonal cycles in weather patterns. However, median annual rainfall over this period at Olympic Dam was 147.6 mm, which is much closer to the long-term median annual rainfall for both Arcoona and Roxby Downs stations.

Badman (1989) reported three different rainfall cycles that have affected the rivers flowing into Lake Eyre since European settlement. The latest, wetter, cycle began in 1949 and is apparently continuing to the present time. It would appear that a similar pattern has occurred in the study areas.

Rainfall during the summer months generally occurs on less days (Table 3.2) but with heavier individual falls than rainfall during the winter months. This is evident in Figure 3.4, where the mean and median rainfall figures are closest together during the cooler months.

Specht (1972) pointed out that there is less than a 20% variability of rainfall from the annual mean in southern parts of the State with annual rainfall of 250 mm or more, but that there is far greater variability in the drier parts of the State. Rainfall recorded at Roxby Downs Station has deviated by 70% below and 360% above the long-term annual mean.

Table 3.1: Annual Rainfall at Olympic Dam, 1981 - 1997.
(Source: Olympic Dam Operations rainfall records.)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1981	106.6	19.5	0.0	7.6	9.4	8.7	14.4	23.4	18.4	25.8	10.8	19.6	**264.2**
1982	13.3	0.0	22.2	0.0	5.0	7.3	0.0	0.6	13.7	0.4	0.0	5.9	**68.4**
1983	0.4	4.8	21.9	6.4	1.3	1.0	5.8	12.8	12.2	8.1	6.1	30.7	**111.5**
1984	20.6	*	0.2	20.0	21.8	9.5	5.5	4.0	24.0	23.5	2.2	2.0	**133.3**
1985	0.8	0.2	15.0	0.0	39.2	0.3	0.8	29.9	0.0	21.2	11.3	2.2	**120.9**
1986	0.0	3.5	0.0	0.0	63.5	8.8	38.8	24.8	1.5	10.8	13.6	11.5	**176.8**
1987	47.9	28.6	0.0	0.5	18.0	10.9	2.0	19.3	2.6	0.0	0.1	17.7	**147.6**
1988	0.5	7.0	22.0	0.2	31.5	23.0	10.5	0.0	3.7	0.0	3.0	114.0	**215.4**
1989	0.0	0.0	285.5	12.0	31.7	29.5	15.5	0.5	1.0	20.2	52.8	11.9	**460.6**
1990	21.9	1.8	5.8	17.0	17.9	3.8	3.7	12.0	5.0	3.6	1.4	22.0	**115.9**
1991	11.2	0.0	27.0	2.8	0.0	19.4	16.3	9.4	0.6	0.0	24.0	0.0	**110.7**
1992	6.9	119.3	0.0	16.9	39.3	4.6	1.2	33.8	36.6	58.7	10.1	118.4	**445.8**
1993	22.3	1.4	6.7	0.0	8.4	6.2	24.5	3.0	10.1	52.5	15.2	26.8	**177.1**
1994	0.4	51.4	0.0	0.0	0.5	71.2	2.0	1.0	4.0	0.0	4.0	3.2	**137.7**
1995	30.0	17.2	0.0	11.7	0.7	18.0	14.5	2.0	3.2	29.3	33.7	18.4	**178.7**
1996	0.9	0.0	0.0	0.0	0.6	7.2	27.5	8.8	34.7	0.4	3.8	22.0	**105.9**
1997	26.6	143.7	0.0	0.0	7.8	5.5	0.0	21.2	23.8	13.8	12.6	1.0	**256.0**
MEAN	**18.3**	**24.9**	**23.9**	**5.6**	**17.4**	**13.8**	**11.4**	**11.6**	**10.7**	**15.9**	**12.0**	**26.6**	**189.8**

- No data available, but neither Arcoona Station nor Roxby Downs Station recorded any rainfall during the month.
- Mean rainfall figures are for the period shown in this table.

Mean monthly rainfall at Marree varies from 9.6 mm in August to 19.9 mm in February, while at Roxby Downs Station the range is from 7.8 mm in April to 20.8 mm in February. The highest monthly total for Marree was 216 mm in April 1941 and a monthly total of 285.5 mm was recorded at Olympic Dam in March 1989.

The mean number of wet days at Olympic Dam for the period 1981-96 is 36.7 (Table 3.2), but much of this rainfall was ineffective. This is especially the case with small falls during summer or following a prolonged dry spell. Fatchen (1981) considered falls of less than about six millimetres to be ineffective for plant growth during dry periods, when no established annuals are present, while Specht (1972) considered the mean number of days when effective rainfall events occurred in this region was nine or less per annum. Records from Olympic Dam show that the wettest years (Table 3.1) do not necessarily have the greatest number of wet days (Table 3.2). The wettest year recorded was 1989, with 46 wet days. There were 64 wet days in 1992, the second wettest year recorded, but more than 46 wet days in both 1981 and 1990. The year 1981 was also a wet one, with a total of 264 mm of rain recorded, but 1990, with a total of 52 wet days, was a year of below average rainfall, with only 115 mm recorded.

Noble (1977) found that the biomass of short-lived species correlated best with rainfall in the previous 12 months, biomass of *Maireana sedifolia* with rainfall in the previous 24 months, and

Atriplex vesicaria with rainfall in the previous 42 months. Omar (1991) found a correlation between rainfall over the 10 years preceding a survey and the amount of vegetation cover. Because of these long carry-over effects of past rainfall events, rainfall totals for one, two, three, six, 12, 24 and 36 months were used in this study to check for correlations between rainfall and plant growth recorded during the various monitoring events.

Table 3.2: Number of wet days at Olympic Dam, 1980-1997.
(Source: Olympic Dam rainfall records. Means are calculated from the data shown in this table.).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	**TOTAL**
1980								1	1	3	2	2	
1981	9	6	0	2	3	4	4	3	3	2	7	4	**47**
1982	2	0	3	0	3	3	0	1	5	1	0	2	**20**
1983	1	4	2	3	1	1	5	6	4	3	4	6	**40**
1984	3	0	0	0	0	1	3	3	4	2	4	1	**21**
1985	1	1	2	0	4	1	2	11	0	5	4	1	**32**
1986	0	1	0	0	3	3	10	4	1	2	3	2	**29**
1987	6	1	0	1	4	9	4	2	2	0	1	4	**34**
1988	1	1	3	1	6	4	3	0	0	0	2	9	**30**
1989	0	0	11	3	6	4	5	1	1	6	7	2	**46**
1990	6	3	2	4	7	5	5	7	3	2	2	6	**52**
1991	5	0	3	2	0	7	7	4	1	0	6	0	**35**
1992	2	5	0	6	8	5	1	8	9	9	2	9	**64**
1993	6	1	2	0	6	3	5	3	4	8	4	3	**45**
1994	1	5	0	0	2	3	1	1	1	0	2	2	**18**
1995	5	3	0	3	2	4	6	3	2	7	5	6	**46**
1996	2	0	0	0	1	4	6	3	5	1	3	3	**28**
1997	4	5	0	0	2	3							
MEAN	**3.2**	**2.1**	**1.6**	**1.5**	**3.4**	**3.8**	**4.2**	**3.6**	**2.7**	**3.0**	**3.4**	**3.6**	**36.7**

3.4.2.2 Rainfall at the Monitoring Sites

Billa Kalina

The closest rain gauge to the Billa Kalina exclosure sites is located at the Billa Kalina Homestead. Readings from this gauge are shown in Figure 3.5[2]. Billa Kalina experienced a very wet year prior to the construction of the exclosures and the start of the monitoring programme. This was followed by four years of below average rainfall, with the overall condition of the vegetation gradually deteriorating until good rainfall was again experienced in February 1997.

Mean rainfall during the period 1991-1997 was 156.7 mm and the median 132 mm, both above the long-term values for the station despite the four dry years that occurred during the monitoring period. The mean rainfall from 114 years of records between 1880 and 1997 is 139.8 mm, with a median value of 129 mm. Annual rainfall has ranged from a low of 32.75 mm in 1961 to a high of 405.25 mm in 1973. If these rainfall records are split into two equal groups, the data then show that the mean annual rainfall has risen by 7 mm and the median by 3.5 mm since 1941. However, both the driest and wettest recorded years fall within this later period.

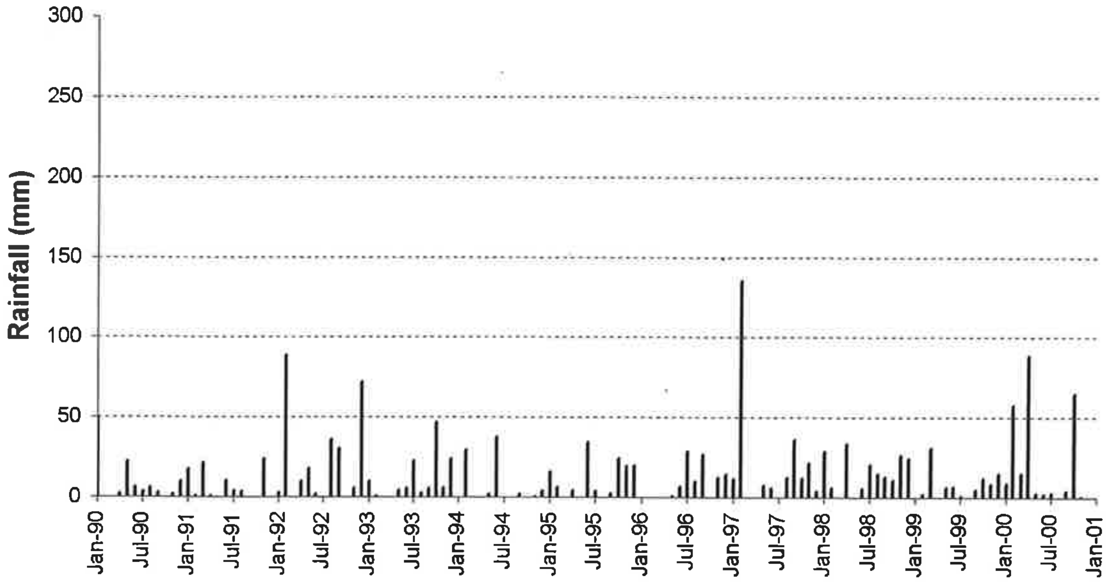

Figure 3.5: Monthly rainfall at Billa Kalina HS.
(Source: Billa Kalina Station rainfall records).

Wilpoorinna

The Wilpoorinna exclosure site is located about 40 km south of Marree. No long-term rainfall data were available for the station, but the rainfall preceding and during the monitoring period is shown in Figure 3.6. Rainfall during this period was generally well above the long-term mean for Marree of 163.7 mm, except in 1994 when only 57.5 mm was recorded at Wilpoorinna Homestead. However, 339 mm was recorded in the previous year. The wettest month recorded was December 1992, just prior to the first monitoring, with 64.3 mm. Monthly rainfall greater than 50 mm was recorded on six separate occasions from December 1992 to December 1995, and monthly totals greater than 24 mm were recorded on a further seven occasions.

Dulkaninna

Mean annual rainfall at Dulkaninna HS was 163.5 mm for the period from 1972-1996, with a median value of 162 mm. Readings from the Dulkaninna rain gauge are shown in Figure 3.7 This

[2] Figures 3.5 - 3.8 are the source of the rainfall data used in Chapters 4 - 6.

mean is almost identical to that for Marree (163.7), but the median for Marree, over a much longer period, is 144.6 mm. Rainfall at Dulkaninna Homestead for the year preceding and during the monitoring (1992-1996) was slightly below average, at 158.2 mm, but rainfall of 178 mm during February 1997 was well above the monthly mean and was the highest monthly total during this period. Monthly totals of 50 mm or more were recorded on four other occasions from 1992-1996, and monthly totals greater than 24 mm were recorded on a further 10 occasions.

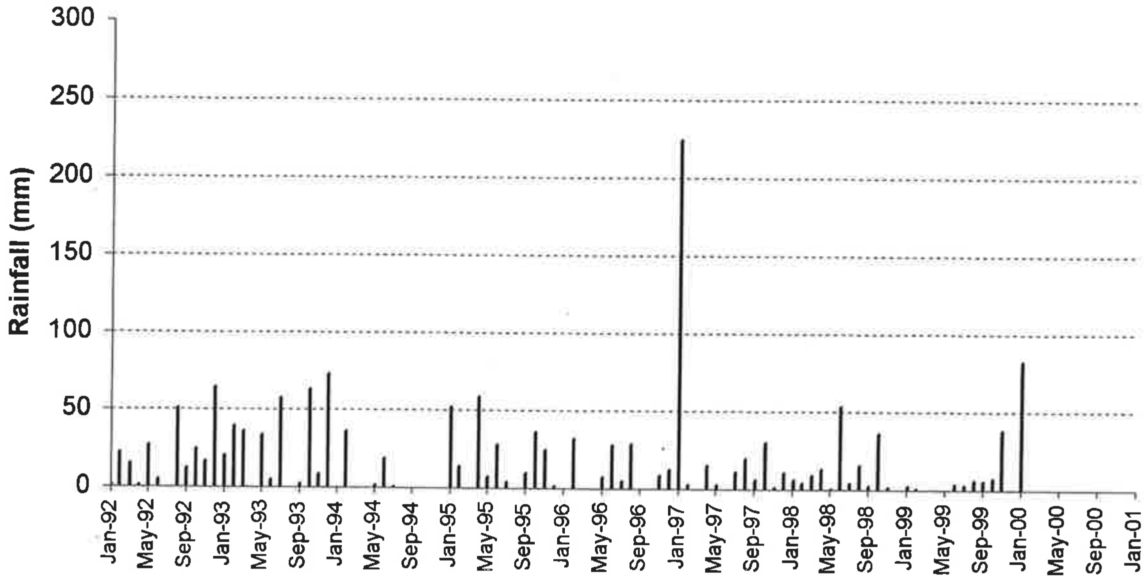

Figure 3.6: Monthly rainfall at Wilpoorinna HS.
(Source: Wilpoorinna Station rainfall records).

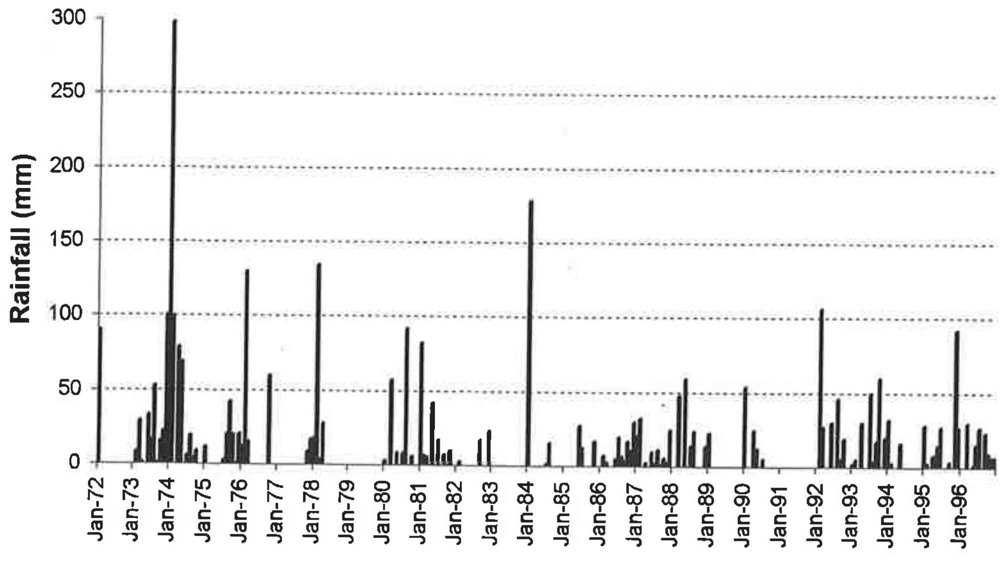

Figure 3.7: Monthly rainfall at Dulkaninna HS.
(Source: Dulkaninna Station rainfall records).

Cowarie

The closest rain gauge to the Cowarie exclosure site is located 35 kilometres to the east-north-east, at the Clifton Hills HS. The rain gauge at the Cowarie HS is more than 70 kilometres to the south-south-west of the exclosure site. Because the Cowarie site was constructed primarily to follow the effects of flooding, rather than of rainfall, this was not seen as a problem and no rainfall records were examined for this site. Rainfall at the Cowarie homestead would probably be similar to that at the exclosure site over a full year, but daily or monthly falls could be quite different.

Olympic Dam

Meteorological records, including rainfall, have been kept at Olympic Dam since August 1980. Details of monthly and annual rainfall totals for the years 1980-1997 are given in Table 3.1 and Figure 3.8. Because of the short period of recording, mean monthly totals cover a wide range. These are slewed for many months by large individual rainfall events, with March and December being the wettest months, followed by May, January and February. The March mean was boosted by a recording of 285.5 mm in 1989, the February mean include a rainfall event of 143.7 mm in 1997 and the December figures include two falls of more than 114 mm. Other falls of over 106 mm have occurred in both January and February, while May remains the only month with a relatively high mean that has been maintained by numerous and more regular rainfall events.

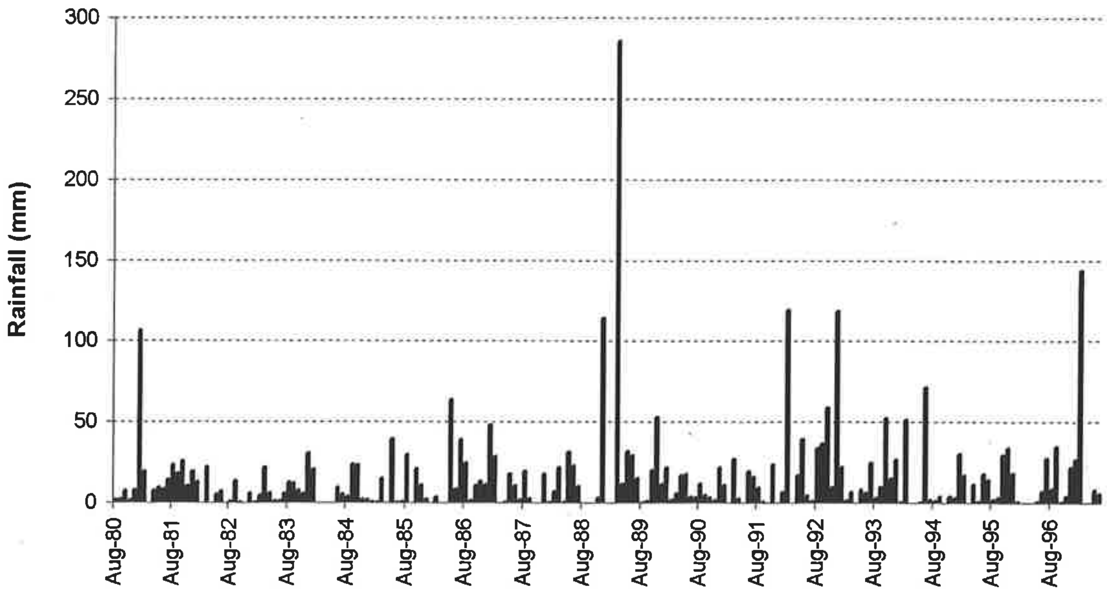

Figure 3.8: Monthly rainfall at Olympic Dam.
(Source: Olympic Dam Operations rainfall data).

The years 1982-1985 all had well below average rainfall, particularly 1982, when only 68.4 mm was recorded. This period represents the longest run of below average rainfall years since 1980, and 1987 was also a below average rainfall year. The only other time when two or more below average rainfall years occurred together was in 1990 and 1991, but their effect was lessened by the very wet years of 1989 and 1992.

3.4.3 Temperature

Temperatures recorded at the Marree Post Office range from a daily mean of 18.9^{0}C in July to 37.5^{0}C in January, with a median daily temperature range from 18.8^{0}C in July to 37.4^{0}C in January (Figure 3.9). The highest annual mean maximum temperatures ranged from 22.6^{0}C in July to 41.9^{0}C in January. In the coolest recorded January the mean daily temperature was more than 10^{0}C lower, at 31.7^{0}C. Minimum mean temperatures in Marree have varied from 21^{0}C in January and February to 5^{0}C in July. In the coolest recorded July the mean daily temperature was 1.9^{0}C.

The annual mean maximum daily temperature at Olympic Dam from 1981-1995 was 27.5^{0}C, with mean daily maxima ranging from 36.1^{0}C in January to 18.2^{0}C in July (ODO 1995, Figure 3.9). Minimum mean daily temperatures ranged from an average of 19.6^{0}C in January to 4.3^{0}C in July (ODO 1995). Summer maxima have reached 47.5°C, while winter minima have fallen to -5°C (Olympic Dam Operations meteorological records).

Mean maximum and minimum temperatures in Marree are generally one or two degrees higher than those recorded at Olympic Dam, with the difference being greatest during summer and mid-winter. There is no difference in Autumn.

3.4.4 Evaporation

Mean annual evaporation at Olympic Dam, measured in a Class A evaporation pan, for the period March 1981-February 1995 was 2786 mm (ODO 1995). Monthly evaporation rates have varied from a maximum mean of 397 mm in January to a minimum mean of 85 mm in June (ODO 1995, Figure 3.10) and have exceeded rainfall in all months except March 1989 (Olympic Dam Operations meteorological data). In that month, rainfall of 285.2 mm exceeded evaporation by 51 mm (ODO 1990a). Mean annual evaporation exceeded mean annual precipitation by a factor of 14:1 for the period 1980-1994. During the wettest year, 1989, evaporation exceeded rainfall by a factor of 5:1. The driest year recorded during this period was 1982, when only 68 mm of rain fell

(ODO 1990a; Table 3.1). Evaporation during 1982 was 2714 mm (ODO 1990a) and exceeded rainfall by a factor of 40:1.

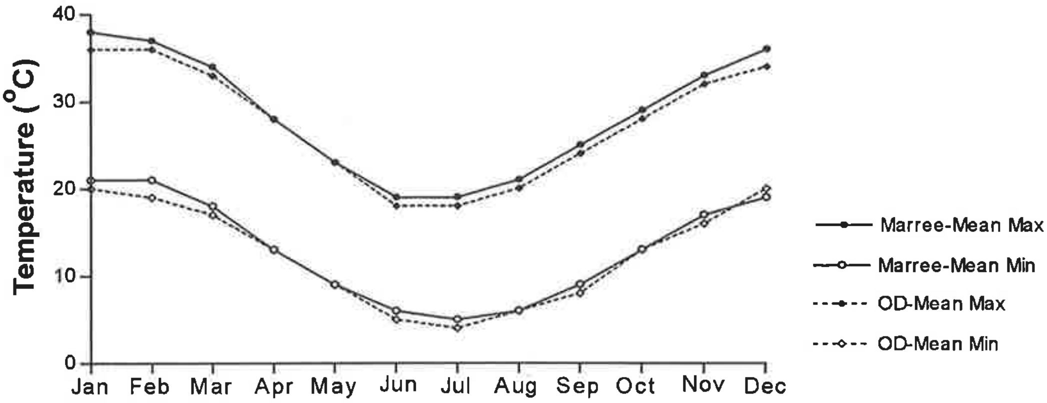

Figure 3.9: Mean Monthly Temperatures at Marree and Olympic Dam.
(sources: Bureau of Meteorology (Marree - data from 1885-1996)), ODO 1995 (Olympic Dam - data from 1980-1995)).

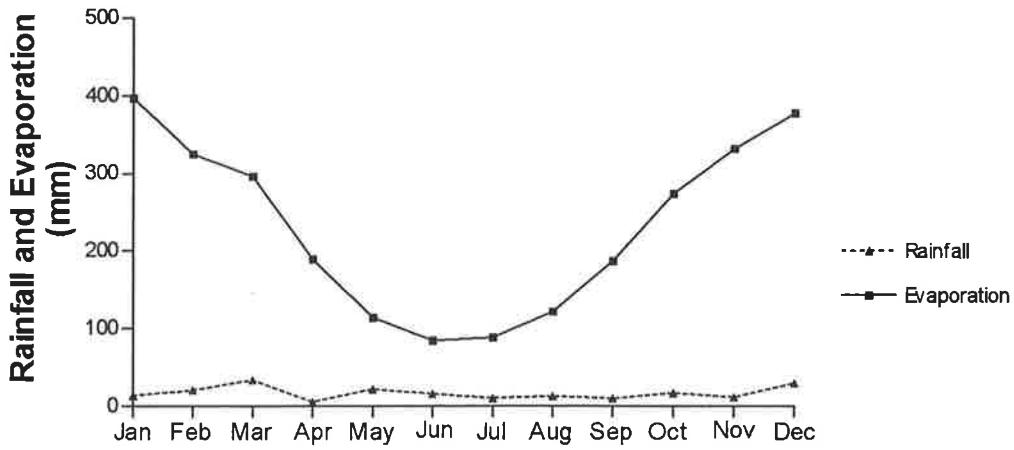

Figure 3.10: Monthly rainfall and evaporation at Olympic Dam (1980-1995).
(Source: ODO 1995).

3.5 DISTURBANCE

The major impact over the whole of the study areas, including the Olympic Dam mine lease before exploration and mining began, were caused by the grazing from domestic stock (Kinhill-Stearns Roger 1982), rabbits and kangaroos (Badman 1995a). Grazing continues to be the main form of disturbance at all the exclosure sites except where various animals have been excluded by fencing. Both sheep and cattle were run on the Olympic Dam mine lease and Roxby Downs municipal lease until they were fenced off from Roxby Downs Station and destocked in 1987. The township of Roxby Downs is enclosed within a 16 km rabbit-proof fence and rabbit control is carried out as an ongoing part of the environmental management programme. Rabbit numbers per unit area within the fence are now much lower than those occurring outside (ODO 1995).

Until their numbers were reduced by RCD in 1996, rabbits were the single greatest threat to the environment over much of the arid zone, including Olympic Dam (see Section 2.5). Depending on the continuing effect of RCD, they are likely to return to their former densities at some time in the future. Graetz (1990), commenting on the effects of oil exploration by Santos in the Cooper Basin, wrote *"The impacts of the exploration and production activities, the subject of this Report, are utterly insignificant in their extent and ecological significance compared with the relentless destruction imposed by rabbits".*

A combination of above average rainfall and high rabbit numbers occurred at Olympic Dam during 1989. Rabbit densities[3] inside the Roxby Downs rabbit-proof fence ranged from 8.6 per km^2 in June to 21 per km^2 in December (Badman 1995a). Numbers in similar habitat immediately outside the fence increased from 37 to 180 per km^2, while rabbit numbers in a more open habitat north of the mine increased from 94 to 586 per km^2 during this period (Badman 1995a). In July 1990, rabbit numbers inside the fence had fallen to 2.5 per km^2 after an intensive eradication campaign, compared to 56 per km^2 immediately outside the fence. During 1990 a smaller population increase occurred in the Olympic Dam rabbit population, but was not sustained due to the rapid desiccation of the limited ephemeral growth produced by light winter rainfall. Rabbit numbers have continued to fluctuate, but by 1999 had not returned to their 1989 levels.

Kangaroo numbers on the Olympic Dam mine lease have increased since the area was annexed from Roxby Downs Station. The station usually has a resident commercial kangaroo shooter, but kangaroo numbers on the mine lease are now determined by seasonal conditions and the availability of water. Shooting is not generally permitted there. Kangaroo numbers in some areas periodically increase to the point where they are having an obvious detrimental effect on vegetation. Fence-line effects equally as bad as anything caused by domestic livestock grazing have been noted on more than one occasion. The problem is often exacerbated by dry seasonal conditions. Control measures are implemented only infrequently.

Another impact on the area is in the form of access tracks. Some tracks left over from the sheep station era or from the early days of mineral exploration have been ripped and rehabilitated, with only those necessary for operation and monitoring of mining and exploration activities being maintained. Despite this, illegal off-road driving continues to be a problem (see Section 2.8).

Disturbance of the soil is generally thought to promote the spread of weedy species, including aliens (Elton, 1958; Amor and Piggin 1977, Buchanan 1989, Wilson 1990), although in some instances it can be used as a control measure (Groves 1986). The relevance of various disturbance hypotheses in relation to invading species was examined by Fox and Fox (1986) who conclude that there is no invasion of natural communities without disturbance, although Groves (1986) pointed out that disturbance can also be used as a control measure. This subject was examined in detail in an earlier thesis (Badman 1995a) and the findings of this study are summarised here in Section 2.9.

3.6 NUTRIENT LEVELS

When compared to Australian coastal zone soils and arid zone soils of other countries, soils from the Australian arid zone are lacking in most elements necessary for plant growth (Charley and Cowling 1968, Stafford Smith and Morton 1990), particularly phosphorus, nitrogen and organic matter (Table 3.3). Charley and Cowling's findings supported those of Jackson (1957), who also looked at arid zone soils in various parts of the world, and Specht (1972), who discussed the soils of South Australia. Although Charley and Cowling (1968) considered that arid zone soils show characteristics indicative of much more humid climatic conditions than those of the present, they also considered the very low levels of phosphorus to be their most striking feature.

Table 3.3: Nutrient content of arid zone soils (after Charley and Cowling 1968).

Nitrogen	
Australian arid zone	0.06 %
Overseas arid zones	0.11 %
Phosphorus	
Australian arid zone	240 p.p.m.
Overseas arid zones	710 p.p.m.

Graetz and Tongway (1980) discussed the nutrient levels of soils at Olympic Dam and Jessup (1951) discussed the soils of the general area. Although the figures on nutrient levels given by the different authors do not entirely agree with each other, all agreed that the soils, whatever their nature, are generally lacking in nutrients and that trends in nutrient levels are the same. Graetz and

[3] Calculated from counts along fixed transects at night.

Tongway (1980) gave readings for phosphorus and nitrogen that were an order of magnitude higher in loam or clay soils than in sandy soils. Fowler (1986) reported the importance of nitrogen in the establishment of winter annuals, including most alien species found in the area (Badman 1995a).

Soil nitrogen is replenished mainly by nodulating herbaceous and woody legumes (Charley and Cowling 1968) and by cryptogamic crusts (Rogers *et al.* 1966). Although legumes are well represented in the flora of the study areas, they do not constitute a large proportion of the vegetation biomass, a factor influenced by the normally short growing season (Charley and Cowling 1968). The proportion of leguminous species in the herbaceous layer falls from south to north in South Australia, as it does in other parts of the world (Grouzis *et al.* 1998). Cryptogamic crusts were not evident at any of the exclosure sites, but were observed at the grazing experiment site. They also occur at some Olympic Dam sites, but are not recorded as part of the vegetation monitoring programme.

Phosphorus content of the soil appears to be only slightly influenced by climatic factors, with the greatest influence being the phosphorus content of the parent material (Charley and Cowling 1968). Charley and Cowling's suggestion that low phosphorus levels are the result of low levels in parent material is in agreement with the findings of Prescott (1952) and Beadle (1962) who suggested that this is due to the rock constituents having been through a series of successive weathering and depletion cycles. Charley and Cowling (1968) also suggested that the low phosphorus content of these soils may be at least partly responsible for their low nitrogen content.

Charley and Cowling (1968) stated that the comments they made about the low nitrogen content of Australian arid zone soils apply equally in regard to organic matter, or organic carbon which is the usual measurement made. Australian arid zone soils appear to be lower in organic carbon than equivalent overseas soils (Jackson 1957).

Both nitrogen and phosphorus capital in soils is concentrated towards the surface where organic carbon resulting from breakdown of vegetable matter is also concentrated (Charley and Cowling 1968). This concentration was in the top 10 cm of the soil profile in the case of one stable *Atriplex vesicaria* community that they studied, where it is more susceptible to erosion by wind and water (Stafford Smith and Morton 1990). This is in direct contrast to younger deserts in other parts of the world where nutrients tend to persist or occur deeper into the profile (Stafford Smith and Morton 1990). Degraded soils allow poor water penetration that limits root growth to the upper soil horizons (Seghieri 1995). Charley and Cowling (1968) also considered that the greater part of the nutrients which are readily available to plants are stored in the top 10 cm of soil, with deeper nutrients available only at a much slower rate of release. However, they considered that chemical analyses are unreliable measures of soil fertility because they seldom correlate well with short-term plant response to rainfall events and they do not give an indication of the rate at which these elements can become available to plants.

Above average rainfall in the Australian arid zone will produce a dramatic burst of plant growth and this has led in the past to the idea that the soils are potentially fertile and that all that is needed to keep on producing such growth is additional rainfall or water subsidy. However, second and subsequent wet years, without an intervening "dry" year to give the soils a chance to recover nutrients through plant and litter decomposition, lead to diminishing returns by way of vegetation biomass for each subsequent rainfall event (Charley and Cowling 1968, Shaw 1993). This highlights the nutrient-poor status of these soils. Drought can also play a part in soil nutrient levels by inhibiting microbial activity and reducing mineralisation of nutrients from litter (Boardman 1994).

Although Groves (1986) considered that grazing increases the amount of nutrients in the soil, this is often offset by increases in erosion of the topsoil. Grazing by domestic stock ceased on the Olympic Dam mine and Roxby Downs municipal leases in 1987. Some subsequent lessening of soil nutrients might have been expected, but this has been offset by increases in the numbers of kangaroos and the periodic high rabbit numbers (Badman 1995a). The process of recovery, or of rehabilitation and return to a stable state, can be a slow one (Kleiner 1983, Brady *et al.* 1989,Borgegård 1990, Omar 1991). Exclusion of grazing from exclosures may also have a long-term effect on soil nutrients, but this was not examined as part of the present study.

It could also be expected that fire would alter the soil nutrient balance (*e.g.* Groves 1986) and return some organic carbon to the soil. This did appear to happen in at least one case, at least in the short-term (Badman 1995a), but fires are not a natural part of the seasonal cycle in the study areas (Badman 1999: Chapter 5). Conditions suitable to sustain fire occurred in the study areas in 1975, 1990 and 1993 following the very wet years of 1974, 1989 and 1992. In the majority of seasons the understorey vegetation biomass is insufficient to carry a fire. Vegetation biomass is also suppressed in these "normal" years by grazing, particularly by rabbits, but also by sheep, cattle and kangaroos (see Sections 2.2 and 2.3). The rare fires that do occur can lead to changes in the vegetation composition which may remain for many years (Wilson 1990). Griffin and Friedel (1984) found that although there were increases in soil nutrients following fires in the Alice Springs area, these increases were not statistically significant.

Increases in soil nutrients, particularly phosphorus, have been recorded in soils near major cities (Clements 1983, Lambert and Turner 1987) but it is unlikely that this would be the case with a small town like Roxby Downs, especially as the town has been in existence for only a relatively short time. Emissions from the Olympic Dam processing plant (Fatchen and Associates 1991) may have an effect on soil nutrient content, but this was not investigated as part of this study.

3.7 LAND SYSTEM AND VEGETATION DESCRIPTION

3.7.1 BILLA KALINA

The Billa Kalina exclosures lie within the Bamboo Swamp environmental association (Laut *et al.* 1977) and the Phillipson land system (McDonald 1992, PISA 1993, KSCB 1996). This is a low-lying area with sandplains, swales and low dunes, with drainage into local claypans and swamps that are often bordered by low gypseous cliffs. Vegetation consists of chenopod low shrublands or sparse low woodland with a chenopod or tussock grass understorey. Two sets of exclosures were constructed on low sandy rises with tussock grassland vegetation and two sets on clay soils with low chenopod shrubland. The tussock grasslands are dominated by mainly *Aristida* and *Enneapogon* species, with other forbs and a few chenopod shrubs. A few scattered trees and tall shrubs are also present. The chenopod shrublands are dominated by *Atriplex vesicaria* and *Maireana astrotricha*, with a few other shrubs, particularly *Frankenia serpyllifolia* and *Maireana pyramidata*, also present. The understorey consists of forbs, particularly chenopods, and tussock grasses.

3.7.2 WILPOORINNA

The Wilpoorinna exclosure site is located on a sandsheet area within the Marree environmental association (Laut *et al.* 1977) and the Paradise land system (MSCB 1997b). The area consists of a gently undulating gypcrete plain, with low dunes and sand sheet. Vegetation is dominated by chenopod low shrublands with a tussock grass understorey, and sparse low woodlands. The main low shrub species are *Atriplex vesicaria, Maireana appressa* and *Maireana astrotricha,* but *Maireana aphylla, Maireana georgei, Rhagodia spinescens and Sclerolaena tatei* are also present. The area also supports sparse *Acacia aneura* and the tall shrubs *Acacia victoriae*, *Acacia tetragonophylla* and

Senna artemisioides. The understorey consists of tussock grasses, especially *Aristida contorta* and *Enneapogon avenaceus,* and forbs.

3.7.3 Dulkaninna

The Dulkaninna exclosure site is located on a gibber plain in the Cooryanna environmental association (Laut *et al.* 1977) and in the Mumpie land system of the MSCB (MSCB 1997b). The area consists of an undulating gibber plain with tablelands and low escarpments. Vegetation is dominated by sparse tussock grasslands and sparse chenopod shrublands. Vegetation cover is very patchy, with large areas of bare gibbers and the densest vegetation growing in run-on areas. The sparse shrubs include *Atriplex vesicaria* and *Frankenia serpyllifolia*, with *Maireana aphylla* and *Maireana appressa* being even less common. Grasslands are dominated by *Enneapogon avenaceus, Aristida contorta* and *Tripogon loliiformis*, with lesser occurrence of the longer-lived *Astrebla pectinata*. *Cullen australasicum* is common in one quadrat and numerous other forbs occur in the understorey.

3.7.4 Cowarie

The Cowarie exclosure site lies on the floodplain within the Warburton environmental association (Laut *et al.* 1977) and the Warburton land system (MSCB 1997b). This is an area of extensive floodplain with sinuous channels, partly overlain by low white dunes. Woodlands of *Eucalyptus coolabah* occur along the channels, but vegetation of the floodplain is dominated by shrublands of *Chenopodium auricomum* and *Muehlenbeckia florulenta*. Almost all other vegetation is ephemeral and grows following flooding or very heavy rainfall events. *Gnephosis eriocarpa* was the most commonly recorded understorey species. In the absence of a flood during the monitoring period, most ephemeral plants were found growing in depressions where water had collected from local rainfall events. The unusual phenomenon of shrub cover increasing as conditions became drier, caused by erect shrubs collapsing and thereby increasing their surface area as their stems died off, was recorded here.

3.7.5 Olympic Dam

The Olympic Dam area lies within the Moondiepitchnie land system (Laut *et al.* 1977) and the Roxby land system (McDonald 1992, Primary Industries South Australia (PISA) 1993, KSCB 1996). This land system consists of a dunefield of stable parallel sand ridges averaging about six metres in height, with individual dunes up to 10 m high. Dunes have an east-west orientation. For the purpose of this study, this land system has been divided into units comprising dunes, dune bases and swales (interdune corridors). There is a sound precedent for adopting this approach; it has already been used by workers such as Crocker (1946), Boyland (1970), Beard (1974) and Fatchen and Barker (1979), as well as at Olympic Dam (Badman 1992a, 1993, 1995a; ODO 1993, 1996b).

Three vegetation associations have generally been recognised in this area and these closely follow the three land forms described above (Badman 1992a, 1993, 1995a; ODO 1993). A fourth vegetation association is recognised for the purpose of this study. The associations previously recognised are those associated with dunes, dune bases and swales. The fourth is *Acacia papyrocarpa* woodland which occurs south of Olympic Dam Village and at some pastoral sites on Roxby Downs and Andamooka stations.

The dune vegetation association consists of a tall shrubland with grasses or ephemeral herbs in the understorey; the dune base vegetation association has low open woodlands with a chenopod or grass understorey; the swale vegetation association is dominated by a chenopod low shrubland with a grass or ephemeral herb understorey; and the *Acacia papyrocarpa* woodlands are dominated by this species and generally have a chenopod low shrubland understorey. Chenopod shrublands are associated with predominantly winter rainfall patterns (Wilson 1990).

Overstorey vegetation of the dunes is typically *Callitris glaucophylla*, *Acacia ramulosa*, *Acacia ligulata* and *Dodonaea viscosa* ssp. *angustissima*. Understorey vegetation typically consists of herbs and ephemeral or short-lived perennial grasses, although these are usually sparse or non-existent in the root influence zone of *Callitris* and *Dodonaea*. The short-lived perennial grasses *Aristida holathera* and *Enneapogon cylindricus* are particularly common on dunes. Long-lived perennial grasses such as *Eriachne helmsii, Eragrostis laniflora* and occasionally *Eragrostis eriopoda* also occur on some dunes, but these are far less common than the shorter-lived grasses.

Dune bases and narrow swales have open to dense stands of *Acacia aneura* with grass or chenopod understorey. These trees are generally most dense at the base of dunes and are more sparse towards the centre of the swale where less water is available as seepage from water stored within the dune core. Understorey is typically of low chenopod shrubs or tussock grasses, with ephemeral herbs dominating during the cooler months of the wetter years.

Vegetation of broad swales and plains is typically dominated by the low shrub *Atriplex vesicaria*, interspersed with *Maireana astrotricha*, *Maireana aphylla*, *Sclerostegia tenuis* and *Frankenia* *serpyllifolia*. *Maireana sedifolia* occurs where limestone is close to the surface, generally on the municipal lease and to the west on Roxby Downs Station. Understorey typically consists of *Sclerolaena* spp., grasses and ephemeral herbs. Grassy understoreys are usually dominated by *Enneapogon avenaceus*, with lesser occurrences of *Aristida contorta* and *Enneapogon polyphyllus*. In some areas, *Atriplex vesicaria* can remain as an almost monotypic community during dry periods when the understorey species are absent.

Swales in the Roxby Downs area, and as far north as the Olympic Dam Village are dominated by *Acacia papyrocarpa*, but this tree is scarce on the mine lease. The understorey is usually of *Atriplex vesicaria*, but other chenopod shrubs and sub-shrubs often occur. *Enchylaena tomentosa* is often found growing beneath these trees, particularly on the municipal lease where there are no sheep. This plant is rarely seen in the same habitat on sheep country to the south of Olympic Dam (Badman 1992b), presumably due to sheep grazing. The grasses *Enneapogon avenaceus, Enneapogon cylindricus, Stipa nitida* and *Aristida contorta* often occur in the understorey.

3.8 PROXIMITY OF EXCLOSURE SITES TO WATER

All exclosure sites are located within what is considered to be the normal grazing range from water of the animals that normally graze the respective paddocks. There are three water sources in the paddock containing the Billa Kalina sites, although only one of these, Maynards Bore, is permanent. This water is of poor quality and is only used when the other water sources are dry. Two other water sources, the Devil's Playground claypan and Hughes Dam on this claypan, are situated just to the west of the exclosures. The claypan was dry throughout the monitoring period and Hughes Dam dried up during the first year. All of the sites except Site 2 are within two kilometres of the Devil's Playground and were more heavily grazed from 1989 to 1992, when the claypan contained water, than they were during the monitoring period.

The Wilpoorinna site is within four kilometres of a permanent water source at the Homestead Dam. Large concentrations of kangaroos occur at this site following local rainfall when the surrounding country is still dry (Gordon Litchfield, Wilpoorinna Station, pers. comm.). At such times this paddock becomes the focus of the station's kangaroo culling programme. Domestic stocking is also kept at a very low level in this paddock, which is used only for grazing rams, ration sheep and a few horses. The Dulkaninna site is about three kilometres from the Six Mile Trough on a pipeline from Dulkaninna Bore. This bore is about seven kilometres from the exclosure site and is also well within the grazing range of cattle. The Cowarie site was not grazed during the monitoring period, but in times of flood there are numerous sources of water on the surrounding floodplain.

3.9 METHODS

3.9.1 THE BILLA KALINA EXCLOSURES

The KSCB undertook the construction of the four sets of exclosures on Billa Kalina Station (see Table 3.4 for construction dates). Exclosures were erected within an area where a rabbit warren ripping experiment was also being carried out. Two areas, one in sandy country and one in clay country and each four kilometres by two kilometres, were selected for rabbit warren ripping. Two areas that were not ripped were selected to act as control sites for the exclosures in the ripped areas.

One area was in sandplain country with scattered *Acacia aneura* and mostly short-lived grasses while the other was in chenopod low shrubland with clay soil. Warrens in half of each area were ripped in one direction only and in the other half were ripped in two directions, one at right angles to the other.

Exclosure sites were chosen by myself and Keith Greenfield the lessee and manager of Billa Kalina Station. Exclosures were constructed in areas that were considered to be typical of each of the two land units in the area. One set of exclosures was constructed in the centre of the double ripped area on each of the different soil types. Exclosures in the ripped areas were positioned so that rabbits had to travel a minimum distance of one kilometre to reach them from unripped warrens. Leigh *et al.* (1989) found that rabbits caused the greatest damage to vegetation within 300 m of their warrens, with most damage within 50 m. One kilometre is generally considered to be beyond the normal foraging range of the rabbit. The actual exclosures and control areas were located so as to avoid having any rabbit warrens within their boundaries. Two additional control areas were set up in the single ripped areas for each land type.

Two other sets of exclosures were constructed on similar soil types on nearby areas where warrens were not ripped.

Rabbit numbers were counted along a transect at night, with counts usually just preceding the vegetation monitoring. The same tracks were used as the transect on each occasion and the same people carried out the counts. Numbers of rabbits counted were calculated as numbers of rabbits per square kilometre using the assumption that rabbits within 50 m of the track could be seen by an observer standing up in the back of a tray-top Toyota on all occasions.

Table 3.4: Dates of fencing or exclosure construction for experimental sites.

Site	Date Site Fenced or Exclosure Constructed
Billa Kalina	March 1993
Cowarie	April 1993
Dulkaninna	April 1993
Wilpoorinna	April 1993
Olympic Dam Mine Lease	1987
Andamooka grazing experiment paddocks	March 1995

3.9.2 THE MARREE SCB EXCLOSURES

Members of the Marree Soil Conservation Board organised construction of three sets of exclosures, one each on Wilpoorinna (Site 1), Dulkaninna (Site 2) and Cowarie (Site 3) stations. Sites were chosen and fencing constructed by the respective station lessees.

The Wilpoorinna site is about four kilometres to the WNW of the homestead, on both sides of an old disused road. The Dulkaninna site is about eight kilometres SSW of the homestead and about 250 m east of the Birdsville Track. The Cowarie site is located adjacent to the “Rig Road” that crosses the Simpson Desert from the Birdsville Track to Pumi Bore. Its control site is located about 300m to the north. All exclosures and control sites are the same size as the Billa Kalina exclosures and the same quadrat layout was used at all sites.

3.9.3 THE GRAZING EXPERIMENT

Two paddocks, each 20 hectares in area (roughly 700 x 300 m), were constructed on Andamooka Station adjoining the eastern boundary of the Olympic Dam mine lease by John Read as part of his PhD fauna experimental work. A new water point was constructed on the common boundary of the two paddocks. The paddocks are referred to as Paddocks “B”, adjoining the mine lease fence, and Paddock “C”. A control area on the mine lease is known as “Area A” (Figure 3.2). This experimental site was used for the vegetation grazing experiment without any modification or input into its design.

Eighty cattle were placed in Paddock B and 80 cattle in Paddock C in June 1995 and removed 18 days later. By this time the amount of forage available to them was negligible and further grazing of these paddocks would have most likely resulted in loss of condition of the cattle. This stocking rate was the equivalent of 400 cattle, or 2800 dry sheep equivalents (dse) per km^2. When spread over a whole year, this first grazing pulse is the equivalent of 138 dse/km^2. This compares to the average stocking rate for Andamooka Station of 5 dse/km^2 (Read 1999). The experimental paddocks were grazed again by 70 cattle for six days in December 1995 and on this occasion the gate was left open, allowing them to move freely between paddocks. This treatment removed much of the regrowth which occurred following the initial grazing pulse. The second grazing treatment was the equivalent of 1225 dse/km^2 calculated on a daily basis, or 23 dse/km^2 when calculated over the whole year. The combined grazing pulses equate to a stocking rate of 161 dse/km^2 when calculated over the whole year.

Vegetation was sampled using random linear transects as described in Section 3.9.4.2. Sampling was carried out prior to each grazing pulse and within a week of the removal of the cattle. The final monitoring was planned for 12 months after the second grazing pulse, but was delayed for about a month in order to record the response to the heavy rainfall event of February 1997.

Cover values for each species were obtained at each sampling event. Each relevé (unique combination of temporal and spatial data) was given a seven digit alpha-numeric code consisting of the survey timing (T1 to T5), "G" for grazing experiment, "CL" for clay swale areas or "SA" for the sandy dune areas, and "C1" or "C2" for the two control transects or "G1" or "G2" for Paddock B and Paddock C respectively. The stone cover of each swale area was determined at the first sampling, but was not recorded subsequently. This was found to be 13% in Area A, 9% in Paddock B and 11% in Paddock C. There was no stone cover on the dunes. Cover of litter and soil lichens was also recorded at each monitoring event.

3.9.4 DATA COLLECTION

3.9.4.1 Exclosure Sites

Vegetation at exclosure sites was monitored using the following methods:

- Paired 5 m x 2 m quadrats to measure cover of short-lived plant species.
- Paired 20 m x 2 m quadrats to measure cover and density of long-lived perennial plant species.
- Paired 50 m x 1 m shrub count quadrats.
- Whole exclosure/control site species lists.

Each exclosure or control area contained two sets of quadrats. The layout of quadrats was the same at each set of exclosures and is shown in Figure 3.1.

A monitoring programme was designed with assistance from Dr Tim Fatchen (Badman and Fatchen 1993) and the seven sets of exclosures were monitored for the first time during March and April 1993. Monitoring was then carried out at approximately six-monthly intervals until October 1996 (Wilpoorinna) or April 1997 (Billa Kalina and Dulkaninna). The Cowarie exclosure was monitored at approximately yearly intervals while waiting for a flood in the Warburton River. No flood occurred here between 1993 and 1997. Monitoring of the Wilpoorinna exclosure was stopped after October 1996 because a horse got inside the rabbit-proof exclosure and destroyed much of the vegetation.

Density and cover for each long-lived perennial species was recorded in the 2 x 20 m quadrat by measuring two crown diameters for each plant. The longest diameter was measured first, followed by the widest diameter at right angles to the first measurement. Only live parts of each plant were measured. These data were later entered into a computer program that calculated the cover value for each plant as an ellipse and added it to the total for each species in the quadrat. The program also added each plant to the density count for each species at each site. Adult and juvenile densities were recorded and calculated separately. Juvenile plants were considered to be those which had only one pair of leaves and no noticeable thickening of the main stem. Cover of plants rooted outside the quadrat was calculated only for that part of the plant overhanging the quadrat and this value was added to the total for the species. No density value was recorded for species rooted outside the quadrat. Density values were multiplied by 1.25 so that the total for the paired quadrats gave a value per 100 m^2.

Cover of short-lived plants was estimated in the 2 x 5 m quadrat by dividing the quadrat into 10 cells, each 1 m x 1 m, and estimating cover of each species in each cell. All standing short-lived vegetation was scored, irrespective of whether it was still alive. The sum of the values for the 10 cells was then calculated and divided by 10 to give the mean cover of each species.

Cover data from the two quadrats in each exclosure or control site were averaged to give a mean value per site. Density data from the two quadrats were added together and multiplied by five to give a value per 100 m^2. Averaging of the data from the two quadrats was considered necessary because of the extreme natural patchiness of some sites, especially on gibber plains.

Shrubs were counted along the two 50 m shrub count quadrats and the values added for each exclosure or control site to give a count per 100 m^2 that is directly comparable to the values obtained from the 2 x 20 m quadrats.

The final stage of monitoring was to inspect the whole exclosure or control site and list any species which were not recorded in the various quadrats at that site.

3.9.4.2 Andamooka Station Grazing Experiment

The line transect method was used to collect data from the Andamooka Station grazing experiment site. This involved running a 100 m tape out along random transects in a north-south direction (across the dunes - Figure 3.2) and recording as one score the plant species beneath each one metre point on the tape, or where there were no plants, whether there was lichen cover or bare ground. All standing short-lived vegetation was scored, irrespective of whether it was still alive. Only living parts of shrubs were scored The tape was allowed to lie slack on the ground or on top of plants and whatever was directly beneath the one metre line on the opposite side of the tape from the observer, who observed from directly above the tape, was recorded. Theoretically, a tight tape would have given more accurate results, but in practice it would have been impossible to work out what was beneath the mark in the frequently windy conditions when a tight tape would swing over more than a metre. The method used may have slightly overestimated the cover of chenopod shrubs, but the tape was run out beneath or through tall shrubs on dunes, so this problem did not occur there. Two transects were recorded in the control site on the mine lease and sufficient transect in each of the two fenced paddocks to obtain a similar number of points for each soil type. The stone (gibber) cover was recorded during the first survey, but was not recorded during subsequent surveys, when stone was scored as bare ground. The number of data points were later converted to cover percentages.

During the initial survey, a total of around 15 000 points was recorded in the control and two paddock sites, around 5000 points in each. This number was reduced in subsequent surveys to between 2000 and 2500 points in each paddock and the control site, giving more than 1000 points on sand and 1000 points on clay for the grazing sites and 1200 points on sand and 1200 points on clay divided between the two transects at the control site.

The timing of the first four surveys was entirely determined by the pulse grazing, which was controlled by John Read of the Olympic Dam Environmental Department. The timing of the 1997 monitoring was planned for about one year after the final grazing pulse, but was eventually determined by a heavy rainfall event of February 1997. Monitoring was carried out in April 1997 when plant growth, particularly of short-lived species, was considered to have reached its maximum.

3.9.4.3 Olympic Dam Vegetation Monitoring Sites

Vegetation monitoring carried out by Olympic Dam Operations is of two types: the first is designed to detect any effects of the mine or related activities on the surrounding vegetation; the second follows the progress of rehabilitation on disturbed areas, particularly drill pads. Only the first is considered in this thesis. The latter was discussed by Badman (1995a).

Data have been collected on the mine and municipal leases and on surrounding pastoral land since March 1981, but more particularly and at approximately six-monthly intervals since May 1986. Data analysed as part of this study are of two kinds:

1) Quantitative data on density of long-lived perennial species and cover of all species (all standing short-lived vegetation was scored, irrespective of whether it was still alive) at 5 m x 2 m quadrats. Data from May 1986 to November 1996 are analysed in this study;

2) Quantitative data on the density of chenopod shrubs, collected at 100 m x 1 m shrub count quadrats since 1986.

The layout of these quadrats is shown in Figure 3.3. Data were also collected on presence and absence of species in a series of nested quadrats, but these data are not considered here.

The first vegetation monitoring undertaken at Olympic Dam (baseline survey) was carried out in 1981 (Fatchen 1981) as part of the studies associated with the Olympic Dam Draft Environmental Impact Statement (Kinhill-Stearns Roger 1982). The principal aims of this study were to place the development site in its appropriate broad regional context; to map and describe the vegetation in the study areas; and to collect detailed and quantitative data which could be used as the basis for future monitoring. The monitoring programme was based on methods first described by Fatchen (1975).

A series of quadrats was set up to monitor any effects of the mine or mine-related activities on vegetation surrounding the mine site, the proposed town site and on surrounding pastoral land. On-going vegetation monitoring was designed to provide an understanding of normal seasonal and long-term changes in the vegetation, the relationship of vegetation to landscape, and influences and effects on vegetation of the mine development and associated land uses (Badman 1994).

The initial location of quadrats is not of great significance because quadrats are used only for comparison with themselves over time. Unlike quadrats used in monitoring the effectiveness of rehabilitation, where positioning of quadrats is open to suggestions of bias in their selection (Badman 1995a), inclusion of lightly or heavily vegetated areas within quadrats is not critical.

Entry on to a computer database was adopted as the most efficient way of handling data. This method allows storage of large amounts of data and examination of a wide range of variables. The most important variables are those related to cover and density over time. The cover and density of perennial plants are important because these plants are the ones which survive in the arid zone through dry periods and so minimise soil erosion. Total cover measurements are less important because these contain a large component of ephemeral species which will not be present during dry times. However, changes in species composition or diversity under similar seasonal conditions are important and may be indicative of long-term change.

3.9.4.4 Timing and Frequency of Surveys

Monitoring of vegetation at the Billa Kalina, Dulkaninna and Wilpoorinna exclosure sites and at Olympic Dam was carried out twice yearly. At the exclosure sites this was generally in March or April and in October or November. The Cowarie exclosure site was monitored only once in each calendar year during the monitoring period because it was located on a floodplain to detect changes in floodplain vegetation brought about by the removal of grazing. No flood occurred during the life of the monitoring, so more frequent monitoring was not considered warranted. At Olympic Dam vegetation monitoring is usually carried out in May and November in order to fulfil statutory Government requirements but also to allow trends in vegetation dynamics caused by both summer and winter rainfall events to be detected. The dates of all surveys at the exclosure sites and at Olympic Dam is given in Table 3.5.

The frequency of monitoring at the grazing experiment site was determined by the timing of grazing pulses. Monitoring was carried out before and after each of the two grazing pulses and 13 months after the second grazing pulse, following an above average rainfall event. The timing of exclosure and Olympic Dam surveys is given in Table 3.5 and of grazing experiment surveys in Table 3.6.

3.10 REASONS FOR USING THESE METHODS

The problems associated with collecting vegetation data from rangeland sites, particularly the differences between observers, have been discussed by numerous workers (e.g. Goodall 1952, Winkworth *et al.* 1962, Walker 1970, Holm *et al.* 1984, Barbour *et al.* 1987, Friedel and Shaw 1987a, 1987b, Wilson *et al.* 1987, Friedel 1990). The use of quadrats is a traditional way of sampling rangelands (Ripley 1987). The methods used for monitoring vegetation at the exclosure sites have the advantage of gathering the maximum amount of data in a relatively short period of time with a minimum amount of effort. They encompass many of the techniques which have been used successfully for more than 17 years to monitor environmental change at the nearby Olympic Dam Operations. The dynamic Olympic Dam vegetation monitoring programme is able to detect change and so be used to modify environmental and engineering practices at the mine.

Table 3.5: Dates and seasons for time codes used for Olympic Dam quadrats and soil board exclosure databases.

Time Code	Year	Season	Month: Olympic Dam Sites	Month: Billa Kalina Exclosures	Month: Marree SCB Exclosures
T01	1981	Autumn	March		
T02	1982	Summer	January		
T03	1982	Spring	November		
T04	1984	Summer	January		
T05	1984	Spring	November		
T06	1985	Spring	November		
T07	1986	Autumn	May		
T08	1987	Autumn	May		
T09	1987	Spring	November		
T10	1988	Autumn	May		
T11	1988	Spring	November		
T12	1989	Autumn	May		
T13	1989	Spring	November		
T14	1990	Autumn	June		
T15	1990	Spring	December		
T16	1991	Autumn	May		
T17	1991	Spring	November		
T18	1992	Autumn	May		
T19	1992	Spring	November		
T20	1993	Autumn	May	March	April
T21	1993	Spring	November	September	September
T22	1994	Autumn	May	April	April
T23	1994	Spring	November	November	September
T24	1995	Autumn	May	April	April
T25	1995	Spring	November	November	October
T26	1995	Summer			December
T27	1996	Autumn	May	April	April
T28	1996	Spring	November	October	October
T29	1997	Autumn	May	April	April
T30	1997	Spring	November		

The above techniques are more accurate than the step-point method (Evans and Love 1957), which is open to bias between observers, or even with the same observer, depending on whether the observer avoids stepping on and destroying plants. The number of large plants is also overestimated and small plants underestimated by this method (Strauss and Neal 1983). Wheel-point monitoring (Griffin 1989) is less open to bias than step-pointing, although bias is still more likely than when using the methods outlined above.

Table 3.6: Dates of monitoring events at the Andamooka grazing experiment site.

Time Code	Date	Grazing Status
T1	March 1995	Prior to first grazing pulse
T2	July 1995	After first grazing pulse
T3	November 1995	Following recovery and prior to second grazing pulse
T4	February 1996	After second grazing pulse
T5	April 1997	After recovery following heavy rainfall event

The line transect method was used for the grazing experiment to obtain a large amount of data in a relatively short time. The step-point method, as used by the South Australian government for rangeland monitoring, was not used because of the problems outlined above. The wheel-point method was the preferred alternative, but is was not possible to obtain a wheel point monitor in the time prior to the introduction of the first mob of cattle. The line transect was chosen as the next best practical alternative.

Biomass, comparative yield and dry-weight-rank estimations (Friedel and Shaw 1987a, Friedel *et al.* 1988) were not considered appropriate for this study because they are extremely time-consuming and require considerable re-training of the observer before each monitoring event. Most information gained by this method can be obtained faster and more reliably by cover and density estimates and measurements. Percentage cover is a good measure of plant abundance (Kershaw and Looney 1985).

The problems of quadrat selection outlined by Kershaw and Looney (1985) and Barbour *et al.* (1987) are not relevant to the soil board exclosures and the Olympic Dam data because the quadrat locations were designed for comparison with themselves over time. Their selection was therefore straightforward (Friedel 1990), because they were not required to give absolute values of the vegetation from a single reading or to compare directly with data from another area.

Mapping of individual trees and shrubs, a technique which has been employed for monitoring numerous exclosures in South Australia, is extremely time intensive. It also produces data that are extremely difficult to analyse and fails to address changes in cover of ephemeral plant species. It is really this latter point which makes this method completely unsuitable for the current study. While long-lived perennial plants are most important as soil stabilisers and to a lesser extent as drought feed for domestic stock, it is the ephemeral and biennial plants which form the majority of species that are of economic importance to the pastoral industry. It is also important to detect long-term changes in species distribution and for this reason it is imperative that a system that uses quantitative data on all species is employed.

The methods employed in this monitoring system fulfil all of these requirements. For the exclosure and grazing experiment monitoring, I performed all cover estimates. I also supervised all shrub cover measurements that I did not make myself, thus removing most of the differences resulting from different observers (Holm *et al.* 1984). Various assistants measured shrub crown diameters and counted shrubs at the exclosure sites, although one observer (Shane Badman) either measured or recorded shrub measurements on the majority of occasions.

3.11 DATA ANALYSIS

Classification and ordination (Foran *et al.* 1986) were the main tools used in analysis of the various datasets used in this study. The computer package PATN (Belbin 1991a) was used to carry out the classifications and ordinations. The value of pattern and ordination in vegetation analysis was discussed above in Section 2.12.5.

3.11.1 Preparation of Data

All monitoring events for the exclosures, the grazing experiment and Olympic Dam sites were given a unique row label (RowLab) for the purposes of data analysis. Each row label included a time code (Tables 3.5, 3.6), a site identification letter (Table 3.7), and a site number (Appendix C). The time codes represented the generally six monthly recording periods for each data set. The only monitoring that did not fall within the six monthly interval, excluding the grazing experiment, was T26 at the Dulkaninna exclosures, which was only two months after the previous monitoring. This monitoring event was carried out specifically to detect any changes brought about by heavy rainfall immediately following a regular monitoring event. So that time could be easily compared in real terms between the data sets, the exclosure data collection began at T20 (Table 3.5).

The short-term grazing experiment was allotted its own time code because the timing of monitoring was dictated by the grazing pulses and was at different and less regular, but often more frequent, intervals when compared to the other monitoring.

Table 3.7: Explanation of RowLab and other codes used in data analysis.

RowLab Code	Position in Code	Applicable Dataset
Time Code		
T01-T30	First three characters	T01-T25, T27-T30, Olympic Dam shrub-count data; T07-T25, T27-T28, Olympic Dam cover data; T20-T25, T27-T29, Billa Kalina exclosure data; T20-T27, Wilpoorinna exclosure data; T20-T27, T29, Dulkaninna exclosure data; T20, T22, T25, T28, Cowarie exclosure data
T1-T5	First two characters	Grazing Experiment data
Location Identifier		
K	Fourth character	All Billa Kalina exclosure data (Kingoonya SCD)
M	Fourth character	All Wilpoorinna, Dulkaninna and Cowarie exclosure data
G	Fourth character	All grazing experiment data
OD	Fourth and fifth characters	All Olympic Dam data
Site Numbers		
1-4	Fifth character	All exclosure data
01-86	Sixth and seventh characters	Olympic Dam data
Site Type		
C	Sixth character	All exclosure data
R	Sixth character	All exclosure data
S	Sixth character	All exclosure data

Other Codes	
Vegetation Association	Olympic Dam cover data
1	Dune vegetation generally dominated by tall shrubland
2	Dune base vegetation with *Acacia aneura* low woodland
3	Swale vegetation dominated by chenopod shrublands
4	Swale vegetation dominated by *Acacia papyrocarpa* low woodland
Land Use	Olympic Dam cover data
0	Pastoral lease
1	Undeveloped parts of the Special Mining Lease and not subject to domestic grazing
2	Parts of the Special Mining Lease used for development or exploration purposes, but not subject to domestic grazing
3	The Roxby Downs Municipal Lease, subject to disturbance by town-related activities but not subject to domestic grazing

Some data were also analysed using the two-way facility within the PATN computer software package (Belbin 1991b).

The Olympic Dam data were also classified according to vegetation association and land use. The codes used are also given in Table 3.5. Detailed descriptions of the vegetation associations are given above in Section 3.7

In order to keep the row label to eight characters or less, and thus conform with the computer package PATN (Belbin 1991a), it was necessary to shorten the original Olympic Dam site identification numbers. Site numbers not used in the analysis were omitted from the new site code (Appendix C).

Rainfall records from Roxby Downs Station, about 30 km from Olympic Dam, were used for the period before Olympic Dam rainfall recording began in mid-1981. These were necessary for use in the calculation of rainfall environmental variables used in the analysis.

All cover values are percentages. All shrub count data have been converted to units per 100 m^2. Section 4.5 deals with the presence or absence of species as a monitoring tool. No cover or density values are used in this section.

3.11.2 Data Analysis

Multivariate analysis of both cover and density data were carried out by means of the PATN computer software package (Belbin 1991b, 1992). The Bray-Curtis measure of dissimilarity (Bray and Curtis 1957) with unweighted pair-group mean association (UPGMA) clustering was used to classify the relevés according to their floristic composition and canopy cover or density and to produce dendrograms by means of agglomerative hierarchical fusion. Ordination of sites was performed using SSH (Belbin 1991a) or Principal Coordinate Analysis (PCoA) (Legendre and Legendre 1983). The group statistics feature of PATN (GSTA) was used to determine the significant plant species in the composition of each group and each cluster. Environmental parameters were compared with the plant-based ordinations using the principal canonical correlation (PCC) feature within PATN.

The Bray-Curtis measure of dissimilarity estimates the association between pairs of objects. It is recommended when matches between higher values of attributes are more significant than matches between lower values of the same attributes (Belbin 1995a). It has consistently performed well in a variety of tests and simulations on different types of data and when used with species composition data, this method has been shown to be robust (Faith *et al.* 1987) and to give site classifications similar to those assigned by experienced field workers (Foran *et al.* 1986). Foran *et al.* (1986) found that ordination of their data showed that range condition and seasonal influences were strongly correlated with the position of sites along ordination vectors.

Ordination methods produce a summary of the data by reducing the number of significant variables. Ordination attempts to reduce the information contained in all attributes into a small number of new attributes with minimal loss of information (Belbin 1995a). If two or three such attributes can be found, it is then possible to produce a scatter plot of objects using these attributes as axes (Belbin 1995b). The distance between objects then represents their degree of similarity, or dissimilarity, as measured by the full set of attributes. Objects that are close in the plot are those that are similar, while objects separated by large spaces are dissimilar. Natural clustering of objects can easily be identified.

Semi-Strong Hybrid Multidimensional Scaling (SSH) is an ordination algorithm developed by Belbin (1991a) to improve the "ecological distance" between sites when they have few species in common. It permits greater flexibility in data handling than other ordination methods (Belbin 1995b) and is an appropriate ordination technique when the Bray-Curtis association measure has been used (Belbin 1995a). It was used as the primary ordination tool for analysis of the exclosure and grazing experiment data.

SSH is most successful on datasets containing 200-500 rows of data, where it is considered by Belbin (1995b) to be superior to other techniques such as principal components/coordinates, correspondence analysis/reciprocal averaging and other multidimensional scaling programs. It is less successful when analysis involves more than 1000 rows of data (Belbin 1991b). The Olympic Dam datasets involved up to 1304 rows of data and the combined exclosure and Olympic Dam datasets, discussed in Chapter 7, contained 1490 rows. In these cases PCoA (Legendre and Legendre 1983) was used to carry out the ordination.

Kershaw and Looney (1985) considered PCoA to be an extremely efficient ordination technique. Although it has now been largely superseded by techniques such as SSH, it is still a valuable tool for ordination of vegetation data, particularly with large datasets. Before this method can be employed in PATN, it is first necessary to carry out the Gower correction to enable association measures to be used in Principal Component Analysis (PCA). The combined transformation is then known as PCoA. The Gower correction converts the association inferred from most proximate values into Euclidian form (Belbin 1995b). PCoA can then be used to find a linear combination of attributes for each new attribute so as to account for decreasing proportions of variance (Belbin 1995b).

Significant species, environmental parameters (Table 3.8) and groups or clusters mentioned in Chapters 4-6 were those that were identified by the analysis as having a statistical probability of <0.05.

Table 3.8: Environmental parameters used in data analysis.

Environmental Parameters	Exclosures	Grazing Experiment	Olympic Dam
Soil type	No	Yes	Yes
Litter cover	No	Yes	Yes
Lichen cover	No	Yes	No
Rainfall in previous month	Yes	Yes	Yes
Rainfall in Previous 2 Months	Yes	Yes	Yes
Rainfall in Previous 3 Months	Yes	Yes	Yes
Rainfall in Previous 6 Months	Yes	Yes	Yes
Rainfall in Previous Year	Yes	Yes	Yes
Rainfall in Previous 2 Years	Yes	Yes	Yes
Rainfall in Previous 3 Years	Yes	Yes	Yes
Rabbit Grazing Impacts	Yes	No	No
Rabbit numbers	Yes	No	No
Stock Grazing Impacts	Yes	No	No

CHAPTER 4 SOIL BOARD GRAZING EXCLOSURES

4.1 INTRODUCTION

There has been a long-running debate between rangeland ecologists over the relative impacts of herbivores and climate on the condition of rangeland ecosystems (Morton 1990, Leigh and Briggs 1992, Reid and Fleming 1992, Morton and Pickup 1992). Construction of exclosures to exclude different herbivores by means of different types of fencing has been used successfully to separate the effects of various grazing animals from those of seasonal conditions (Foran *et al.* 1982, Bock *et al.* 1984, Orr and Evenson 1991, O'Reilly 1998).

Traditionally, ungrazed rangeland ecosystems were seen as either having a single persistent state, or as following a defined path following disturbance by factors such as fire, until they reached a climax state (Section 2.12). Grazing was seen as causing regressive changes. Manipulation of the grazing pressure was expected to maintain a condition that produced an acceptable yield for the pastoralist and also maintained biodiversity at an acceptable level in the long-term.

Early ecological research was often biased by research on a small number of taxa that may not always be functionally significant in arid ecosystems and was often based on work carried out in the Northern Hemisphere (Stafford Smith and Morton 1990). Some researchers considered that conditions are simply different in Australia, but because of a lack of conceptual models were left without fundamental explanations (Stafford Smith and Morton 1990).

More recent work (Westoby *et al.* 1989) has suggested the use of a model based on "state and transition". In this model, drought is considered to affect vegetation in the same way as grazing and above-average rainfall years to have effects that accelerate transitions. It is the responsibility of management to respond to drought by reducing grazing pressure so that the combined effects of drought and grazing are kept in a more or less stable condition. This will maintain the balance of these two factors (Westoby *et al.* 1989) and the condition of vegetation thus remains stable. This model was discussed in more detail in Section 2.12.3.

Rabbits are often held responsible for the lack of recruitment of some shrub species (Section 2.5.1). Exclosures can also be used to investigate the relative recruitment of some shrub species in the absence of rabbit or stock grazing, although the time frame for this may be beyond the scope of the present study. The effectiveness of exclosures for determining the effects of rabbits in the present study was further impaired by the spread of RCD and the death of most rabbits in the study areas during the monitoring period. Some long-lived plant species or populations may also require the occurrence of a set of unusual events for recruitment to be successful (Westoby *et al.* 1989, Read 1995). These events may include such things as random successive heavy rainfall over small areas. Resultant populations may then persist for a long time. In such cases exclosures such as those used in this study may be too small or too few in number to exploit these events.

4.2 AIMS

The soil board exclosure project was designed as several experiments (replicates) to the same design. These were intended to obtain long-term data on the effects of grazing by domestic stock and rabbits on three types of vegetation community. These communities are chenopod shrubland on clay soils (Billa Kalina) and sandy soils (Wilpoorinna), grassland and herbland on sandplains (Billa Kalina) and gibber plains (Dulkaninna), and shrubland and ephemeral vegetation of the Warburton River floodplain (Cowarie). The present analysis represents the second stage of this project, following earlier preliminary reports (Badman 1998a, 1998b). It is intended that monitoring will continue, but at less frequent intervals than was the case during data collection for this thesis.

The aims of the present study are to find out whether the exclusion of exotic herbivores results in increased:

- vegetation cover
- species richness
- recruitment of perennial shrubs

in chenopod shrublands and associated dunefields in northern South Australia.

Two further aims are to find out whether:

- Exclusion of cattle and rabbits affects the vegetation of the Warburton River floodplain.
- This type of study requires the collection and analysis of cover data for each species, and density data for long-lived perennials, or will the presence or absence of species supply the same results.

4.3 RESULTS

4.3.1 GRAZING IMPACTS

The exclosures were generally effective in excluding the animals that they were designed to exclude. The few exceptions are listed in the following sections.

4.3.1.1 Rabbits

The initial analysis of grazing impacts used the qualitative data (Tables 4.1 and 4.2) on the presence at two levels or the absence of grazing impacts at all sites for both rabbits and domestic stock. Results of this analysis showed that neither rabbit nor cattle impacts were significant. In order to check this, data from the Billa Kalina sites, where quantitative data on rabbit densities were available (Figure 4.1), were examined separately.

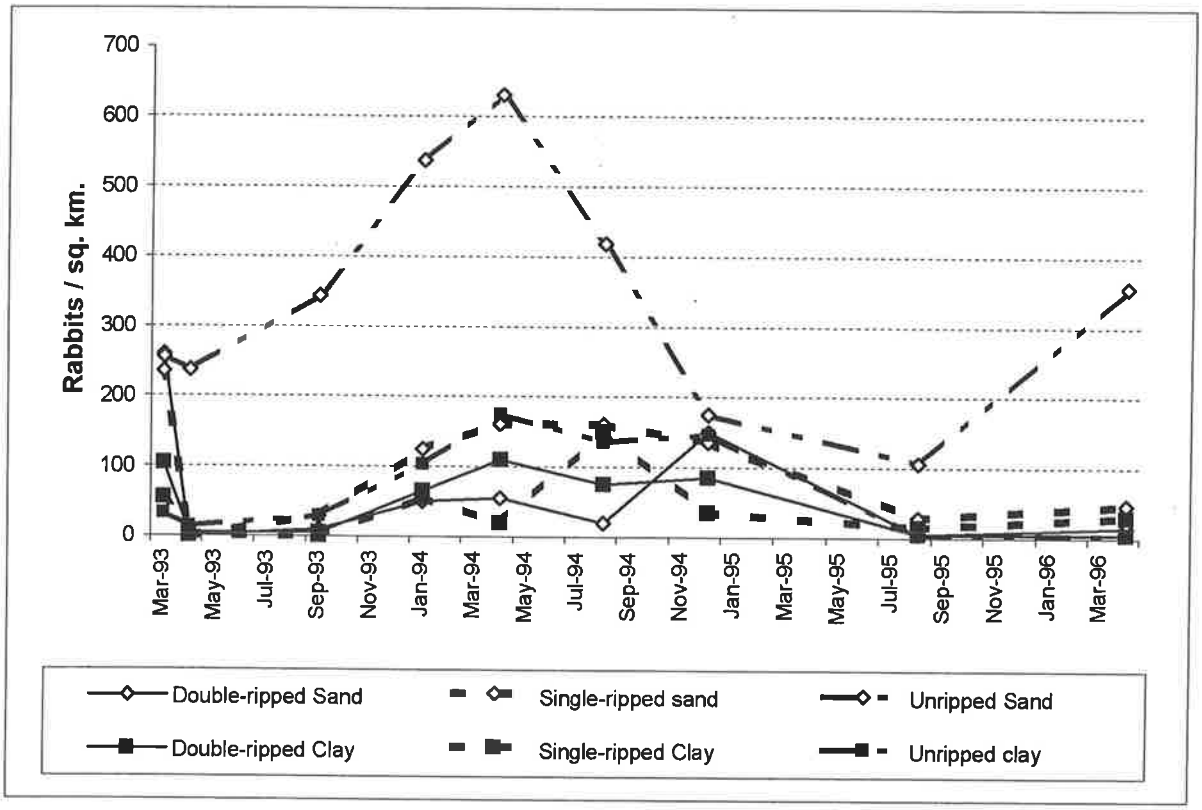

Figure 4.1: Rabbit densities in the vicinity of the Billa Kalina exclosures.
(2R = double-ripped country, 1R = single-ripped country, UR = unripped country).

Preparation of data from the Billa Kalina sites for this secondary analysis involved separating the data for the four individual sites and the two extra control sites, the six areas for which rabbit density data were available, and removing those relevés (unique combinations of temporal and spatial monitoring events) from two monitoring periods when no rabbit counts were available. The rabbit densities were added to the other environmental variables (Table 3.8). These are discussed in Section 4.3.2.7. Data were then analysed using the methods described in Section 3.11.2.

The recorded incidence of rabbit grazing at exclosure sites is shown in Tables 4.1 and 4.2. Apart from the sandy sites at Billa Kalina, the only site where consistent evidence of rabbit grazing was observed was at Wilpoorinna. No evidence of rabbits was seen at Cowarie and light grazing was recorded only infrequently at Dulkaninna. The highest rabbit densities were recorded on unripped sandplain country at Billa Kalina during 1994, with a lesser peak in 1996. The ripping programme was generally successful in reducing rabbit numbers, at least in the short-term. RCD spread through the rabbit population at Billa Kalina towards the end of the monitoring period and the growth pulse in the vegetation recorded in April 1997 was hardly affected by rabbit grazing.

There was a single case of one or two rabbits having been inside the rabbit-proof exclosure at Billa Kalina Site 2 in November 1994.

Table 4.1: Incidence and severity of grazing pressure at Billa Kalina monitoring sites.
(Stock = stock-proof exclosure, C1 = 1st control site, C2 = 2nd control site, - = no grazing evident, L = light grazing evident, H = heavy grazing evident). No grazing indicates that there was no sign of plants having been chewed, or of the tracks of herbivores. Light grazing indicates that there was evidence of a small number of plants (<10) having been grazed or a small number (1-3) of herbivore tracks were recorded. Heavy grazing indicates grazing of >11 plants, or a large number of tracks of hervivores recorded.

Cattle Impacts	Site										
	1			2			3		4		Totals	
	Stock	C1	C2	Stock	C1	C2	Stock	C	Stock	C	H	L
September 1993	-	L	L	-	L	L	-	L	-	L	0	6
April 1994	-	H	-	-	L	L	-	-	-	-	1	2
November 1994	-	L	L	-	-	L	-	H	-	L	1	4
April 1995	-	L	L	-	-	-	-	-	-	-	0	2
December 1995	-	L	H	-	L	L	-	H	-	L	2	4
April 1996	-	-	-	-	-	-	-	-	-	-	0	0
October 1996	-	-	-	-	-	L	-	L	-	-	0	2
April 1997	-	-	-	-	-	-	-	-	-	-	0	0
Total - High	0	1	1	0	0	0	0	2	0	0	4	
Total - Low	0	4	3	0	3	5	0	2	0	3		20
Totals	**0**	**5**	**4**	**0**	**3**	**5**	**0**	**4**	**0**	**3**		**24**

Rabbit Impacts	1			2			3		4		Totals	
	Stock	C1	C2	Stock	C1	C2	Stock	C	Stock	C	H	L
September 1993	L	L	-	L	L	L	L	L	L	L	0	9
April 1994	L	L	H	L	L	L	H	H	L	H	4	6
November 1994	H	H	L	L	L	L	H	H	L	L	4	6
April 1995	H	H	H	L	L	-	H	H	-	L	5	3
December 1995	L	L	L	L	L	L	H	H	L	L	2	8
April 1996	-	-	L	-	-	L	L	H	-	L	1	4
October 1996	-	-	-	L	L	-	-	-	-	-	0	2
April 1997	-	-	-	-	-	-	-	-	-	-	0	0
Total - High	2	2	2	0	0	0	4	5	0	1	16	
Total - Low	3	3	3	6	6	5	2	1	4	5		38
Totals	**5**	**5**	**5**	**6**	**6**	**5**	**6**	**6**	**4**	**6**		**54**

4.3.1.2 Domestic Stock

The fencing at the Billa Kalina, Dulkaninna and Cowarie sites was effective in excluding the animals for which it was designed. There were no cases of cattle entering the stock-proof exclosures at these sites. Stock impacts were recorded within the perimeter of the Wilpoorinna exclosures in the April 1993 baseline survey, but these remained from before the fence was completed. A horse was trapped inside the rabbit-proof exclosure at Wilpoorinna for several days after the April 1996 reading and this ended the monitoring at this site for the present study.

The incidence of grazing by cattle at the Billa Kalina sites is shown in Table 4.1 and at the Marree SCB sites in Table 4.2. The impact of cattle grazing was greatest at sandplain sites (Billa Kalina Sites 1 and 3). There was only light grazing by horses in control sites at Wilpoorinna and by cattle in control sites at Dulkaninna.

No grazing of any kind was recorded at the Cowarie exclosure site. The minimal cattle grazing at control sites reflected the low grazing pressure at all sites during the survey. At Billa Kalina and Cowarie this was due to dry seasonal conditions.

4.3.1.3 Kangaroos

One case of light kangaroo grazing and one case of heavy kangaroo grazing were recorded within the stock-proof exclosure at Billa Kalina Site 1 in April and November 1994 respectively. Heavy kangaroo grazing was recorded at the control site at Billa Kalina Site 1 in November 1994. At the Wilpoorinna site, kangaroos had sometimes camped in the shade of an *Acacia aneura* tree that subsequently became part of one of the quadrats. This area had been scraped out by the kangaroos and was heavily disturbed, but kangaroos did not use this place once the fence was erected. No evidence of kangaroo grazing was recorded at any other sites.

4.3.2 COVER DATA

4.3.2.1 Classification of the Cover Data

The initial analysis involved 186 rows of data. All species with a cover value < 0.1% were omitted from the analysis. The dendrogram obtained from a classification of the cover data, presented in Appendix D, was cut at the Bray-Curtis 0.96 level of dissimilarity to give 14 groups. A simplified dendrogram was then produced from the means of the 14 groups. This is presented in Figure 4.2, with group membership shown in Appendix E. Four clusters were identified at the 1.6

level of dissimilarity. The plant-based and soil features of each cluster are shown in the stylised dendrogram presented in Figure 4.3.

Table 4.2: Incidence and severity of grazing pressure at Marree monitoring sites.

(Stock = stock-proof exclosure, C1 = 1st control site, C2 = 2nd control site, - = no grazing evident, L = light grazing evident, H = heavy grazing evident, nr = quadrat not read). No grazing indicates that there was no sign of plants having been chewed, or of the tracks of herbivores. Light grazing indicates that there was evidence of a small number of plants (<10) having been grazed or a small number (1-3) of herbivore tracks were recorded. Heavy grazing indicates grazing of >11 plants, or a large number of tracks of hervivores recorded.

Stock Impacts

	Wilpoorinna			Dulkaninna			Cowarie		
	Rabbit	Stock	Control	Rabbit	Stock	Control	Rabbit	Stock	Control
April 1993	L	L	L	-	-	-	-	-	-
September 1993	-	-	L	-	-	L	nr	nr	nr
April 1994	-	-	L	-	-	L	-	-	-
September 1994	-	-	L	-	-	-	nr	nr	nr
April 1995	-	-	L	-	-	-	nr	nr	nr
September 1995	-	-	L	-	-	L	-	-	-
December 1995	nr	nr	nr	-	-	-	nr	nr	nr
April 1996	-	H	L	-	-	L	nr	nr	nr
September 1996	nr	nr	nr	nr	nr	nr	-	-	-
April 1997	nr	nr	nr	-	-	-	nr	nr	nr
Total - High	0	1	0	0	0	0	0	0	0
Total - Low	1	1	7	0	0	4	0	0	0
Totals	**1**	**2**	**7**	**0**	**0**	**4**	**0**	**0**	**0**

Rabbit Impacts

	Wilpoorinna			Dulkaninna			Cowarie		
	Rabbit	Stock	Control	Rabbit	Stock	Control	Rabbit	Stock	Control
April 1993	L	L	L	L	L	L	-	-	-
September 1993	L	L	L	-	-	-	nr	nr	nr
April 1994	L	L	L	-	-	L	-	-	-
September 1994	L	L	L	-	L	L	nr	nr	nr
April 1995	-	L	L	-	L	-	nr	nr	nr
September 1995	L	L	H	-	L	L	-	-	-
December 1995	nr	nr	nr	-	-	-	nr	nr	nr
April 1996	-	-	-	-	-	-	nr	nr	nr
September 1996	nr	nr	nr	nr	nr	nr	-	-	-
April 1997	nr	nr	nr	-	-	-	nr	nr	nr
Total - High	0	0	1	0	0	0	0	0	0
Total - Low	5	6	5	1	4	4	0	0	0
Totals	**5**	**6**	**6**	**1**	**4**	**4**	**0**	**0**	**0**

Summary information on each cluster and group is given in Table 4.3 and a brief description in Table 4.4. A description of each group is given in Section 4.3.2.2. The most significant species (as determined from the probabilities from the PATN GST files) in the composition of each group are included in the group descriptions, with a full list of these species presented in Appendix F. An ordination of all relevés at the cluster level is shown in Figure 4.4 and the centroids of the 14 groups in Figure 4.5. These are discussed in more detail below.

4.3.2.2 Description of Classification Groups

The term "group", as used in this thesis, is an artificial one representing vegetation "associations" that meet certain criteria and describe a certain condition. Changes in seasonal conditions or other events caused "shifts" between groups when the vegetation at a site changed and met the criteria of a different group. These shifts are discussed in Section 4.3.2.4.

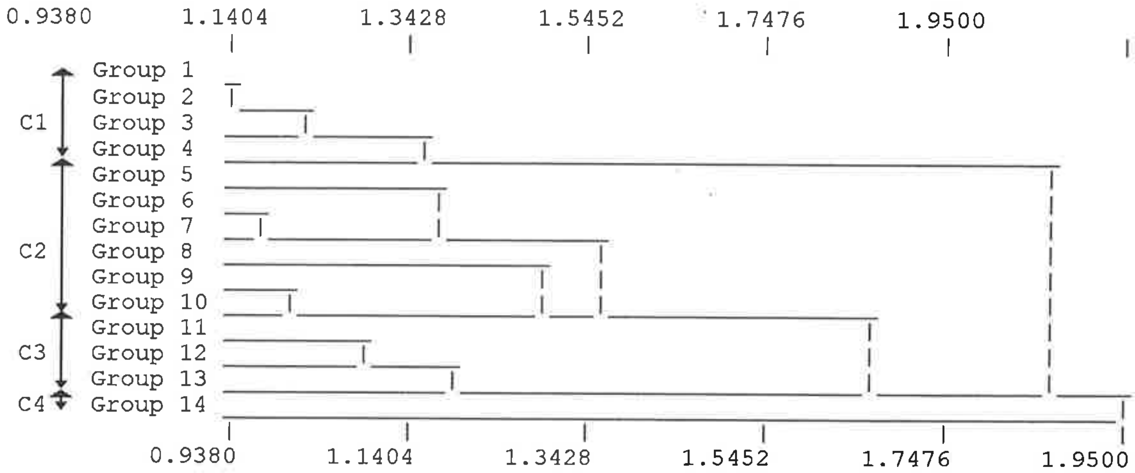

Figure 4.2: Dendrogram showing the 14 groups in four clusters (C1-C4) obtained by classification of the exclosure sites cover data.

Cluster 1

This cluster contains most of the relevés from the sandy sites at Billa Kalina and the control site at Wilpoorinna. Median cover and species richness are relatively high (Table 4.3). *Enneapogon avenaceus* is the most important species in this cluster, with a mean cover of just under 5%.

<u>*Group 1*</u>

Relevés in this group are all from sandy sites at Billa Kalina. They have mid-range median cover and species richness. Vegetation is dominated by *Enneapogon avenaceus*, with *Gunniopsis quadrifida*, *Sclerolaena diacantha*, *Othonna gregorii*, *Brassica tournefortii*, *Salsola kali* and *Sida ammophila* also important. *Maireana astrotricha* is significant in the composition of this group, but *Atriplex vesicaria* is not. Relevés from Billa Kalina Site 3 attained the criteria of this group and shifted into it at the third monitoring event as seasonal conditions changed (Table 4.5). No sites remained in this group at the end of the monitoring period.

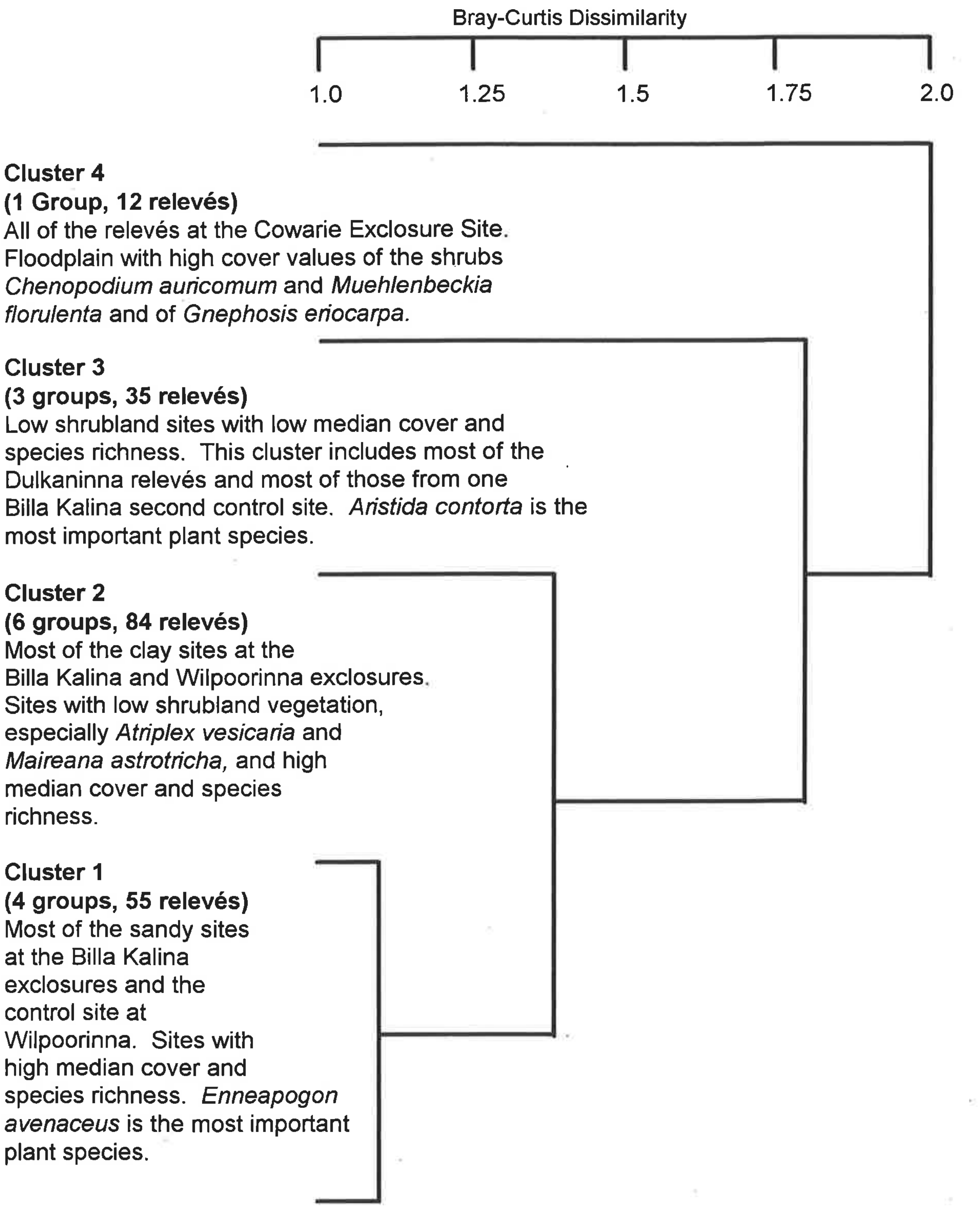

Figure 4.3: Stylised dendrogram of cluster relationships with plant and soil indicators for each cluster from the classification of the exclosure cover data (Appendix D).

<u>Group 2</u>

This group includes sandy sites at Billa Kalina with lower median cover but higher median species richness than Group 1 sites. This group was not represented in the pattern analysis until May

1995 when some sites that were previously in Group 1 had shifted into it. Other Group 1 sites had shifted to Group 2 by November 1995 and November 1996. No single species dominates in Group 2, although eight ephemeral species reached their highest mean cover values here. *Maireana astrotricha* is significant in the composition of this group, but *Atriplex vesicaria* is not.

Table 4.3: Details of the composition of the four clusters and 14 groups identified from classification of the exclosure sites cover data (Appencix C).
The number of significant species refers to all species that were identified by PATN analysis as being significant ($p<0.05$, as determined from the probablilities from the PATN GST files) to the make up of that cluster or group. Median species richness and cover are the median values for all relevés for that group.

	No. Of Relevés	No. of Significant Species	Total no. of Species	Median Cover (%) (Range)	Median Species Richness (Range)
Cluster 1	55	36	103	14.5 (5.8-29.4)	21 (8-34)
Cluster 2	84	43	129	15.8 (4.5-49.6)	15 (4-39)
Cluster 3	35	39	83	7.6 (2.0-28.6)	20 (9-40)
Cluster 4	12	20	37	22.9 (16.8-29.4)	13 (6-19)
Group 1	25	39	70	15.0 (7.3-29.2)	19 (9-33)
Group 2	15	38	61	12.5 (5.8-16.7)	25 (13-32)
Group 3	8	29	53	25.6 (19.2-29.4)	24 (16-34)
Group 4	7	29	45	14.2 (9.4-23.7)	16 (8-29)
Group 5	24	32	62	14.4 (11.2-19.7)	13 (5-27)
Group 6	15	38	62	21.4 (12.1-31.6)	13 (4-30)
Group 7	7	38	59	36.3 (32.9-49.6)	24 (16-39)
Group 8	24	38	66	11.5 (4.5-24.0)	16 (9-32)
Group 9	6	40	52	31.3 (19.8-48.9)	26 (22-30)
Group 10	8	31	43	18.5 (8.6-31.6)	16 (7-21)
Group 11	8	26	39	11.2 (7.5-19.7)	17 (14-25)
Group 12	9	42	65	14.4 (7.6-28.6)	26 (20-40)
Group 13	18	35	57	4.3 (2.0-13.9)	18 (9-38)
Group 14	12	21	37	22.9 (16.8-29.4)	13 (6-19)

Group 3

This group is composed of relevés from sandy sites at Billa Kalina that have higher median cover values than groups 1 and 2 and median species richness similar to Group 2. Vegetation is dominated by the grass *Aristida holathera*, which reaches its highest mean cover value here, and to a lesser extent *Enneapogon avenaceus*. *Maireana astrotricha* is significant in the composition of this group, but *Atriplex vesicaria* is not. Although nine other species reach their highest mean cover values here, none of these are long-lived perennial species.

Group 4

All of the relevés from the Wilpoorinna control site are contained in this group, which has mid-range median cover but low median species richness. *Maireana appressa* is the distinctive species at this site, but does not dominate. This species, together with *Maireana aphylla* and *Gnephosis arachnoidea,* attains its highest mean cover value here. *Atriplex vesicaria* is also significant in the group's composition. There were no shifts of sites either into or out of this group.

Table 4.4: Main characteristics of the groups and clusters obtained by PATN analysis of the exclosure cover data.

Group	
	Cluster 1 (relevés from the Billa Kalina sandy sites and the Wilpoorinna control site)
1	Sandy sites at Billa Kalina with mid-range values for cover and species richness. Vegetation is dominated by *Enneapogon avenaceus.*
2	Sandy sites at Billa Kalina with lower median cover but higher median species richness than Group 1 sites.
3	Sandy sites at Billa Kalina with higher median cover values than groups 1 and 2 and median species richness similar to Group 2. Vegetation is dominated by *Aristida holathera* and to a lesser extent by *Enneapogon avenaceus.*
4	All of the relevés from the Wilpoorinna control site. Mid-range values for median cover and low species richness. *Maireana appressa* is the distinctive species at this site, but does not dominate.
	Cluster 2 (most of the low shrubland sites at Billa Kalina and Wilpoorinna)
5	Low shrubland relevés at Billa Kalina and Wilpoorinna with a mid-range value for median cover, but low median species richness. Vegetation is dominated by *Maireana astrotricha.*
6	Low-shrubland relevés at Billa Kalina and Wilpoorinna with higher median cover values than Group 5, but similar median species richness. Vegetation is dominated by *Atriplex vesicaria.*
7	All of the relevés from the rabbit-proof exclosure at Wilpoorinna. Very high median cover values and high median species richness. Vegetation is dominated by both *Atriplex vesicaria* and *Maireana astrotricha.*
8	This group is composed of relevés entirely from Site 2 at Billa Kalina. Low median cover and species richness. No single species dominates the vegetation.
9	All members of this group are from sandy sites at the April 1997 monitoring at Billa Kalina. High median cover and species richness. Vegetation is dominated by *Dactyloctenium radulans, Salsola kali* and *Tribulus eichlerianus.*
10	All members of this group are from low shrubland sites at the April 1997 monitoring at Billa Kalina. Mid-range median cover and low species richness. Vegetation is dominated by *Dactyloctenium radulans.*
	Cluster 3 (low shrubland sites with low median cover and species richness; includes all of the Dulkaninna relevés and some from Billa Kalina)
11	All members of this group are from the second control site at Billa Kalina Site 2. Low median cover and mid-range median species richness. *Frankenia serpyllifolia* and *Sclerolaena brachyptera* are the characteristic species at this site but do not dominate the vegetation.
12	This group is composed entirely of relevés from the Dulkaninna rabbit-proof exclosure. Mid-range median cover, but high median species richness. *Aristida contorta* dominates the vegetation.
13	This group is composed entirely of relevés from the Dulkaninna control site and stock-proof exclosure. Very low median cover, but mid-range median species richness. No single species dominates the vegetation.
	Cluster 4 (all of the relevés from the Cowarie site)
14	All of the relevés from the Cowarie site. High median cover but low median species richness. Vegetation is dominated by *Chenopodium auricomum, Muehlenbeckia florulenta* and *Gnephosis eriocarpa.*

Cluster 2

This cluster includes most of the relevés from the chenopod low shrubland sites at Billa Kalina and Wilpoorinna. Vegetation is dominated by *Atriplex vesicaria* and *Maireana astrotricha*, both with a mean cover value of just under 4%. Relevés within this cluster have mid-range median cover values and low median species richness.

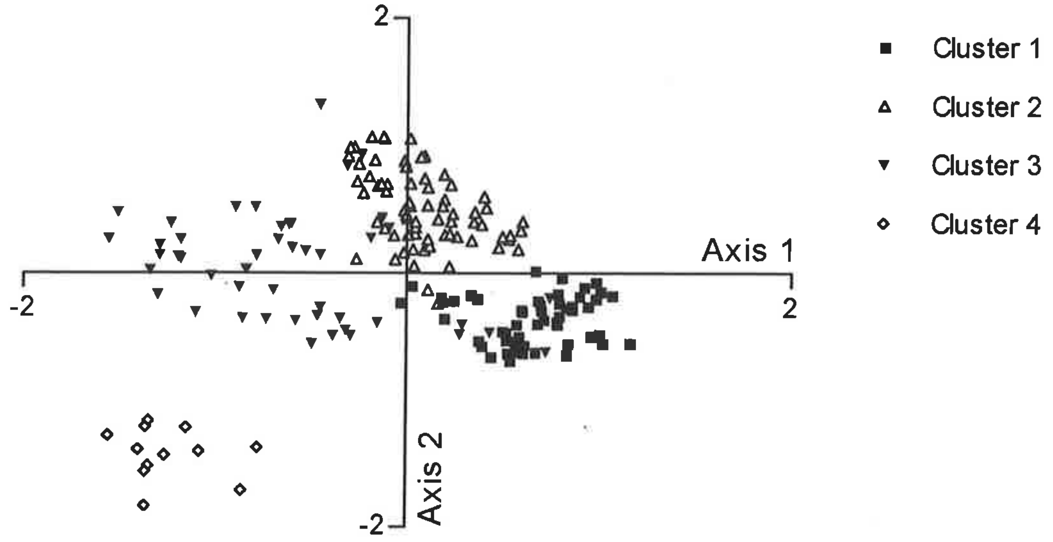

Figure 4.4: Plot of the first and second axes from a semi-strong hybrid scaling (SSH) ordination of the 186 relevés in four clusters of the exclosure sites cover data. Clusters are derived from the dendrogram presented in Appendix D.

Stress = 0.17 (stress values of<2 are generally considered to be indicative of an acceptable analysis).

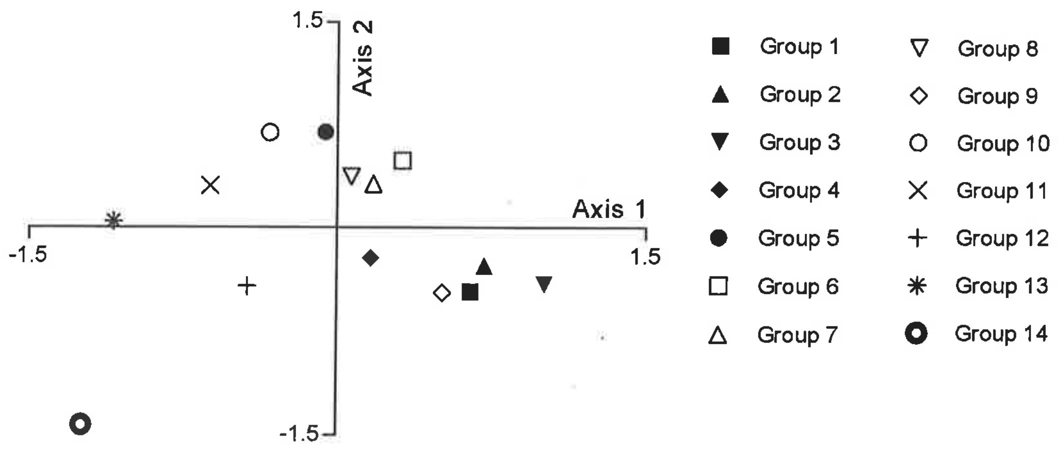

Figure 4.5: Plot of the first and second axes of a SSH ordination of the exclosure sites cover data on the basis of species composition. The 14 groups (Figure 4.2, Table 4.4) were obtained from the dendrogram presented in Appendix D and the centroids of these groups were used in the ordination.

Stress = 0.17.

Table 4.5: Distribution of sites within the groups identified by classification of the exclosure cover data.

Site	T20	T21	T22	T23	T24	T25	T26	T27	T28	T29
K1C1	1	1	1	1	1	2	-	2	2	9
K1C2	5	5	5	5	5	5	-	5	5	10
K1R	1	1	1	1	2	2	-	2	2	9
K1S	1	1	1	1	1	2	-	2	2	9
K2C1	8	8	8	8	8	8	-	8	8	10
K2C2	11	11	11	11	11	11	-	11	11	10
K2R	8	8	8	8	8	8	-	8	8	10
K2S	8	8	8	8	8	8	-	8	8	10
K3C	3	3	1	1	1	2	-	2	2	9
K3R	3	3	1	3	1	1	-	1	2	9
K3S	3	3	1	3	1	1	-	1	2	9
K4C	5	5	5	5	5	5	-	5	5	10
K4R	5	5	5	5	5	5	-	5	5	10
K4S	6	6	6	6	6	6	-	6	6	10
M1C	4	4	4	4	4	4	-	4	-	-
M1R	7	7	7	7	7	7	-	7	-	-
M1S	6	6	6	6	6	6	-	6	-	-
M2C	13	13	13	13	13	13	13	13	-	13
M2R	12	12	12	12	12	12	12	12	-	12
M2S	13	13	13	13	13	13	13	13	-	13
M3C	14	-	14	-	-	14	-	-	14	-
M3R	14	-	14	-	-	14	-	-	14	-
M3S	14	-	14	-	-	14	-	-	14	-

<u>*Group 5*</u>

This group includes relevés at Billa Kalina and Wilpoorinna with low chenopod shrubland vegetation. Its members have mid-range values for median cover, but low median species richness. Vegetation is dominated by *Maireana astrotricha,* with *Atriplex vesicaria* and *Maireana aphylla* also significant to the group's composition. No species attained its highest mean cover value here.

<u>*Group 6*</u>

Chenopod low shrubland relevés at Billa Kalina and Wilpoorinna with higher median cover values than Group 5 but similar median species richness are included here. Vegetation is dominated by *Atriplex vesicaria*, with *Enneapogon avenaceus* and *Sclerolaena ventricosa* also being important. The low shrubs *Maireana appressa, Maireana astrotricha* and *Maireana pyramidata* are also significant to the composition of this group. *Sclerolaena ventricosa* and *Sclerolaena tatei* both reached their highest mean cover values here.

<u>*Group 7*</u>

All of the relevés from the rabbit-proof exclosure at Wilpoorinna are in this group, which has very high median cover values and high median species richness. Vegetation is dominated by both *Atriplex vesicaria* and *Maireana astrotricha,* but the high cover values are also due in part to the presence of a large *Acacia aneura* tree that overhangs one quadrat. *Maireana astrotricha* and *Acacia aneura* both reach their highest mean cover values in this group, as do two other low shrubs, *Maireana pyramidata* and *Rhagodia spinescens*, and three short-lived species.

Group 8

This group is composed of relevés entirely from Billa Kalina Site 2. It has low median cover and species richness. No single species dominates the vegetation, although *Atriplex lindleyi* and *Sclerolaena lanicuspis* attain their highest median cover values here. *Atriplex vesicaria, Maireana astrotricha* and *Maireana pyramidata* are also significant in the make up of this group.

Group 9

All members of this group are from sandy sites at Billa Kalina at the April 1997 monitoring. They have high median cover and species richness values. Vegetation is dominated by two short-lived species, *Dactyloctenium radulans* and *Tribulus eichlerianus,* that grew following the heavy rainfall of February 1997. *Salsola kali* and *Sclerolaena diacantha* are also important components of the vegetation of this group. *Salsola kali, Sclerolaena diacantha, Tribulus eichlerianus* and nine other short-lived species attained their highest median cover values here. *Maireana astrotricha* is significant in the composition of this group, but *Atriplex vesicaria* is not.

Group 10

All members of this group are from chenopod low shrubland sites at the April 1997 monitoring at Billa Kalina. The group has mid-range median cover and low species richness. Vegetation is dominated by the ephemeral grass *Dactyloctenium radulans,* and to a lesser extent by *Maireana astrotricha,* while *Atriplex vesicaria, Frankenia serpyllifolia, Gunniopsis quadrifida, Maireana appressa* and *Maireana pyramidata* are all significant to the group's composition. *Enneapogon cylindricus* and two other short-lived species attain their highest median cover values here.

Cluster 3

Low shrubland sites with low median cover and species richness are included in this cluster. It includes all of the relevés from the Dulkaninna site as well as all but one of those from the second control site at Billa Kalina Site 2. The grass *Aristida contorta* dominates the vegetation of this cluster, with a mean cover value of just over 2% and a mean cover value plus one standard deviation of about 5.5%.

Group 11

All members of this group are from the second control site at Billa Kalina Site 2. The group has low median cover and low to mid-range median species richness. *Frankenia serpyllifolia* and *Sclerolaena brachyptera* are the characteristic species at this site. Although both attained their highest mean cover values here, they did not dominate the vegetation. Four other shorter-lived species also reached their highest mean cover values here. *Atriplex vesicaria* is also significant to the composition of this group.

Group 12

This group is composed entirely of relevés from the Dulkaninna rabbit-proof exclosure. These have mid-range median cover values, but high median species richness. *Aristida contorta* dominates the vegetation and attained its highest mean cover value here. The low shrubs *Atriplex vesicaria, Frankenia serpyllifolia* and *Maireana aphylla* are all significant to this group's composition. Ten other species that are significant to the group's composition attained their highest mean cover values here, including *Cullen australasicum* and *Astrebla pectinata*.

Group 13

This group is composed entirely of relevés from the Dulkaninna control site and stock-proof exclosure. It has very low median cover, the lowest of any of the exclosure sites, but mid-range median species richness. No single species dominates the vegetation. *Atriplex vesicaria* and *Frankenia serpyllifolia* are significant in the group's composition, while four short-lived species attained their highest mean cover values here.

Cluster 4

This cluster contains all of the relevés from the Cowarie site, with no other sites represented here. Vegetation is dominated by *Chenopodium auricomum* with a mean cover value of 10.6%. *Muehlenbeckia florulenta,* with a mean cover value of 2.4%, and *Gnephosis eriocarpa,* with a mean cover value of over 3%, are also important in this cluster.

Group 14

The Cowarie site is very dissimilar to all other exclosure sites on the basis of its plant composition and separates from the other groups at the 1.95 Bray-Curtis level of dissimilarity. All of the relevés from the Cowarie site lie within this group, which has high median cover but low median species richness. Vegetation is dominated by *Chenopodium auricomum, Muehlenbeckia florulenta* and *Gnephosis eriocarpa*. These three species, together with 11 other species, attained their highest median species richness in this group. Only 21 species were recorded as being significant ($p<0.05$) to the composition of this group, a further indication of the dissimilarity of its floristic composition to that of other groups at exclosure sites.

4.3.2.3 Group Shifts to Better and Worse Condition

The concept of rangeland condition and trend has been widely accepted as a basis for judging the effectiveness of management (Smith 1978). This concept is not a new one, with its origins going back to about the late 1800s or early 1900s (Tueller 1973). It need not be restricted to rangelands, but can also include roughly similar terms such as habitat type or land unit as long as the units are relatively homogenous internally with regard to either the kind or amount of vegetation (Smith 1978).

An ecologically based approach to rating land condition was proposed by Hacker (1973) and supported by Smith (1978). This approach rated land condition in relation to the observed or inferred "climax" or pristine state of the site, based on reference areas (Landsberg and Gillieson 1996). This model also assumes that climax vegetation represents stability and that the degree of departure from climax condition at which site deterioration becomes significant may vary from one site to another (Smith 1978).

The undeveloped and ungrazed parts of the Olympic Dam mine lease and the Roxby Downs municipal lease, discussed in Chapter 6 of this thesis, can be regarded as reference areas as far as the present analysis is concerned. Their lack of domestic grazing since 1996 should mean that these are in as good a condition as they are likely to reach in this area. Therefore the relative condition of sites on pastoral land or on the developed parts of the mine lease should be able to be gauged by comparing them to sites in the undisturbed areas.

The term "shift" is used here to indicate a conceptual change in a dynamic vegetation community. Shifts are from one condition (Westoby *et al.* 1989) that meets the criteria of one of the groups or clusters derived from the classification of the cover data, to a condition that meets the criteria of a different group or cluster. Shifts in plant communities are considered to be to a "better condition" if the new group or cluster has higher median species richness and to a lesser extent median cover values, has more long-lived perennial or otherwise "desirable" species, or has less alien species. Shifts to a "worse condition" are considered to have occurred if the criteria for a shift to a better-condition are reversed. Shifts to a condition that could not be considered to be either better or worse than the original condition are referred to as shifts to a "different condition".

The definition of desirable and undesirable in this context depends on the planned use for the site (Smith 1978). On pastoral land, desirable species are those that are the most palatable to livestock, as well as perennial species that provide soil stability. On the mine and municipal leases, where the primary aim is to preserve soil stability and species diversity (ODO 1996b), all native species are desirable but long-lived perennials are the most desirable.

It is likely that some "shifts" are in fact just "transitions" between two different states. Transitions may last for several months, or perhaps even a year or two in some cases where they are caused by slowly occurring natural events rather than by catastrophic incidents. No transitions could be identified with absolute certainty from the group shifts from the exclosure data, although the Group 2 condition may in fact represent a transition (see Section 4.3.3). Greater temporal collection of data is required to clarify this.

As shown in Tables 4.5 and 4.6, several sites changed their affinities to groups and in a few cases to clusters, during the course of the monitoring. All of these changes occurred at Billa Kalina sites and were mainly due to changes in seasonal conditions. More shifts in group affinity occurred following the heavy rainfall of February 1997 than at any other time, and all of these involved changes to a better condition, although because many of these changes were caused by the temporary dominance of ephemeral species it could be argued that these should be considered to be to a different, rather than better, condition

4.3.2.4 Shifts of Sites Between Groups and Between Clusters

Shifts of sites between groups are shown in Table 4.5 and between clusters in Table 4.6. Possible reasons for these shifts are suggested in Table 4.7. There were no changes at the Wilpoorinna, Dulkaninna or Cowarie sites, where exclosures and control sites remained in their original groups throughout the monitoring period. Most shifts of sites from one group to another at

Billa Kalina correlate with changes in seasonal conditions. Many sites that were in Group 1 during the driest part of the monitoring period shifted to other groups after rain fell.

Table 4.6: Distribution of sites within the four clusters identified by classification of the exclosure cover data.

Site	T20	T21	T22	T23	T24	T25	T26	T27	T28	T29
K1C1	1	1	1	1	1	1	-	1	1	2
K1C2	2	2	2	2	2	2	-	2	2	2
K1R	1	1	1	1	1	1	-	1	1	2
K1S	1	1	1	1	1	1	-	1	1	2
K2C1	2	2	2	2	2	2	-	2	2	2
K2C2	3	3	3	3	3	3	-	3	3	2
K2R	2	2	2	2	2	2	-	2	2	2
K2S	2	2	2	2	2	2	-	2	2	2
K3C	1	1	1	1	1	1	-	1	1	2
K3R	1	1	1	1	1	1	-	1	1	2
K3S	1	1	1	1	1	1	-	1	1	2
K4C	2	2	2	2	2	2	-	2	2	2
K4R	2	2	2	2	2	2	-	2	2	2
K4S	2	2	2	2	2	2	-	2	2	2
M1C	1	1	1	1	1	1	-	1	-	-
M1R	2	2	2	2	2	2	-	2	-	-
M1S	2	2	2	2	2	2	-	2	-	-
M2C	3	3	3	3	3	3	3	3	-	3
M2R	3	3	3	3	3	3	3	3	-	3
M2S	3	3	3	3	3	3	3	3	-	3
M3C	4	-	4	-	-	4	-	-	4	-
M3R	4	-	4	-	-	4	-	-	4	-
M3S	4	-	4	-	-	4	-	-	4	-

Changes in group affinity at Billa Kalina rabbit- and stock-proof exclosures were duplicated at control sites on all but two occasions (discounting the second control sites at sites 1 and 2, which proved to be dissimilar (Table 4.5) to the other control sites and exclosures in both cases). In the first case, at Site 1, the stock-proof exclosure and control site attained the same group affinity as the rabbit-proof exclosure by the next monitoring event after the first recorded shift. In the second case, at Site 3, the control site did not shift from a Group 1 condition to a Group 3 condition, as did both exclosures. Instead it shifted to a Group 2 condition in the following year, a full year before this shift was recorded at the two exclosures. The first case may have been due to rabbit and stock grazing: a relationship between rabbit and stock grazing and Site 1 is shown in Figure 4.6, although this was non-significant (Table 4.8). However, when the Billa Kalina sites were examined alone, rabbit grazing (but not cattle grazing) was found to be significant (Figure 4.7a and b).

The major changes in group affinity at the Billa Kalina sites occurred following the heavy rainfall event of February 1997. All sites changed their group affinity at this time, with all changes being to either a better or different condition (see above). Fifty two percent of all changes from one group to another were recorded in April 1997 and 74% of all recorded shifts in group affinities were on sandplain sites.

The only shifts between clusters were recorded at Billa Kalina sites in April 1997 (Table 4.6) and involved shifts to a better or different condition.

Table 4.7: Explanation of shifts between classification groups.

Comments apply to the group as a whole when there are more than three shifts, or to the actual event(s) leading up to the change in the case of one, two or three shifts. When the shift is to a new cluster the number in the second column is in bold font. See text and Appendix F for more information on species composition of groups.

From Group	To Group	No. of Cases	Comments
1	2	6	Reduced cover as vegetation from the 1992 rains, especially the grass *Enneapogon avenaceus*, continued to be removed or break down. Increased species diversity as small individuals of ephemeral species appeared in response to light falls of rain.
1	3	2	Increased cover and species richness following heavier rainfall. Increased cover of the grass *Aristida holathera* in particular, but also of *Enneapogon avenaceus.*
2	**9**	6	Increased cover and species richness following heavy rainfall in February 1997. Increased cover of the grasses *Dactyloctenium radulans* in particular and *Aristida holathera* to a lesser extent, and also of the summer growing species *Salsola kali* and *Tribulus eichlerianus.*
3	1	5	Reduced cover and species richness due to drier seasonal conditions. Reduced cover of the grasses *Aristida holathera* and *Enneapogon avenaceus.*
5	**10**	3	Increased cover and slightly increased species richness. The shift was caused mainly by a large increase in cover of the ephemeral grass *Dactyloctenium radulans* following the February 1997 rainfall event.
6	**10**	1	Similar cover but higher species richness. The ephemeral grass *Dactyloctenium radulans* became dominant and additional species appeared following the February 1997 rainfall event.
8	10	3	Large increase in cover and small increase in species richness. The shift was caused mainly by the growth of grasses, particularly the ephemeral grass *Dactyloctenium radulans* following the February 1997 rainfall event.
11	10	1	Large increase in cover and similar species richness. The shift was caused mainly by the growth of the ephemeral grass *Dactyloctenium radulans* following the February 1997 rainfall event.

4.3.2.5 Spatial Relationship Between Clusters and Between Groups

The spatial relationships between clusters and between groups, obtained by SSH ordination, are shown in Figure 4.4 and Figure 4.5 respectively. Clusters are reasonably well separated, with the main overlap being between the Cluster 1 Wilpoorinna control site and Cluster 2 relevés. An outlying group of Cluster 2 relevés is comprised entirely of relevés from the final monitoring at Billa Kalina after the heavy rainfall of February 1997. There is also some overlap between Cluster 2 and Cluster 3 relevés, but this also largely involves Cluster 2 relevés from Billa Kalina sites overlapping Cluster 3 relevés after the February 1997 rainfall event. All relevés from the Cowarie site are well separated from the other clusters as would be expected given the very dissimilar nature of its vegetation.

No groups, as defined from the group means and shown in Figure 4.5, encroach on each other. However, the centroid of Group 9 lies close to the majority of the Cluster 1 sites. Group 9 is made up of former Cluster 1 sites that shifted to Cluster 2 following the heavy rainfall of February 1997 and the subsequent domination in this group of the ephemeral grass *Dactyloctenium radulans*.

4.3.2.6 Comparisons Between Exclosures and Control Sites

Apart from the minor differences discussed in Section 4.3.2.4, no differences were detected between exclosure sites and control sites that were not present at the start of monitoring. Even for those control sites where differences were detected during the monitoring, these sites returned to the same group as the corresponding exclosure sites by the end of the monitoring. There were no differences in the exclosure sites that could be attributed to the fencing and exclusion of herbivores.

4.3.2.7 Environmental Parameters

The r-values and significance of the measured environmental parameters as determined by PCC ordination are shown in Table 4.8. The only parameters that were significant ($p<0.05$) were litter and rainfall in the month prior to monitoring. The correlation of all environmental parameters to the four plant-based clusters, obtained by SSH ordination of the data, is presented in Figure 4.6.

Table 4.8: Summary of PCC ordination of environmental parameters with the exclosure sites cover data showing whether or not they are significantly correlated ($p<0.05$) on the basis of plant species clusters derived from the dendrogram in Appendix D.

Environmental Parameters	R	Significance
Soil Type	0.1619	ns
Litter	0.6184	*
Rainfall in Previous Month	0.2493	*
Rainfall in Previous 2 Months	0.1237	ns
Rainfall in Previous 3 Months	0.0758	ns
Rainfall in Previous 6 Months	0.0847	ns
Rainfall in Previous Year	0.1023	ns
Rainfall in Previous 2 Years	0.1356	ns
Rainfall in Previous 3 Years	0.1318	ns
Rabbit Grazing Impacts	0.1981	ns
Stock Grazing Impacts	0.0925	ns

Cluster 1 has a strong positive correlation to the cover of litter and a non-significant positive correlation to rabbit and stock grazing. Soil type shows a non-significant positive correlation towards Cluster 3. Rainfall during the preceding month is positively but weakly correlated with Cluster 2, which also has a non-significant positive correlation to rainfall during the previous six months.

Cluster 2 also has an indirect negative non-significant correlation to rainfall during the preceding year. Cluster 3 shows a non-significant positive correlation to rainfall during the previous two and three months.

4.3.2.8 The Effects of Rabbits and Cattle

When the cover data from all exclosure sites are analysed together there is no significant impact from either stock or rabbits (using the data from Tables 4.1 and 4.2) at these sites. This was an unexpected result, given the periodic high rabbit densities near some of the Billa Kalina sites during the monitoring period (Figure 4.1).

It was suspected that the effects of rabbits at these sites were masked by the overall low rabbit numbers at the Dulkaninna and Cowarie sites (Table 4.2). Because quantitative data on rabbit numbers were available only at Billa Kalina, data from these sites were analysed separately using the PATN computer package (Belbin 1991a, 1991b) and the same techniques as previous analyses of the exclosure cover data. Separate rabbit density data were available for the four sites and the two secondary control sites and each of these six areas was analysed separately. The ordination of the relevés and significant environmental data ($p<0.05$) and of relevés and significant species ($p<0.05$) are shown in Figures 4.7 - 4.12. Because of the numbers involved it was not possible to include all significant species in all of the figures. Additional significant species for sites 1 and 2 are listed in Table 4.9. Non-significant environmental parameters and species have been omitted from these ordination plots.

Table 4.9: Potential position on scatter plot of significant species that are not included in Figures 4.7b-4.8b.

Sectors are numbered in a clockwise direction from the right hand side of the upper (positive) Y axis. Each sector represents a 45 ^{0} arc.

Species	Sector	Species	Sector
Site 1			
Stenopetalum lineare	1	*Zygophyllum howittii*	2
Blennodia canescens	2	*Triraphis mollis*	3
Plantago drummondii	2	*Paspalidium basicladum*	6
Rhodanthe moschata	2	*Tribulus eichlerianus*	6
Rhodanthe stuartiana	2	*Convolvulus erubescens*	8
Senecio glossanthus	2	*Omphalolappula concava*	8
Site 2			
Brachyscome lineariloba	2	*Urochloa praetervisa*	3
Eragrostis falcata	2	*Sclerolaena parallelicuspis*	5
Rhodanthe pygmaea	2	*Rhodanthe floribunda*	6
Salsola kali	2	*Tripogon loliiformis*	6
Sclerolaena intricata	2	*Triraphis mollis*	7
Senecio glossanthus	2	*Plantago drummondii*	8

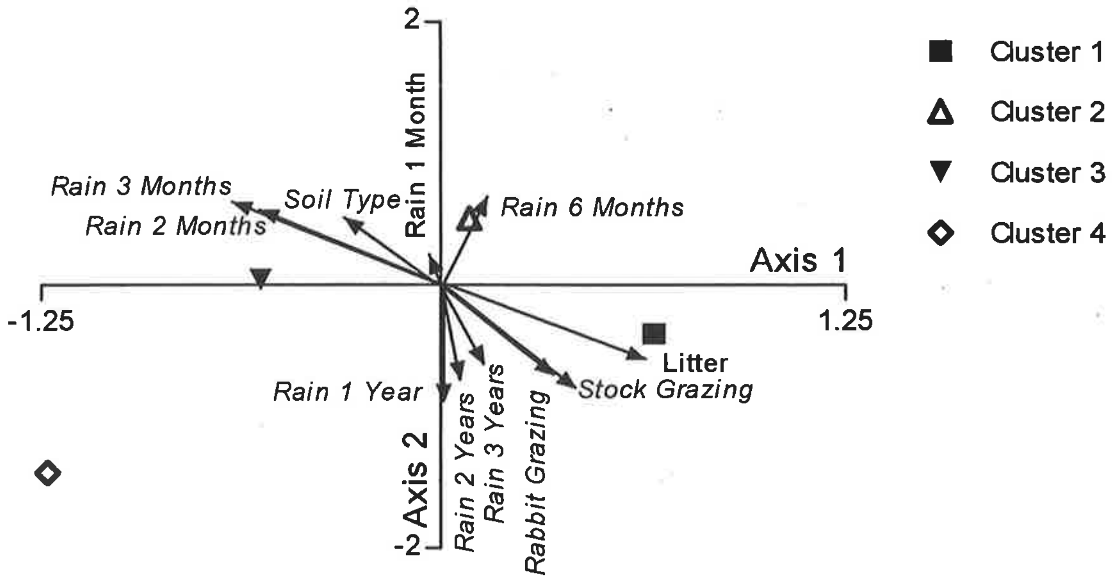

Figure 4.6: Plot of the first and second axes from a SSH ordination showing the centroids of the four clusters from the dendrogram in Appendix D with the PCC ordination of 11 environmental parameters from the exclosure sites cover data superimposed on the clusters.

The time period after "rain" refers to the total rainfall for the stated period preceeding the monitoring. The only significant environmental parameters ($p<0.05$) are litter and rainfall during the preceding month. Non-significant parameters are shown in italics. Stress = 0.17.

Site 1

The ordination of Site 1 relevés and significant environmental data ($p<0.05$) is shown in Figure 4.7a and of Site 1 relevés and significant species ($p<0.05$) in Figure 4.7b. Of the 10 environmental parameters measured (Table 4.10), both rabbit numbers and impacts are significant, as is rainfall over the preceding one, two, three and six months and one, two and three years. Stock impact is the only non-significant parameter at this site.

There are no close positive correlations of rabbit numbers or rabbit impacts to any species at this site, but there is a negative correlation between both these variables and the herbs *Othonna gregorii* and *Pycnosorus pleiocephalus* and the grass *Triraphis mollis*.

Of the other environmental parameters, rainfall during the preceding month correlates to cover of several ephemeral species, and rainfall over the preceding two months to cover of the shrub *Gunniopsis quadrifida* and the herb *Goodenia lunata*. There is also a negative correlation between rainfall during the previous two, three and six months and the forbs *Sclerolaena diacantha* and *Sida ammophila* and the grass *Aristida contorta*.

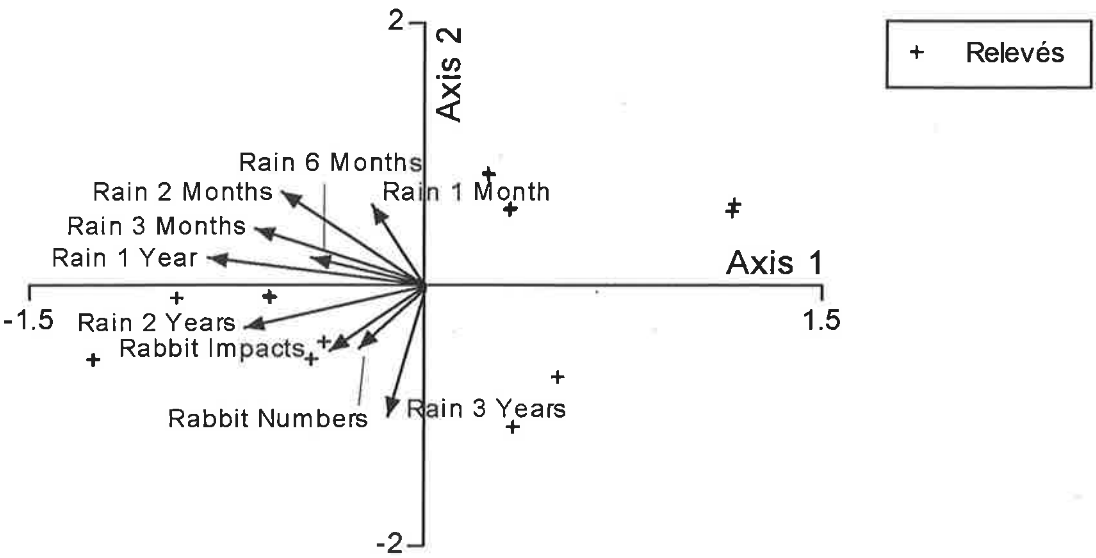

Figure 4.7a: Plot of the first two axes of a SSH ordination of the relevés of Billa Kalina Site 1 with a PCC ordination of the significant environmental parameters (p<0.05) superimposed on the relevés.
Stress = 0.12.

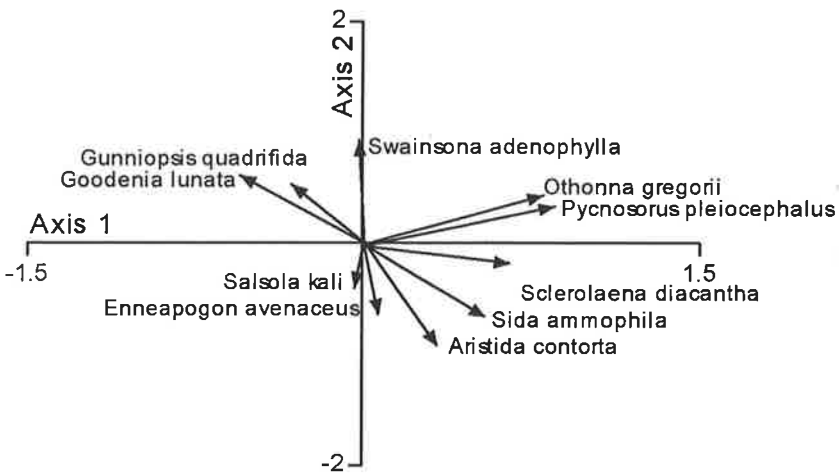

Figure 4.7b: Plot of the first and second axes of a PCC ordination of significant species (p<0.05) at Billa Kalina Site 1.
Stress = 0.11. Other significant species are listed in Table 4.9.

Site 2

The ordination of Site 2 relevés and significant environmental data ($p<0.05$) is shown in Figure 4.8a and of Site 2 relevés and significant species ($p<0.05$) in Figure 4.8b. All of the environmental parameters measured here are significant except stock impacts and rainfall during the previous two and three months (Table 4.10).

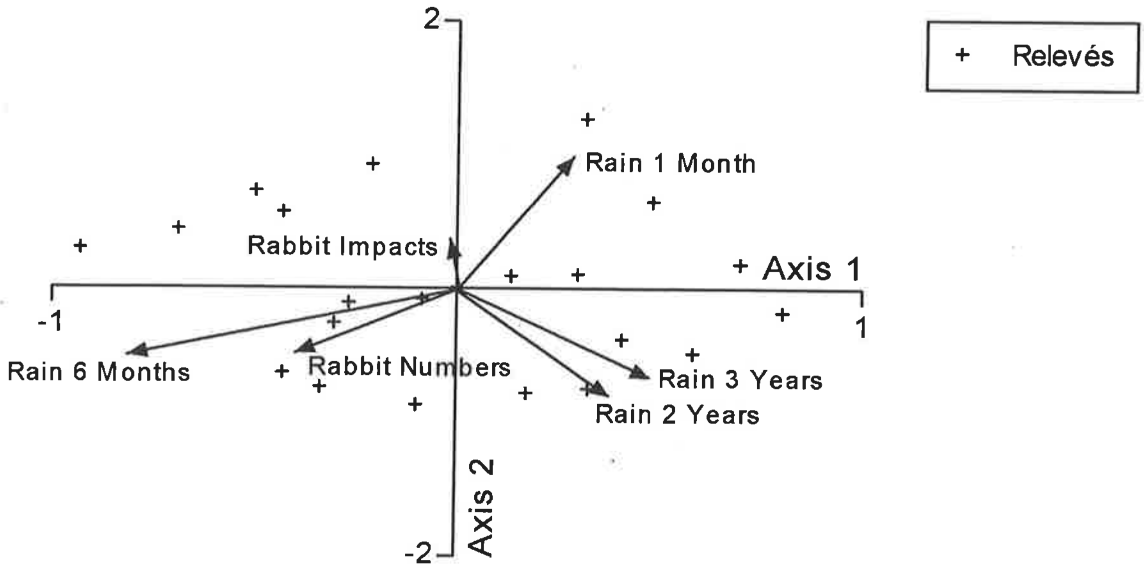

Figure 4.8a: Plot of the first two axes of a SSH ordination of the relevés of Billa Kalina Site 2 with a PCC ordination of the significant environmental parameters ($p<0.05$) superimposed on the relevés.
Stress = 0.11.

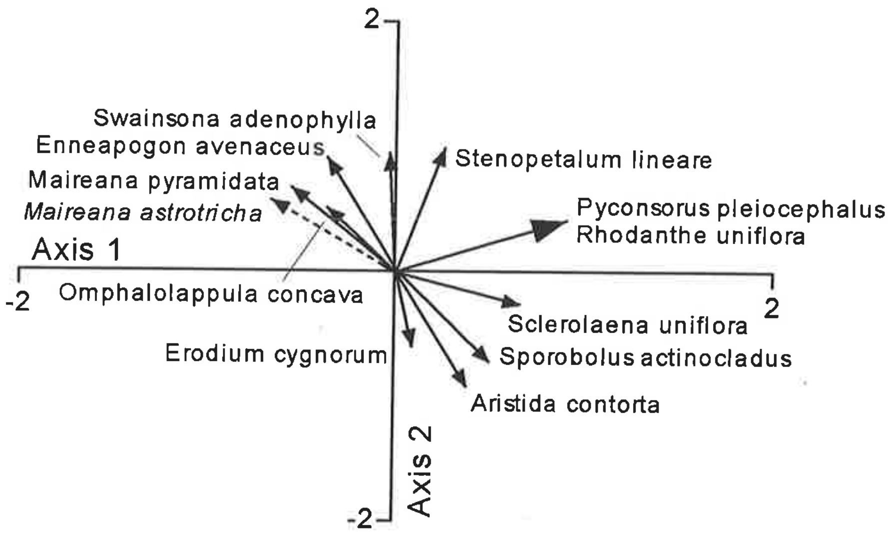

Figure 4.8b: Plot of the first and second axes of a PCC ordination of significant species ($p<0.05$) at Billa Kalina Site 2.
Stress = 0.11. *Maireana astrotricha* (italics and dotted line) is the most common species at this site but is non-significant in this analysis. Large arrowhead denotes more than one species at this point. Other significant species are listed in Table 4.9.

Rabbit numbers show a positive correlation to cover of the grass *Triraphis mollis* and a negative correlation to cover of several other ephemeral species. There is a negative correlation between rabbit numbers and rainfall during the previous month. A weak positive correlation also shows between rabbit impacts and cover of the herbs *Swainsona adenophylla* and *Plantago drummondii.* There is a negative correlation between rabbit impacts and cover of *Erodium cygnorum.*

Table 4.10: Summary of significance ($p<0.05$) of environmental parameters obtained from PCC ordination of the data from individual sites at Billa Kalina.
(Sites 1a and 2a are the second control sites on single-ripped country for Site 1 and 2 respectively).
* = significant, ns = non-significant.

Environmental Parameter	Site					
	1	2	3	4	1a	2a
Rabbit Numbers	*	*	*	ns	*	ns
Rabbit Impacts	*	*	*	ns	ns	ns
Stock Impacts	ns	ns	ns	ns	ns	ns
Rainfall in Previous Month	*	*	*	ns	*	ns
Rainfall in Previous 2 Months	*	ns	ns	ns	ns	ns
Rainfall in Previous 3 Months	*	ns	ns	ns	ns	ns
Rainfall in Previous 6 Months	*	*	*	ns	ns	ns
Rainfall in Previous Year	*	*	*	*	*	*
Rainfall in Previous 2 Years	*	*	*	*	*	*
Rainfall in Previous 3 Years	*	*	*	*	ns	ns

Of the other environmental parameters, there is a positive correlation between rainfall during the preceding month and cover of several ephemeral species. Rainfall over the previous six months is correlated to cover of *Tripogon loliiformis* and *Rhodanthe floribunda.* Rainfall over the previous two years correlates with cover of the grasses *Aristida contorta* and *Sporobolus actinocladus* and rainfall over the previous three years shows a weak positive correlation to cover of *Sclerolaena uniflora.*

Site 3

The ordination of Site 3 relevés and significant environmental data ($p<0.05$) is shown in Figure 4.9a and of Site 3 relevés and significant species ($p<0.05$) in Figure 4.9b. All of the environmental parameters measured here are significant except for the impacts of cattle and rainfall over the previous two and three months.

Rabbit numbers correlate to cover of the perennial herb *Brachyscome ciliaris*. Rabbit impacts show a positive correlation to cover of *Paspalidium basicladum* and a negative correlation to cover of 12 species, including the shrub *Maireana astrotricha*, the forbs *Sida ammophila* and *Sclerolaena diacantha,* and three grasses (Figure 4.9b, Table 4.9).

Rainfall during the previous month shows a close positive correlation to cover of *Swainsona adenophylla* and six other ephemeral species, including the grass *Tripogon loliiformis,* and with the sub-shrub *Ptilotus sessilifolius.*

Site 4

The ordination of Site 4 relevés and significant environmental parameters ($p<0.05$) is shown in Figure 4.10a and of Site 4 relevés and significant species ($p<0.05$) in Figure 4.10b. Neither rabbit numbers nor rabbit and cattle impacts are significant at this site. The only significant environmental parameters are rainfall during the previous one, two and three years.

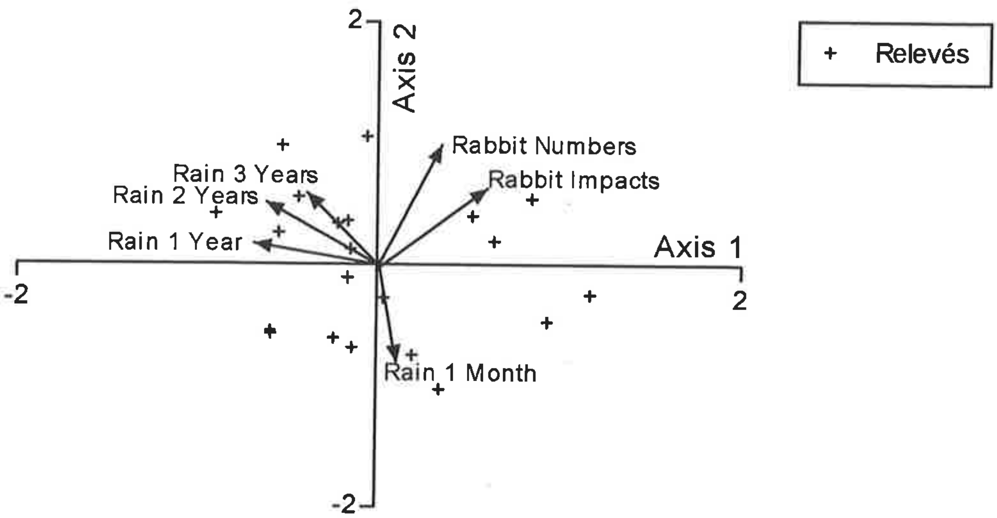

Figure 4.9a: Plot of the first two axes of a SSH ordination of the relevés of Billa Kalina Site 3 with a PCC ordination of the significant environmental parameters ($p<0.05$) superimposed on the relevés.
Stress = 0.11.

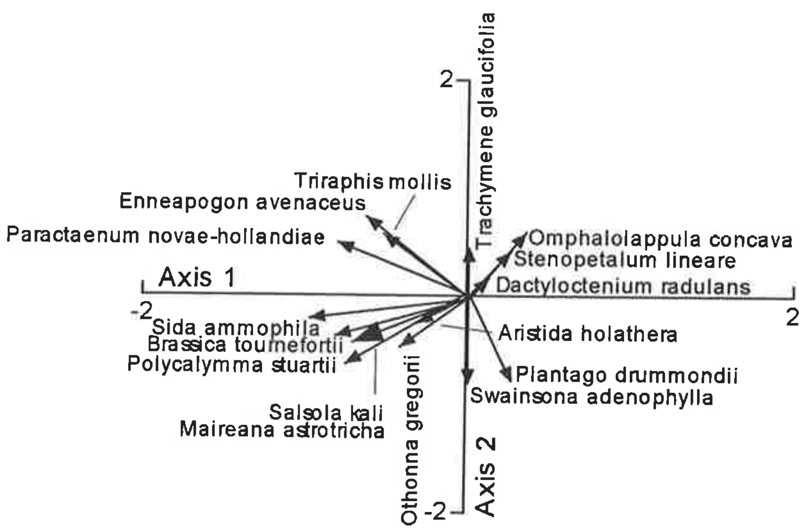

Figure 4.9b: Plot of the first and second axes of a PCC ordination of significant species ($p<0.05$) at Billa Kalina Site 3.
Stress = 0.11.

The only species to show a positive correlation to rainfall during the previous one, two and three years are short-lived species. These include the grasses *Aristida contorta, Enneapogon avenaceus* and *Enneapogon cylindricus*.

Site 1 Second Control Site

The ordination of relevés from the second control site at Site 1 and significant environmental parameters ($p<0.05$) is shown in Figure 4.11a and of Site 1 second control site relevés and significant species ($p<0.05$) in Figure 4.11b. The only significant environmental parameters at this site are rabbit numbers and rainfall during the previous month and one and two years.

Rabbit numbers at this site correlate with cover of *Atriplex vesicaria, Sclerolaena ventricosa* and *Sclerolaena diacantha.* Rabbit numbers also show a negative correlation to rainfall during the previous month and to cover of the herb *Brachyscome lineariloba.*

Of the other environmental parameters, there is a positive correlation between rainfall during the previous year, the shrub *Maireana astrotricha* and the grasses *Aristida contorta, Enneapogon avenaceus, Eragrostis dielsii* and *Triraphis mollis.*

Site 2 Second Control Site

The ordination of relevés from the second control site at Site 2 and significant environmental parameters ($p<0.05$) is shown in Figure 4.12a and of Site 2 second control site relevés and significant species ($p<0.05$) in Figure 4.12b. Neither rabbit numbers nor cattle and rabbit impacts are significant at this site.

The only environmental parameters that are significant here are rainfall during the previous one and two years. Rainfall during the previous year is strongly and closely correlated to cover of the grasses *Enneapogon avenaceus* and *Aristida contorta,* and to the herb *Euphorbia drummondii.* There is a negative correlation between rainfall during the previous year and cover of the forb *Sclerolaena brachyptera.*

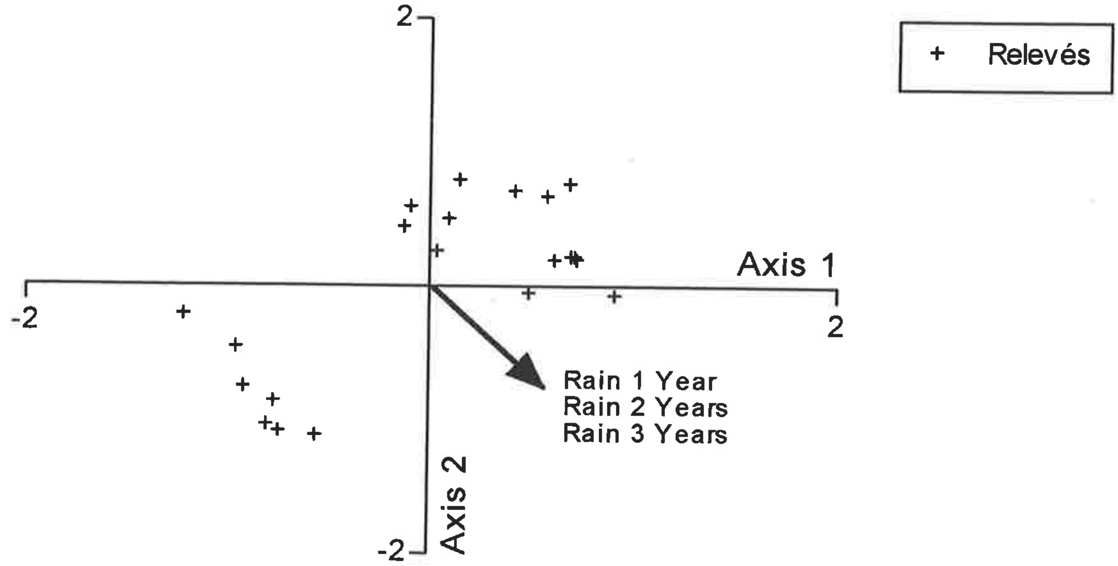

Figure 4.10a: Plot of the first two axes of a SSH ordination of the relevés of Billa Kalina Site 4 with a PCC ordination of the significant environmental parameters ($p<0.05$) superimposed on the relevés.
Stress = 0.05.

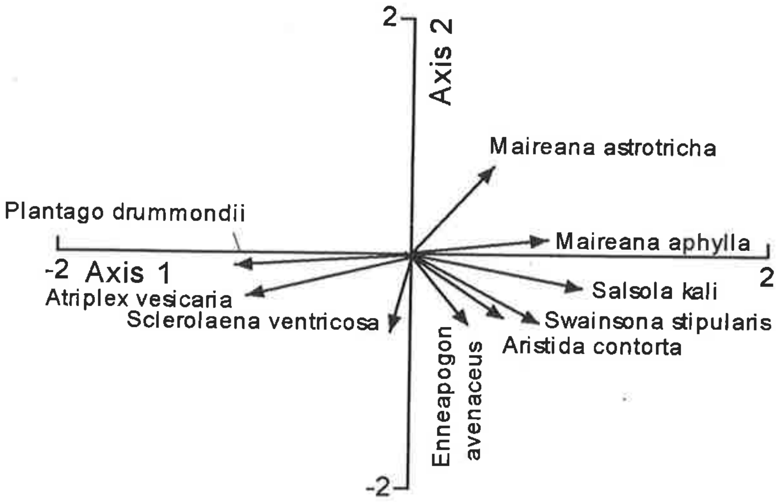

Figure 4.10b: Plot of the first and second axes of a PCC ordination of significant species ($p<0.05$) at Billa Kalina Site 4.
Stress = 0.05.

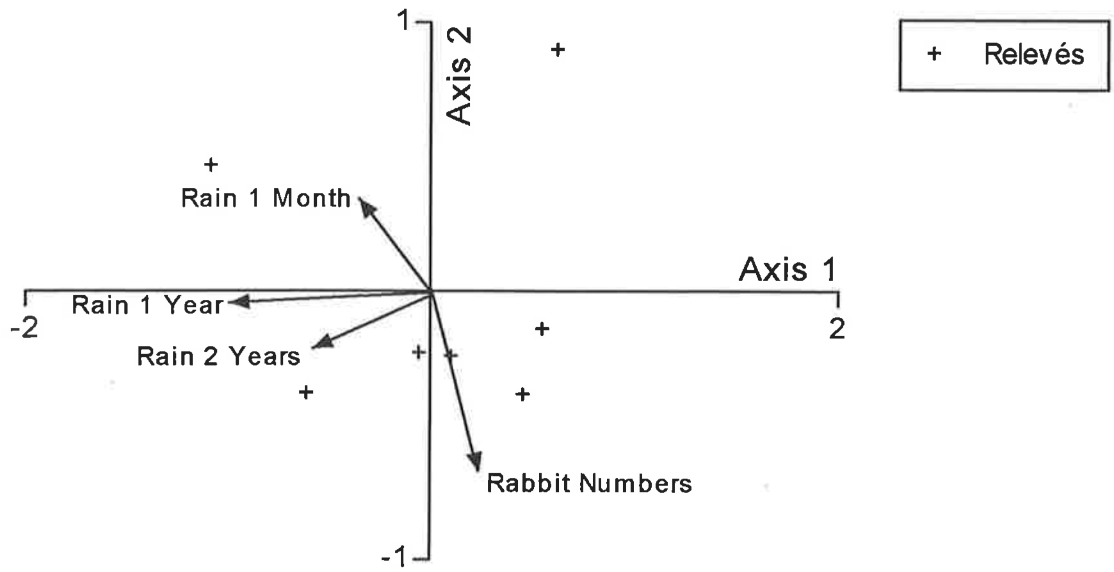

Figure 4.11a: Plot of the first two axes of a SSH ordination of the relevés of the second control site at Billa Kalina Site 1 with a PCC ordination of the significant environmental parameters ($p<0.05$) superimposed on the relevés.
Stress = 0.04.

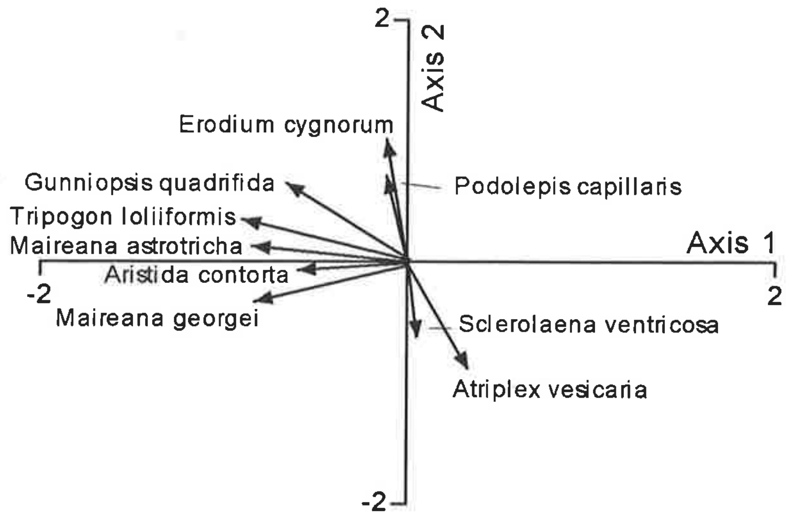

Figure 4.11b: Plot of the first and second axes of a PCC ordination of significant species ($p<0.05$) at the second control site at Billa Kalina Site 1.
Stress = 0.04. The large arrowhead denotes more than one species at this point.

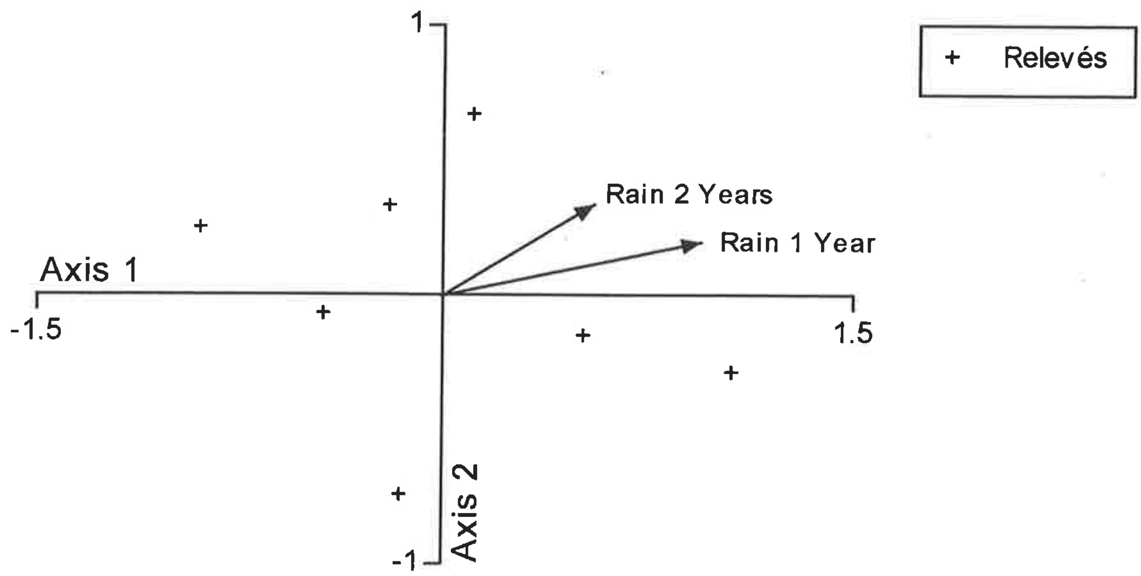

Figure 4.12a: Plot of the first two axes of a SSH ordination of the relevés of the second control site at Billa Kalina Site 2 with a PCC ordination of the significant environmental parameters ($p<0.05$) superimposed on the relevés.
Stress = 0.04.

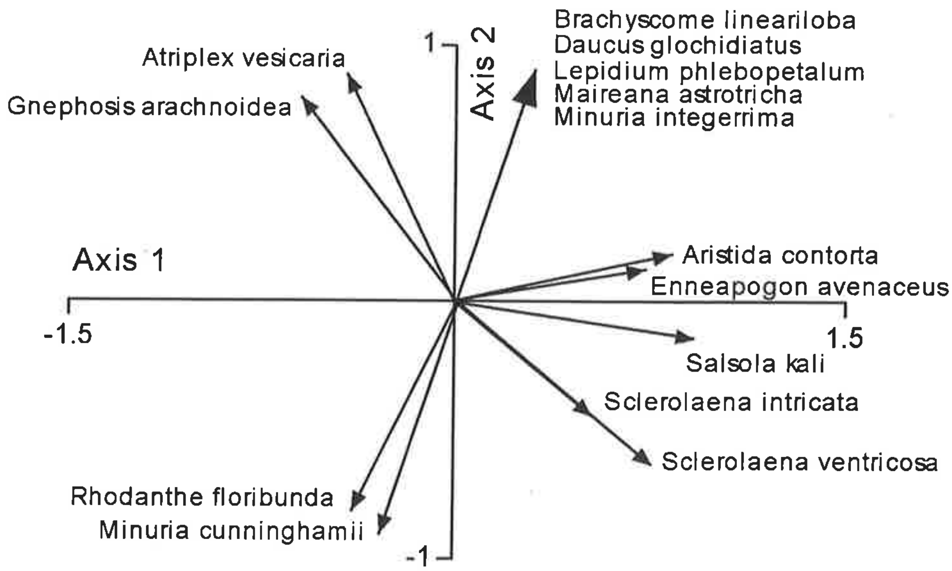

Figure 4.12b: Plot of the first and second axes of a PCC ordination of significant species ($p<0.05$) at the second control site at Billa Kalina Site 2.
Stress = 0.04.

4.3.2.9 The Cowarie Exclosures

The Cowarie exclosures did not fulfil their intended purpose as far as this study is concerned because there was no flood in the Warburton River during the four years of monitoring. However, heavy local rainfall produced some run-off across parts of the floodplain during 1996. This resulted in good growth of short-lived species over parts of the floodplain, but inundation at the exclosure site was restricted to a few of the lowest areas. It did not produce any regrowth in the shrubs *Chenopodium auricomum* and *Muehlenbeckia florulenta.*

In order to determine whether this rainfall had effects on the vegetation sufficient to cause shifts to different groups, the site data were analysed without the shrub cover (*Chenopodium auricomum* and *Muehlenbeckia florulenta* were removed from the dataset). PATN was used for this analysis in the same way as in previous analyses. Two groups can be identified from the resultant dendrogram (Figure 4.13) at the Bray-Curtis 0.96 level of dissimilarity (the same cut-off point used in the original cover data classification). However, the second group, which was separated at the 0.72 level of fusion, consisted entirely of relevés from the 1994 monitoring. The three relevés from the 1996 monitoring did not form a separate group at any level of dissimilarity.

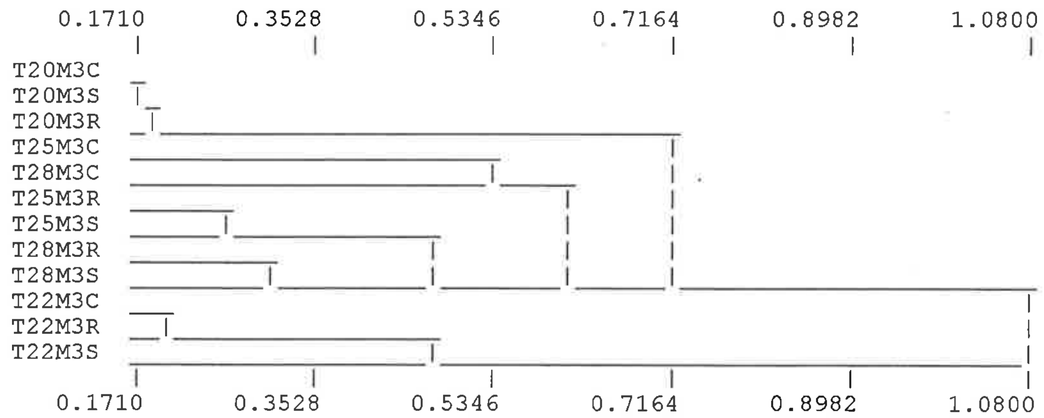

Figure 4.13: Dendrogram obtained by classification of the Cowarie cover data.

It is therefore inferred that the heavy rainfall of 1996, although sufficient to increase cover and species richness at the site, was insufficient to produce significantly different plant growth from that which had occurred following lighter falls of rain during the early part of the monitoring. The local vegetation has undoubtedly adapted to produce its maximum growth following prolonged inundation such as occurs during a flood.

4.3.3 Discussion

Rainfall, or lack of it, appears to have been responsible for the majority of shifts between classification groups. A possible transition stage between groups was identified that may have lasted as long as two years. The apparently coarse scale of measuring grazing impacts shown in Tables 4.1 and 4.2 was found to produce results that correlate closely with those obtained by more precise rabbit counts. Cover of some perennial shrubs was found to correlate to recent rainfall events, rather than to long-term rainfall. Problems with site selection were also identified by the classification.

Monitoring of all sites began following a year of well above average rainfall. At Billa Kalina, the presence of water in the Devil's Playground resulted in relatively high cattle stocking rates during the previous three years and herbivores had removed much of the vegetation biomass before the start of monitoring. Despite low rainfall over the next four years, there were occasional positive vegetation responses that were sufficient to cause shifts at the group level that are hard to explain on the basis of available rainfall data. It is unlikely that total rainfall at the Billa Kalina exclosure sites differed greatly to that recorded at the homestead, although there are likely to have been differences in rainfall on individual days.

The greatest changes in vegetation at monitoring sites occurred following the heavy rainfall event of February 1997. This event was responsible for all shifts at the cluster level, as well as more than half of the shifts at group level. Other shifts, including those caused by lesser rainfall events and by high rabbit densities in 1994 and 1996, occurred only at the group level.

Rainfall in the Marree area remained above average except for one dry year. This single dry year was insufficient to cause any shifts in group alliance. There were no shifts to different states at any of the Marree SCB exclosures, suggesting that a balance was maintained between rainfall, available forage and grazing (Westoby *et al.* 1989), even during the dry year. The generally lower rabbit numbers at these sites, compared to the Billa Kalina sites, helped to maintain this balance.

The main factor influencing changes from Group 1 to Group 2 criteria appears to have been a reduction in cover and cessation of dominance of the grass *Enneapogon avenaceus* together with the growth of several additional ephemeral species following light falls of rain. No sites that shifted into Group 2 returned to Group 1 during the monitoring period. All members of Group 2 attained the criteria of Group 9 and shifted into that group following the heavy rainfall event of February 1997.

The Billa Kalina Site 3 relevés all fell within Group 3 at the start of the monitoring, but shifted to Group 1 as seasonal conditions became drier and vegetation condition deteriorated. There was some oscillation between these two groups in the two exclosures at Site 3, but not at the control site.

When seasonal conditions improved, many members of Group 5 attained the criteria of Group 6 and shifted to that group, but there were no shifts from the Group 5 sites with the lowest median cover or species richness values. Improved seasonal conditions also appear to have been responsible for one of the Billa Kalina sites shifting from Group 6 into Group 10 by April 1997.

There were no changes during the course of the monitoring that caused any members of other groups to attain the criteria that would place them within Group 8, but some members of Group 8 had shifted to Group 10 by the end of the monitoring period.

Because sites only attained the criteria that placed them in Group 9 during the final monitoring, there were no recorded shifts from this group to any other. Shifts into the group were entirely from Group 2. Similarly, because Group 10 did not appear until after the heavy rainfall event of February 1997, there were no recorded shifts out of the group. Its membership came from sites that had previously met the criteria of groups 5, 6, 8 and 11. All members of Group 11 shifted to Group 10 after the heavy rainfall event of February 1997.

Shifts at the cluster level represent shifts to different states (Westoby *et al.* 1989). Those at the group level, caused by gradual seasonal changes and by grazing, may also represent shifts to different states, although this is less certain. No transitional phases were identified with certainty, possibly because of the relatively short-term of the monitoring or to rapid unrecorded transitions between states occurring between monitoring events. Changes following the February 1997 rainfall event were certainly completed before the next and final monitoring, with the growth peak of all short-lived species having passed and plants drying off.

However, it is possible that Group 2 may represent a transition from Group 1 to a different state. This group was always preceded by a Group 1 state and occurs as the significant species in that group, especially grasses, are removed or break down. The increase in species richness in Group 2, which accounts for little of the vegetation cover of the group, may be less important than decreases in the main character species of Group 1. The presence of additional species at low density may also suggest that this is a transitional stage rather than a stable state. Stable state may only be reached when these species grow in sufficient quantity to become significant to the group's composition following heavier rainfall. If Group 2 does represent a transition rather than a stable state, it means that transitions can last for a period of at least two years. There were no shifts from the Group 2 condition until the major rainfall event of February 1997. It is not known how long this condition would have persisted if this rainfall event had not occurred.

The effects of both stock and rabbit grazing were non-significant when using data from all sites, but rabbit grazing became significant at some sites when their data were analysed alone. This highlights the importance of scale in any monitoring programme (Coughenour 1991). Community stability can often be inferred through the use of a low level of resolution, while the use of a different scale with greater resolution may suggest that the community is unstable (Rahel 1990). Small scales, both temporal and spatial, make conceptual modelling easier, while larger scales make the boundaries of hierarchical patches within the community more ambiguous (Kotliar and Wiens 1990).

The initial ordination of all relevés and environmental parameters suggested that the use of only three scores (none, low or high) for measuring the impacts of cattle and rabbits was an imprecise measure. However, ordination of rabbit numbers and rabbit impacts at the individual Billa Kalina sites showed that this was not necessarily the case. The two measures were usually closely correlated, at least at sandplain sites where rabbit numbers are highest. Only at one site (Site 1a) was one parameter significant and the other non-significant.

Rabbit impacts may have been underscored at some sites. Rabbit tracks do not persist and their impacts were based mainly on visible damage to plants in the form of grazed leaves or stems. These may be difficult to detect during or immediately following growth pulses. On the other hand, cattle hoof marks may persist in some soils for long periods. These were often the only indication of the presence of cattle between monitoring events and were the criteria most often used to score their impact. No cattle were actually seen at any of the exclosure sites during any monitoring event.

The closest correlations between rabbits and individual species were negative correlations between rabbits and the cover of numerous ephemeral species. Significant rabbit impacts were greatest at sandplain sites, where rabbit numbers have always been greatest. Rabbits were a statistically significant factor at only one of the chenopod low shrubland sites.

As was to be expected (Stafford Smith and Morton 1990), cover of ephemeral species generally correlated well to rainfall over the preceding month. More environmental parameters were significant at Sites 1 and 2, perhaps because of some recovery of vegetation following the initial removal of rabbits and lower rabbit numbers in the longer term. This was due to the warren-ripping programme at these sites.

Surprisingly, there were generally poor correlations between rainfall over the preceding two and three years with the growth of long-lived chenopod shrubs. The exception was a positive correlation between cover of *Maireana astrotricha* and rainfall during the last year. Noble (1977) found that biomass of *Maireana sedifolia* at the Koonamore reserve correlated with rainfall over the preceding two years and *Atriplex vesicaria* with rainfall over the previous 42 months.

An unexpected finding of this study was the positive correlation between *Gunniopsis quadrifida* and rainfall over the previous two months. A possible reason for this finding is that this species drops many or all of its leaves as a response to extended dry conditions, and the shrub may then appear to be dead. These leaves quickly grow again once it rains. Cover values for shrubs were calculated only on green foliage, with separate measurements taken for different green leafy areas on the same plant. The positive correlation to recent rainfall events reflects these rapid short-term responses. The fact that defoliated bushes are not necessarily dead was also noted by Osborn *et al.* (1932) and Fatchen (1975).

Sclerolaena spp. often had a negative correlation to recent rainfall, suggesting that members of this genus are able to survive and grow after other plants have reached the end of their growth cycle following a particular rainfall event (Dunham 1990). Many of the grasses also have correlations with rainfall over periods greater than one year. In the case of short-lived perennials such as *Enneapogon avenaceus*, this reflects their ability to resprout following rainfall after their initial growth cycle. In the case of some annual grasses, particularly *Aristida contorta* and *Triraphis mollis*, it reflects their ability to remain in the ground long after they have died unless removed by herbivores (although the former at least is only grazed when nothing better is available) or by trampling.

Rabbit impacts on sands showed a negative correlation to a greater number of individual species at the unripped control site at Billa Kalina (Site 3) than was the case at the double-ripped Site 1 or the Site 1 second control site in single-ripped country. As expected, rabbit impacts on clay soils were non-significant at both the unripped control area (Site 4) and at the second control site at Site 2 in single-ripped country. However, they were significant at the double-ripped Site 2. The reasons for this are unknown, especially as rabbit impacts were generally low at all clay-soil sites.

The introduced forb *Malvastrum americanum* had a cover value of 2.4% in the rabbit-proof exclosure at Wilpoorinna at the start of monitoring. This was then the highest cover value of any alien species at the exclosure sites. This plant was growing in a scrape beneath an *Acacia aneura* tree, in a heavily disturbed place that had sometimes been used as a camping area by kangaroos. Its cover value rose to 8.7% in April 1994, following exclusion of kangaroos, but then fell to 0.7% at the end of the monitoring as native species recolonised the scrape.

The Wilpoorinna exclosures in particular, and the Dulkaninna exclosures to a lesser extent, demonstrate the problems inherent in choosing sites for exclosures, or for monitoring in general. At Wilpoorinna, even though the two adjoining exclosures and the nearby control site appeared to be in similar vegetation types, pattern analysis showed their vegetation structure to be different and that they have affinities to different plant-based groups. At Dulkaninna the control site and stock-proof exclosure were in one group while the rabbit-proof exclosure was in another.

These differences can be explained in all cases. At Wilpoorinna, the large *Acacia aneura* overhanging one of the quadrats in the rabbit-proof exclosure gave this group the highest median cover value of all groups. Although not immediately obvious in the field, the rabbit-proof exclosure also had the highest median species richness of all sites, while the adjoining stock-proof exclosure had a much lower median species richness. The relative abundance of individual shrub species was also different. The presence of a run-on area in one of the Dulkaninna rabbit-proof exclosure quadrats resulted in its relevés being placed in a different group. Without the presence of this feature it is possible that relevés from this exclosure would have been in the same group as the Dulkaninna stock-proof exclosure and control site. The importance of spatial patterning such as those presented by gilgais and run-on areas on gibber plains has often been overlooked by ecologists who have seen only a uniform topography (Stafford Smith and Morton 1990).

Similar problems to the above were experienced in the location of the two additional control sites on Billa Kalina. The necessity to locate them near the centres of the single-ripped areas meant that no nearby areas could be found where they could be placed in exactly the same type of vegetation as the other exclosures and control site, despite considerable time spent searching for suitable locations. Both sites were shown by the PATN analysis to have vegetation that was in different classification groups to the rest of their respective sites. In retrospect, a better approach in the selection of these sites would have been to select the monitoring sites in suitable country and where no warrens were located within them and to then rip the surrounding area after the fences were constructed and the control site marked out.

The evidence from the exclosure sites suggests that under their current grazing regime they meet the expectations of the state and transition model proposed by Westoby *et al.* (1989).

4.4 SHRUB DENSITY

This section examines the shrub density data collected from the 2 x 20 m quadrats and from the 1 x 50 m transects (Section 3.9.4.1, Figure 3.1). In the interests of clarity, the 2 x 20 m quadrats are referred to in this section as the "quadrat", or by "Q" in classification groupings, and the 1 x 50 m transects as the "transect", or by "T" in classification groupings. The letter is placed before the number in the case of adult shrub groups, or after the number in the case of juvenile shrub groups.

Mean, rather than median, densities were calculated for shrubs in order to maintain consistency throughout this section. Median densities could not be used for juvenile shrubs because of the large number of occasions on which no juveniles were recorded, giving a potential median density of zero.

4.4.1 RESULTS

4.4.1.1 Adult Shrub Densities

The classification groupings of shrub density data from the two different quadrat types at the Bray-Curtis 0.96 level of dissimilarity are shown in Table 4.11. Descriptions of the groups identified from the two dendrograms (Appendices G and H) are given in Table 4.12. Seven groups from each of the two classifications were similar enough to be considered to represent the same plant associations, even though mean densities sometimes differed by a factor of two.

Group Q3 contains the shrubs from the Cowarie site. As with the cover data discussed above, ordination of the shrub data shows that the group containing the shrubs from this site is very dissimilar to other groups (Figure 4.14a).

Group Q4 contains sites with the highest mean density of *Maireana astrotricha*, but also with mid-range density values for *Atriplex vesicaria.* This group occurs at the second control site at Billa Kalina Site 1, at Billa Kalina Site 4 and at the Wilpoorinna rabbit-proof exclosure. In the transects, the equivalent Group T3 also occurs in the rabbit- and stock-proof exclosures at Wilpoorinna.

Group Q5 has higher mean density of *Atriplex vesicaria* than Group Q4, but lower mean density of *Maireana astrotricha.* In the transects, this group is included with Group T3.

Table 4.11: Affinities of exclosure sites to classification groups on the basis of adult shrub densities: (a) based on densities in the two 2x20 m quadrats; (b) based on densities from two 1x50 m transects. Blank spaces in the table indicate that no shrubs were present at that time.

(a)

Site	T20	T21	T22	T23	T24	T25	T26	T27	T28	T29
K1C1	Q1	Q1	Q2	Q2	Q2	Q2		Q2	Q2	Q1
K1C2	Q4	Q4	Q4	Q4	Q4	Q4		Q4	Q4	Q4
K1R									Q1	
K1S	Q2	Q2	Q2	Q2	Q2	Q2		Q2	Q2	Q2
K2C1	Q11	Q11	Q11	Q11	Q11	Q11		Q11	Q11	Q11
K2C2	Q5	Q8	Q8	Q8	Q8	Q8		Q8	Q8	Q8
K2R	Q11	Q11	Q11	Q11	Q11	Q11		Q11	Q11	Q4
K2S	Q11	Q11	Q11	Q11	Q11	Q11		Q11	Q11	Q11
K3C										
K3R	Q12	Q12	Q12	Q12	Q12	Q12		Q12	Q11	Q12
K3S										
K4C	Q4	Q4	Q4	Q4	Q4	Q4		Q4	Q4	Q4
K4R	Q4	Q4	Q4	Q4	Q4	Q4		Q4	Q4	Q4
K4S	Q5	Q5	Q5	Q5	Q5	Q5		Q5	Q5	Q5
M1C	Q6	Q6	Q6	Q6	Q6	Q6		Q6		
M1R	Q4	Q4	Q4	Q4	Q4	Q4		Q6		
M1S	Q5	Q5	Q5	Q5	Q5	Q5		Q5		
M2C	Q9	Q9	Q10	Q10	Q9	Q10	Q9	Q9		Q9
M2R	Q7	Q7	Q7	Q7	Q7	Q7	Q7	Q7		Q7
M2S	Q7	Q7	Q7	Q7	Q9	Q7	Q7	Q7		Q7
M3C	Q3		3			Q3			Q3	
M3R	Q3		3			Q3			Q3	
M3S	Q3		3			Q3			Q3	

(b)

Site	T20	T21	T22	T23	T24	T25	T26	T27	T28	T29
K1C1	T1			T2		T2		T2	T2	T1
K1C2	T3	T3	T3	T3	T3	T3		T3	T3	T3
K1R	T1		T1	T1		T1			T1	T1
K1S	T2	T2		T2	T2	T2		T2	T2	T2
K2C1	T11	T11	T11	T11	T11	T11		T11	T11	T11
K2C2	T4	T4	T4	T4	T4	T4		T4	T4	T4
K2R	T11	T11	T11	T11	T11	T11		T11	T11	T11
K2S	T11	T11	T11	T11	T11	T11		T11	T11	T11
K3C				T1				T1		T1
K3R	T7			T7					T11	
K3S	T8		T8	T8						
K4C	T3	T3	T3	T3	T3	T3		T3	T3	T3
K4R	T3	T3	T3	T3	T3	T3		T3	T3	T3
K4S	T3	T3	T3	T3	T3	T3		T3	T3	T3
M1C	T10	T10	T10	T10	T10	T10		T10		
M1R	T3	T3	T3	T3	T3	T3		T3		
M1S	T3	T3	T3	T3	T3	T3		T3		
M2C	T9	T9	T9	T9	T9	T3	T3	T3		T3
M2R	T5	T5	T5	T5	T4	T4	T4	T4		T5
M2S	T6	T6	T6	T5	T6	T5	T5	T5		T5
M3C	T12		T12			T12			T12	
M3R	T12		T12			T12			T12	
M3S	T12		T12			T12			T12	

Table 4.12: Descriptions of adult shrub count groups derived from the PATN analysis of the exclosure shrub density data. Groups are derived from the two dendrograms in Appendices G-H.

Opposite codes in the first two columns refer to cases where similar groups have been identified from the two different classifications. Where two mean values are given in the third column, the first refers to the quadrat data and the second to the transect data.

Group Number		Description
2x20 m quadrat data	1x50 m transect data	
Q1	T9	Very low density of *Atriplex vesicaria* (mean 1.3 and 1.2 shrubs/100m^2). No other shrubs present.
Q2	-	Low density of *Atriplex vesicaria* (mean 6.7 shrubs/100m^2). No other shrubs present.
Q3	T12	Moderate density of *Chenopodium auricomum* (mean 15.5 and 15.1 shrubs/100m^2) and low density of *Muehlenbeckia florulenta* (mean 3.0 and 6.9 shrubs/100m^2).
Q4	T3	Low to moderate density of *Atriplex vesicaria* (mean 19.3 and 31.1 shrubs/100m^2) and *Maireana astrotricha* (mean 19.9 and 14.1 shrubs/100m^2); very low densities of *Gunniopsis quadrifida* (mean 1.5 and 0.5 shrubs/100m^2) and *Maireana appressa, Maireana georgei, Maireana pyramidata* and *Rhagodia spinescens* (all with mean densities <1 shrub/100m^2). *Maireana aphylla* also occurs in the quadrats and *Senna artemisioides* subspp. in the transects (all with mean densities <1 shrub/100m^2).
Q5	-	Moderate density of *Atriplex vesicaria* (mean 42.7 shrubs/100m^2) and low density of *Maireana astrotricha* (mean 5.2 shrubs/100m^2); very low densities of *Maireana appressa* and *Sclerolaena tatei* (both with mean densities <1 shrub/100m^2).
Q6	T10	Low density of *Atriplex vesicaria* (mean 17.3 and 11.3 shrubs/100m^2) and *Maireana astrotricha* (mean 9.4 and 0.6 shrubs/100m^2) high density of *Maireana appressa* (mean 111.9 and 75.0 shrubs/100m^2); very low densities of *Maireana aphylla, Maireana pyramidata* and *Rhagodia spinescens* (all with mean densities <1.5 shrubs/100m^2). *Enchylaena tomentosa* also occurs in the 2x5 m quadrats and *Acacia tetragonophylla* and *Maireana georgei* in the 1x50m quadrats (all with mean densities ≤1 shrub/100m^2).
Q7	T5	Low density of *Atriplex vesicaria* (mean 6.0 and 14.8 shrubs/100m^2), moderate to low density of *Frankenia serpyllifolia* (mean 21.6 and 13.2 shrubs/100m^2) and very low density of *Maireana aphylla* (mean density <1 shrub/100m^2); the quadrats also have very low density of *Maireana appressa* (mean density <1 shrub/100m^2).
Q8	T4	Moderate density of *Atriplex vesicaria* (mean 47.2 and 39.7 shrubs/100m^2), very high density of *Frankenia serpyllifolia* (mean 158.8 and 118.2 shrubs/100m^2) and very low density of *Maireana astrotricha* (mean density <1 shrub/100m^2); the transects also have very low density of *Maireana aphylla* (mean density <1 shrub/100m^2).
Q9	-	Very low density of *Atriplex vesicaria* (mean 1.2 shrubs/100m^2) and *Frankenia serpyllifolia* (mean 0.2 shrubs/100m^2).
Q10	-	Low density of *Atriplex vesicaria* (mean 5.4 shrubs/100m^2). No other shrubs occur here (this group is very similar to Group Q2).
Q11	T11	Low to very low density of *Maireana astrotricha* (mean 6.9 and 6.3 shrubs/100m^2), *Maireana pyramidata* (mean 2.2 and 2.1 shrubs/100m^2) and *Maireana georgei* (mean <1 shrub/100m^2); very low densities *Atriplex vesicaria* (mean <1 shrub/100m^2) occur in the transects.
12	-	Very low density of *Maireana astrotricha* (mean 1.3 shrubs/100m^2). No other shrubs occur here.
-	T1	Very low density of *Gunniopsis quadrifida* (mean 1.0 shrubs/100m^2). No other shrubs present.

Table 4.12 (cont.): Descriptions of adult shrub count groups derived from the pattern analysis of the exclosure shrub density data.

Group Number 2x20 m quadrat data	1x50m transect data	Description
-	T2	Low density of *Gunniopsis quadrifida* (mean 3.3 shrubs/100m^2) and very low density of *Acacia aneura* (mean 0.1 shrubs/100m^2).
-	T6	Very low density of *Atriplex vesicaria* (mean 1.0 shrubs/100m^2) and low density of *Frankenia serpyllifolia* (mean 5.8 shrubs/100m^2).
-	T7	Very low density of *Enchylaena tomentosa* (mean 2.0 shrubs/100m^2). No other shrubs occur in this group.
-	T8	Very low density of *Acacia aneura* (mean 1.0 shrubs/100m^2). No low shrubs occur in this group.

Group Q6 has the highest mean density of *Maireana appressa.* It was identified only from the Wilpoorinna site and then mainly from the control site, with a limited occurrence within the two exclosures. The similar Group T10 is restricted to the Wilpoorinna control site.

Group Q8 has the highest mean density values for *Frankenia serpyllifolia*, with mid-range mean density of *Atriplex vesicaria.* It was identified only at the second control site at Billa Kalina Site 2. The equivalent of this group in the transects is Group T4, which was also identified at the Dulkaninna rabbit-proof exclosure.

Group Q7 has lower mean densities for both *Frankenia serpyllifolia* and *Atriplex vesicaria* than Group Q8 and was identified only in the stock-proof exclosure and at the control site at Dulkaninna. Its counterpart from the transects, Group T5, was replaced at the Dulkaninna site by two groups with higher mean cover values (Tables 4.11-4.12).

4.4.1.2 Significant Adult Shrubs and Environmental Parameters

An ordination of significant ($p<0.05$) shrub species and environmental parameters superimposed on the centroids of the shrub groups identified from the dendrogram (Appendix G) is shown in Figure 4.14b. No environmental parameters are significant in the quadrats, while rainfall during the previous one and six months was identified as being significant in the transects. Six shrub species are significant in the quadrats, while 11 shrub species are significant in the transects. Correlations between individual species and groups generally support the observations made in Table 4.12. There are no major differences between the quadrats and the transects in the ordination of species shown in Figures 4.14 and 4.15.

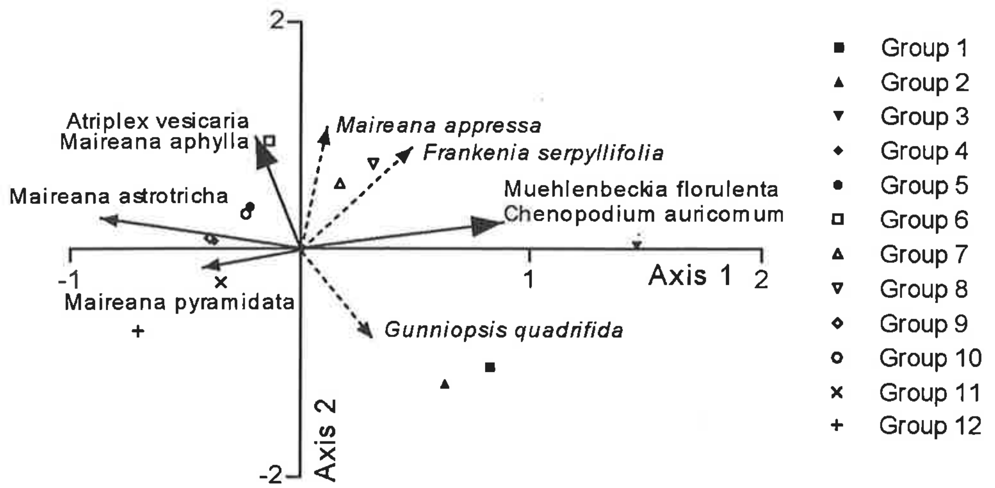

Figure 4.14a: Plot of the first two axes of a SSH ordination of the centroids of the groups derived from the dendrogram (Appendix G) of the exclosure sites 2x20 m quadrat adult shrub density data with a PCC ordination of significant ($p<0.05$) and other main species superimposed on the groups.

Stress = 0.15. Large arrowheads indicate more than one species at the point; dotted lines and names in italics denote non-significant species. No environmental parameters are significant in this ordination.

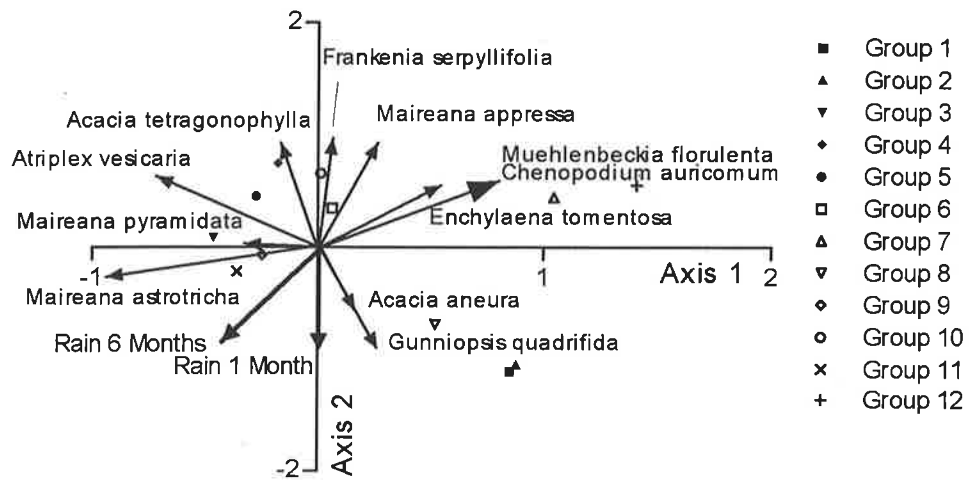

Figure 4.14b: Plot of the first two axes of a SSH ordination of the centroids of the groups derived from the dendrogram (Appendix H) of the exclosure sites 1x50 m transects adult shrub density data with a PCC ordination of significant environmental parameters and species ($p<0.05$) and other main species superimposed on the groups.

Stress = 0.16. The large arrowhead indicates two species at this point; thicker lines denote significant environmental parameters.

4.4.1.3 Juvenile Shrub Densities

Juvenile shrub density data were collected and analysed in the same way as adult shrub densities described in Section 4.3.2.1. The classification groupings of juvenile shrub density data from the two different quadrat types, at the Bray-Curtis 0.96 level of dissimilarity, are shown in Table

4.13. Descriptions of the groups identified from the two dendrograms (Appendices I and J) are given in Table 4.14. Eleven groups from each of the two classifications are similar enough to be considered to represent the same associations, even though mean densities sometimes differ by a factor of up to five. Despite this, many groups had closer mean density values for the quadrats and transects than was the case for adult shrub groups.

Group 4Q is the main group containing juveniles of *Maireana appressa.* It and its counterpart from the transects (Group 2T) were identified only from the Wilpoorinna control site and rabbit-proof exclosure. Group 6Q includes the highest juvenile densities of *Frankenia serpyllifolia* and was identified only from the second control site at Billa Kalina Site 2. However, its transect counterpart (Group 8T) was also identified inside the Dulkaninna rabbit-proof exclosure. Groups 10Q and 9T include the highest juvenile density of *Maireana astrotricha* and were identified only at Billa Kalina Sites 2 and 4. Group 11Q and 10T include the highest juvenile density of *Atriplex vesicaria* and high density of *Maireana astrotricha* and were identified only from Billa Kalina Site 4. Other groups derived from the classifications include various species or combinations of species at much lower densities (Table 4.14).

4.4.1.4 Significant Juvenile Shrubs and Environmental Parameters

An ordination of significant ($p<0.05$) juvenile shrub species and environmental parameters superimposed on the centroids of the shrub groups identified from the dendrogram (Appendices I-J) is shown in Figure 4.15b. Five environmental parameters are significant ($p<0.05$) in the quadrats: soil type, rainfall during the previous one and two years, and rabbit and stock grazing. Soil type, rainfall during the previous one, two and three years, and rabbit and stock grazing are significant environmental parameters in the transects. Seven shrub species are significant in the quadrats, while nine shrub species are significant in the transects. All groups correlate well with the species that are important in these groups as outlined in Table 4.14.

There is a strong negative correlation between rabbit and stock impacts and soil type in both quadrats and transects, and between stock grazing impacts and juveniles of *Frankenia serpyllifolia* in the transects. A positive correlation exists between rainfall during the previous year and juveniles of *Maireana appressa* and *Acacia aneura* in the quadrats and between rainfall during the previous one and two years and *Maireana georgei* and *Maireana appressa* in the transects. There are some differences between the ordinations presented in Figures 4.15a and 4.15b, with the ordination of the transect data providing the better representation of the data when compared to Tables 4.15 and 4.16.

Table 4.13: Affinities of exclosure sites to classification groups on the basis of juvenile shrub densities: (a) based on densities in the two 2x20 m quadrats (Appendix I); (b) based on densities from the two 1x50 m transects (Appendix J).

Blank spaces in the table indicate that no shrubs were present at that time.

(a)

Site	T20	T21	T22	T23	T24	T25	T26	T27	T28	T29
K1C1	1Q									1Q
K1C2	1Q					14Q		14Q	13Q	15Q
K1R										
K1S										
K2C1						2Q		10Q		
K2C2		6Q	12Q		12Q	13Q		12Q	12Q	12Q
K2R						10Q		10Q		
K2S	2Q					10Q		10Q		
K3C		1Q				3Q				
K3R										
K3S										
K4C	2Q	2Q	13Q			10Q		10Q	13Q	
K4R	13Q	15Q	13Q	13Q	15Q	10Q		13Q	13Q	2Q
K4S			15Q			11Q		11Q	13Q	
M1C	4Q		13Q	4Q		14Q		4Q		
M1R	13Q	2Q	14Q	3Q				4Q		
M1S	5Q	7Q	8Q					9Q		
M2C	12Q		3Q				13Q	12Q		15Q
M2R	12Q	15Q	12Q	13Q		14Q	12Q	12Q		13Q
M2S		13Q	15Q	15Q		13Q		12Q		15Q

(b)

Site	T20	T21	T22	T23	T24	T25	T26	T27	T28	T29
K1C1	1T	1T	1T							1T
K1C2	1T					11T		11T	12T	12T
K1R										
K1S						1T				
K2C1						7T		14T		
K2C2	11T	8T	8T			12T		8T	8T	11T
K2R		14T	14T			9T		9T	13T	
K2S	13T					9T		9T		
K3C		1T				13T				
K3R		4T								
K3S										
K4C	14T	13T	13T			9T		10T	11T	
K4R	14T	14T	14T	12T		10T		10T	14T	14T
K4S		12T				10T		10T	12T	
M1C	2T	3T	3T	2T		11T		2T		
M1R	11T		11T	11T		12T		2T		
M1S		5T	6T							
M2C			11T					12T		12T
M2R								8T		11T
M2S			12T	12T		10T		11T		12T

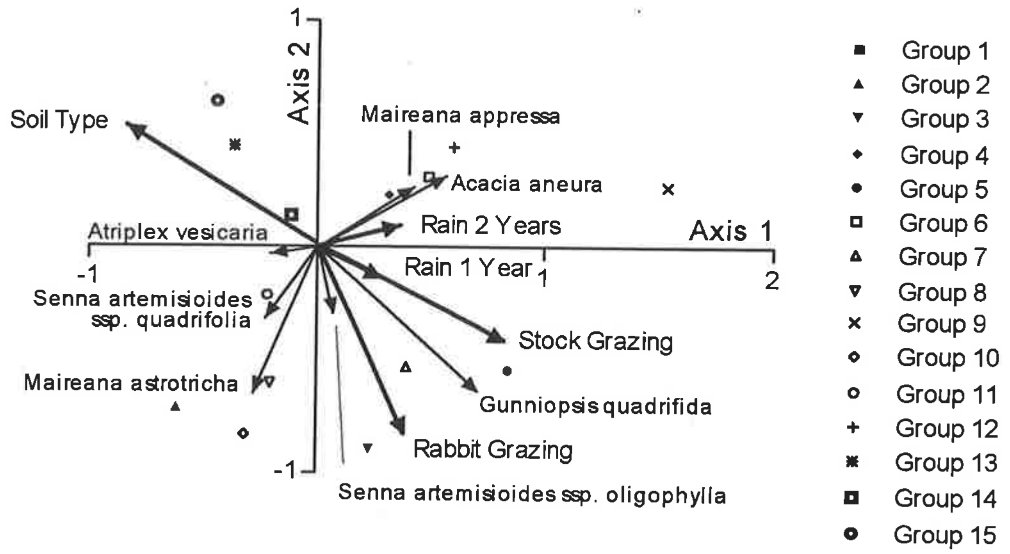

Figure 4.15a: Plot of the first two axes of a SSH ordination of the centroids of the groups derived from the dendrogram (Appendix I) of the exclosure sites 2x20 m quadrat juvenile shrub density data with a PCC ordination of significant (p<0.05) environmental parameters and species superimposed on the groups.
Stress = 0.19.

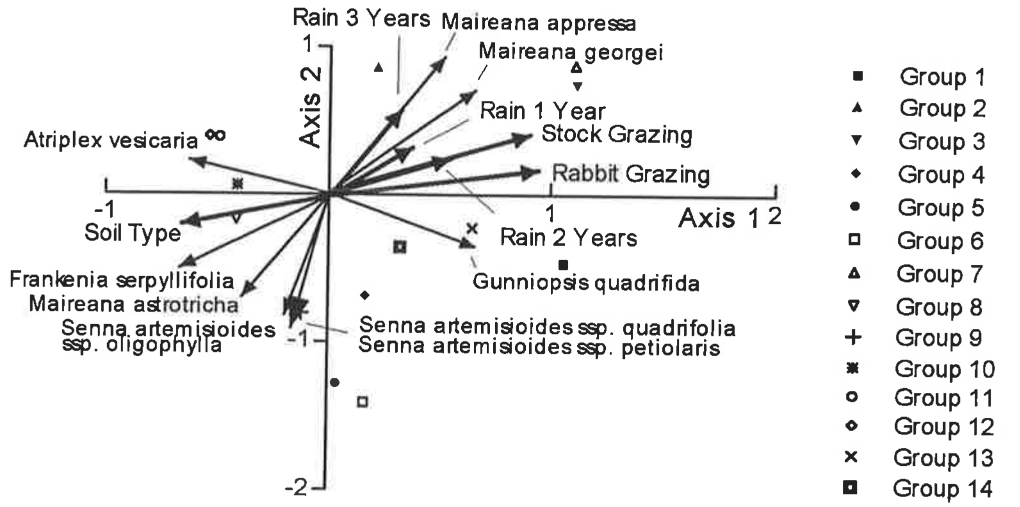

Figure 4.15b: Plot of the first two axes of a SSH ordination of the centroids of the groups derived from the dendrogram (Appendix J) of the exclosure sites 1x50 m transect juvenile shrub density data with a PCC ordination of significant environmental parameters and species (p<0.05) superimposed on the groups.
Stress = 0.19. The large arrowhead denotes two species at this point; thicker lines denote environmental parameters.

4.4.2 Discussion

Shrub density data were collected from paired 2 x 20 m quadrats rather than the 2 x 5 m cover quadrats in order to overcome problems caused by the natural heterogeneity of arid land systems, especially in low shrubland communities on gibber plains. The 2 x 5 m quadrats can either miss patches of shrubs completely, or else concentrate on a patch of shrubs and miss the bare ground that lies between them. Both cases fail to give a true representation of the relative cover and density of these shrubs. Use of the 1 x 50 m shrub count transects appears, from the data analysed in this study, to give an even better representation of density than the 2 x 20 m quadrats. These longer transects provided data that produced fewer shifts in classification groupings than did the 2 x 20 m quadrat data. Minimal shifts between groups would be expected from counts of long-lived perennial species, particularly those protected by the various types of fencing used here.

Table 4.14: Descriptions of juvenile shrub count groups derived from the pattern analysis of the exclosure shrub density data.

Opposite numbers in the first two columns refer to cases where two very similar groups have been identified from the two different classifications. Groups are derived from the dendrograms in Appendices I-J.

Group Number		Description
2x20 m quadrat data	1x50m transect data	
1Q	1T	Very low density of *Gunniopsis quadrifida* (mean 3.0 and 2.4 shrubs/100m^2); also very low density of *Maireana astrotricha* (mean 2.2 shrubs/100m^2) and *Maireana pyramidata* (mean 1.3 shrubs/100m^2) in the quadrats. This group was identified only at sandy sites at Billa Kalina.
2Q	-	Very low density of *Maireana astrotricha* (mean 3.8 shrubs/100m^2), *Atriplex vesicaria* and *Maireana georgei* (mean <1 shrub/100m^2). This group was identified at low shrubland sites at Billa Kalina and Wilpoorinna.
3Q	-	Very low density of *Acacia ligulata* (mean 1.3 shrubs/100m^2) and *Maireana astrotricha* (mean <1 shrub/100m^2). This group was identified at sandy sites at Billa Kalina and Wilpoorinna.
4Q	2T	Moderate density of *Maireana appressa* (mean 61.3 and 61.0 shrubs/100m^2) and very low densities of *Atriplex vesicaria* (mean 4.1 and 1.8 shrubs/100m^2) and *Enchylaena tomentosa* (mean 1.3 and <1 shrubs/100m^2); *Maireana astrotricha* (mean 3.5 shrubs/100m^2); *Acacia aneura* (mean 1.3 shrubs/100m^2) and *Rhagodia spinescens* (mean <1 shrub/100m^2) also occur in the quadrats. This is the main group representing juveniles of *Maireana appressa* and occurs only at the Wilpoorinna site.
5Q	6T	Very low density of *Senna artemisioides* subsp. *petiolaris* (mean 1.3 and 1.0 shrubs/100m^2); *Senna artemisioides* subsp. *quadrifolia* also occurs in the transects (mean 4.0 shrubs/100m^2). This group was identified only at Wilpoorinna and is quite similar to Group 8Q.
6Q	8T	Very high to moderate density of *Frankenia serpyllifolia* (mean 170.0 and 34.8 shrubs/100m^2) and very low density of *Atriplex vesicaria* (mean 1.3 and 2.6 shrubs/100m^2); very low density of *Maireana astrotricha* (mean <1 shrub/100m^2) in the transects. This is the main group representing juveniles of *Frankenia serpyllifolia* and occurs only at the second control site at Billa Kalina Site 2.
7Q	5T	Very low density of *Senna artemisioides* subsp. *oligophylla* (mean 1.3 and 1.0 shrubs/100m^2). This group was identified only at the Wilpoorinna site.
8Q	6T	Low density of *Senna artemisioides* subsp. *quadrifolia* (mean 7.5 and 4.0 shrubs/100m^2); *Senna artemisioides* subsp. *petiolaris* also occurs in the transects (mean 1.0 shrubs/100m^2). This group was identified only at the Wilpoorinna site.
9Q	3T	Very low density of *Maireana appressa* (mean 1.3 and 3.5 shrubs/100m^2); *Acacia aneura* occurs in the quadrats (mean 1.3 shrubs/100m^2). This group was identified only at the Wilpoorinna site.

Table 4.14 (cont.): Descriptions of juvenile shrub count groups derived from the pattern analysis of the exclosure shrub density data.

Group Number 2x20 m quadrat data	1x50m transect data	Description
10Q	9T	Very high density of *Maireana astrotricha* (mean 179.5 and 169.6 shrubs/100m^2); low densities of *Atriplex vesicaria* (mean 11.4 shrubs/100m^2) and very low densities of *Maireana appressa* (mean <1 shrub/100m^2) occur in the quadrats; very low densities of *Maireana pyramidata* (mean <1 shrub/100m^2) occur in the transects. This is the main group for juveniles of *Maireana astrotricha* and occurs only at Billa Kalina Sites 2 and 4.
11Q	10T	Very high or high density of *Atriplex vesicaria* (mean 289.4 and 80.2 shrubs/100m^2) and moderate to high density of *Maireana astrotricha* (mean 56.9 and 43.8 shrubs/100m^2). This is the main group for juveniles of *Atriplex vesicaria.* It was recorded only in the stock proof exclosure at Billa Kalina Site 2.
12Q	8T	Low density of *Atriplex vesicaria* (mean 4.2 and 2.6 shrubs/100m^2) and low to moderate densities of *Frankenia serpyllifolia* (mean 12.5 and 34.8 shrubs/100m^2). *Maireana astrotricha* (mean <1 shrub/100m^2) also occurs in the transects. This group was identified at sites with clay soils at Billa Kalina and Dulkaninna.
13Q	-	Very low density of *Atriplex vesicaria* (mean 5.2 shrubs/100m^2) and *Maireana appressa* and *Maireana astrotricha* (both with mean densities of <1. shrub/100m^2). This group was identified at sites with clay soils at Billa Kalina and Dulkaninna, and at the second control site at Billa Kalina Site 1.
14Q	11T	Low density of *Atriplex vesicaria* (mean 17.8 and 11.8 shrubs/100m^2) and very low density of *Maireana astrotricha* (mean 5.3 and 1.6 shrubs/100m^2), *Frankenia serpyllifolia* and *Maireana appressa* (all with mean densities ≤1.5 shrubs/100m^2); *Enchylaena tomentosa* also occurs in the quadrats and *Atriplex nummularia* subsp. *nummularia* in the transects (all with mean densities <1 shrub/100m^2). This group was identified only at the Wilpoorinna and Dulkaninna sites.
15Q	12T	Very low density of *Atriplex vesicaria* (mean 1.3 and 1.8 shrubs/100m^2); *Frankenia serpyllifolia, Gunniopsis quadrifida* and *Maireana astrotricha* all occur in the transects (all with mean densities <1 shrub/100m^2). This group was identified only at clay soil sites at Billa Kalina and Dulkaninna.
-	4T	Very low density of *Enchylaena tomentosa* (mean 2.0 shrubs/100m^2). This group was identified only at one sandy site at Billa Kalina.
-	7T	Very low density of *Maireana georgei* (mean 3.0 shrubs/100m^2). This group was identified only at one clay site at Billa Kalina.
-	13T	Very low density of *Maireana astrotricha* (mean 1.0 shrubs/100m^2). This group was identified at both clay and sandy sites at Billa Kalina.
-	14T	Very low density of *Maireana appressa* (mean 4.7 shrubs/100m^2) and *Atriplex vesicaria* (mean <1 shrub/100m^2). This group was identified only at clay sites at Billa Kalina.

Shifts in group affinities of adult shrubs occurred at 32% of sites, both for the quadrats and the transects. However, the shifts were not always at the same sites or at the same times for the two different types of site. More than twice as many shifts in group affinities were recorded in the transects as in the quadrats, mostly at sites with very low shrub densities. Many of these shifts were brought about by no shrubs being recorded at a site, but being recorded at the next or subsequent monitoring. This was often caused by shrubs, especially *Gunniopsis quadrifida,* appearing dead at one monitoring, but having fresh leaf growth following subsequent rainfall.

There was only one shift in group affinities for adult shrubs in the 2 x 20 m quadrats at the low shrubland sites at Billa Kalina, including within the second control site at Site 1 which has sandy rather than clay soil. There were no shifts at these sites in the transects. The majority of shifts were at sandy sites at Billa Kalina, and at Dulkaninna. These are all sites with very low shrub densities. Shrub communities at all sites were in an equivalent or better condition group at the end of the monitoring than they were at the start.

More environmental parameters and almost twice as many species were significant in the 1 x 50 m transects than in the 2 x 20 m quadrats, although there were no major differences between species in the ordinations of the two data sets. This may also imply that data from the transects are of superior quality and a more robust nature than data from the quadrats.

The positive correlation between rainfall for periods greater than one year and juveniles of some shrub species is caused by the time required for adult plants to set seed following heavy rainfall and for a subsequent rainfall event, or usually events, being necessary to cause germination. The period between seed set and germination is usually more than one year in an arid environment. The problem is exacerbated by the relatively short period over which the seed of *Atriplex vesicaria*, the main shrub species, remains viable in the field in the study areas (Badman 1992a).

There were no changes in adult shrub densities within exclosures that were not also recorded at unfenced control sites. Changes at control sites were usually also recorded within the exclosures. The exceptions to this all involved cases where the control site(s) and exclosures were in different groups at the start of monitoring. Most of the changes in group affinities recorded in the 2 x 20 m quadrats were at the Dulkaninna site, while the majority of changes recorded in the 1 x 50 m transects involved the sandy sites at Billa Kalina. All of these sites, and similar surrounding areas, have very low shrub densities. There were very few shifts in group affinities in the quadrats at the Billa Kalina low shrubland sites, and none in the transects in this vegetation community.

The only rainfall that was significant in relation to juvenile shrub densities was rainfall during the previous one, two and three years. Although shorter-term rainfall is non-significant here, the greatest densities of juvenile shrubs were nevertheless recorded following rainfall events of at least 25 mm and more usually 50 mm. The much heavier rainfall event of February 1997 produced only limited numbers of juvenile shrubs at most sites. The largest numbers of juvenile shrubs were recorded at the main low shrubland sites at Billa Kalina following rainfall of at least 25 mm during the winter months, or 50 mm at other times. The majority of major germination events were recorded at these sites in November 1995 and April 1996, with the greater number recorded in April 1996. In November 1995, juvenile shrubs were recorded that germinated following about 30 mm of rain in June 1995, while in April 1996, juvenile shrubs were recorded following three consecutive months with rainfall between 20-25 mm, giving a total of more than 60 mm.

Conditions such as those that occurred from October to December 1995, with three consecutive months with rainfall above 20 mm, are most likely to produce large numbers of shrub seedlings because additional rainfall following germination allows the seedlings to continue to grow. Single rainfall events at this time of the year, even when very heavy, do not keep the soil moist for long enough for seedlings to germinate and become established. However, despite the large numbers of juvenile shrubs that were recorded in April 1996, and also in November 1995, there were no corresponding shifts of adult shrubs to better-condition groups (Table 4.5). Recruitment of these shrubs must have been sufficient only to replace shrubs lost through natural attrition.

4.5 PRESENCE OR ABSENCE OF SPECIES AS A MONITORING TOOL

Data collected in the 2 x 5 m quadrats, giving a total area of 20 m^2 for each exclosure or control site, were analysed on the presence or absence of species using the same components of the PATN software package described in Section 3.11.2. During each monitoring, the 50 x 50 m exclosures and control sites were also checked for any species that were not present in the small quadrats. These species were added to those recorded in the small quadrats to give the presence or absence of species at the 2500 m^2 level of monitoring.

The Bray-Curtis 0.96 level of dissimilarity, as previously used in this chapter, was again used as the cut-off point on the two dendrograms to determine the number of groups.

In order to supplement the pattern analysis techniques used previously, the data were also subject to two-way analysis using the PATN software package (Belbin 1991b). However, this technique proved to have limited value.

4.5.1 Results

4.5.1.1 Classification at the 20 m^2 and 2500 m^2 Scales of Monitoring

Six groups were identified at the 0.96 level of dissimilarity from the classification of the small quadrat data (20 m^2) and five groups at the same level of dissimilarity from the whole exclosure and control site (2500 m^2) data. The dendrogram from which the small quadrat groups are derived is presented in Appendix K and the dendrogram for the transect groups in Appendix L. For the sake of simplicity and clarity, groups identified in this section from the 20 m^2 classification are pre-fixed with the letter "S" and those from the 2500 m^2 classification with the letter "L".

Groups S1 and L1 both contain the same 54 relevés from the sandy sites, Sites 1 and 3, at Billa Kalina, but excluding relevés from the second control site at Site 1. However, the dendrogram arrangement of the relevés included in the two groups is not the same.

Groups S2 and L2 include the same 30 relevés, all of those from the second control site at Billa Kalina Site 1 and from the Wilpoorinna site. However, as with the previous two groups, the dendrogram order was not the same for the two groups, although the Billa Kalina relevés are separated from the Wilpoorinna relevés in both groups.

The main difference between the two classifications lies in group distribution of the next 53 relevés from the dendrogram. Group S3 contains 33 relevés from the Billa Kalina Site 2 and Site 4 low shrubland communities on clay soils, but with the majority from Site 2 (26 relevés). The remaining relevé from Billa Kalina Site 2 (excluding the second control site) is included in Group S5. The remaining 20 relevés from Billa Kalina Site 4 are included in Group S4. In contrast, Group L3 contains all the relevés included in Groups S3 and S4 and one additional control site relevé from Billa Kalina Site 2 (T25K2C1).

Groups S5 (37 relevés) and L4 (36 relevés) contain relevés from low shrubland sites with clay soils at the second control site at Billa Kalina Site 2 and at Dulkaninna. They are almost identical in their composition, except that Group S5 contains one relevé, T25K2C1, that is included in Group L3.

As is the case with all other classifications of the exclosure sites data, a single group includes all 12 relevés from the Cowarie site. These are included in Group S6 and Group L5.

4.5.1.2 Significant Species in Individual Group Composition

The numbers of species that occur in each group and of species that are significant ($p<0.05$, as determined from the probabilities from the PATN GST files) to each group's composition are shown in Table 4.15. Because no cover or density data are considered in this analysis, all species have equal rank, with no single species being more important than any other. This means that there are no "character" species for groups, as is the case with the cover and shrub density data. Several species are important in the composition of more than one group, especially in Groups L1 - L5.

Table 4.15: Numbers of species that occur in each classification group and the number of these that are significant to each group's composition.

Groups are derived from the dendrograms in Appendices K-L. Groups S1 - S6 include a total of 182 individual species and Groups L1 - L5 include 215 individual species.

Group	No. of Significant Species	Total No. of Species	Group	No. of Significant Species	Total No. of Species
S1	35	100	L1	55	133
S2	42	97	L2	57	123
S3	33	73	L3	43	97
S4	23	42			
S5	45	88	L4	58	125
S6	20	37	L5	27	47

4.5.1.3 Shifts Between Classification Groups

The membership of groups is given in Table 4.16. Seven shifts in group affinities were identified from the 20 m^2 classification, while only two shifts were identified from the 2500 m^2 classification. These shifts occurred at three sites in the case of the 20 m^2 data and one site in the case of the 2500 m^2 data. Two shifts were recorded at the first control site at Billa Kalina Site 2 at both scales of monitoring, and both involved temporary shifts recorded on only a single occasion. All shifts in group affinities involved chenopod low shrubland sites at Billa Kalina and included cases in both types of exclosure and at one control site.

4.5.1.4 Two-Way Analysis

Two-way analysis (Belbin 1991b) was carried out on the two datasets. Neither provided useful results. The stress values of the ordinations were found to be unacceptably high (0.32 in both cases). The two-way tables both failed to show the blocks of species that are indicative of a robust analysis using this technique (Belbin 1991b). Because of the high stress values and the lack of robustness in the two-way tables, this analysis was not continued beyond this point.

Table 4.16: Distribution of sites in groups derived from the dendrograms (Appendices J-K) of the classification of the presence or absence of species in (a) the 2 x 5 m quadrats and (b) the 50 x 50 m exclosures and control sites.

(a)

	T20	T21	T22	T23	T24	T25	T26	T27	T28	T29
K1C1	1	1	1	1	1	1		1	1	1
K1C2	2	2	2	2	2	2		2	2	2
K1R	1	1	1	1	1	1		1	1	1
K1S	1	1	1	1	1	1		1	1	1
K2C1	3	3	3	3	3	5		3	3	3
K2C2	5	5	5	5	5	5		5	5	5
K2R	3	3	3	3	3	3		3	3	3
K2S	3	3	3	3	3	3		3	3	3
K3C	1	1	1	1	1	1		1	1	1
K3R	1	1	1	1	1	1		1	1	1
K3S	1	1	1	1	1	1		1	1	1
K4C	3	3	4	4	4	4		4	4	3
K4R	3	4	4	3	4	4		4	3	3
K4S	4	4	4	4	4	4		4	4	4
M1C	2	2	2	2	2	2		2		
M1R	2	2	2	2	2	2		2		
M1S	2	2	2	2	2	2		2		
M2C	5	5	5	5	5	5	5	5		5
M2R	5	5	5	5	5	5	5	5		5
M2S	5	5	5	5	5	5	5	5		5
M3C	6		6			6			6	
M3R	6		6			6			6	
M3S	6		6			6			6	

(b)

	T20	T21	T22	T23	T24	T25	T26	T27	T28	T29
K1C1	1	1	1	1	1	1		1	1	1
K1C2	2	2	2	2	2	2		2	2	2
K1R	1	1	1	1	1	1		1	1	1
K1S	1	1	1	1	1	1		1	1	1
K2C1	3	3	3	3	3	5		3	3	3
K2C2	4	4	4	4	4	4		4	4	4
K2R	3	3	3	3	3	3		3	3	3
K2S	3	3	3	3	3	3		3	3	3
K3C	1	1	1	1	1	1		1	1	1
K3R	1	1	1	1	1	1		1	1	1
K3S	1	1	1	1	1	1		1	1	1
K4C	3	3	3	3	3	3		3	3	3
K4R	3	3	3	3	3	3		3	3	3
K4S	3	3	3	3	3	3		3	3	3
M1C	2	2	2	2	2	2		2		
M1R	2	2	2	2	2	2		2		
M1S	2	2	2	2	2	2		2		
M2C	4	4	4	4	4	4	4	4		4
M2R	4	4	4	4	4	4	4	4		4
M2S	4	4	4	4	4	4	4	4		4
M3C	5		5			5			5	
M3R	5		5			5			5	
M3S	5		5			5			5	

4.5.2 Discussion

This form of survey and data analysis, excluding both cover and density values, does not provide the robust results that were found in earlier analyses (Sections 4.3.2, 4.4.1). There are large savings in survey time when using this method (Noy-Meir 1971), but the resulting data do not allow an informed judgement to be made on the stability of the community (e.g. Rahel 1990) and do not provide the level of detail required from the type of vegetation survey and analysis used for this thesis. The savings in time when no cover data are collected are considerable. A list of species present could be obtained from an exclosure in 10-15 minutes, while the average time taken to read the two 2 x 5 m quadrats was usually in the order of 30-45 minutes and occasionally up to one hour, depending on the number of species present and the difficulty in finding small plants amongst dense cover of common species. Classification based entirely on the presence or absence of species is probably more useful when used for comparing vegetation communities over much larger areas.

The whole exclosure and control site data (2500 m^2) were more consistent than the small quadrat data, as indicated by a lesser number of shifts between groups in Table 4.16. However, this may not always be an advantage because it could hide trends that become evident at the smaller scale of monitoring. Without the advantage of cover or density values, such trends may not agree with trends identified by more comprehensive techniques.

The shifts identified at both the 20 m^2 and 2500 m^2 scales were restricted to low shrubland sites with clay soils at Billa Kalina, whereas shifts identified by classification of the cover data were mainly at sandy sites at Billa Kalina, with shifts at clay soil low shrubland sites limited to the final monitoring event. None of the shifts that were identified in the final monitoring at Billa Kalina sites were identified by either of the analyses discussed in this section. However, analysis of the presence or absence data did provide the same consistent result as the cover data analysis at the Wilpoorinna, Dulkaninna and Cowarie sites, where no changes in group affinities were detected by any of the analyses (excluding juvenile shrubs).

4.6 CONCLUSIONS

There were no increases in either vegetation cover or species richness in fenced exclosures that were not also identified at control sites, although there were differences in the timing of responses to rainfall between exclosures and control sites. However, the response sometimes occurred first in the exclosures and sometimes at the control sites, so nothing can be inferred from this in relation to the exclosures. It is likely that the time scale of the monitoring at exclosure sites was too short to obtain meaningful answers about the effects of grazing on the vegetation, given the slow rate of change reported by other workers (e.g. Gardner 1950, Hall *et al.* 1964, Robertson 1971). Most of the changes that occurred correlate with rainfall, especially heavy rainfall events. Swale sites were more stable than dune sites, with clear-cut distinctions and rapid changes between stable states. The monitoring sites conformed to the state and transition model, although changes between states were less well defined on sandy soils and may have involved a long transition period.

Species richness did not increase in the exclosure sites compared to the control areas as might have been expected. In fact there was an increase in species richness at some control sites that was not matched in the corresponding exclosures. The common species tended to dominate in exclosures, particularly in the rabbit-proof exclosures. Control sites generally had less cover, but often had a greater number of species.

There was no sustained increase in recruitment of low shrub species in exclosures. This result may have been affected to some extent by the dry conditions at Billa Kalina. Differences between exclosures and control sites may have also been affected by low rabbit numbers after RCD wiped out most of the rabbit populations towards the end of the monitoring. Rabbit impacts were found to be significant at Billa Kalina sandy sites early in the monitoring. Very high germination of seed at some Billa Kalina swale sites did not lead to corresponding increases in shrub densities and recruitment appeared to be only sufficient to compensate for natural attrition in the shrub populations. Very little germination or recruitment of shrubs was noted at sandy sites.

No conclusions could be drawn on the effect of exclusion of cattle from the Warburton River floodplain because no flooding occurred at the exclosure site during the four years of monitoring. In addition, this site may have been only lightly grazed during the flood prior to the first monitoring event.

The detailed collection and analysis of cover and density data as described in the first part of this chapter was found to be more appropriate to studies of this type than the use of data based only on presence or absence of species. Use of presence or absence data alone would not have achieved the aims of this section, particularly as they relate to potential increases in cover and shrub density following removal of domestic herbivores. The latter method is likely to be more relevant to studies over a much larger area and covering a greater range of species and plant associations.

CHAPTER 5 ANDAMOOKA STATION GRAZING EXPERIMENT

5.1 INTRODUCTION

The harmful effects and ecological unsustainability of long-term high stocking rates have been well documented, both in Australia and overseas (Dixon 1892, Ratcliffe 1936, Pick 1944, Box and Perry 1971, Ares 1974, Williams 1974, Le Houerou 1989, Friedel *et al.* 1990, Galaty and Johnson 1990). Yet several contemporary pastoralists have expressed to me the view that heavy but short-term grazing pulses do not have these same impacts on the vegetation. They suggested that the damage to vegetation was done when heavy stocking rates were maintained in the longer-term.

Foran *et al.* (1982) suggested that environmental change is more easily detected in carefully managed experiments with high but controlled grazing pressure. To give the best results, replicated studies need to be conducted before the grazing impact occurs and for at least two years afterwards (Green 1979) in order to separate the effects of grazing and natural habitat variation. Chenopod low shrublands are particularly heterogenous because of the banding effects of run-on and run-off areas on slopes of as little as 0.5 degrees (Dunkerley and Brown 1995). However, this natural spatial heterogeneity of arid zone ecosystems has frequently been a confounding factor in ecological research (Stafford Smith and Morton 1990).

Earl and Jones (1996) suggested that cell (or pulse) grazing may be the answer to problems caused by set stocking rates under adverse seasonal conditions. Cell grazing has been found in some studies to prevent selective grazing (Coughenour 1991) while giving greater control over grazing and the time allowed for plants to recover between grazing events (Earl and Jones 1996). It was found to maintain desirable pasture species in the long-term, while at the same time reduce undesirable and unpalatable species, including alien species (Earl and Jones 1996). However, grazing pulses need careful management. Although this method gives greater control over both the grazing animal and the rate of vegetation consumption, initial plant recovery may be slow following severe defoliation, with root extension virtually ceasing and roots becoming shorter and thinner (Earl and Jones 1996). Continuous or frequent defoliation results in a reduction in root mass and lessened ability to acquire nutrients and water, and therefore to withstand periods of moisture stress or insect damage (Earl and Jones 1996). Rainfall is still the most important factor in recovery between grazing pulses and can nullify the effects of grazing (Roe and Allen 1993).

5.2 AIMS

The aim of this experiment was to investigate whether short-term intensive grazing pulses have a long-term effect on the vegetation of chenopod low shrubland communities of swales and of tall shrubland communities of dunes in an arid zone environment.

Specific questions to be answered were:

- Do short-term grazing pulses by cattle have a lasting detrimental effect on arid chenopod shrublands in the Australian rangelands?
- Is there a different response between grazing pulses by cattle on chenopod low shrubland of swales and tall shrubland vegetation of adjacent dunes in the arid Australian rangelands?

During the course of the experiment it was noticed that the cryptogamic soil crust was less affected by trampling than was expected from reports in the literature. A supplementary aim of the experiment was therefore to investigate whether the effects of cattle trampling on the cryptogamic soil crust differ from those of published accounts of sheep trampling.

5.3 RESULTS

5.3.1 CLASSIFICATION OF THE GRAZING EXPERIMENT DATA

The dendrogram produced by the PATN analysis of the grazing experiment data is presented in Figure 5.1. Seven groups in three clusters were identified from the dendrogram at the Bray-Curtis 0.56 and 0.96 levels of dissimilarity respectively. The three clusters with their identifying features are shown in the stylised dendrogram in Figure 5.2. Details of the number of species in each group and the median cover and species richness are given in Table 5.1. A brief description of each group and cluster is given in Table 5.2 and a fuller description in Section 5.3.2.

The SSH ordination of clusters is shown in Figure 5.3 and of groups in Figure 5.4. The most significant species for each group are given below under the group descriptions in Section 5.3.2 and a full list is given in Appendix M.

5.3.2 DESCRIPTIONS OF GROUPS

5.3.2.1 Cluster 1

This cluster contains all of the swale relevés from the first monitoring event and all of the subsequent control area and pre-grazing swale relevés. It also includes one sandy control area relevé. Vegetation is dominated by *Atriplex vesicaria* and *Enneapogon avenaceus*, and in one group by *Dactyloctenium radulans.*

T1 and T3 represent the monitoring events preceding the grazing pulses, T2 and T4 are the post-grazing monitoring events, and T5 represents monitoring in April 1997.

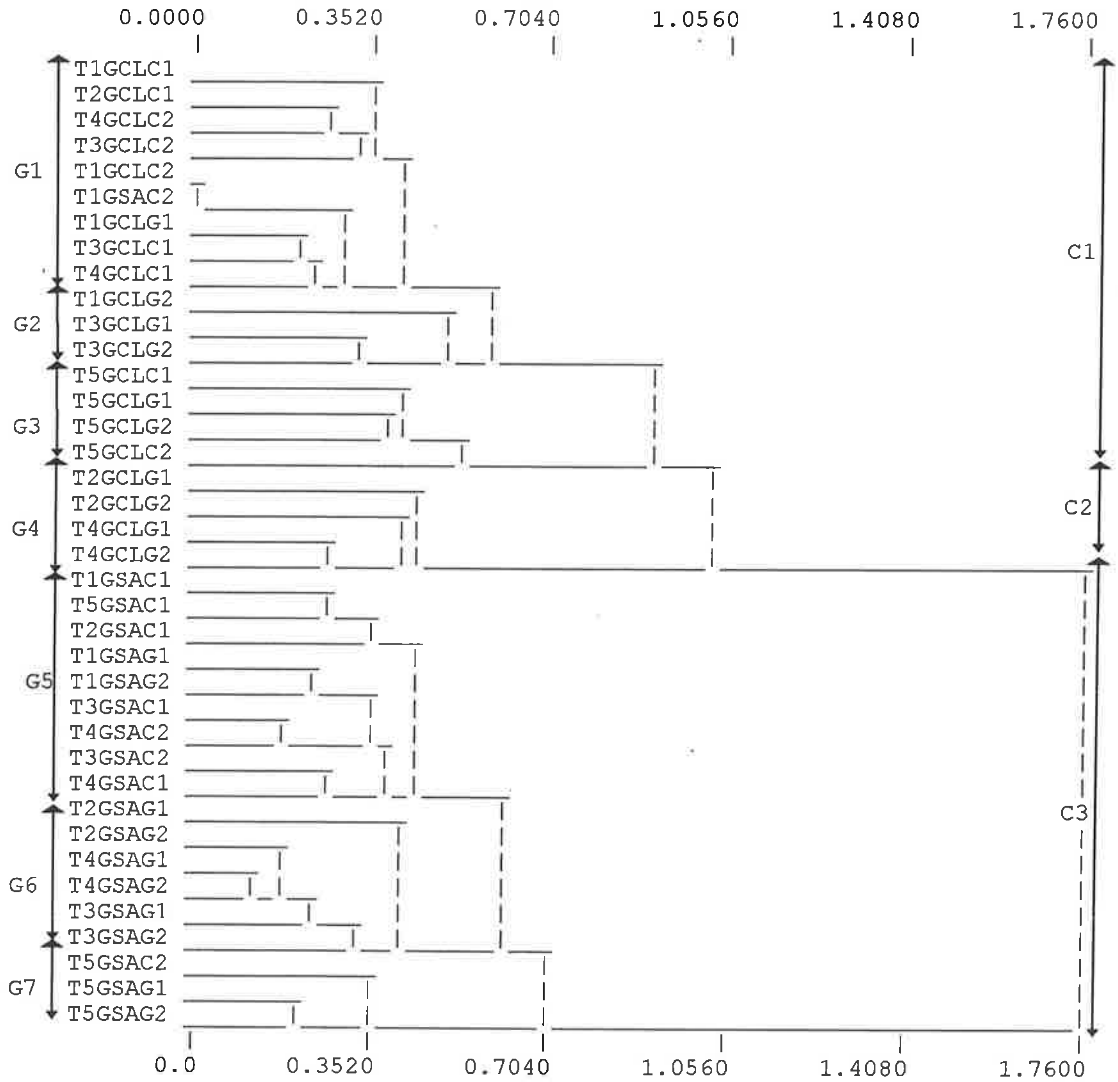

Figure 5.1: Dendrogram showing the classification of the grazing experiment data into seven groups (G1-G7) and three clusters (C1-C3).

Group 1

Most of the control area relevés, excluding those from the final monitoring event, and one pre-grazing relevé from Paddock B, are included here. Group members have high median cover and mid-range median species richness, with vegetation dominated by *Atriplex vesicaria* and *Enneapogon avenaceus.* Both these species attained their highest mean cover values here. *Maireana astrotricha* is also significant in the composition of this group and three other significant species attained highest mean cover values here. This group also includes one dune relevé, but it is thought that one of the transects included in this relevé crossed a sandy swale between two dunes. It was included here because of its soil type, but had vegetation that was actually more closely allied to that of the nearby clay swales, especially in cover of *Enneapogon avenaceus*, but also of *Atriplex vesicaria.*

Table 5.1: Details of the composition of the three clusters and seven groups identified by PATN analysis of the grazing experiment data.

The number of significant species refers to all species that were identified by PATN analysis as being significant ($p<0.05$, as determined from the probablilities from the PATN GST files) to the make up of that group; median cover and species richness values are the median values for all species recorded in that group.

	No. of Relevés	No. of Significant Species	Total no. of Species	Median Cover (%) (Range)	Median Species Richness (Range)
Cluster 1	16	13	76	22.8 (9.0-25.5)	19 (11-35)
Cluster 2	4	9	23	4.1 (3.7-4.9)	11 (7-13)
Cluster 3	18	13	62	22.1 (8.6-40.0)	17 (6-32)
Group 1	9	10	43	22.6 (17.7-28.3)	19 (11-25)
Group 2	3	11	39	9.8 (9.0-22.3)	17 (15-29)
Group 3	4	14	58	39.0 (38.0-46.7)	34 (21-35)
Group 4	4	9	23	4.1 (3.7-4.9)	11 (7-13)
Group 5	9	11	49	25.1 (17.1-40.0)	18 (6-29)
Group 6	6	8	32	13.7 (8.6-19.7)	15 (6-18)
Group 7	3	13	42	37.3 (36.5-39.3)	27 (26-32)

Table 5.2: Main characteristics of the groups and clusters obtained by PATN analysis of the grazing experiment data.

Cluster 1 (mainly swale relevés from pre-grazing and the final monitoring and from control areas)	
Group 1	Most of the pre-grazing and control area relevés on swales, but excluding those from the final monitoring event. High median cover and mid-range median species richness. Vegetation is dominated by *Atriplex vesicaria* and *Enneapogon avenaceus.*
Group 2	Three swale relevés from pre-grazing and between-grazing (first recovery) monitoring events. Low median cover and mid-range median species richness. Vegetation is dominated by *Atriplex vesicaria.*
Group 3	All swale relevés from the final monitoring. Very high median cover and species richness. Vegetation dominated by *Dactyloctenium radulans.*
Cluster 2 (post-grazing swale relevés)	
Group 4	All swale relevés from grazed paddocks immediately after both grazing pulses. Very low median cover and low median species richness. No species dominate.
Cluster 3 (dune relevés from all monitoring events)	
Group 5	Pre-grazing and control area dune relevés. High median cover and mid-range median species richness. Vegetation is dominated *by Dodonaea viscosa, Aristida holathera* and *Acacia ligulata.*
Group 6	Grazed dune relevés, including those from between the grazing pulses. Low median cover and species richness. Vegetation is dominated by *Dodonaea.viscosa* and *Acacia ligulata.*
Group 7	Three dune relevés from control and grazed areas in April 1997. Very high median cover and species richness. Vegetation is dominated by *Dodonaea viscosa* and *Acacia ligulata.*

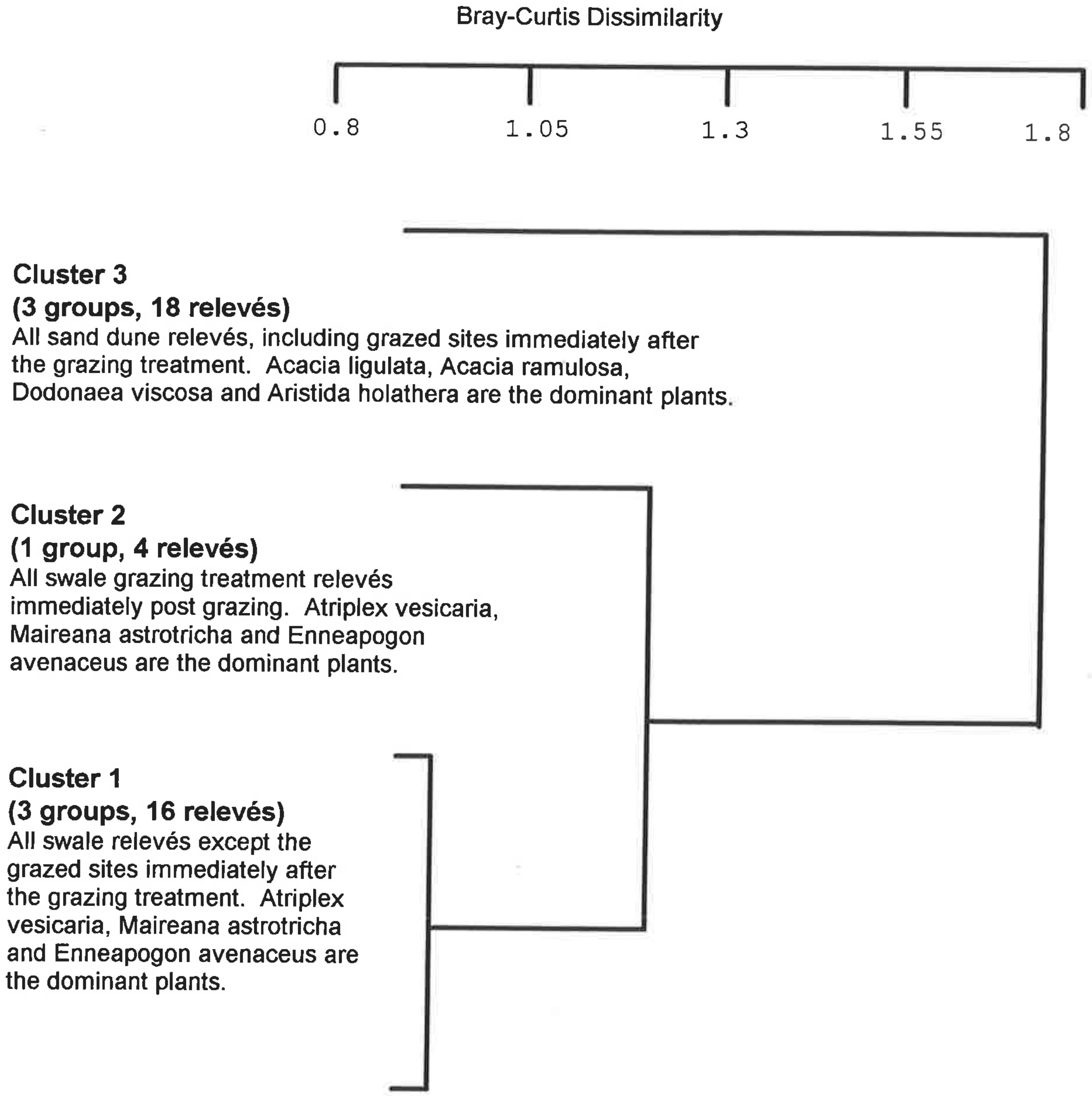

Figure 5.2: Stylised dendrogram of cluster relationships with plant and edaphic indicators for each cluster from the grazing experiment data.

Group 2

This group includes three swale relevés from pre-grazing monitoring events. They have low median cover and mid-range median species richness, with vegetation dominated by *Atriplex vesicaria*. This group is separated from Group 1 relevés mainly because of much lower median cover, particularly of the grass *Enneapogon avenaceus.* Only one species, *Enchylaena tomentosa*, reached its highest mean cover value in this group. All of the members of this group are located on Andamooka Station and one area, in Paddock C, is represented twice.

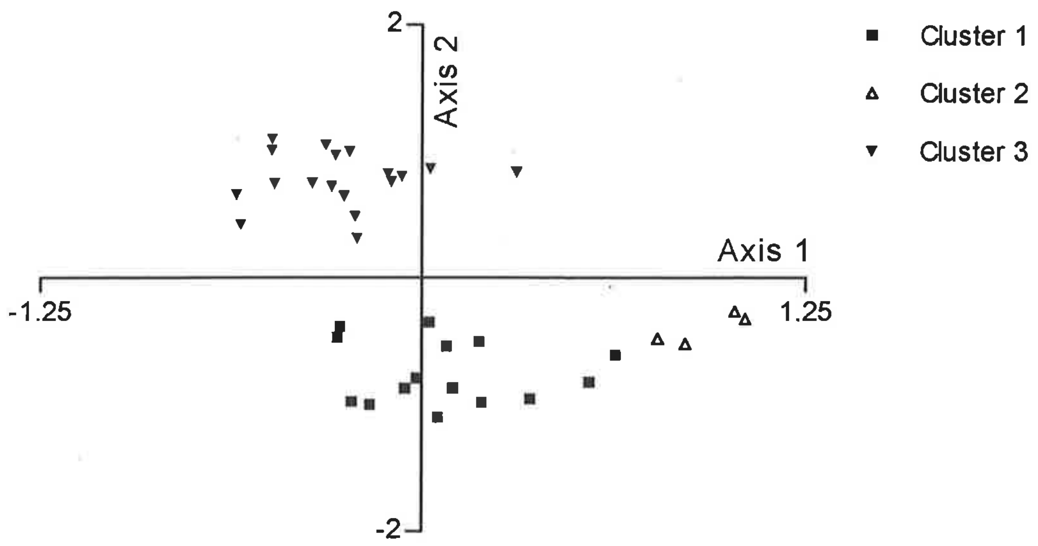

Figure 5.3: Plot of the first and second axes from a semi-strong hybrid scaling (SSH) ordination of the grazing experiment data showing the three clusters derived from the dendrogram in Figure 5.1.
Stress = 0.09.

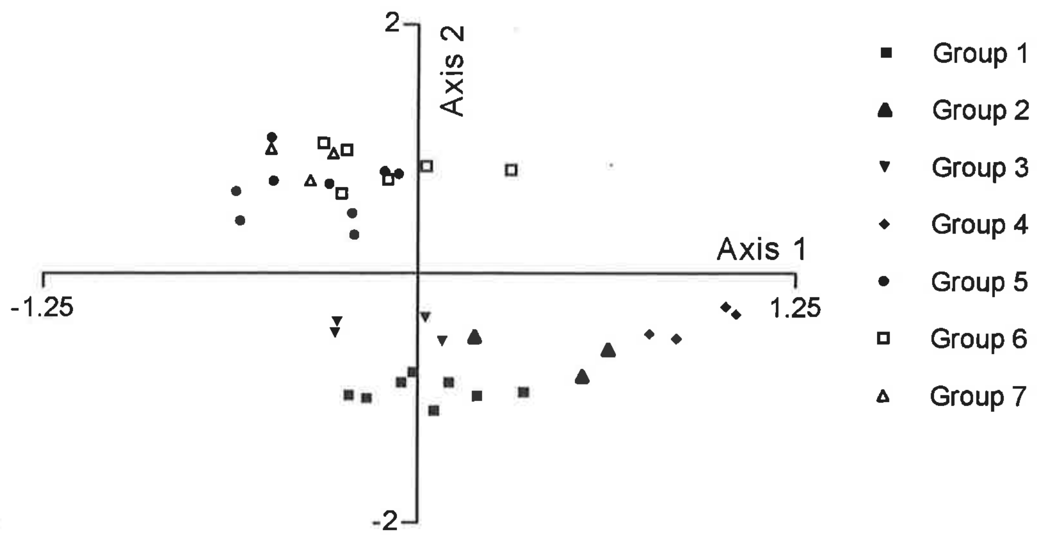

Figure 5.4: Plot of the first and second axes from a SSH ordination of the grazing experiment data showing the seven groups derived from the dendrogram in Figure 5.1.
Stress = 0.09.

Group 3

This group includes all swale relevés from the final monitoring in April 1997. They have very high median cover and species richness values, with vegetation dominated by *Dactyloctenium radulans*, which reaches its highest mean cover value here. *Atriplex vesicaria, Enneapogon avenaceus* and *Maireana astrotricha* are all significant to group make-up and the latter species reaches its highest mean cover value here. Six other species attain their highest mean cover values in this group, including three grasses and the mainly summer-growing *Tribulus terrestris.*

5.3.2.2 Cluster 2

This cluster contains the four grazed swale relevés from the two post-grazing surveys.

Group 4

This group is made up of all of the swale relevés from grazed paddocks immediately after the grazing pulses. Its members reflect the effects of heavy grazing by having very low median cover and low median species richness. No species dominate here. Of the nine significant species in this group, four are shrubs, one is a grass and four are chenopodiaceous forbs.

5.3.2.3 Cluster 3

This cluster contains all but one of the relevés from dune areas. Unlike Cluster 1, the post-grazing relevés are also included here. Also unlike the swale areas in Cluster 1, vegetation is dominated by generally unpalatable species, the shrubs *Dodonaea viscosa* and *Acacia ligulata* and the grass *Aristida holathera.*

Group 5

Members of this group are dune relevés from pre-grazing monitoring events and from control areas. They have high median cover and mid-range median species richness, with vegetation dominated *by Dodonaea viscosa, Aristida holathera* and *Acacia ligulata*. The first two of these species and *Acacia ramulosa* all attain their highest mean cover values here. Only one relevé from the final monitoring event is included in this group, from the ungrazed control area. This group is the dune equivalent of Group 1.

Group 6

This group is made up of grazed dune relevés. It includes all the post-grazing dune relevés and also the two grazed dune relevés from between the two grazing pulses. These relevés all have low median cover and species richness values, with vegetation dominated by *Dodonaea viscosa* and *Acacia ligulata.* The latter species is the only one to attain its highest mean cover value in this group. This group is the dune equivalent of Group 2.

Group 7

The three dune relevés from control and grazed areas from the April 1997 monitoring form this group. It has very high median cover and species richness values, with vegetation dominated by *Dodonaea viscosa* and *Acacia ligulata*. Two annual grasses, *Paractaenum refractum* and *Triraphis mollis*, reach their highest mean cover values here. The short-lived perennial grass *Aristida holathera* is still significant in this group and has a much higher median cover than in Group 6, but does not quite recover to its former Group 5 value. This group is the dune equivalent of Group 3.

5.3.3 Shifts Between Groups

The term "shift" is used here to indicate a conceptual change in a dynamic vegetation community from a condition (Westoby *et al.* 1989) that meets the criteria of one of the groups or clusters derived from the dendrogram clustering of the data to a condition that meets the criteria of a different group or cluster. This was discussed in more detail in Section 4.3.2.3.

The shifts of areas with different treatments between groups at different monitoring events are shown in Table 5.3. Reasons for these shifts are suggested in Table 5.4.

Apart from the shift from swale Group 1 to dune Group 5 at one of the dune control areas, which is believed to be an artefact of the monitoring technique and was mentioned above and is discussed in more detail in Table 5.4, all changes can be ascribed directly to the effects of grazing, release from grazing coupled with rainfall, or the heavy rainfall event of February 1997.

Table 5.3: Alliance of areas with different treatments to the seven conceptual groups derived from the dendrogram in Figure 5.1 at different monitoring events.
nr = not recorded.

Area	Pre-Grazing Pulse 1	Post-Grazing Pulse 1	Pre-Grazing Pulse 2	Post-Grazing Pulse 2	Two Years After First Grazing Pulse
Swale Control 1	1	1	1	1	3
Swale Control 2	1	nr	1	1	3
Swale Paddock B	1	4	2	4	3
Swale Paddock C	2	4	2	4	3
Dune Control 1	5	5	5	5	5
Dune Control 2	1	nr	5	5	7
Dune Paddock B	5	6	6	6	7
Dune Paddock C	5	6	6	6	7

At swale sites, there was a well defined shift after grazing to groups with much lower median cover values and slightly lower species richness. This trend was reversed following release from grazing and good but not exceptional falls of rain. Recovery following the first grazing pulse involved a shift to Group 2 condition, which was the original condition of Paddock C but has lower median cover and species richness than Group 1. Following the second grazing pulse, swale sites again returned to the same condition as after the first grazing pulse. Recovery following the second grazing pulse was to an even better condition than that recorded after the first pulse. All swale sites, including ungrazed controls, shifted to the better Group 3-condition following the much heavier rainfall event (144 mm) in February 1997. This group has the highest median cover and species richness recorded on swales.

The same clear-cut changes in group alliances were not evident in the classification of dune sites. There was no recovery between grazing pulses. The grazed dune areas shifted to Group 6 after the first grazing pulse and remained there until after the heavy rainfall event of February 1997.

Table 5.4: Suggested reasons for shifts between conceptual groups derived from Figure 5.1 at different monitoring events.

Shifts From Group	Shifts to Group	No. of Cases	Suggested Reasons for Shift
1	3	2	Shift on swale areas to a group with much higher median cover and species richness following a very heavy rainfall event and growth of *Dactyloctenium radulans*. A shift to a better condition.
1	4	1	Shift on swale areas to a group with much lower median cover and species richness following the first grazing pulse. A move to a worse condition.
1	5	1	This shift is an artefact of the monitoring technique used and is the only case of a shift from one cluster to another. This area shifted from a swale vegetation community to a dune community (where it should have been in the first place), presumably because of the inclusion of a sandy interdune area with swale type vegetation in one of the transects.
2	4	3	Shift on swale areas from a group with lower pre-grazing median cover and species richness than the control areas to one with even lower median cover and species richness after the first grazing pulse. A shift to a worse condition.
4	2	2	Shift on swale areas from a post-grazing condition with very low median cover and species richness to a better group after partial recovery of the vegetation. A shift to a better condition.
4	3	2	Shift on swale areas from a post-grazing condition to a better condition following very heavy rainfall. Vegetation changes included a large increase in cover of *Dactyloctenium radulans.* A shift to a much better condition.
5	6	2	Shift from pre-grazing to post grazing condition on dunes. Large reduction in cover, especially of *Aristida holathera,* and a smaller reduction in species richness. A change to a worse condition.
5	7	1	Shift caused by large increases in cover and species richness on ungrazed dunes following a heavy rainfall event. A shift to a better condition.
6	7	2	Shift caused by large increases in cover and species richness on grazed and ungrazed dunes following a heavy rainfall event. A shift to a better condition.

It was thought that changes on dune areas between grazing pulses may have been masked by the fact that the main species, *Dodonaea viscosa, Acacia ligulata* and the grass *Aristida holathera,* are unpalatable to cattle, although the latter is eaten when nothing better is available. To test this, the two shrubs were removed from the dataset and the pattern analysis was repeated. This showed that the first analysis was in fact correct and there was no post-grazing recovery of the ground cover species on dunes until the heavy rainfall event of February 1997.

5.3.4 ENVIRONMENTAL PARAMETERS

The r-values and significance of the measured environmental parameters as determined by PCC ordination are shown in Table 5.5. All parameters were significant ($p<0.05$) except rainfall during the previous month and rainfall during the previous three years. The significant environmental parameters are plotted with the three clusters in Figure 5.5a. The main significant species are plotted with the seven groups in Figure 5.5b, while other significant species are listed in Table 5.6, together with the sectors they would occur in if plotted in the same way as those in Figure 5.5b. There is a marked separation in the ordination between the dune species in Sector 7 and the swale species in Sector 6.

Table 5.5: Summary of PCC analysis of environmental parameters with the Andamooka Station grazing experiment cover data showing whether or not they are significantly correlated ($p<0.05$) with the ordination of the relevés.

Environmental Parameters	R	Significance
Soil Type	0.9246	*
Lichen	0.5554	*
Litter	0.7204	*
Rainfall in Previous Month	0.4061	ns
Rainfall in Previous 2 Months	0.8656	*
Rainfall in Previous 3 Months	0.8431	*
Rainfall in Previous 6 Months	0.8490	*
Rainfall in Previous Year	0.8250	*
Rainfall in Previous 2 Years	0.8277	*
Rainfall in Previous 3 Years	0.1679	ns

Soil samples containing cryptogams were collected at the grazing experiment sites in April 1998. These were examined by Mr Graham Bell of the State Herbarium of South Australia and the identified taxa are listed in Table 5.7. Cover values of the cryptogamic crust are shown in Figure 5.6.

Both soil type and lichen cover show a strong positive correlation with the swale clusters 1 and 2. Lichen cover correlates most closely with Group 1, which is the best-condition swale group (Section 5.3.2). There is a strong negative correlation between lichen cover and all of the dune groups, and between litter and the majority of the swale species.

Table 5.6: Potential position on scatter plot of significant species that are not included in Figure 5.5.
Sectors are numbered in a clockwise direction from the right hand side of the upper (positive) Y axis. Each sector represents a 45 ^{0} arc.

Species	Sector	Species	Sector
Dichanthium sericeum	1	*Sclerolaena divaricata*	6
Iseilema sp.	1	*Sclerolaena lanicuspis*	6
Erodium cygnorum	2	*Alectryon oleifolius*	7
Aristida contorta	6	*Atriplex velutinella*	7
Atriplex holocarpa	6	*Tripogon loliiformis*	7
Dissocarpus paradoxus	6	*Boerhavia dominii*	8
Eragrostis setifolia	6	*Maireana erioclada*	8
Euphorbia wheeleri	6	*Nicotiana velutina*	8
Panicum decompositum	6	*Paractaenum refractum*	8
Rhodanthe floribunda	6	*Portulaca oleracea*	8
Sclerolaena diacantha	6	*Triraphis mollis*	8

There is a strong positive correlation between rainfall during the previous year and a suite of shrubs that occur on dunes and are significant to the composition of the dune groups. There is also a strong positive correlation between rainfall during the previous 3 years and a suite of species that are significant in the composition of the best-condition swale groups. *Salsola kali* correlates closely to rainfall during the previous two and six months, as do a suite of mostly dune inhabiting species listed in Table 5.6. There is a less strong positive correlation between rainfall over these periods and the ephemeral grass *Dactyloctenium radulans* and the annual grasses *Sporobolus actinocladus* and *Eragrostis dielsii*. *Salsola kali* also shows a positive correlation with the heavily grazed dune Group 6. There is a close positive correlation between the best of the ungrazed dune relevés in Groups 5 and 7 and cover of the grass *Aristida holathera.*

Table 5.7: Cryptogams collected from swales at the grazing experiment site.
(Determinations courtesy of Graham Bell.)

Species	Comments
Psora decipiens	A common pink soil lichen that was very common at the site.
Eremastrella crystallifera	A common dark brown soil lichen that was common at the site.
Peltula sp(p).	Common dark green and/or brown soil lichen(s). More than one species was possibly involved.
Synalissa sp.	This is a black soil lichen that was fairly common at the site.
Collema sp.	A black soil lichen that was fairly common at the site.
Desmatodon convolutus	This dark green moss was represented by a few plants collected with the lichens. This species could not be detected with the naked eye.

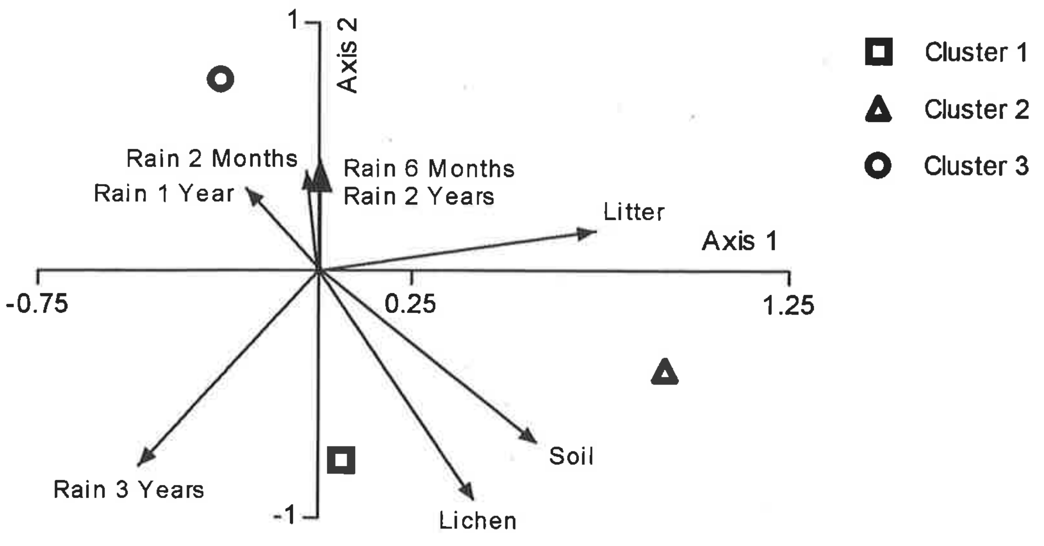

Figure 5.5a: Plot of the first and second axes from a SSH ordination of the centroids of the three clusters dervied from the dendrogram in Figure 5.1 with a PCC ordination of the significant environmental parameters superimposed on the clusters.

The time period after "rain" refers to the total rainfall for the stated period preceeding the monitoring. The large arrowhead indicates that two parameters occupy the same point. Stress = 0.09.

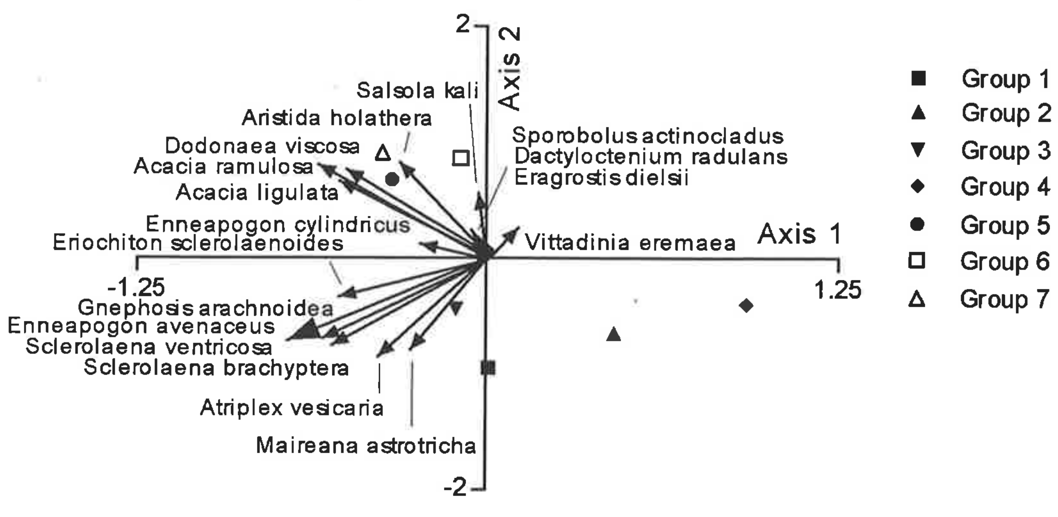

Figure 5.5b: Plot of the first and second axes from a SSH ordination of the centroids of the seven groups obtained from classification of the grazing experiment data (Figure 5.1), with a PCC ordination of the main significant species overlain on the groups.

Stress = 0.09. Other significant species are listed in Table 5.6. Large arrowheads indicate that more than one parameter occupies the point.

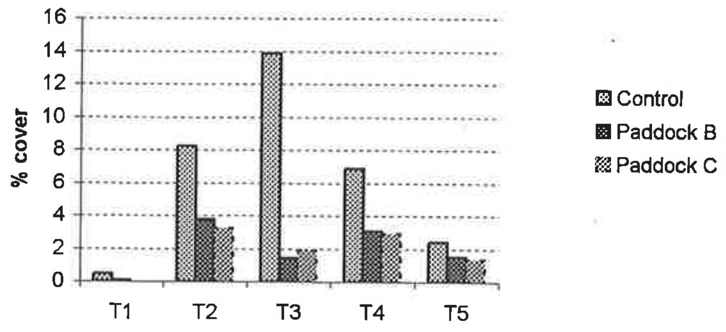

Figure 5.6: Cover of cryptogams at the grazing experiment site.
T1=March 1995, T2=July 1995, T3=November 1995, T4=February 1996, T5=April 1997.

5.3.5 CHANGES IN SPECIES' COVER

Figures 5.7 and 5.8 show changes in total vegetation cover for clay and sandy soils respectively, while Figures 5.9-5.15 show changes in cover for selected species. Total cover was much higher in April 1997 than in March 1995 (Figures 5.7 - 5.8) following the two grazing pulses and then the heavy rainfall event of February 1997.

Although the swale areas had a superficially similar appearance and similar total cover values (Figure 5.7) before the start of the experiment, it is apparent from the analysis that the more easterly of the two paddocks on Andamooka Station (Paddock C) contained vegetation that was in poorer condition prior to the grazing pulses than either the control Area A or Paddock B (Figure 5.1, Table 5.2). This may have been due to previous light grazing, or to a natural heterogeneity of the vegetation in this area (e.g. Figures 5.9 - 5.10), but I have no data to support or refute either hypothesis.

The effects of grazing and of post-grazing recovery were more pronounced on the swale areas than on the dunes. Following grazing, all species on swales had low cover values (Figure 5.7), with no particular species dominant. Following release from grazing, there was a rapid recovery, but to less than pre-grazing cover values. There were no gross long-term effects of the grazing pulses that could be detected at the level of monitoring and analysis that were used in this experiment, although the graphing of data for the two most important shrubs on swales (*Atriplex vesicaria* and *Maireana astrotricha*) shows that both had lower cover at the end of the experiment than at the beginning (Figures 5.9 - 5.10). Cover values of *Atriplex vesicaria* (Figure 5.9) and *Maireana astrotricha* (Figure 5.10) in April 1997 were still below those recorded at the start of the experiment, particularly in Paddock B *Atriplex vesicaria* was more heavily grazed than *Maireana astrotricha* during the first grazing pulse, but *Maireana astrotricha* was more severely affected by the second grazing pulse (Figures 5.9 - 5.10).

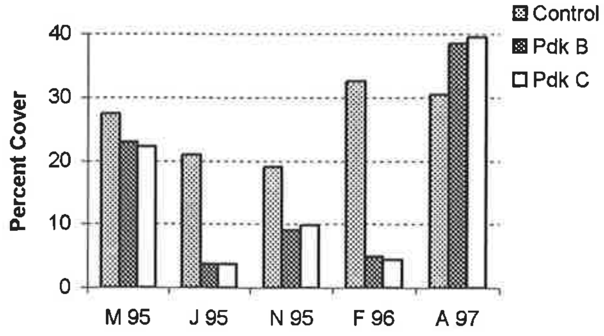

Figure 5.7: Total vegetation cover on swales at grazing sites.
(M 95=March 1995, J 95=July 1995, N 95=November 1995, F 96=February 1996, A 97=April 1997)

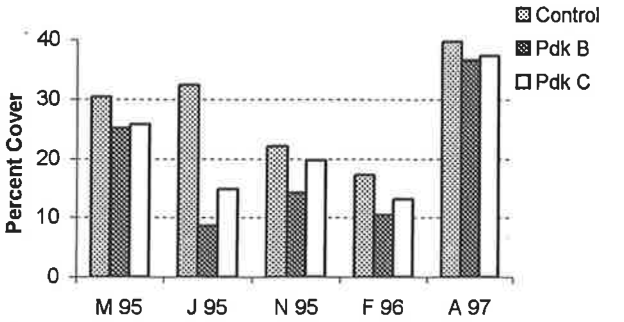

Figure 5.8: Total vegetation cover on sand dunes at grazing sites.

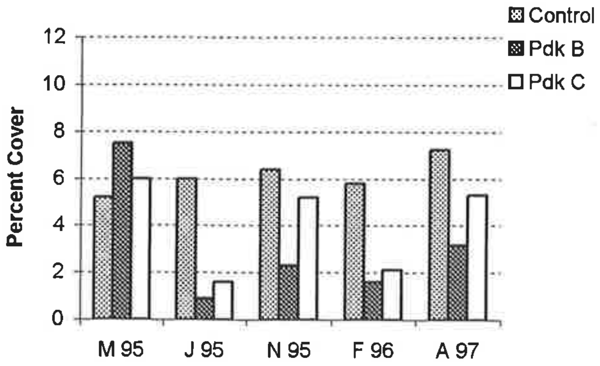

Figure 5.9: Cover values on swales for *Atriplex vesicaria* at the grazing experiment site.

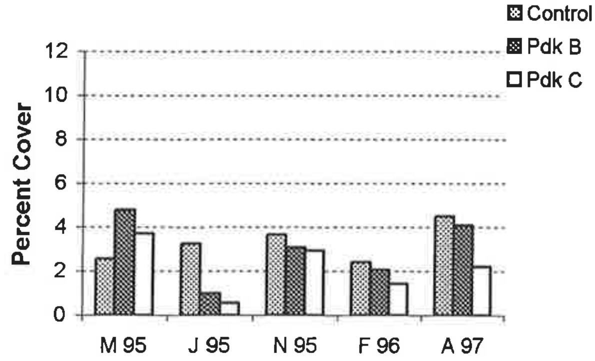

Figure 5.10: Cover values on swales for *Maireana astrotricha* at the grazing experiment site.

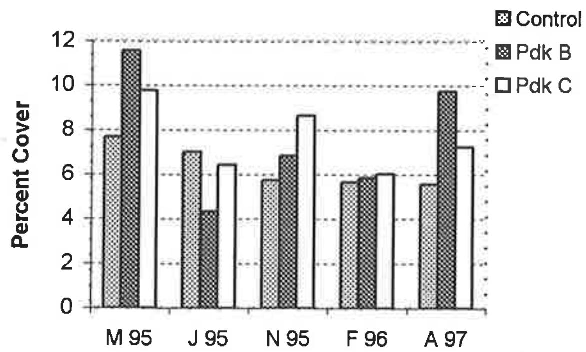

Figure 5.11: Cover of *Dodonaea viscosa* on sand dunes at the grazing experiment site.

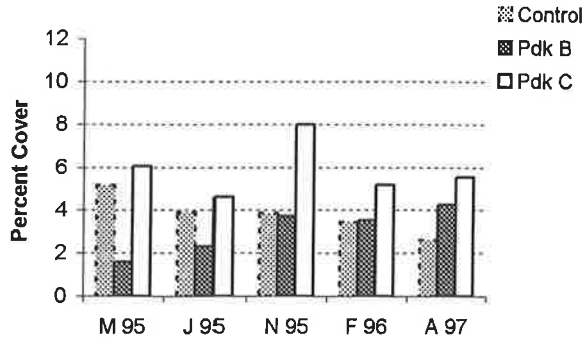

Figure 5.12: Cover of *Acacia ligulata* on sand dunes at the grazing experiment site.

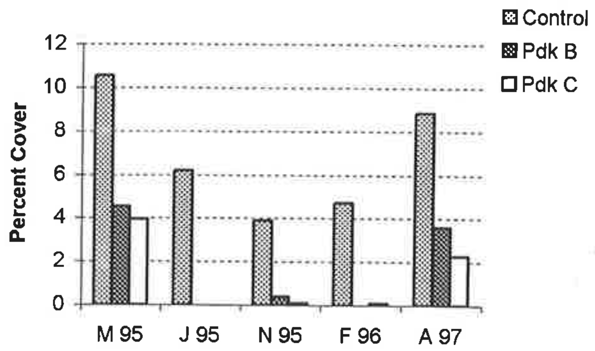

Figure 5.13: Cover of *Aristida holathera* on sand dunes at the grazing experiment site.

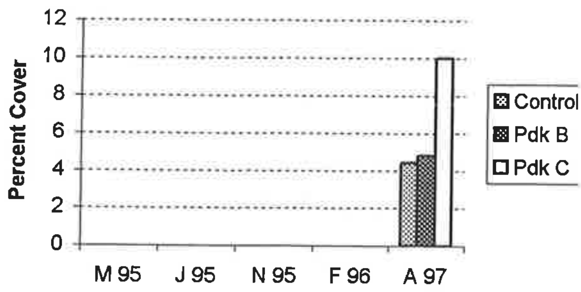

Figure 5.14: Cover values on swales *Dactyloctenium radulans* at the grazing experim site.

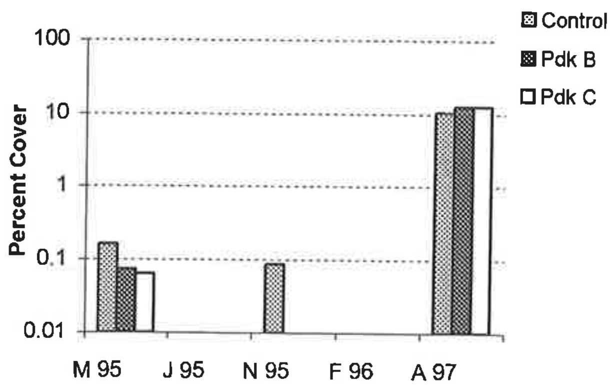

Figure 5.15: Cover of *Salsola kali* on sand dunes at the grazing experiment site.

The effects of grazing on dunes were different from those on the swale areas (Section 5.3.2). There was little recovery on dunes following the first grazing pulse and dune vegetation in both paddocks remained in the worst-condition dune classification group with low cover values until after the heavy rainfall of February 1997 (Figures 5.1 and 5.8). One control area and both paddocks then shifted to the best-condition dune classification group, a group with similar median cover and species richness values to the best-condition swale group identified at this time. There was no change at the other control area, which stayed in the same group throughout the experiment and never achieved the best condition that was attained by dune areas in the other control area and in both grazed paddocks after the February 1997 rainfall event (Figure 5.1).

The most important ground cover species on dunes at the experimental site is *Aristida holathera*. This species was almost completely removed from the two paddocks during the first grazing pulse, but also had reduced cover in the control area at this time. There was little recovery of this species in the grazed paddocks until after the heavy rainfall event of February 1997 (Figure 5.13). Even then, cover in Paddock C was only about half of its pre-grazing level.

The positive correlation between rainfall during the previous two and six months and the increased cover of the short-lived grasses *Dactyloctenium radulans, Eragrostis dielsii* and *Sporobolus actinocladus* (Figure 5.5b) was due to the February 1997 rainfall event, two months before the final monitoring.

Salsola kali is considered by some people to be an undesirable, or even an alien (e.g. Wilson 1986) species and had increased cover in both control and grazed areas following the February 1997 rainfall event. However, this species is not significant in the composition of any of the seven groups identified here, even though its cover values were similar and above 10% in both grazed and control areas following the February 1997 rainfall event (Figure 5.15).

5.3.6 The Effects of Cattle Grazing on Cryptogamic Cover

Cryptogamic soil crusts are very susceptible to damage by ungulate hooves. Various authors reporting on the results of cryptogamic studies have discussed the effects of "stock", but have also failed to specify which animal is involved (Rogers and Lange 1971, Belnap 1993, Grondin and Johansen 1993, Hodgins and Rogers 1997). Where both cattle and sheep are stated to have had effects on cryptogamic crusts, differences in trampling effects of each animal species have usually not been discussed (Eldridge 1996). Although it is often possible to work out whether sheep or cattle are involved because of geographical location of the experimental site, the particular animal involved was obviously not considered important by these researchers. In addition, few researchers have attempted to separate the effects of trampling by livestock from other impacts (West 1990).

Although St Clair *et al.* (1993) considered that the impacts of smaller ungulates is less than that of larger ones, based entirely on the size of the animals, this is not supported by African studies (e.g. Parker and Graham 1971, Ssemakula 1983, Plumptre 1993). Fatchen (1975) considered that many herbivores are less destructive than sheep. He gave the reasons for this as:

- fewer hooves per weight or dollar value of the animals, therefore less overall trampling;
- cattle tracking patterns are less intense;
- grazing habits of cattle and sheep are different, sheep are said to be uneven and destructive grazers and remove small plants completely but rarely touch rank growth, cattle graze less closely and more evenly;

- cattle graze further from water than sheep.

In addition, larger species typically have greater diversity in species selection (Mower and Smith 1989) and utilise more of the older rank vegetation, even when fresh green vegetation is available (Wilsey 1996).

During this experiment there was a noticeable difference in the effect of cattle on the cryptogamic soil crust to that described by many other workers. The cover of cryptogams in the two grazed paddocks was slightly lower than that of the control area at the start of the experiment (Figure 5.6), perhaps because of previous grazing pressure. The highest cryptogamic cover values at the control site coincided with the period between grazing pulses when cover was reduced on the grazed areas, and yet the relative cover values were higher, and bore a similar relation to each other, at the end of the experiment than they were at the beginning. The fact that a large part of this crust remained at the end of the experiment is contrary to the findings of the majority of other workers, most of whom worked in country where sheep are the dominant domestic herbivore. The exception is the case reported by West (1986 - cited in West 1990), where well developed microphytic crusts are still evident in parts of Israel that have had unrestricted grazing for centuries.

In order to compare the relative hoof pressure on the ground of sheep and cattle, a limited sample of sheep and cattle hooves was measured and compared to the animals' weight (Table 5.8). Results from this small sample showed cattle hoof pressure to be greater than that of sheep. A more comprehensive study by Ssemakula (1983), although carried out on animals with lower mean body weights, produced mean hoof pressure values for sheep and cattle similar to those for the ewe and Cow #1 in Table 5.8. However, in addition to the differences in grazing patterns noted by Fatchen (1975) and listed above, there are other differences in animal behaviour while grazing. The most important of these involves the way in which the two animals walk. Cattle, unless sick or in extremely poor physical condition, generally pick up their feet as they move, while sheep often drag their hind feet, leaving a continuous track on the ground. The latter point is supported by the fact that all hind hooves of sheep, but not cattle, examined for the hoof-pressure comparisons shown in Table 5.8 were rounded at the front. Front hooves are usually more pointed, especially in sheep. This foot dragging, coupled with the fact that sheep have shorter legs and must take more steps to walk a given distance, means that they disturb a far greater area of ground while feeding than do cattle. Their shorter necks also mean that they must move their feet more often in order to reach different plants. Sheep hooves also have a chisel effect on the soil which imparts a greater force at the point of impact than do the broader hooves of cattle. Plumptre (1993) considered that the African buffalo causes less damage to vegetation for a given number of animals than many other ungulate species because of their use of the same trails whilst moving about. Cattle exhibit this same trait.

Table 5.8: Comparisons of sheep and cattle hoof pressure. Measurements are for one front and one hind foot per animal.

Animal	Weight (kg)*	Hoof Area (cm^2)							Hoof Pressure on Ground kg/cm^2
		Front 1	Front 2	Front Total	Hind 1	Hind 2	Hind Total	Total all 4 Feet	
Lamb 1	13.1	5.20	4.84	10.04	4.44	3.80	8.68	37.44	0.35
Lamb 2	13.5	6.76	5.92	12.68	4.76	4.76	9.52	44.40	0.30
Ewe	57.0	11.60	10.72	22.32	11.08	10.68	21.76	88.16	0.65
Bull	1100	81.00	83.50	164.50	61.75	53.75	115.5	560.0	1.96
Cow 1	450	56.00	56.25	112.25	57.25	59.25	116.5	457.5	0.98
Cow 2	400	40.75	43.50	84.25	48.25	44.00	92.25	353.0	1.13

* Sheep were weighed; cattle weights are estimates by experienced observers

5.4 TWO-WAY ANALYSIS

5.4.1 DATA ANALYSIS

Two-way analysis, where the site and species classifications, through the dendrogram groups, are imposed on the data matrix (Belbin 1991b), is a useful way of displaying the results of a classification. This method also allows a pre-determined level of abundance to be shown for each species. In this case four levels were used: dominant, common, uncommon and absent. The results of the two-way analysis are presented in Table 5.9 and the dendrogram in Appendix N. Table 5.9 shows species associations as blocks in the various groups. Dense localisation of species and site groups demonstrates robustness of both the data and the analysis (Belbin 1991b). Where there are outliers from the main blocks in the present analysis (Table 5.9), these outliers are generally present only at the lowest abundance score. This is discussed for individual cases in the association descriptions below, but is largely due to problems of sandy-clay soils of dune-bases providing a habitat for both dune and swale species.

Table 5.9: Results of two-way analysis of the grazing experiment data. Six species associations are superimposed on the seven dendrogram groups from Figure 5.1.

Column headings are the relevés and row headings are abbreviated species names. D = dominant, C = common, U = uncommon, . = absent. Other codes are explained in Section 3.9.4.

	TTTTTTTTT	TTT	TTTT	TTTT	TTTTTTTTT	TTTTTT	TTT
	124311134	133	5555	2244	152113434	224433	555
	GGGGGGGGG	GGG	GGGG	GGGG	GGGGGGGGG	GGGGGG	GGG
	CCCCCSCCC	CCC	CCCC	CCCC	SSSSSSSSS	SSSSSS	SSS
	LLLLLALLL	LLL	LLLL	LLLL	AAAAAAAAA	AAAAAA	AAA
	CCCCCCGCC	GGG	CGGC	GGGG	CCCGGCCCC	GGGGGG	CGG
	112222111	212	1122	1212	111121221	121212	212
Association 1							
Acacaneu	UU....U..	UUU	..U.	UCUU	UUU....UU	UU....	U.U
Acacramu	....	...	....	....	CCCUUCCUU	UUUUU.	U..
Enchtome	UU.......	D..	....	....	UUUUUUUUU	.UUUUU	UUU
Alecolei	....	...	....	....	U.UUU..U.	.UUU.U	.UU
Paranova	....	...	....	....	UUUUU....	....UU	.UU
Brastour	.U.......	...	.UU.	....	UUCUUU.UU	UU..U.	UUU
Calaremo	....	...	....	....	.UC..U.U.	UU..U.	UU.
Tracglau	....	...	....	....	UUUU.U.U.	.U..UU	UUU
Triczeyl	....	...	....	....	.UUU.U.U.	.....U	..U
Acacligu	........U	..U	.U..	...U	CUCUCCCDC	CCCDCD	UCC
Dodovisc	......U..	.U.	....	..U.	CCDDDDDDD	DDDDDD	UDC
Arishola	....	...	....	....	DDDCCCCDD	...UUU	CCU
Salskali	.U.U...U.	UU.	UCCU	....	UC.UU..U.	......	DDD
Boerdomi	....	...	..U.	....	....	....U.	UUU
Pararefr	....	...	....	....	.U.......	......	UUU
Gunnquad	....	..U	....	....	.U..U....	U.....	U..
Mairerio	..U......	U..	....	....	.UUU.U...	U.....	UUU
Nicovelu	....	...	....	....	.U...U.U.	.U..UU	UU.
Portoler	....	...	....	....	.U...U...	......	UU.
Scledecu	....	...	....	....	....	......	UU.
Goodcycl	....	...	....	....	..U....U.	.U..U.	U.U
Uhagspin	....	U..	....	....	...U.....	....UU	U.U
Croterem	....	...	....	....	U.U.U.UUU	......	.UU
Sidaammo	....	...	....	....	.U.......	......	.UU
Tephspha	....	...	....	....	..U......	......	.UU
Trirmoll	....	...	....	....	....	......	UUU
Amarsp.	....	...	....	....	.......U.	......	..U
Eragerio	....	...	....	....	.......U.	......	...
Tragaust	....	...	....	....	.......U.	......	...
Calaerem	....	...	....	....	.......U.	......	...
Gneptenu	....	...	....	....	.UU....U.	......	...
Tetrerem	.U.U...U.	.UU	..U.	UU..	..U..U.U.	UU....	...
Amyeprei	....	...	..U.	U...	..U......	....U.	U..
Santlanc	....	...	....	....	U.U......	....U.	...
Zygosimi	....	...	....	....	..U......	......	...
Citrsp.	....	.U.	..U.	....	.......U.	....UU	.U.
Euphwhee	....	...	....	....	..U..U.U.	....UU	...
Eremglab	....	...	....	..U.	....	UU..UU	...
Zygopara	....	...	....	....	....	.....U	...
Atrilind	..U.....U	...	....	....	....	......	...
Plandrum	........U	...	....	.U..	....	......	...
Eremlatr	....	...	....	....	U........	......	...
Schibarb	....	...	....	....	....	.U....	...
Zygohowi	....	...	....	....	....	.U....	...

Table 5.9 (cont.): Results of two-way analysis of the grazing experiment data. Six species associations are superimposed on the seven groups from the dendrogram in Figure 5.1. Column headings are the relevés and row headings are abbreviated species names. D = dominant, C = common, U = uncommon, . = absent.

	TTTTTTTTT	TTT	TTTT	TTTT	TTTTTTTTT	TTTTTT	TTT
	124311134	133	5555	2244	152113434	224433	555
	GGGGGGGGG	GGG	GGGG	GGGG	GGGGGGGGG	GGGGGG	GGG
	CCCCCSCCC	CCC	CCCC	CCCC	SSSSSSSSS	SSSSSS	SSS
	LLLLLALLL	LLL	LLLL	LLLL	AAAAAAAAA	AAAAAA	AAA
	CCCCCCGCC	GGG	CGGC	GGGG	CCCGGCCCC	GGGGGG	CGG
	112222111	212	1122	1212	111121221	121212	212
Association 2							
Arisanth	....	U..	....	....	....	......	...
Pittphyl	....	U..	....	....	..U......	......	...
Mairaphy	....	UU.	....	....	....	......	...
Atriholo	U...UUU..	U..	....	U...	....	......	...
Uhodflor	U...UUU..	UU.	....	....	....	......	...
Bulbalat	....UUU..	...	....	....	....	......	...
Uhodstri	....UUU..	...	....	U...	....	......	...
Uhodpygm	UU....U..	...	....	....	....	......	...
Scleunif	.U....U..	U..	....	....	....	......	...
SenArtCo	U.....U..	...	....	..U.	....	......	...
Convremo	....	...	..U.	....	....	......	...
SenArtPe	......U..	...	..U.	....	...U.....	......	...
Goodfasc	.U.......	...	..U.	....	....	......	...
Franserp	.U.......	U.U	..U.	...U	....	......	...
Association 3							
Ariscont	UU..UUU..	C..	UUUU	....	UUCUUU.CU	..UU..	U.U
Erioscle	.UU.UUUUU	UUU	UCUU	U...	....	......	...
Sclebrac	UUUUUUUUU	UCU	UUUU	UUUU	....	......	...
Sclevent	CUUUCCUUC	UUU	UUUU	UUUU	....	......	.U.
Atrivesi	CDDDDDDDD	DDD	.CC.	DDDD	UUUUUU..U	UU.U.U	U.U
Mairastr	UCUCCCCCC	CDC	CCUC	DCDC	.UUUU....	U.....	UUU
Enneaven	CCCUDDCCC	UUU	UUUU	C...	UUUUUU.UU	U.....	.UU
Eragseti	DCDDUU...	.U.	.C.C	..U.	....	......	...
Gneparac	CUUUUUUUU	U.U	....	UU..	....	......	...
Sclelani	U...UUU..	U..	.UU.	..U.	....	......	...
Sclediva	UU.UUUUUU	U..	...U	....	....	......	...
Scleobli	UC.UUUUUU	U..	UUU.	....	..U......	......	...
Atrivelu	....	...	D..C	....	U...U....	......	U.U
Dactradu	....	...	DCDD	....	.U.......	......	UUU
Ennecyli	U...UUU..	...	CDCU	....	.U.UU....	......	.UU
Association 4							
Atriangu	....	...	.U..	....	....	......	...
SenArtHe	....	...	.U..	....	....	......	...
Sidafibu	....	...	.U..	....	....	......	...
Solaelli	....	...	.U..	....	....	......	...
Zygoemar	....	...	.U..	.U..	....	......	...
Goodluna	....	..U	.U..	....	....	......	...
Mairappr	....	U..	.U..	....	....	......	...
Ptilsess	......U..	...	.U..	....	.U.......	......	...

Table 5.9 (cont.): Results of two-way analysis of the grazing experiment data. Six species associations are superimposed on the seven dendrogram groups from Figure 5.1. Column headings are the relevés and row headings are abbreviated species names. D = dominant, C = common, U = uncommon, . = absent.

	TTTTTTTTT	TTT	TTTT	TTTT	TTTTTTTTT	TTTTTT	TTT
	124311134	133	5555	2244	152113434	224433	555
	GGGGGGGGG	GGG	GGGG	GGGG	GGGGGGGGG	GGGGGG	GGG
	CCCCCSCCC	CCC	CCCC	CCCC	SSSSSSSSS	SSSSSS	SSS
	LLLLLALLL	LLL	LLLL	LLLL	AAAAAAAAA	AAAAAA	AAA
	CCCCCCGCC	GGG	CGGC	GGGG	CCCGGCCCC	GGGGGG	CGG
	112222111	212	1122	1212	111121221	121212	212
Association 5							
Calohisp	U........	U..	...U	....	....	......	...
Euphdrum	....	..U	.UUU	....	....	......	...
Marsdrum	....	...	...U	....	....	......	...
Erodcygn	.U.......	...	UUUU	CU..	..U......	UU....	...
Dichseri	....	...	.UUU	....	....	......	...
Vitterem	....	.U.	U.UU	....	....	......	...
Dissbifl	....	U..	...U	....	....	......	...
Eraglept	....	...	...U	....	....	......	...
Lepiphle	....	...	...U	....	....	......	...
Erioaust	....	...	...U	....	....	......	...
Iseilsp.	....	...	U..U	....	....	......	...
Minudent	....	...	..UU	....	....	......	...
Nicosimu	....	...	...U	....	....	......	...
Triatriq	....	...	..UU	....	....	......	...
Disspara	UUU...U..	U..	.UUU	....	.......U.	......	...
Tribterr	....	...	UUU.	....	....	......	...
Malvamer	......U..	U..	.UU.	....	....	......	...
Eragdiel	....	...	UUUU	....	....	......	U..
Triploli	....	...	UUUU	....	....	......	...
Sporacti	UU.......	U..	U.UU	....	....	......	...
Panideco	U...UU...	...	UU.U	....	....	......	...
Sclediac	.U..UU...	UUU	UUUU	....	.U.......	......	...
Eragfalc	....	...	U...	....	....	......	...
Minucunn	.U.U.....	.U.	.U.U	.U..	....	......	...
Osteacro	...U.....	...	....	....	....	......	...
Association 6							
Amyemaid	....	...	....	....	....	......	..U
Calocymb	....	...	....	....	....	......	..U
Lyciaust	....	...	....	....	....	......	..U
Ptilpoly	....	...	....	....	....	......	..U

5.4.2 Association Descriptions

Association 1

Association 1 includes 44 species that are the majority of species occurring on dunes. Following the grazing pulses, the perennial shrubs *Acacia ligulata* and *Dodonaea viscosa* are the only species in this association that remain in any abundance score greater than "uncommon". Several species from this association also occurred on swales, where most were never in an abundance class other than "uncommon". The three exceptions are *Acacia aneura, Enchylaena tomentosa* and *Salsola kali.*

The majority of species in this association remained in the same or a lower abundance class after the February 1997 rainfall event than they were in at the start of the experiment. The only exception was *Salsola kali.* Both *Dodonaea viscosa* and *Acacia ligulata* had lower abundance values on one control area following the February 1997 rainfall event than they did previously.

Association 2

This association contains 14 species that did not attain an abundance score greater than "uncommon" in any relevé. It occurred mainly on swales, although rarely on post-grazing relevés.

Association 3

This association contains 15 species and is the swale equivalent of Association 1. *Aristida contorta* is the only species in this association to have been classified as being anything other than "uncommon" on dunes and even then it exceeded this abundance score only on control areas.

Two shrubs, *Atriplex vesicaria* and *Maireana astrotricha,* remained the only species with an abundance score greater than "uncommon" on grazed swales after the second grazing pulse. The only other species to be rated higher than "uncommon" after the first grazing pulse was the grass *Enneapogon avenaceus*, which was still classified as "common". However, it was not recorded on grazed swales immediately following the second grazing pulse. *Maireana astrotricha* had a decreased abundance score following both grazing pulses, but recovered each time to be near its former score at the next monitoring. *Atriplex vesicaria* remained as the dominant species on grazed swales, despite a greater reduction in cover than was recorded for *Maireana astrotricha.* The ephemeral grass *Dactyloctenium radulans* was common or abundant in all swale areas following the February 1997 rainfall event, even though this species was not previously recorded here. There were several occurrences of this species on sands, but in this habitat the species was never more abundant than "uncommon", while it was either "dominant" (3 cases) or "common" (1 case) on swales. *Enneapogon cylindricus* also attained its greatest abundance on swale areas following the February 1997 rainfall event.

Association 4

This association contains eight species that occurred in low abundances mainly in swale areas of the grazed Paddock B after the February 1997 rainfall event. One species, the sub-shrub *Ptilotus sessilifolius*, was also recorded on a dune area, presumably on a dune-base.

Association 5

Twenty five species that occur in low abundance on swale areas form this association. Most occurrences of members of this group are from the final monitoring event. The only species in this association to occur at any abundance greater than "uncommon" was *Erodium cygnorum* in Paddock B following the first grazing pulse.

Association 6

This association contains four species that were recorded on dunes as being "uncommon" only during the final monitoring event. (*Amyema maidenii* was recorded here, but its host was missed by the method used.)

5.5 DISCUSSION

Fatchen (1975, 1978) found that after 45 years of domestic grazing, livestock (mainly cattle) had removed most of the *Atriplex vesicaria* shrubs and significantly reduced the number of *Maireana astrotricha* shrubs at his study site at Mount Victor Station, just to the east of Koonamore. Fatchen (1975) considered *Maireana astrotricha* to be more resilient than *Atriplex vesicaria* under cattle grazing. *Maireana astrotricha* is regarded by most local pastoralists as the preferred cattle fodder shrub of these two species (Keith Greenfield, pers. comm.). The results of the Andamooka Station grazing experiment show a greater reduction of *Atriplex vesicaria* than *Maireana astrotricha* in one paddock, and the reverse in the other. The present experiment was almost certainly conducted over too short a time frame to give definitive results on the effects of heavy grazing on these species.

Much of the damage to tall shrubs on dunes, especially to *Dodonaea viscosa* was caused by cattle rubbing on them and breaking off branches. This is a common occurrence in cattle country in this region when feed is in short supply (Keith Greenfield, pers. comm.). *Acacia ligulata* was the second most common shrub on dunes. It is not grazed by cattle and changes in its cover values were not consistent between areas during the experiment. *Aristida holathera,* which provided much of the ground cover on dunes at the start of the experiment, is not a preferred grazing species

(Jessup 1951, Badman 1995b), but is important for dune stability. Its cover fluctuated on the control area (Figure 5.13), presumably as a result of changing seasonal conditions. When it is heavily grazed it is slow to recover and did not regain its former mean cover on grazed dunes during the life of this experiment, even after the February 1997 rainfall event, to the same extent as it did on the control area.

It was suggested in Chapter 4 that shifts to a different state following summer rainfall and involving a high proportion of cover of the ephemeral grass *Dactyloctenium radulans* should not necessarily be considered as shifts to a better condition, but rather as shifts to a different condition. However, in the present case, when changes also included large increases in median cover and species richness and occurred in both control and grazed areas, the changes recorded in April 1997 are more likely to be changes to a better condition.

The period required for recovery from the grazing pulses, particularly on dunes, may have been shortened considerably by the heavy rainfall event of February 1997. Without such an event, the recovery and final condition of the vegetation, as indicated by group affinities, may have been quite different.

Fatchen (1975, 1978) also found that the grazing had led to the establishment of two shrubs, *Maireana aphylla* and *Maireana pyramidata*, that were not recorded in the original survey. Neither of these shrubs were recorded at the present grazing experiment site, due either to lack of seed, which is plentiful on nearby areas, or to lack of time for them to become established.

There were no increases of any alien or otherwise undesirable species following the two grazing pulses. This was also the finding of Earl and Jones (1996) on the northern tablelands of New South Wales.. Also in line with their findings, all of the palatable species had recovered by the final monitoring, although with reduced cover values. The results of this experiment support the finding that *Salsola kali* responds to summer rainfall, as was found during the analysis of the exclosure data (Chapter 4 of this thesis). Because it responds rapidly to summer rainfall it may be able to utilise available resources faster than the more desirable native species, particularly native grasses.

Two-way analysis of the grazing experiment data supported the findings of the earlier pattern analysis, particularly in regard to the cover of shrubs on grazed dunes. The majority of the swale species occur in one vegetation association and the majority of the dune species in another. The four other associations contain species that, in almost all cases, have low cover values. *Erodium cygnorum* is the only species that was more common on a grazed area than on ungrazed areas.

The upper canopies of *Acacia aneura* trees in the grazed areas are too high to be reached by cattle. Even though it is highly likely that the biomass of the lower part of the crown was reduced by grazing, this was not measured and the crown diameter would have been unaltered by the grazing pulses. This would have resulted in an increase in the proportion of this species in the total cover value and so increase its importance in the two-way analysis. Similarly, reductions in the abundance scores of *Dodonaea viscosa* and *Acacia ligulata* in Association 1 following the grazing pulses are likely to have been due to a reduction in their overall importance because of increased cover of ephemeral species, rather than purely a decrease in the cover values of these species.

Enneapogon cylindricus was never more abundant than "uncommon" (the lowest category when plants were present) on dune areas, even though this is generally considered to be its favoured habitat and it attains its greatest size in this area on sandy soils (Badman 1995b). The reason for this difference at the grazing experiment site is not known.

Because two of the species that form Association 6 are perennials, one a shrub and the other a mistletoe, it is unlikely that they were totally absent before the February 1997 rainfall event. It is more likely that they were just so uncommon that they were not present along transects used in previous surveys or, less likely, that their cover had increased sufficiently at this time so that they were detected by the survey. This may also have been the case with the two outliers on sandy soils In Association 2. These were a shrub (*Senna artemisioides*) and a tree (*Pittosporum phylliraeoides*) with low palatability that may simply have been missed by some surveys because they were few in number and the sampling method used here did not follow fixed transects.

The classification of plant species as "increasers" or "decreasers" under grazing is still a controversial one, despite its long use in rangeland ecology (Landsberg 1999). Although many species have been found to react to grazing in the same way in several different environments, some species have been classified as increasers under one set of circumstances, but as decreasers under another (Landsberg 1999). *Dactyloctenium radulans* was cited by Landsberg (1999) as being in this category. My own experience in northern South Australia has been that this species dominates only following rainfall in February, especially following a dry summer when other grasses have not become established in any quantity. This was the case in both 1992 and 1997. The same outcome would arise if earlier growing summer grasses had been removed by grazing and rain fell in late summer (February). This set of events would make this species an increaser under grazing. In the present study, it was most common at both control and grazed sites at the end of the monitoring, following the heavy rainfall of February 1997, rather than only at grazed sites, and is therefore not an increaser species.

Sporobolus actinocladus is another grass that is known to decrease under grazing, but to be a pioneer increaser species in the reclamation of some scalded areas (Roberts and Silcock 1982, Landsberg 1999). In the present study, this species was present although uncommon in all Cluster 1 groups, both before and after grazing. *Eragrostis dielsii* is also considered to be a particularly robust indicator of heavy grazing (Landsberg 1999). It appeared on both grazed and ungrazed swales in the grazing study areas only during the final monitoring. There was a single occurrence from a dune site, probably from the dune-base ecotone (see below). It is therefore likely that the appearance of this species was due to the rainfall event of February 1997 rather than the grazing events.

The main swale species in Association 3 are less restricted to the clay soils of the swales than the dune species of Association 1 are to sandy soils. I suggest that this is associated with the presence of these species in the ecotone at the dune-base. There was also more overlap of Association 3 species into areas with different soil type than was the case for any other associations. This was also largely due to encroachment of both dune and swale species on to sandy-clay soils of dune bases, as is also thought to have occurred in Association 5.

The problem of the occurrence of both dune and swale species at dune bases is one that has no ready solution. Species were recorded as being on the dune or swale on the basis of soil type. Transects were run across the dunes so that all landforms would be sampled equally. If dune bases had been treated as a separate landform, it would have been necessary to sample along rather than across the dune in order to obtain a sample that would give statistically meaningful results. If dune bases had been treated as an ecotone and omitted from the sample, by sampling only on obvious dune and swale areas, part of the landform would have been omitted from the study and the analysis.

The two-way analysis also highlighted the problem of uncommon or outlying species that are not detected in every survey. There is no solution to this problem when using random line transects and the problem may not be an important one in the present context. A larger number of survey points may have detected these species on more occasions, but this would really have an effect only on species richness. Cover values would still be so low for these species (<0.1%) that they would not have been used in the PATN analysis. The only practical solution is to ignore them except when calculating species richness.

Although the different grazing preferences of sheep and cattle have been studied (Graetz and Wilson 1980), many authors have failed to identify which domestic herbivore is involved (e.g. Tueller and Blackburn 1974, Barker 1979, Oba 1992). The particular species of herbivore may not be important when total grazing pressure is the key factor (Smith 1940, Thurow and Hussein 1989, Pandey and Singh 1991, Wilson 1994), or when grazing is only one of several factors being considered (Fox 1990), but may be very important when the impact of animal feet is being considered. This appears to have been overlooked by many workers, but appears to be worthy of further study because the affects of cattle grazing and trampling appear to be dissimilar to those reported by other workers for sheep grazing..

5.6 CONCLUSIONS

No gross long-term effects to swale vegetation as a result of the two intensive grazing pulses were detected by this relatively short-term experiment, although there were reductions in cover of the most important perennial species on swales (*Atriplex vesicaria* and *Maireana astrotricha*). Swale areas recovered quickly following release from grazing and moderate falls of rain, with full recovery of most species after a heavier rainfall event. Total cover was similar in both grazed and ungrazed areas at the end of the experiment and was higher in all areas than at the start of the experiment.

Dune areas are less resilient, with only a limited recovery between grazing pulses. This was partially masked by the unpalatable tall shrubs that dominate on dunes in this area. Dune areas recovered to be in the same condition as one control area and in a better condition than the other at the end of the experiment. The taxon most affected by heavy grazing on dunes was the generally unpalatable *Aristida holathera,* which never recovered its former cover values. It is not known whether the dune areas would have recovered without the heavy rainfall event of February 1997.

There was no increase in undesirable or alien species following the grazing pulses, perhaps because the first major rainfall event after the second release from grazing came during summer. Any alien species that did grow were removed by the grazing, or the trampling that occurred at this time. They did not grow back during the winter of 1995 because suitable conditions for their establishment did not occur. High cover values of *Salsola kali* were recorded on both grazed and ungrazed sites following the February 1997 rainfall event.

The similarity between the cover of cryptogams on grazed and ungrazed areas at the end of the grazing experiment suggests that cattle may be less damaging than sheep to these organisms and that the type of grazing animal should always be specified when reporting on experiments concerning the effects of grazing on vegetation.

CHAPTER 6 THE OLYMPIC DAM VEGETATION DATA

6.1 INTRODUCTION

A considerable amount of work has been done in recent years on the effects of grazing by domestic herbivores. However, in South Australia, most of this work has focused on sheep-grazing country to the south and south-east of the present study areas (e.g. Lange *et al.* 1984, Hall *et al.* 1964, Carrodus *et al.* 1965, Crisp 1975, Noble 1977). The study of Read (1999) appears to be the only one from the Olympic Dam area. A limited amount of work has been carried out in cattle country to the north-west of the study areas (e.g. Jessop 1994) and to the south-east (Fatchen 1975, 1978), but most work on the effects of cattle grazing in similar arid habitats has been carried out in the southern half of the Northern Territory (e.g. Foran *et al.* 1982, Friedel and Shaw 1987a, 1987b, Friedel *et al.* 1988, 1990) and in south-western Queensland (e.g. Griffiths *et al.* 1974, Hodgins and Rogers 1997). Apart from the work of Fatchen (1975, 1978) studies of cattle grazing effects have not been in country dominated by chenopod low shrublands. Jessop's study was in an area with some chenopod shrublands, but also larger areas of grassland and open mulga woodland.

In overseas countries, studies on cattle grazing have usually been from areas with higher rainfall or different vegetation structure (Buffington and Herbel 1965, Turner 1971, Walker *et al.* 1986, Pandey and Singh 1991, Kumar and Bhandari 1992, Scholes and Walker 1993). Other studies have been from areas with different socio-economic problems (Le Houerou 1989, Fratkin 1999). Despite the increased fiscal pressures placed on some overseas rangelands and the inability of some governments to deal with the problem, some traditional management systems have proven to be extremely flexible and able to cope with these increased pressures (Rae *et al.* 1999).

Traditionally there has been a popular conception that formal conservation objectives could be met on pastoral land only by the complete removal of domestic stock (Curry and Hacker 1990). However, conservation-orientated pastoralism as a legitimate land-use is now being suggested as a viable alternative, although Curry and Hacker (1990) suggest that this is being prejudiced by these old preconceptions. Pringle (1995) suggested that a cooperative approach to nature conservation by all stakeholders is imperative in order to maintain biodiversity. Use of old mine sites as conservation reserves has also been suggested (Turner 1992), although if this is to happen, the post-mining land use should ideally be established early in the exploration phase (Bell 1996).

Effects on arid zone vegetation of long-term exclusion of domestic stock have been studied at numerous sites around the world. At a central Australian site, Foran *et al.* (1982) found that the removal of cattle for 11 years had less influence on vegetation than did seasonal conditions. This finding was supported by the work of Leigh *et al.* (1989). in central New South Wales. In Kuwait, Omar (1991) reported that vegetation cover continued to decline 10 years after release from grazing. This decline was correlated to the amount of seasonal precipitation in the 10 years preceding each survey. Omar's study found that drought, erosion and sand encroachment slowly continued to contribute to land degradation, irrespective of the degree of protection from grazing.

Mining is often considered to have a negative effect on local vegetation communities (Reid 1992), sometimes with good justification (Quinn 1992), although quantitative data on the effects on local vegetation communities are seldom cited. Opal mines are usually less controlled than other forms of mining (see Section 2.7.1). In the past these mines have been largely unregulated and usually owned by individuals or private companies. Mullock from shafts, drives and open cut workings is usually dumped in scattered heaps across the landscape, rather than being placed in managed waste dumps. The pale colour of the parent material further exacerbates this problem. Only recently has any form of regulation been imposed on opal miners in South Australia: a bond is now placed on new opal mines to cover rehabilitation costs.

Most of the worst examples of visible impacts caused by the mining industry are from operations which took place many years ago (Farrell and Kratzing 1996). Modern mineral exploration and mining activities disturb only a small proportion of the local land area, far less than domestic grazing. Quantitative data are available on the effects on vegetation of some open cut mines (e.g. Buckney and Morrison 1992) and for arid zone petroleum exploration (Woodburn and Fatchen 1998), but are less common for underground mines in arid areas. Effects of mining on arid zone vegetation have also been less well documented than the effects of grazing.

There appear to be no published quantitative studies on the effects of town establishment and urban living on arid zone vegetation communities.

The present analysis of the Olympic Dam cover data examines data from the time when the land use of the mine and municipal leases changed from pastoralism to mining, processing and urban living. No quantitative vegetation data are available from the beginning of mineral exploration in 1975 until 1981, so no data are available on the effects of exploration activities on the area.

However, apart from the direct impacts caused by road and drill pad construction (Badman 1992a) and probably also by dust from the use of unformed roads, indirect impacts on vegetation were probably not significant.

6.2 AIMS

The aim of the analysis of the Olympic Dam vegetation data was to detect any long-term trends that have not been detected by the annual comparisons of data with the previous year's data. In particular, the following questions were to be answered:

- What effect have the mine and processing plant had on the surrounding vegetation?
- Has the removal of domestic stock from the mine and municipal leases led to changes in the vegetation of these areas when compared to adjacent pastoral land?
- What effect has establishment of the town of Roxby Downs had on the surrounding vegetation?
- Has there been an increase in recruitment of long-lived perennial species since the mine and municipal leases were fenced and domestic herbivores excluded?
- How does rainfall, especially the effects of very wet and very dry years, affect the vegetation?

6.3 COVER DATA

This chapter examines data collected by WMC (Olympic Dam Operations) Pty Ltd as part of its environmental monitoring programme since 1981, but more particularly since 1986. Data were collected by various consultants and Olympic Dam environmental officers, including myself, but mainly by T.J. Fatchen and Associates and Fatchen Environmental Pty Ltd. These data have regularly been analysed for year to year changes (e.g. Fatchen Environmental 1995) but the dataset has not previously been examined in its entirety. Data from 1981 to 1985 are examined in this study only as far as shrub counts are concerned. Data from this period are from a small number of sites and are incomplete in many areas, especially in identification of ephemeral species. Data are missing for all sites for one 18 month period. Plant cover data from May 1986 to November 1996 are examined here, together with shrub count data from May 1981 to November 1997. The data from May 1986 cover the period that includes the fencing and removal of domestic stock from the mine and municipal leases, construction of the town of Roxby Downs, the commencement of production from the mine and processing plant and several expansion phases. It does not include, other than for 1997 shrub count data, the major expansion that was carried out from 1997-1999.

Because of the large size and unwieldy nature of the dendrogram produced by classification of the whole dataset, relevés were assigned to an arbitrary 50 groups. This number of groups still proved to be unwieldy, so the means of these groups were used to compile a new simplified dendrogram (Figure 6.1). From this new dendrogram, 21 groups were identified at or above the 0.81 fusion level. This cut-off point was chosen because it provided meaningful groups that could be explained in terms of their floristic composition or their soil types, or a combination of the two. PATN was again used to produce a third dendrogram based on these 21 groups (Figure 6.2).

6.3.1 RESULTS

6.3.1.1 Classification of the Cover Data

The dendrogram produced by the PATN analysis of the 1304 relevés is presented in Appendix O. A simplified dendrogram compiled from the means of an arbitrary 50 groups from the initial classification is shown in Figure 6.1. Another dendrogram showing 21 groups from the arbitrary 50 group dendrogram at the Bray-Curtis 0.81 level of dissimilarity is shown in Figure 6.2. Group membership is shown in Appendix P and the distribution of the 21 groups in relation to landforms and land use is shown in Table 6.1. Details of the number of relevés and species in each group and the median cover and species richness are given in Table 6.2.

SSH (Belbin 1991a) was used to obtain the ordination shown in Figure 6.3 from the means of the 21 groups in Figure 6.2. A list of species that are significant to the composition of each site was obtained by means of the GSTA (group statistics) component of PATN (Belbin 1991b). The most significant species ($p<0.05$) for each group are given below under the group descriptions in Section 6.3.1.2 and a full list of significant species is given in Appendix Q.

The 21 groups were divided into four clusters at the Bray-Curtis 0.96 level of dissimilarity. A stylised dendrogram showing the relationships and main identifying features of each cluster is shown in Figure 6.4. A brief description of each cluster and each group is given in Table 6.3 and a full description in Section 6.3.1.2.

6.3.1.2 Description of Classification Groups

Cluster 1

This cluster contains the majority of the dune and sandy dune-base sites. These include relevés with high cover and species richness values and most groups contain one or more long-lived perennial species. The percentage of groups in this cluster was generally greatest in the wettest years and least in the driest years.

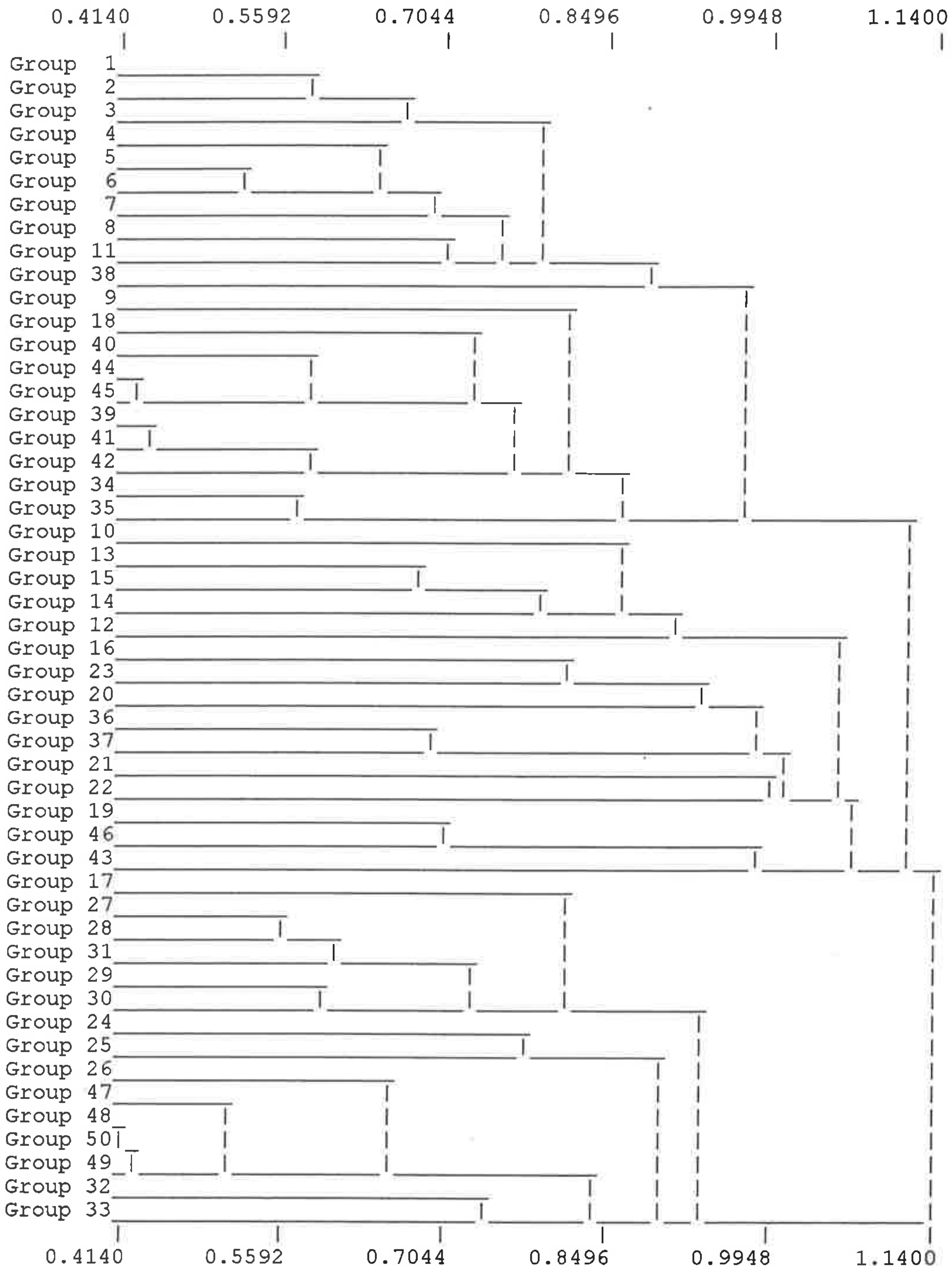

Figure 6.1: Dendrogram of the arbitrary 50 groups obtained by cluster analysis of the 1304 relevés of the Olympic Dam cover data (see Appendix O for the full dendrogram).

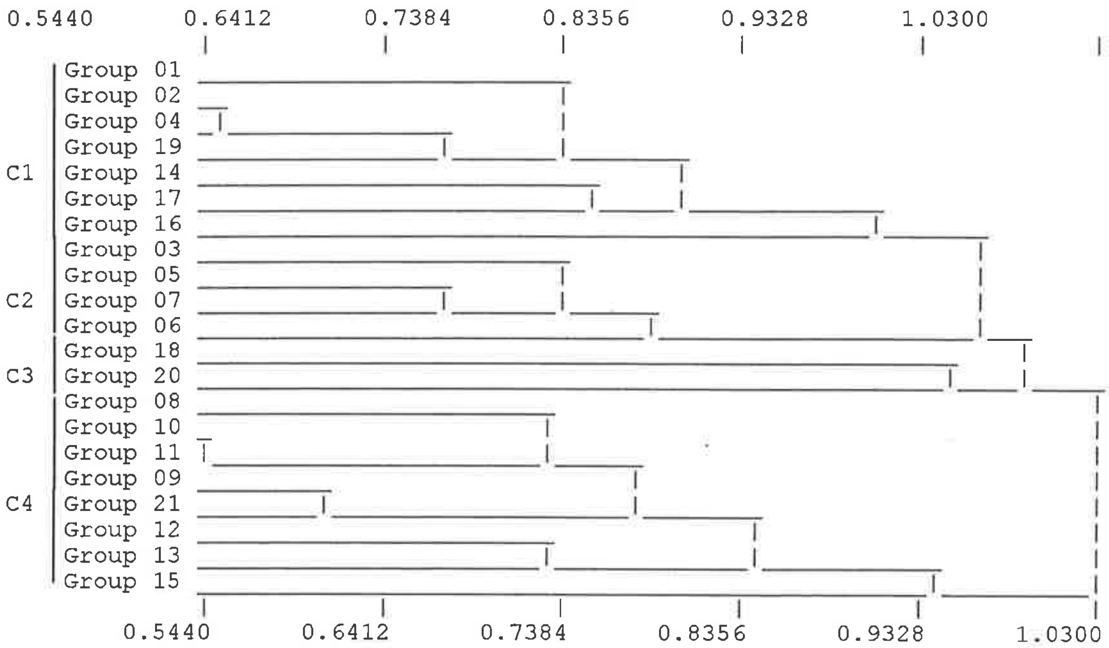

Figure 6.2: Dendrogram of the 21 groups in four clusters obtained by pattern analysis of the Olympic Dam cover data (derived from the arbitrary 50 groups shown in the dendrogram in Figure 6.1).

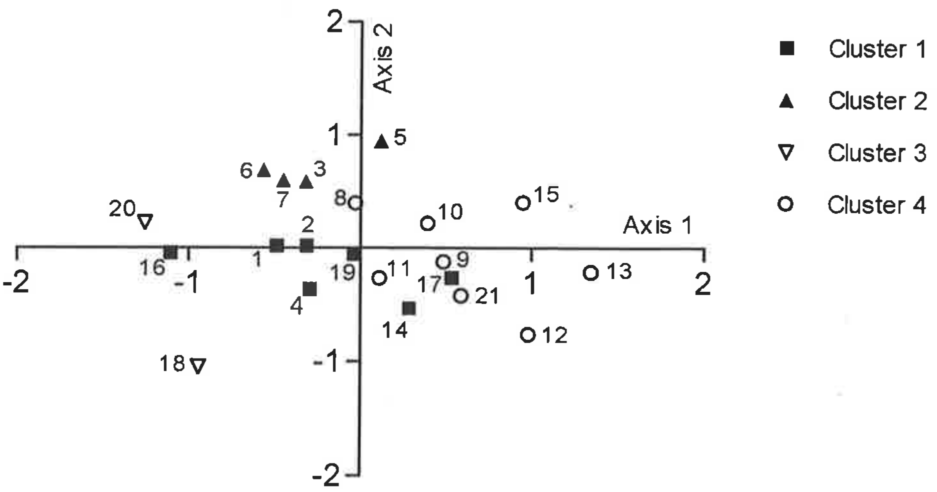

Figure 6.3: Plot of the first and second axes from a SSH ordination of the 21 groups in four clusters derived from classification of the 1304 relevés of the Olympic Dam vegetation cover data (Appendix O). Numbers by the cluster symbols refer to the individual group numbers. Stress = 0.13.

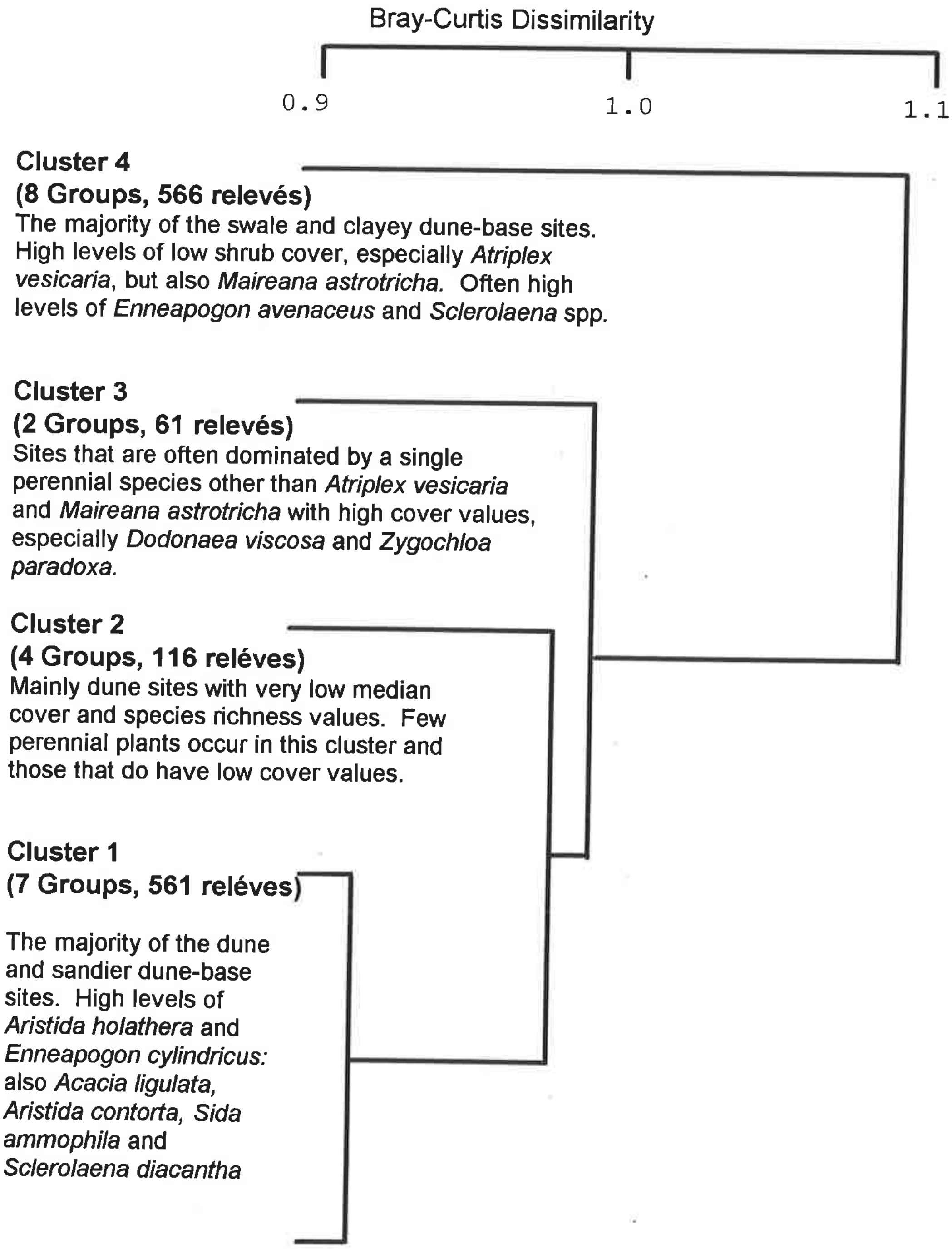

Figure 6.4: Stylised dendrogram of cluster relationships with plant and edaphic indicators for each cluster from the Olympic Dam cover data.

<u>*Group 1*</u>

This group contains mainly dune sites with vegetation dominated by the exotic *Brassica tournefortii*. It occurred only at sites monitored up to May 1991, with most records prior to May 1989. This correlates with the decline of *Brassica tournefortii* (Figure 6.5) and its replacement by perennial native grasses (Badman 1995a) following the heavy rainfall of March 1989. Perennial plants are not dominant in this group. Relevés occurred mainly in the mine lease area, both in developed and undeveloped areas, with equal but smaller numbers occurring on pastoral land and in the town area.

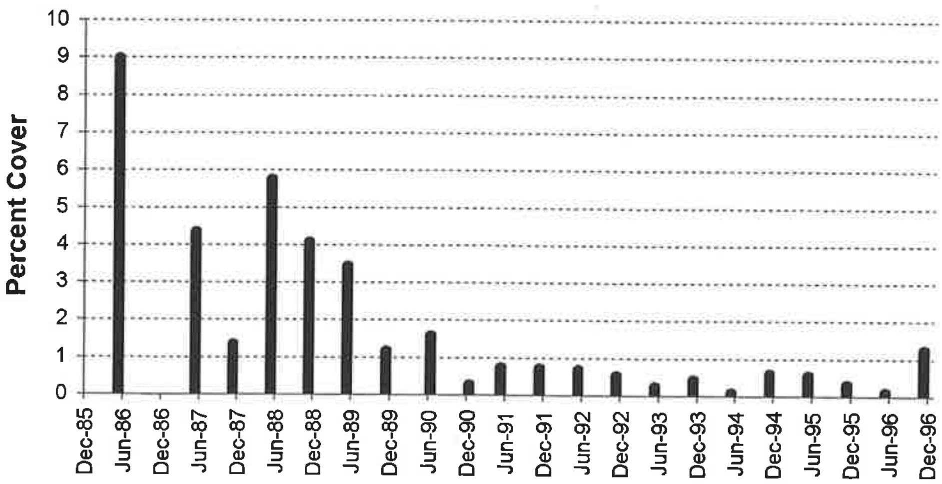

Figure 6.5: Average cover of *Brassica tournefortii* at Olympic Dam Cluster 1 sites.

Table 6.1: Percentage of relevés in each group that lie within each landform and each land-use area (ML = Olympic Dam mining lease).

		Landform				Land Use			
Group	No. of Relevés	Dune	Dune-base (Mulga)	Dune-base (Myall)	Swale	Pastoral	Undevel-oped ML	Developed ML	Town
1	53	69.8	13.2	7.5	9.4	15.1	35.8	34.0	15.1
2	156	74.4	17.9	1.3	6.4	6.4	23.1	49.4	21.2
3	41	95.1	0.0	4.9	0.0	2.4	7.3	61.0	29.3
4	29	58.6	24.1	3.4	13.8	13.8	31.0	34.5	20.7
5	26	92.3	7.7	0.0	0.0	3.8	15.4	57.7	23.1
6	17	100.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0
7	32	100.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0
8	52	23.1	36.5	23.1	17.3	55.8	25.0	11.5	7.7
9	38	2.6	0.0	18.4	78.9	31.6	5.3	63.2	0.0
10	93	11.8	15.1	25.8	47.3	21.5	9.7	40.9	28.0
11	37	0.0	40.5	43.2	16.2	13.5	27.0	16.2	43.2
12	28	3.6	0.0	57.1	39.3	10.7	35.7	0.0	53.6
13	12	0.0	0.0	0.0	100.0	0.0	0.0	100.0	0.0
14	47	68.1	0.0	4.3	27.7	12.8	40.4	2.1	44.7
15	42	2.4	0.0	0.0	97.6	100.0	0.0	0.0	0.0
16	12	100.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0
17	89	34.8	41.6	11.2	12.4	23.6	58.4	0.0	18.0
18	12	100.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0
19	175	72.6	26.9	0.0	0.6	8.6	34.3	22.3	34.9
20	49	100.0	0.0	0.0	0.0	40.8	10.2	49.0	0.0
21	264	0.0	0.0	9.1	90.9	27.3	12.1	52.7	8.0

Group 2

The majority of dune sites occur in this group. These are sites with lower median cover than Group 1, due to less *Brassica tournefortii,* but slightly higher median species richness. This group has more perennial species than Group 1. Although no single species dominates the vegetation, the highest cover values of *Erodium cygnorum, Gnephosis tenuissima* and *Maireana erioclada* were recorded here. Relevés in this group occurred in all land-use areas, but were most common on developed mine lease areas and least common on pastoral land. Membership of this group was highest before the heavy rainfall of March 1989.

Table 6.2: Details of the composition of the 21 groups identified by PATN analysis of the Olympic Dam cover data (groups are from the dendrogram in Figure 6.2).
The number of significant species refers to all species that were identified by PATN analysis as being significant (p<0.05, as determined from the probablilities from the PATN GST files) to the make up of that group; median species richness and cover are the median values for all relevés for that group.

Group	No. of Relevés	No. of Significant Species	Total no. of Species	Median Cover (%) (Range)	Median Species Richness (Range)
1	53	61	70	12.3 (3.2-59.0)	7 (1-24)
2	156	65	94	4.8 (0.9-28.2)	9 (1-26)
3	41	37	40	1.4 (0.1-3.6)	4 (1-12)
4	29	60	74	13.8 (4.4-29.9)	11 (5-27)
5	26	19	25	0.9 (0.1-2.2)	3 (1-8)
6	17	11	14	0.7 (0.1-1.8)	3 (1-7)
7	32	13	15	2.8 (0.8-8.4)	5 (1-10)
8	52	60	79	1.4 (0.1-100)	5 (1-22)
9	38	62	82	10.4 (3.1-41.4)	12 (3-38)
10	93	70	87	6.2 (0.7-36.1)	10 (1-27)
11	37	59	76	11.3 (1.5-36.7)	14 (4-25)
12	28	38	44	26.5 (10.9-37.1)	9 (3-19)
13	12	13	18	17.6 (9.3-32.1)	8 (4-12)
14	47	66	90	22.9 (7.7-45.1)	14 (4-30)
15	42	49	67	10.8 (2.7-24.7)	9 (4-33)
16	12	16	17	11.0 (5.6-18.6)	5 (1-10)
17	89	61	86	19.8 (4.8-50.3)	11 (3-31)
18	12	28	32	33.3 (21.4-51.1)	10 (4-22)
19	175	56	73	12.1 (2.2-32.2)	9 (1-19)
20	49	32	33	17.8 (4.3-38.5)	6 (2-14)
21	264	81	128	16.7 (3.0-66.4)	5 (2-35)

Group 4

This group contains mainly dune sites, but with some dune-base sites, dominated by *Salsola kali.* It has higher median cover and species richness than Group 1. Several perennial species occur in this group, including *Acacia aneura, Atriplex vesicaria, Callitris glaucophylla* and *Gunniopsis* *quadrifida.* None of these dominate the vegetation, although *Gunniopsis quadrifida* is more common in this group than elsewhere. Maximum cover values of *Abutilon otocarpum, Boerhavia dominii, Calandrinia disperma, Euphorbia wheeleri* and *Sida ammophila* were all recorded here. Relevés were spread across all land-use areas, but were least common on pastoral land. Membership of this group was greater following the heavy rainfall of March 1989.

Table 6.3: Main characteristics of the groups and clusters obtained from PATN analysis of the Olympic Dam cover data (Figure 6.2).

Group	Cluster 1 (n=561: majority of the dune and sandy dune-base sites)
1 (n=53)	Mainly dune sites monitored before 1989. Vegetation dominated by *Brassica tournefortii*, with very few perennial plants.
2 (n=156)	Mainly dune sites with lower median cover values than Group 1, due to less *Brassica*, and slightly higher median species richness.
4 (n=29)	Mainly dune sites dominated by *Salsola kali* and with higher median cover and species richness than Group 1.
19 (n=175)	Mainly dune and some dune-base sites dominated by grasses, especially *Aristida holathera.*
14 (n=47)	Mainly dune sites, with some swale sites, dominated by *Callitris glaucophylla* with a largely grassy understorey.
17 (n=89)	Mainly dune-base and dune sites with *Acacia aneura* but dominated by grasses, especially *Aristida contorta* and to a lesser extent *A. holathera.*
16 (n=12)	Dune quadrats at site 49 (EV61) in the developed part of the mine lease. Vegetation is dominated by *Acacia ligulata.*
	Cluster 2 (n=116: dune sites with very low cover and species richness)
3 (n=41)	Dune sites with very low median cover and species richness and few or no perennial species.
5 (n=26)	Dune sites with very low median cover and species richness, but with more *Aristida holathera* than Group 3.
7 (n=32)	Dune sites with low median cover and species richness and few or no perennial species, but with some *Crotalaria eremaea.* Cover is higher than for Groups 3 and 5.
6 (n=17)	Dune sites with very low median cover and species richness and few or no perennial species. *Paractaenum refractum* is the main grass species here.
	Cluster 3 (n=61: sites often dominated by a single perennial species; high cover and species richness)
18 (n=12)	All dune sites with vegetation dominated by *Zygochloa paradoxa.*
20 (n=49)	Dune sites dominated by *Dodonaea viscosa.*
	Cluster 4 (n=566: majority of the swale and dune-base sites)
8 (n=52)	A group of sites in all landforms with low median cover and species richness, but with some perennial species, especially *Dodonaea viscosa.* Also *Sclerolaena diacantha* and *Chenopodium desertorum.*
10 (n=93)	Mainly swale and dune-base sites with some *Atriplex vesicaria* but generally high grass cover, especially *Aristida contorta* and *Enneapogon avenaceus.*
11 (n=37)	Mainly dune-base sites with *Acacia papyrocarpa* and an understorey with *Enneapogon avenaceus, Sclerolaena obliquicuspis* and *Stipa nitida.*
9 (n=38)	Mainly swale sites, with *Atriplex vesicaria, Chenopodium desertorum, Sclerolaena ventricosa* and *Enneapogon avenaceus.*
21 (n=264)	The main group of swale sites, with good cover of *Atriplex vesicaria,* and *Enneapogon avenaceus* prominent in the understorey. Median species richness is low.
12 (n=28)	Mainly dune-base and swale sites with vegetation dominated by *Enneapogon avenaceus* and *Atriplex vesicaria. Ptilotus obovatus* also occurs in this group.
13 (n=12)	Restricted to the swale site 61 (EV 96). Vegetation is dominated by *Maireana astrotricha*, with *Enneapogon avenaceus* and *Eriochiton sclerolaenoides* in the understorey.
15 (n=42)	Mostly swale sites and all on pastoral country. Vegetation is dominated by *Sclerolaena brachyptera,* with *Frankenia serpyllifolia* and *Sporobolus actinocladus.*

Group 14

Mainly dune sites, but with some swale sites, dominated by *Callitris glaucophylla* and with a largely grassy understorey of *Enneapogon cylindricus*. Shrubs include *Acacia ligulata, Atriplex vesicaria, Maireana astrotricha, Maireana integra* and *Ptilotus obovatus*. The highest cover values of *Atriplex spongiosa, Eragrostis laniflora, Euphorbia drummondii, Paspalidium constrictum*, two *Rhodanthe* spp. and *Tetragonia eremaea* occurred in this group. Most relevés were on undeveloped mine lease sites and in the town area, with very few records from developed mine lease sites. Membership of this group was higher following the heavy rainfall of March 1989.

Group 16

Relevés in this group all belonged to dune quadrats at Site 49 (EV 61) in the developed part of the mine lease. Vegetation is dominated by *Acacia ligulata* which had higher cover values here than in any other group. No other long-lived perennials were recorded within this group, although the short-lived perennial *Maireana erioclada* occurs here.

Group 17

Mainly dune-base and dune sites, with *Acacia aneura* but dominated by grasses, especially *Aristida contorta* and to a lesser extent *Aristida holathera*. Maximum cover values for both *Acacia aneura* and *Aristida contorta* were recorded here, as well as for *Ptilotus polystachyus*, *Portulaca oleracea, Tragus australianus* and three other small ephemeral species. The majority of sites were on undeveloped parts of the mine lease, with none recorded from development areas.

Group 19

Mainly dune and some dune-base sites dominated by grasses, especially *Aristida holathera* which reached its maximum cover value here. The only other species to attain their maximum cover values in this group were *Citrullus colocynthis, Goodenia cycloptera* and *Trachymene glaucifolia*. The long-lived perennials *Acacia ligulata, Atriplex vesicaria, Callitris glaucophylla, Dodonaea viscosa* and *Enchylaena tomentosa* all occur here. This group occurred across the mine lease and town areas, with very few relevés on pastoral land. Group membership was much higher following the heavy rainfall of March 1989.

Cluster 2

The poorer condition dune sites with very low median cover and species richness values are contained in this cluster. There was a general shift away from this cluster following the heavy rainfall of March 1989 (Figure 6.6), although this shift was later reversed following several relative dry years in the mid 1990s. Membership of this cluster was greatest in dry years.

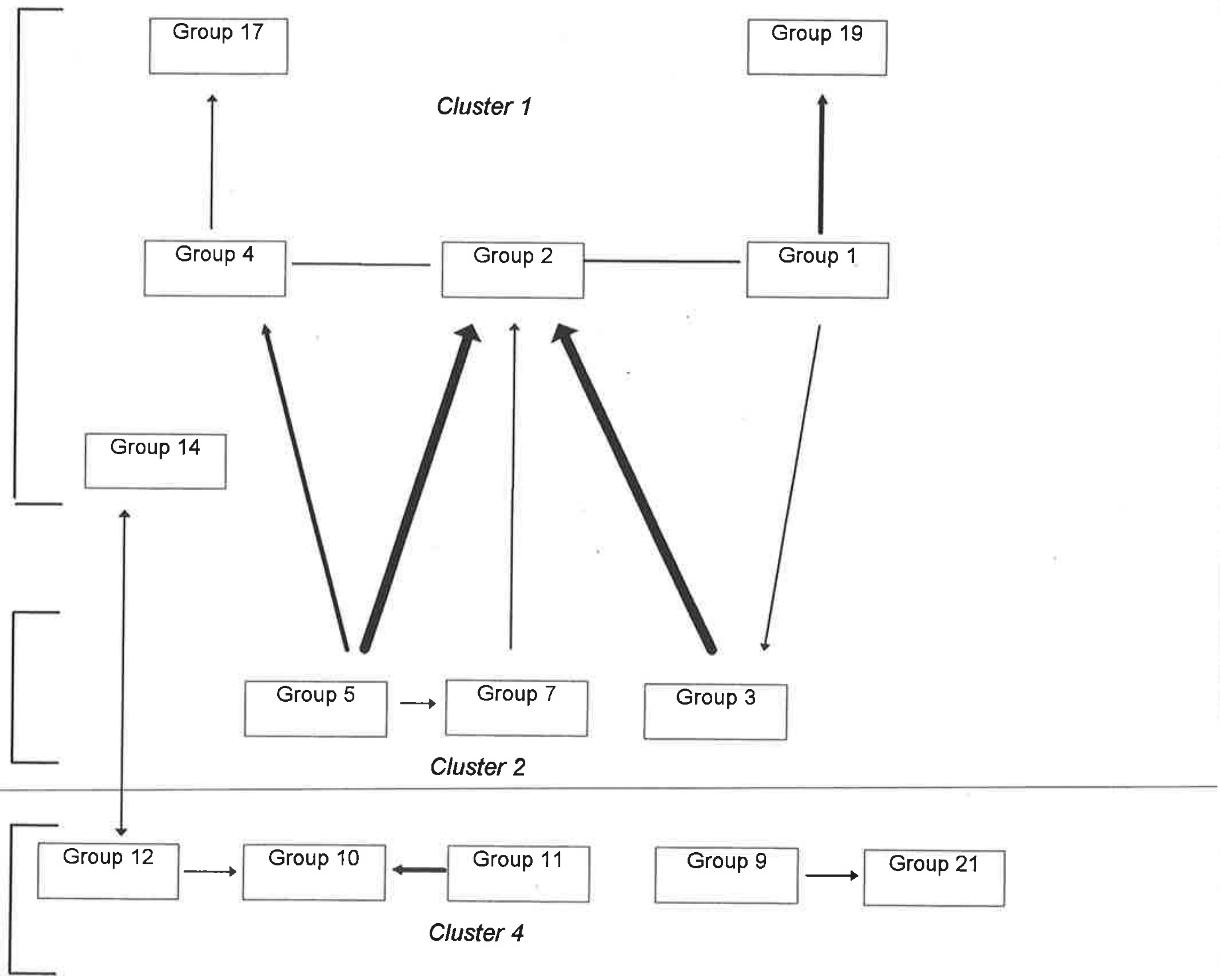

Figure 6.6: Conceptual model of the major shifts between groups derived from classification of the Olympic Dam cover data.

Only shifts occurring on at least 10% of available chances are shown, with a minimum of 20 available chances. Thicker lines indicate shifts on >15% of available chances and the thickest lines on >20% of available chances. For smaller shifts see Appendix R.

<u>*Group 3*</u>

This group includes dune sites with very low median cover and species richness and few or no perennial species, although *Acacia ligulata* and *Gunniopsis quadrifida* both occur here. *Ptilotus* *sessilifolius* attained its highest recorded cover in this group. The majority of the relevés in this group are from developed mine lease areas, with the next largest group from the town area. Almost three quarters of group members were relevés from before the heavy rainfall events of 1989.

Group 5

Mostly dune sites with very low cover and species richness, but with greater cover of *Aristida holathera* than Group 3. The shrub *Acacia ligulata* occurs here, but is not dominant. No species attained their greatest cover values in this group. This group was most common on developed mine lease areas and least common on pastoral land. The group's membership increased after early 1989. Most shifts into this group were from Group 2, but there were more shifts in the opposite direction (Figure 6.6).

Group 6

Relevés in this group are all located on dunes with very low median cover and species richness and few or no perennial species. *Acacia ligulata* and *Enchylaena* tomentosa are the only shrubs recorded from this group and no species had their greatest cover values here. *Paractaenum refractum* is the main grass species. All relevés in this group are from after the heavy rainfall of March 1989 and from developed parts of the mine lease.

Group 7

Relevés in this group are all located on dunes with very low median cover and species richness and few or no perennial species, although *Acacia ligulata* occurs here. *Crotalaria eremaea* and *Trichodesma zeylanicum* reached their highest cover values in this group. Median cover values are higher than in Group 3 and Group 5. All relevés in this group are from after the heavy rainfall of March 1989 and from developed mine lease areas.

Cluster 3

This cluster contains sites that are often dominated by a single perennial species that does not dominate in Cluster 1 and Cluster 4. Relevés in this cluster have high median cover and species richness. There was a higher percentage of groups in this cluster from about a year after the exceptional rainfall event of March 1989 (Table 6.4), mostly in Group 20, following increased growth of *Dodonaea viscosa*.

Table 6.4: Percentage of sites in each cluster at each monitoring event.
Numbers in parenthis after the percentage figures are the actual number of sites involved.

Time	Cluster 1	Cluster 2	Cluster 3	Cluster 4
May 1986	50.9 (29)	7.0 (4)	1.8 (2)	40.4 (22)
May 1987	45.6 (26)	7.0 (4)	1.8 (2)	45.6 (25)
Nov 1987	30.2 (19)	14.3 9()	4.8 (4)	50.8 (30)
May 1988	43.9 (29)	4.5 (3)	4.5 (4)	47.0 (30)
Nov 1988	40.6 (26)	15.6 10()	4.7 (4)	39.1 (24)
May 1989	50.8 (33)	3.1 (2)	3.1 (2)	43.1 (28)
Nov 1989	40.0 (26)	9.2 (6)	4.6 (4)	46.2 (29)
May 1990	45.5 (30)	4.5 (3)	6.1 (5)	43.9 (28)
Nov 1990	33.9 (20)	5.1 (3)	5.1 (4)	55.9 (32)
May 1991	43.2 (32)	6.8 (5)	4.1 (4)	45.9 (32)
Nov 1991	45.9 (34)	6.8 (5)	4.1 (4)	43.2 (31)
May 1992	47.3 (35)	6.8 (5)	4.1 (4)	41.9 (30)
Nov 1992	46.6 (27)	8.6 (5)	1.7 (2)	43.1 (24)
May 1993	44.8 (26)	10.3 (6)	1.7 (2)	43.1 (24)
Nov 1993	44.8 (26)	10.3 (6)	1.7 (2)	43.1 (24)
May 1994	43.1 (25)	13.8 (8)	1.7 (2)	41.4 (23)
Nov 1994	43.1 (25)	12.1 (7)	1.7 (2)	43.1 (24)
May 1995	52.6 (30)	1.8 (1)	1.8 (2)	43.9 (24)
Nov 1995	37.9 (22)	13.8 (8)	1.7 (2)	46.6 (26)
May 1996	26.3 (15)	19.3 (11)	1.8 (2)	52.6 (29)
Nov 1996	44.1 (26)	8.5 (5)	1.7 (2)	45.8 (27)

Group 18

Relevés in this group are all located on the dune at Site 12 (EV 14), with vegetation dominated by *Zygochloa paradoxa* and with some *Acacia ligulata*. *Zygochloa paradoxa* and eleven other species reached their highest cover values at this site. Relevés in this group have the highest median cover values of any group but only mid-range median species richness. The 12 relevés in this group represent the full extent of monitoring at this site, which is located on pastoral land.

Group 20

All relevés in this group were located on dunes dominated by *Dodonaea viscosa,* which reached its highest cover values here. Relevés have high median cover values but low median species richness. *Paractaenum refractum* and *Santalum lanceolatum* attained their highest cover values here and the shrubs *Acacia ligulata* and *Enchylaena tomentosa* also occur. This group occurs mainly on developed mine lease areas and on pastoral land, with no occurrences in the town area.

Cluster 4

The majority of the swale and dune-base sites with good cover of *Atriplex vesicaria* and, apart from groups 8 and 10, high median cover values occur in this cluster. Unlike Cluster 1, it included a higher percentage of relevés during dry periods (Table 6.4).

Group 8

A group of sites in all landforms with low median cover and species richness, but with some perennial species, especially *Dodonaea viscosa*. *Sclerolaena diacantha, Sclerolaena divaricata* and *Zygophyllum prismatothecum* reached their greatest cover values here. The long-lived perennials *Acacia ligulata, Acacia papyrocarpa, Callitris glaucophylla, Maireana astrotricha* and *Ptilotus obovatus* are also significant in the composition of this group, but none of them dominates the vegetation. The majority of sites in this group were located on pastoral land, with those on undeveloped mine lease areas being next most common.

Group 9

Mainly swale and some dune-base sites with mid-range median cover and species richness values. *Atriplex vesicaria, Chenopodium desertorum, Dactyloctenium radulans* and *Sclerolaena ventricosa* dominate the vegetation. The last three species attained their highest cover values here, as did *Chenopodium desertorum, Eragrostis dielsii, Osteocarpum acropterum, Plantago drummondii, Rhodanthe stricta* and *Sclerolaena lanicuspis.* This group is most common on developed mine lease areas and on pastoral land, with no relevés from the town area. This group had its greatest membership prior to the heavy rainfall of March 1989.

Group 10

Mainly swale and dune-base sites with some *Atriplex vesicaria* but generally high grass cover, especially *Aristida contorta* and *Enneapogon avenaceus.* No single species dominates. Median cover values for this group are low and median species richness only mid-range. *Goodenia lunata* and *Isoetopsis graminifolia* were the only species to attain their greatest cover values here. Members of this group are spread across all land use areas, with the majority of members on developed parts of the mine lease and a smaller number on undeveloped parts of the mine lease. This group had its greatest membership following the heavy rainfall of March 1989.

Group 11

Mainly dune-base sites with *Acacia papyrocarpa,* which attained its greatest cover value in this group, and an understorey with *Enneapogon avenaceus, Sclerolaena obliquicuspis* and *Stipa nitida.* The last two species also reached their greatest cover values here. Other shrub species represented in the group are *Acacia ligulata, Atriplex vesicaria, Maireana astrotricha* and *Maireana integra.* This group has mid-range median cover values and high species richness. It is most commonly found at sites in the town area and is least common on pastoral land.

Group 12

Mainly dune-base and swale sites with vegetation dominated by *Enneapogon avenaceus* and *Atriplex vesicaria. Euphorbia tannensis* ssp. *eremophila, Ptilotus obovatus* and *Sclerolaena cuneata* all reached their greatest cover values here. The group has a high median cover value and mid range species richness. It occurred most frequently in the town area and on undeveloped parts of the mine lease, but not on developed areas of the mine lease. It was not recorded until after the heavy rainfall of March 1989.

Group 13

This group is restricted to swale Site 61 (EV 96), with this site remaining in the group throughout the monitoring. Vegetation is dominated by *Maireana astrotricha*, which reached its highest cover value here, with *Enneapogon avenaceus* co-dominant. No other shrub species were present, although the site had high median cover values and mid-range median species richness. Site 61 is on the developed part of the mine lease.

Group 15

Mostly swale sites and all on pastoral country. Vegetation is dominated by *Sclerolaena brachyptera.* This species, *Frankenia serpyllifolia, Sporobolus actinocladus* and eight other species, attained their highest cover values here.

Group 21

This is the main group of swale sites, but also includes a few dune-base sites. The group is dominated by a low shrubland of *Atriplex vesicaria,* with *Enneapogon avenaceus* prominent in the understorey. *Atriplex vesicaria* and six other species attained their highest cover values here. The group has a high median cover value, but low median species richness and occurs in all land use areas, although it is most common on the developed parts of the mine lease. Because of a lack of suitable swale habitat it does not occur in the town area.

6.3.2 Spatial Relationships Between Groups

The spatial relationships between the 21 groups are shown in the ordination presented in Figure 6.3. There is some overlap between groups in clusters 1 and 4, which is to be expected because both contain dune-base sites that often shift from one group or cluster to another depending on rainfall and subsequent species composition or abundance. There is also an overlap between Group 16 in Cluster 1 and the two groups in Cluster 3. Again, this is to be expected because although Group 16 falls within Cluster 1 in the plant-based classification, it contains relevés from a single site that is dominated by *Acacia ligulata* and therefore meets one of the criteria of Cluster 3, i.e. its groups are dominated by a single perennial species other than the chenopod shrubs of the swale vegetation communities. Cluster 2 groups are separated from all other groups. This is also to be expected given their very low median cover and species richness.

6.3.3 Shifts Between Classification Groups

6.3.3.1 Group Shifts to Better and Worse Condition

As in previous sections, the term "shift" is used here to indicate a conceptual change in a dynamic vegetation community from a condition (Westoby *et al.* 1989) that meets the criteria of one of the groups or clusters derived from the dendrogram clustering of the cover data to a condition that meets the criteria of a different group or cluster (Figure 6.4). This was discussed in Section 4.3.2.4.

A summary of the shifts between groups for each landform and land use area is shown in Table 6.5, seasonal occurrence of shifts between groups in Table 6.6 and the total number of shifts into and out of each group in Table 6.7. The relationship of these shifts to the major rainfall event of March 1989 is shown in Table 6.8. A conceptual model of the major shifts is shown in Figure 6.6.

The number of available shifts can be counted in two ways: as the total number of available shifts, or, when seasonal data are required, only as the number of possible shifts when there are data from the preceding monitoring period. This excluded all the May 1996 data because there was no monitoring in November 1996, and also the first reading of all new sites after May 1996.

6.3.3.2 Shifts in Early 1989

Early 1989 was an important time for several groups. The exceptional rainfall event of March 1989 correlated with the end of domination by *Brassica tournefortii* at former Group 1 sites (Figure 6.6). This group was recorded only four more times, all at the one site, after this rainfall event.

Group 3, a group with very low median cover and species richness, became less common (Table 6.8) as relevés within it shifted to better-condition groups, especially to Group 2 (Figure 6.6).

Table 6.5: Percentage of shifts to different conditions for each landform and land use.

	Possible Shifts	Actual Shifts	Percent			
			Shifts as % of Those Possible	Shifts to a Better Condition	Shifts to a Worse Condition	Shifts to a Similar Condition
Landform						
Dune	536	180	33.6	15.9	13.2	4.5
Dune-Base (mulga)	165	47	28.5	10.9	9.1	8.5
Dune-Base (myall)	115	36	31.3	10.4	8.7	12.2
Swale	410	46	11.2	3.9	3.4	3.9
Land Use						
Pastoral	265	33	12.5	4.9	4.9	2.6
Mine Lease - Undeveloped	267	84	31.5	14.2	10.5	6.7
Mine Lease - Developed	464	121	26.1	11.6	10.6	3.9
Town Area	230	71	30.9	11.3	8.7	10.9

Table 6.6: Total number of possible shifts away from each group (shifts were ignored where there were missing data from the preceding season).

Group	Shifts Possible in Autumn	Actual Shifts in Autumn	% of Those Possible	Shifts Possible in Spring	Actual Shifts in Spring	% of Those Possible
1	16	14	87.5	21	11	52.4
2	61	24	39.3	77	37	48.1
3	23	19	82.6	11	5	45.5
4	15	1	6.7	12	11	91.7
5	13	10	76.9	11	11	100.0
6	9	3	33.3	5	4	80.0
7	16	4	25.0	14	4	28.6
8	27	11	40.7	22	5	22.7
9	18	5	27.8	17	4	23.5
10	37	4	10.8	51	20	39.2
11	19	5	26.3	16	2	12.5
12	15	6	40.0	12	3	25.0
13	6	0	0.0	5	0	0.0
14	20	2	10.0	27	8	29.6
15	28	0	0.0	29	1	3.4
16	5	0	0.0	6	0	0.0
17	45	10	22.2	44	3	6.8
18	5	0	0.0	6	0	0.0
19	88	13	14.8	86	8	9.3
20	14	1	7.1	14	0	0.0
21	123	3	2.4	123	0	0.0

Another group that was more common prior to the 1989 rainfall events was Group 11, which included many dune-base sites in the town and undeveloped mine lease areas. Many of its members shifted to the more common Group 10 as a result of a species shift in the dominant grass that correlated with the March 1989 rainfall: *Enneapogon avenaceus* was largely replaced by *Aristida contorta* and the situation was not reversed during the rest of the monitoring period.

Table 6.7: Total number of shifts into and out of each group.

Group	Shifts Into Group	Shifts Out of Group	Group	Shifts Into Group	Shifts Out of Group
1	16	32	12	7	9
2	68	73	13	0	0
3	26	30	14	14	10
4	24	13	15	0	1
5	20	23	16	0	0
6	10	7	17	18	13
7	9	8	18	0	0
8	17	18	19	26	21
9	9	10	20	3	1
10	26	26	21	7	7
11	10	7			

Table 6.8: Group membership before and after the 1989 rains. Numbers are a percentage of the total number of relevés recorded before and after the March 1989 rain.

Group	Membership Before1989 Rain	Membership After 1989 Rain	Group	Membership Before1989 Rain	Membership After 1989 Rain
1	15.4	0.6	12	0.0	2.8
2	16.1	10.7	13	0.0	1.2
3	9.5	1.2	14	1.3	4.3
4	2.0	2.3	15	3.3	3.2
5	0.3	2.5	16	1.6	0.7
6	0.0	1.7	17	3.3	7.9
7	0.0	3.2	18	1.6	0.7
8	5.9	3.4	19	2.6	16.7
9	4.9	2.3	20	3.6	3.8
10	3.3	8.3	21	19.0	20.6
11	6.2	1.8			

Several groups became more common following the March 1989 rainfall event. One of these was Group 17 and at all sites this involved shifts by its members to a better condition. Group 19 also gained more members, partly as a result of shifts to a better condition, but also as relevés that had shifted to an even better condition than Group 19 shifted to a slightly worse condition, but not to their original group. This correlated with the waning of the positive effects of the 1989 rainfall event. Group 14 also had increased membership after March 1989, but this was due in part to the setting up of a new monitoring site that fell within this group.

Four groups did not appear in the classification prior to March 1989. Group 13 included a single site that was monitored for the first time in May 1991 and Group 12 included relevés that had shifted from Group 14 as a result of a change in species dominance of the grassy understorey, from *Enneapogon cylindricus* to *Enneapogon avenaceus.* This represents a shift to a different condition, rather than to a better or worse condition.

Groups 6 and 7 did not appear until the June and November 1989 readings respectively. These are both groups with low median cover and species richness (Table 6.2, Figures 6.7 and 6.8) and their appearance is unlikely to have been related to the heavy rainfall. All occurrences of both groups are from developed areas on the mine lease and it is likely that both groups reflect mine or processing plant related activities. All sites in these groups are within 500 m of the processing plant, the tailings retention system, or a raise bore (ventilation shaft) with a known saline aerosol emission problem at that time (Fatchen Environmental 1993). During 1989, vegetation at dune sites surrounding the tailings retention system generally showed a much smaller response to the rainfall event than did those of dune sites elsewhere (Figures 6.12 - 6.13). Mean cover values increased by 380% at the Group 6 and 7 sites, compared to 314% at other dune sites, but mean species richness increased by only 115% compared to 335% at the other dune sites. Both cover and species richness values remained very low at the Group 6 and 7 sites.

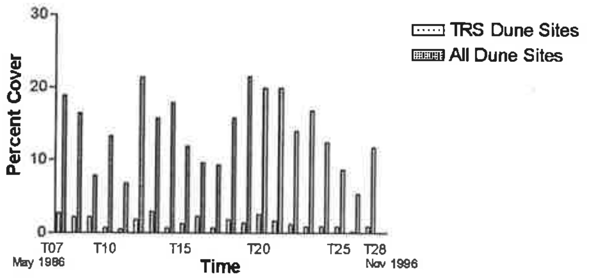

Figure 6.7: Total cover at dune sites around the Olympic Dam tailings retention system and at all other Olympic Dam dune sites.
March 1989=T12.

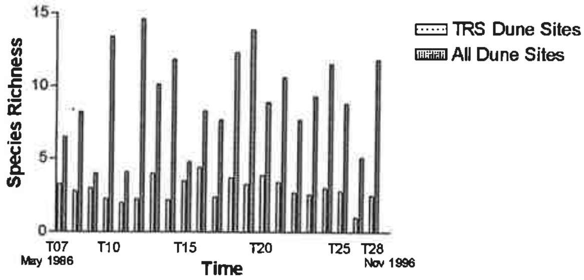

Figure 6.8: Species richness at dune sites around the Olympic Dam tailings retention system and at all other Olympic Dam dune sites.
March 1989=T12.

Fatchen (Fatchen and Associates 1993, Fatchen Environmental 1993, 1995) has for several years referred to the poor condition of vegetation at some sites around the tailings retention system, but decided that the evidence was inconclusive as to whether this was a development related effect or caused by the originally poorer condition, in a regional context, of vegetation on unstable dunes in this area. This higher dune mobility was reported during the baseline vegetation survey (Kinhill-Stearns Roger 1982, Fatchen Environmental 1993). In 1991, Fatchen and Associates (1993) considered the poor condition of vegetation monitoring sites in the tailings area to be a consequence of prolonged drought conditions. The evidence presented here suggests that the poor condition of these sites may be related to the presence of the tailings retention system, possibly either to dust blowing off dried out areas or to aerosol spray drift during tailings deposition, although the original unstable condition of the dunes is also likely to be a contributing factor. However, recent work by

WMC Limited suggests that the problem may be related to the processing plant in general, rather than to the tailings ponds in particular (Vic Farrington, WMC Limited, pers. comm. June 2000).

The rainfall of March 1989 also correlated with the shifting of many Cluster 2 relevés into Cluster 1 (Figure 6.6). The only shifts in which more than 15% of available relevés moved to another group involved shifts from Cluster 2 to Cluster 1. All of these are shifts to a better condition, correlating with increased cover of native perennial grasses.

In contrast, membership of Groups 8 and 9 was greatest prior to the heavy rainfall of March 1989. Many Group 9 sites moved to Group 10 after this date. Higher membership of Cluster 4 during dry periods appears to be due to dune base sites shifting into it as species richness declines.

6.3.3.3 Relationship Between Season and Group Shifts

As a very general rule, shifts to a worse-condition state during Autumn correlated with decreases in cover, after a dry summer, of short-lived plants or grasses that had grown one or two years earlier. Shifts to a better condition in Autumn correlated with the growth of grasses or the forb *Salsola kali.* Shifts to a worse-condition condition in Spring correlated with reductions in cover of grasses, and shifts to a better condition in Spring with increased cover of ephemeral plants.

Shifts away from groups 1, 3, 8 and 17 were recorded most frequently in Autumn, while shifts from groups 4, 10 and 14 were recorded most frequently in Spring (Table 6.6). Only one of these, Group 3, involves shifts away from one of the poor-condition Cluster 2 groups. Although most recorded shifts involved sites moving away from this cluster to a better-condition group (Group 2, Figure 6.6), this correlated with rainfall rather than the time of year. Relevés in Cluster 2 are usually in such poor condition that heavy rainfall at any time of the year results in shifts to a better condition.

Two groups in Cluster 1 had more shifts away in Autumn than Spring and two groups in this cluster had more shifts away in Spring than in Autumn. At Group 1 sites, the majority of shifts in Autumn is to be expected because the winter-growing *Brassica tournefortii* was more likely to be replaced by summer-growing grasses (Badman 1995a), especially in shifts to Group 19. Shifts that did not involve large increases in cover of *Aristida holathera* were generally to Group 2. All but one of the shifts from Group 17 in Cluster 1 were shifts to a worse-condition and many involved a reduction in the cover of grasses and occurred during dry summers. These shifts were mostly to groups 1, 2, 10 and 19.

The majority of shifts away from Group 4 in Cluster 1 occurred in Spring. These usually correlated with reductions in cover during winter of the summer-growing forb *Salsola kali*. If this plant remained as a significant part of the cover, shifts were generally to Group 4, otherwise the most likely shift was to Group 17. The other group that had a majority of shifts recorded in Spring was Group 14, also in Cluster 1. These also usually correlated with reductions in cover of summer-growing grasses, but not necessarily ones that had grown in the preceding summer. Most shifts were to Group 12 in Cluster 4. At least one of the shifts from Group 14 was thought to be an artefact of the monitoring (Appendix R).

Two groups in Cluster 4 had more shifts in one season than the other. Twice as many shifts were recorded away from Group 8 in Autumn as in Spring. Most of these were to a better condition and involved increased cover of summer-growing grasses. When *Enneapogon cylindricus* was the grass involved, the shift was to Group 14, while increases in *Aristida contorta* and *Enneapogon avenaceus* caused shifts to Group 10. Although many shifts away from Group 10 correlated with reductions in cover of grasses, such as those to Group 2, some shifts correlated with an increase in cover and were to a better condition. These included shifts to Group 11.

6.3.3.4 Correlation Between Rainfall and Group Shifts

The most important shifts that correlate closely with rainfall are those that occurred following the rainfall event of March 1989 (Section 6.3.3.2). This rainfall event resulted in a 69% decrease in relevés in the poor-condition Cluster 2 groups and a 25% increase in the better condition Cluster 1 groups (Table 6.4). There was also a 10% increase in the number of relevés in the Cluster 4 groups. There was far less correlation to this rainfall event in the two Cluster 3 groups. This cluster showed less variation over the monitoring period than the other clusters and appears to show a delayed response to rainfall, possibly due to an absence of non-dormant seed, sometimes of more than two years. Membership of this cluster was greatest from November 1987 to May 1992, largely as a result of changes in the number of monitored sites rather than to shifts to and from other groups.

In contrast to the effects of the 1989 rainfall event, only slightly less total annual rainfall in 1992 correlated with few group shifts (Table 6.4). This was probably due to the fact that, because of the lasting effects of the 1989 rainfall events, there were far fewer relevés in Cluster 2 at the end of 1991 than there were at the end of 1988. There were less poor-condition relevés available to shift to a better condition.

Below average rainfall in 1987, 1990 and 1996 correlated with decreases in the number of relevés in Cluster 1 and, in 1987 and 1996, with large increases in the number of relevés in Cluster 2 (Table 6.4). The same dry conditions that caused decreases in Cluster 1 relevés in these three years correlated with increases in Cluster 4 relevés. This was due largely to sites with *Atriplex vesicaria* losing most of their short-lived understorey species and shifting into groups with *Atriplex vesicaria* and lower species richness.

6.3.4 ENVIRONMENTAL PARAMETERS

6.3.4.1 Environmental Parameters at the Group Level

The relationship of 10 environmental parameters to the distribution of the 21 groups is shown in Figure 6.6. Although all of the environmental parameters were shown to be significantly correlated with the plant-based groups (Table 6.9), the vegetation association was least strongly correlated to any group, followed by the soil type and land use. Land-use was most strongly correlated with Group 11 which is dominated by the *Acacia papyrocarpa* relevés that are most common in the town area (one of the reasons the town was placed where it is), and also with Group 14 which contains dune sites with *Callitris glaucophylla*, also most common in the town area. Rainfall over all periods was most strongly correlated to long-lived trees, mainly in groups within Cluster 4, the swale and clayey dune-base sites. The only group from another cluster to be closely correlated with rainfall is Group 17 in Cluster 1 which contains most of the relevés with *Acacia aneura.* This group correlated most strongly with rainfall over the preceding three years, reflecting the slow growth rate of this species.

Groups in Cluster 2 showed a weak positive correlation to soil type. These groups all occur on sandy soil of dunes and have very low median cover and species richness. Groups in Cluster 3 are not strongly correlated to any of the environmental variables. Most other groups in Cluster 1, the best condition dune groups, also show a weak positive correlation to the environmental variables, with a closer positive correlation to soil type and land use than to rainfall.

6.3.4.2 Environmental Parameters at the Cluster Level

Data from the relevés comprising the four clusters identified by the original classification of the Olympic Dam cover data, discussed above, were examined separately using the PCC ordination component of the PATN computer package. The results of these ordinations are shown in Figures 6.9 - 6.12 and Table 6.9.

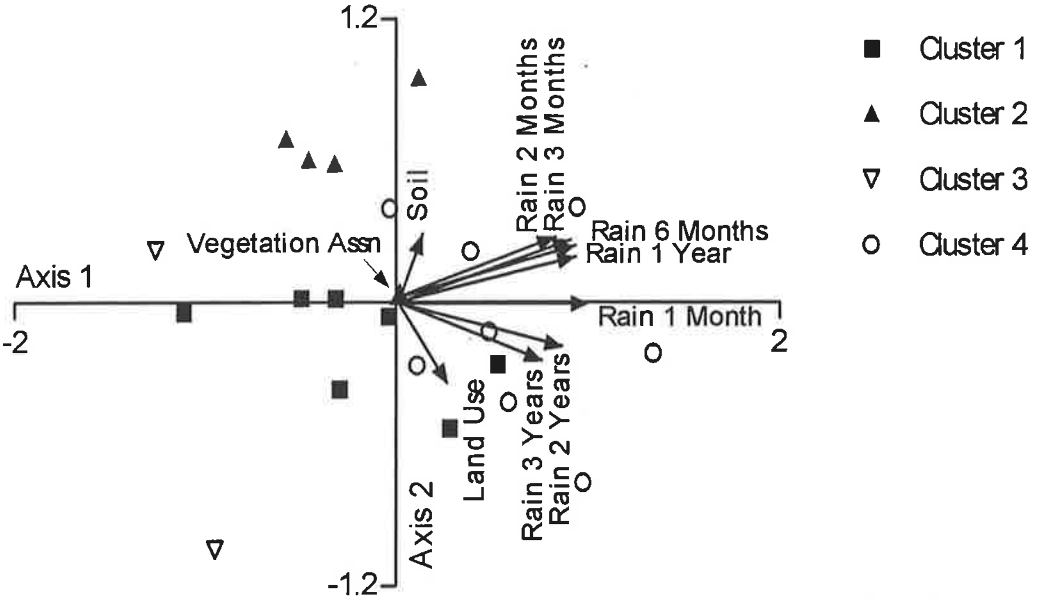

Figure 6.9: Plot of the first and second axis of a SSH ordination of the centroids of the 21 groups in four clusters from the classification of the Olympic Dam cover data (Appendix O). A PCC ordination of the environmental parameters measured for these data is superimposed on the dendrogram groups. Stress = 0.13.

Cluster 1

The ordination of relevés from Cluster 1 and significant environmental parameters ($p<0.05$) is shown in Figure 6.10a. An ordination of the significant species ($p<0.05$) is presented in Figure 6.10b and Table 6.10. All environmental parameters are significant in this cluster.

There are weak correlations between soil type and vegetation community and *Acacia aneura, Aristida contorta* and several ephemeral species. *Salsola kali* shows a weak positive correlation to land use. The strongest correlations are between *Aristida holathera* and rainfall during the previous two years and *Enneapogon cylindricus* and rainfall over the previous year. *Enneapogon avenaceus* has a weaker positive correlation to rainfall during the previous year. *Atriplex vesicaria, Maireana integra* and *Sclerolaena parallelicuspis* all show a positive correlation to rainfall during the previous six months. Twenty one species show a positive correlation to rainfall during the previous month, with three perennial grasses and one sub-shrub showing a positive correlation to rainfall over the previous one and two years.

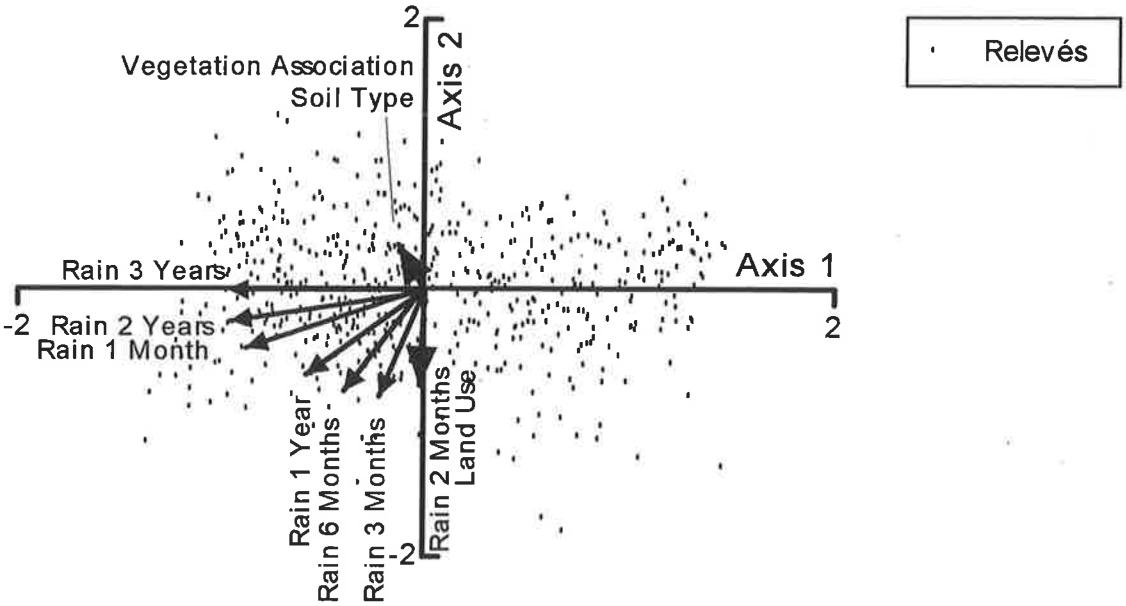

Figure 6.10a: Plot of environmental parameters obtained from a PCC ordination of the Olympic Dam Cluster 1 cover data overlain on Cluster 1 relevés from the dendrogram in Appendix O.

Stress = 0.21.

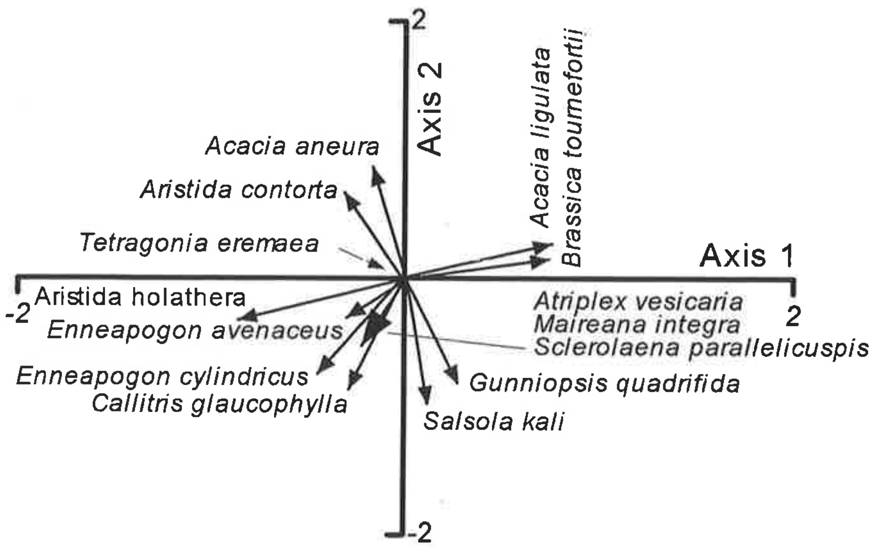

Figure 6.10b: Plot of significant species ($p<0.05$) obtained from a PCC ordination of the Olympic Dam Cluster 1 cover data. Cluster 1 is derived from the Dendrogram in Appendix O.

The large arrowhead denote more than one species at this position. Stress = 0.21. Other significant species for this cluster are listed in Table 6.10.

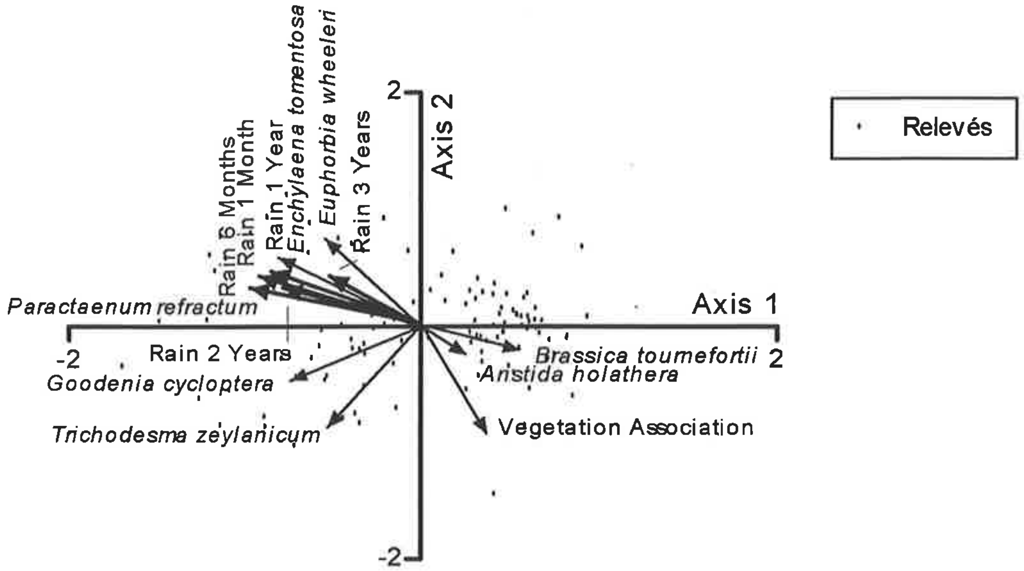

Figure 6.11: Plot of environmental parameters (thick lines) and significant species (p<0.05) obtained from PCC ordinations of the Olympic Dam Cluster 2 cover data overlain on Cluster 2 relevés from the dendrogram in Appendix O.

Stress = 0.19.

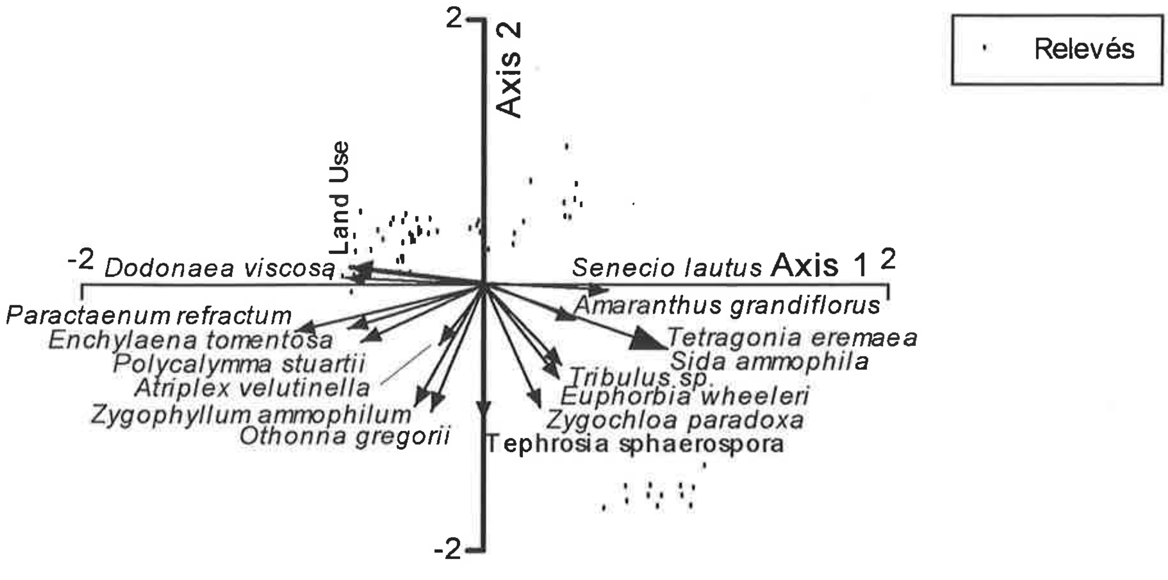

Figure 6.12: Plot of environmental parameters (thick lines) and significant species (p<0.05) obtained from PCC ordinations of the Olympic Dam Cluster 3 cover data overlain on Cluster 3 relevés from the dendrogram in Appendix O.

Stress = 0.05.

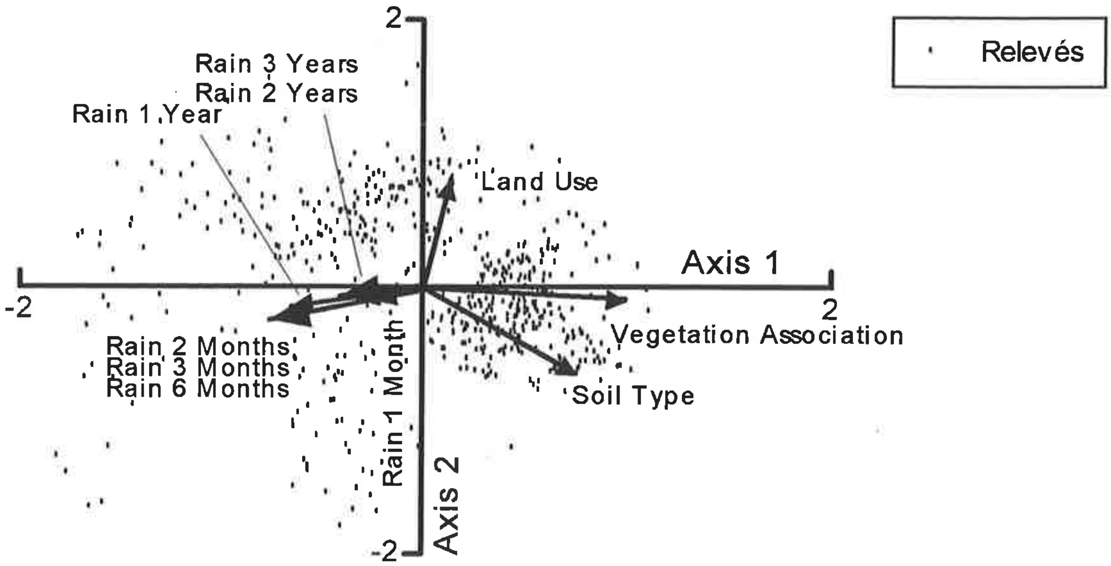

Figure 6.13a: Plot of environmental parameters obtained from a PCC ordination of the Olympic Dam Cluster 4 cover data overlain on Cluster 4 relevés from the dendrogram in Appendix O.
Stress = 0.22.

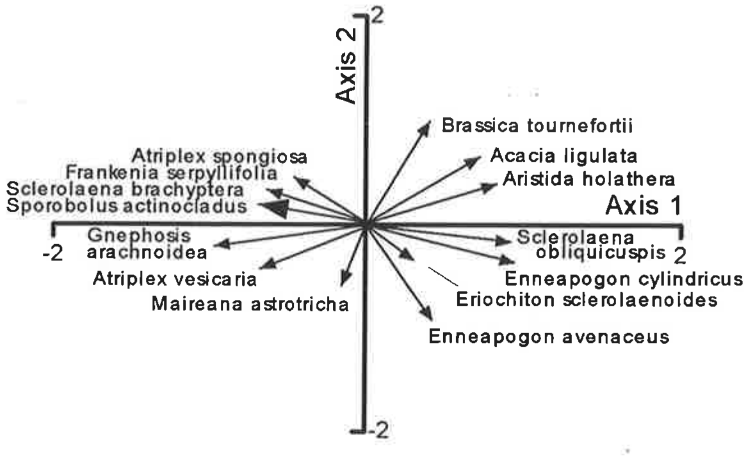

Figure 6.13b: Plot of significant species ($p<0.05$) obtained from a PCC ordination of the Olympic Dam Cluster 4 cover data. Cluster 4 is derived from the dendrogram in Appendix O.
Stress = 0.22.

Cluster 2

The ordination of relevés from Cluster 2 and significant environmental parameters ($p<0.05$) and significant species ($p<0.05$) is shown in Figure 6.11. The significant environmental parameters in this cluster are the vegetation association and rainfall during the previous one and six months and one, two and three years.

Only seven species are significant in this ordination. The only close correlations are between rainfall during the previous year and *Enchylaena tomentosa*, and rainfall during the previous six months and the grass *Paractaenum refractum.*

Table 6.9: Summary of PCC analysis of environmental variables with the Olympic Dam cover data showing whether or not they are significantly correlated ($p < 0.05$) with the ordination on the basis of the plant species clusters from the dendrogram in Appendix O.

Environmental Variables	R	Significance
Soil Type	0.9041	*
Vegetation Association	0.8363	*
Land Use	0.4128	*
Rainfall in Previous Month	0.3338	*
Rainfall in Previous 2 Months	0.4751	*
Rainfall in Previous 3 Months	0.4626	*
Rainfall in Previous 6 Months	0.4319	*
Rainfall in Previous Year	0.4381	*
Rainfall in Previous 2 Years	0.5553	*
Rainfall in Previous 3 Years	0.5057	*

Cluster 3

The ordination of relevés from Cluster 3 and significant environmental parameters ($p<0.05$) and 15 significant species ($p<0.05$) is shown in Figure 6.12. The only significant environmental parameters in this cluster is land use.

Land use correlates closely with the cover of *Dodonaea viscosa* and there is a negative correlation between land use and cover of *Tetragonia eremaea* and *Sida ammophila.*

Cluster 4

The ordination of relevés from Cluster 4 and significant environmental parameters ($p<0.05$) is shown in Figure 6.13a and of significant species ($p<0.05$) in Figure 6.13b and Table 6.10. All environmental parameters are significant in this cluster.

There is a positive correlation between land use and cover of *Brassica tournefortii*, and between vegetation and cover of *Sclerolaena obliquicuspis* and *Enneapogon cylindricus.* There is a weak positive correlation between soil type and *Eriochiton sclerolaenoides.* Cover of *Atriplex vesicaria* correlates weakly with rainfall during the previous month, but more strongly with rainfall during the previous two, three and six months. There is a negative correlation between land use and cover of *Maireana astrotricha,* and between rainfall over the last few months and cover of *Acacia ligulata, Aristida holathera* and fourteen other species,. The latter species are mostly either short-lived perennials or short-lived grasses that remain in the ground for long periods even when dead. At least seven ephemeral species show a positive correlation with rainfall during the previous month.

Table 6.10: Distribution of significant species for each cluster that are not included in Figures 6.10 and 6.13.

Sectors are numbered in a clockwise direction from the right hand side of the upper (positive) Y axis. Each sector represents a 45^0 arc. * = introduced species.

Species	Sector	Species	Sector
Site 1			
Calotis hispidula	1	**Erodium cicutarium*	6
Centipeda thespidioides	1	*Euphorbia drummondii*	6
Crassula colorata	1	*Euphorbia tannensis*	6
Cyperus squarrosus	1	*Omphalolappula concava*	6
Eragrostis dielsii	1	*Paractaenum novae-hollandiae*	6
Gnephosis tenuissima	1	*Paspalidium constrictum*	6
Triglochin calcitrapum	1	*Podolepis capillaris*	6
Dissocarpus paradoxus	2	*Ptilotus obovatus*	6
Erodium cygnorum	2	*Ptilotus polystachyus*	6
Goodenia lunata	2	*Pycnosorus pleiocephalus*	6
Atriplex velutinella	3	*Rhodanthe pygmaea*	6
Brachyscome ciliaris	3	*Sida ammophila*	6
Calandrinia remota	3	*Swainsona oliveri*	6
Convolvulus erubescens	3	*Tragus australianus*	6
Polycalymma stuartii	3	*Trichodesma zeylanicum*	6
Rhodanthe moschata	3	*Tripogon loliiformis*	6
Zygophyllum ammophilum	3	*Triraphis mollis*	6
Paractaenum refractum	4	*Vittadinia eremaea*	6
**Schismus barbatus*	4	*Calandrinia sp.*	7
Sclerolaena obliquicuspis	4	*Dactyloctenium radulans*	7
Calocephalus platycephalus	6	*Portulaca oleracea*	7
Calotis multicaulis	6	*Sclerolaena diacantha*	7
Chenopodium desertorum	6	*Sida fibulifera*	7
Enchylaena tomentosa	6	*Chenopodium pumilio*	8
Eragrostis laniflora	6	*Chthonocephalus pseudevax*	8
Eragrostis xerophila	6	*Gnephosis arachnoidea*	8
Eriochiton sclerolaenoides	6	*Plantago drummondii*	8
Site 4			
Atriplex velutinella	1	*Hibiscus krichauffianus*	3
Dodonaea viscosa	1	*Paspalidium constrictum*	3
Paractaenum refractum	1	*Sclerolaena cuneata*	3
Portulaca oleracea	1	*Calocephalus platycephalus*	6
Zygophyllum ammophilum	1	*Eragrostis laniflora*	6
Zygophyllum prismatothecum	1	*Eragrostis xerophila*	6
Abutilon otocarpum	2	*Minuria cunninghamii*	6
Boerhavia dominii	2	*Panicum decompositum*	6
Dissocarpus paradoxus	2	*Podolepis capillaris*	6
Goodenia lunata	2	*Sclerolaena decurrens*	6
Maireana integra	2	*Angianthus brachypappus*	7
Ptilotus polystachyus	2	*Chenopodium desertorum*	7
Salsola kali	2	*Dactyloctenium radulans*	7
**Schismus barbatus*	2	*Eragrostis dielsii*	7
Sclerolaena diacantha	2	*Eragrostis sp.*	7
Sida ammophila	2	*Lepidium phlebopetalum*	7
Sida fibulifera	2	*Lotus cruentus*	7
Stipa nitida	2	*Maireana ciliata*	7
Tetragonia eremaea	2	*Pimelea simplex*	7
Triraphis mollis	2	*Maireana erioclada*	8
Callitris glaucophylla	3	*Polycalymma stuartii*	8
Euphorbia tannensis	3	*Zygophyllum* sp.	8

6.3.5 DISCUSSION

Rainfall, particularly the rainfall events of 1989 when Olympic Dam received more than three times the district's long-term average annual rainfall, was found to have the greatest correlation with vegetation patterns. Heavy rainfall events such as this even up conditions because new plants establish and perennials revive. Numerous patches become more similar. Many sites shifted to better- or different-condition vegetation associations following the 1989 rainfall events, but returned to their former associations, even if only temporarily, with the return of drier seasonal conditions.

It is again difficult to state with any certainty, as was the case with the exclosure data discussed in Chapter 4, whether any of the groups represent transitions between states rather than the states themselves. This is further complicated by the inherent subjectivity in deciding what is a stable state and what is a transitional community. However, no evidence was found to suggest that any of these associations was actually a transition between states. Because of the longer time span covered by this dataset, it seems likely that all associations represent states.

The only shifts that correlated with a change of land use occurred near the processing plant and tailings retention system. During 1989, at a time when vegetation elsewhere was shifting to better-condition states following an exceptionally heavy rainfall event, sites in this area shifted into worse-condition groups. Previous analyses had hinted that this might be the case (Fatchen and Associates 1993), but it required analysis of the whole data set, rather than those from individual years, to provide a stronger case for this. This was also the case with mound spring vegetation monitoring to the north of Olympic Dam, where reduced spring flows and wetland areas were not identified by analysis of the data on a year-by-year basis, but became evident when the whole dataset was examined (Fatchen and Fatchen 1993).

The importance of rainfall, particularly large rainfall events, is in agreement with the framework for the ecology of arid Australia proposed by Stafford Smith and Morton (1990). Heavy rainfall in the Australian arid zone is temporally variable and unpredictable on a world scale (Griffin and Friedel 1985), but it is these heavier rainfall events that are responsible for the high diversity and persistence of perennial plants (Stafford Smith and Morton 1990). These rainfall events are responsible for the major patterns in both physical and biotic environments, often with quite abrupt boundaries, that can sustain unexpectedly high levels of biomass. The persistence of these perennial species is controlled by moisture deficiency. Smaller rains cause changes in short-lived species, demonstrated in this study by the large number of ephemeral species that correlated with short-term rainfall. Vegetation associations that contained a high proportion of woody perennial species were the most stable of all associations at Olympic Dam, even though they sometimes had low species richness. These shrubs probably make use of available soil moisture and exclude many ephemeral species in all but the wettest years.

The spatial heterogeneity of the arid zone (Stafford Smith and Pickup 1990) is emphasised here by the fact that the Bray-Curtis 0.96 level of dissimilarity was the cut-off point for clusters, although it was the cut-off point for groups in the exclosure data analysis. The 0.96 level is also the same cut-off used for clusters in the grazing experiment. The greater similarity between relevés in the Olympic Dam and grazing datasets is a reflection of the much closer spatial grouping of sites sampled, covering tens of kilometres, compared to the exclosure data which included the very dissimilar and geographically distant Cowarie site and which were spread over hundreds of kilometres.

No changes were detected from the PATN analysis that can be directly attributed to the removal of domestic stock from the mine and municipal leases. This offers further support to the findings of Badman (1995a) that there was little change in total grazing pressure following release from domestic grazing. Domestic stock were replaced by increases in the numbers of rabbits and kangaroos (Badman 1995a). As pointed out by previous researchers such as Grice and Barchia (1992), it is total grazing pressure rather than the species of herbivore that is the important factor.

The only vegetation communities that were found to correlate with a particular land use involved groups dominated by a species, or suite of species, that was largely or entirely restricted in this study to that particular land use area. This was particularly true of sites in the town area, which was in itself placed where it is to take advantage of these trees, with *Callitris glaucophylla* and *Acacia papyrocarpa.* These species are resistant to change unless physically removed or, in the case of *Callitris glaucophylla*, destroyed by fire. The latter species is very susceptible to fire, as was demonstrated in an area south of the township that was burnt in 1991.

Some short-lived species showed correlations to rainfall over periods greater than a year. This is thought to be due to the persistence of these species in the ground, although already dead.

Correlations between two shrubs, *Atriplex vesicaria* and *Gunniopsis quadrifida*, to rainfall over the previous few months was at first considered to be a strange finding. However, as noted in Chapter 1, both species have a habit of dropping many of their leaves in response to very dry seasonal conditions and to grow them again just as quickly when it does rain. *Gunniopsis quadrifida* can often appear dead at one reading but have growing shoots at the next (Chapter 4). Osborn *et al.* (1932) also found that many apparently dead chenopod shrubs at Koonamore Reserve later re-sprouted following rain. Correlations between cover and short-term rainfall are considered to reflect the rapid growth of new leaves after rain.

Only one environmental parameter and seven species were found to be significant on dune sites with the poorest vegetation cover.. This is hardly surprising because they usually support few plant species. Once individual species attain sufficient cover to become significant, sites shift into an association that contains other better-condition sites.

The classification of vegetation on dune-base sites, discussed in Chapter 5, again provided some interesting results here. These sites shifted between groups depending on which species dominated the understorey. Dune base sites had a much higher percentage of shifts that were regarded as being to a "different" condition than was the case in any other land form. The long-lived trees and shrubs remain, but understorey vegetation is dominated by grasses following summer rainfall or by forbs after winter rain, with both dune and swale species present. Changes in the dominant grass species also causes shifts between vegetation associations.

Badman (1995a) discussed the clay layer, within the top 50-100 cm of most dunes in this area, that impedes water infiltration into the dune core. This results in water gravitating along the top of this layer to the dune base. In the Roxby Downs area this helps to maintain the bands of *Acacia papyrocarpa* that grow along dune bases and also *Callitris glaucophylla* that grow on the dunes but send near-surface roots above the clay layer to the dune base. Dune base soils therefore usually retain a higher moisture content for a longer period than soils of either dunes or swales. This gives dune bases a greater chance of maintaining stable condition states for longer periods and with less fluctuations than dune sites. Swale sites remain more stable because of their higher content of perennial shrubs, although the species richness of their understoreys fluctuates widely between wet and dry years.

6.4 SHRUB DENSITY

This section examines the shrub density data from the 1 x 100 m shrub-count transects at Olympic Dam from 1981 to 1997. The number of adult, small adult and juvenile shrubs were recorded from each transect. Units used in this section are the number of shrubs per 100 m^2. Adult and small-adult shrub density data collected by Olympic Dam Operations were combined and the classification carried out on the resulting data.

As was the case with the exclosure data, mean, rather than median, densities were used because median densities could not be calculated for juvenile shrubs (see Section 4.4).

6.4.1 RESULTS

6.4.1.1 Classification of the Shrub Density Data

Analysis of the adult shrub density data resulted in 20 groups for each age-class at the Bray-Curtis 0.96 level of dissimilarity. This analysis resulted in more than half of the groups having *Atriplex vesicaria* as their dominant species. *Maireana astrotricha* was the second most common species in several groups. The differences between groups often consisted only of differences in densities of each species.

Analysis of the adult data identified 12 groups at the Bray-Curtis 0.96 level of dissimilarity and seven clusters at the 1.6 level of dissimilarity (Figure 6.14). The full dendrogram from this classification is given in Appendix S. Mean density values for the various species in the groups and clusters are given in Table 6.11.

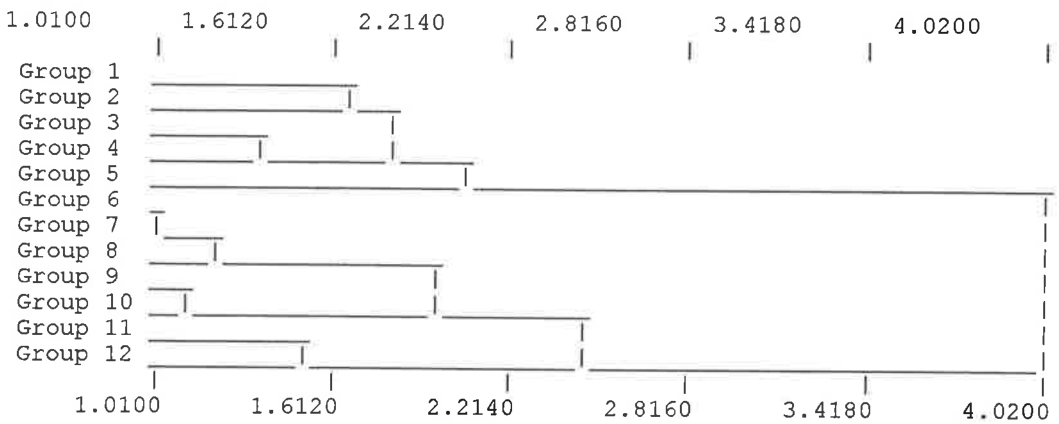

Figure 6.14: Dendrogram of the 12 groups obtained by classification of the Olympic Dam shrub count data (excluding juveniles). The full dendrogram from the classification is presented in Appendix S.

6.4.1.2 Descriptions of Clusters and Groups

Cluster 1

This cluster includes only the 334 relevés of Group 1. *Atriplex vesicaria* dominates the group and has a high mean density here (see Table 6.11 for mean density values). *Ptilotus obovatus*, with low mean density, is the next most common species, with very low mean densities of *Maireana astrotricha* and *Frankenia serpyllifolia*.

Cluster 2

This cluster also contains a single group. It contains the 74 relevés of Group 2 and is again dominated by *Atriplex vesicaria*, which attains its highest mean density value here, more than double that of Group 1. *Maireana astrotricha* is the next most common species, with low mean density. *Frankenia serpyllifolia* also occurs at a low mean density in this group. Despite having low mean density values, the latter two species reach their second most common status here.

Table 6.11: Mean densities of shrubs per 100 m^2 in the 12 groups (Figure 6.14) at the Bray-Curtis 0.96 level of dissimilarity and 7 clusters at the 1.6 level of dissimilarity derived from the Olympic Dam shrub count data (excluding juveniles).

	n	Atrivesi	Mairastr	Franserp	Ptilobov	Gunnquad	Enchtome	Sennarte	Scletenu
Group 1	334	85.8	4.2	4.3	6.1	0.1	0.0	0.0	0.1
Group 2	74	206.3	17.4	6.8	0.0	0.0	0.0	0.0	0.0
Group 3	14	0.0	60.9	0.9	0.0	0.0	0.0	0.0	0.0
Group 4	25	17.1	0.0	61.2	0.0	7.2	0.0	0.0	0.0
Group 5	139	38.3	1.6	0.0	0.6	1.0	0.3	0.1	0.0
Group 6	96	16.1	0.0	0.8	0.3	0.3	2.8	0.0	0.0
Group 7	79	9.3	0.1	0.1	0.1	1.0	0.2	0.0	0.0
Group 8	32	3.7	0.0	0.0	0.0	0.0	8.4	0.0	0.0
Group 9	23	3.9	15.2	0.0	0.0	0.0	0.0	0.0	0.0
Group 10	32	0.0	7.1	0.0	0.7	0.0	0.0	0.0	0.0
Group 11	30	2.7	0.0	0.0	0.0	0.0	0.3	0.0	0.0
Group 12	11	0.0	0.3	0.0	0.0	0.0	1.5	0.0	0.0
Cluster 1	334	85.8	4.2	4.3	6.1	0.1	0.0	0.0	0.1
Cluster 2	74	206.3	17.4	6.8	0.0	0.0	0.0	0.0	0.0
Cluster 3	39	10.9	21.8	39.6	0.0	4.6	0.0	0.0	0.0
Cluster 4	139	38.3	1.6	0.0	0.6	1.0	0.3	0.1	0.0
Cluster 5	207	11.6	0.0	0.4	0.2	0.5	2.7	0.0	0.0
Cluster 6	55	1.6	10.5	0.0	0.4	0.0	0.0	0.0	0.0
Cluster 7	41	2.0	0.1	0.0	0.0	0.0	0.6	0.0	0.0

Cluster 3

Cluster 3 includes the 39 relevés of Groups 3 and 4 and is dominated by *Frankenia serpyllifolia* at low to mid-range density. *Maireana astrotricha* is also important in this cluster, with a mean density about half that of the former species. *Atriplex vesicaria* is also important here. The two groups that form this cluster have the highest mean densities of all groups that are not dominated by *Atriplex vesicaria*. Group 3 is dominated by *Maireana astrotricha*, which reaches its highest mean density here, although with only a mid-range value. It is the only shrub present at many sites in this group. The only other shrub occurring here is *Frankenia serpyllifolia*, with a very low mean density value. Group 4 is dominated by *Frankenia serpyllifolia*, with mid-range mean density. *Atriplex vesicaria* is the next most common shrub, but with only a low mean density. *Gunniopsis quadrifida* is present in the group, again with a low mean density.

Cluster 4

Cluster 4 contains the 139 relevés of Group 5. It is dominated by *Atriplex vesicaria,* with low to mid-range mean density that is less than half that of Group 1. Several other shrubs are present at very low mean densities, namely *Maireana astrotricha, Gunniopsis quadrifida, Ptilotus obovatus, Enchylaena tomentosa* and *Senna artemisioides.*

Cluster 5

This cluster contains the 207 relevés of Groups 6, 7 and 8. Cluster 5 is dominated by *Atriplex vesicaria*, but with a mean density less than one third that of Cluster 4. *Enchylaena tomentosa* has the next highest mean density in the cluster, but this is very low. Group 6 is dominated by *Atriplex vesicaria,* but with a mean density less than half of that for Group 5. *Enchylaena tomentosa* has the next highest mean density. *Frankenia serpyllifolia, Gunniopsis quadrifida* and *Ptilotus obovatus* are also present at very low mean densities. Group 7 is also dominated by *Atriplex vesicaria*, but with a mean density about half that of Group 6. *Enchylaena tomentosa, Maireana astrotricha, Frankenia serpyllifolia, Ptilotus obovatus* and *Gunniopsis quadrifida* are present in the group at very low mean densities. Group 8 is dominated by *Enchylaena tomentosa,* which occurs at a low mean density. *Atriplex vesicaria* is the only other species in this group, with a mean density of about one third that of Group 7.

Cluster 6

The 55 relevés of Groups 9 and 10 form this cluster, which is dominated, although at quite low mean densities, by *Maireana astrotricha*. Group 9 is dominated by this species, although at only about one third of its Group 3 value. *Atriplex vesicaria* has the next highest mean density, but this is very low. No other species occur in the group. *Maireana astrotricha* is also the most common species in Group 10, but with a mean density of less than half that of Group 9. *Ptilotus obovatus* is the only other species in the group, with a very low mean density.

Cluster 7

Cluster 7 includes the 41 relevés of Groups 11 and 12 and has the lowest mean density of all clusters. *Atriplex vesicaria* has the highest mean density of any individual species, but this is still very low. Group 11 has very low mean densities of *Atriplex vesicaria* and *Enchylaena tomentosa*, while Group 12 has very low mean densities of *Enchylaena tomentosa* and *Maireana astrotricha.*

6.4.1.3 Shifts Between Classification Groups

Shifts between groups occurred on 10% of the occasions on which shifts were possible (i.e. excluding the first time each site was monitored). This is considerably less than the percentage of times that there were shifts between groups in the analysis of the Olympic Dam cover data (Table 6.5), but still a higher than expected for long-lived perennial plants. In order to examine whether these shifts were caused by grazing prior to the fencing of the mine and municipal leases, the distribution of sites in groups was examined for the periods before and after the fencing. A summary of these results is given in Table 6.12. Although there were differences in the percentage of shifts before and after fencing at both the pastoral sites and at all monitoring sites, there was little difference after fencing between the results for all the different land-use areas at either the group or cluster level. If removal of domestic grazing had been responsible for the decrease in percentage of shifts, it would seem likely that there would be major differences between the results for the different land use areas. The fact that there are not suggests that the differences before and after fencing were caused by something other than the removal of domestic livestock.

The 1989 rainfall event was shown above to have correlated with many of the shifts in cover groups, so the percentage of shifts either side of the main March 1989 rainfall event were also calculated. This indicated a greater difference in shifts before and after the rainfall events of 1989 than between the pre- and post-fencing results, suggesting that above average rainfall was again a contributing factor in the increase in shifts between groups.

6.4.1.4 Relationship of Classification Groups to Environmental Parameters

An ordination of the significant environmental parameters ($p<0.05$) superimposed on the seven clusters derived from the classification of the adult shrub count data is shown in Figure 6.15. The only significant environmental parameter is rainfall, but this is significant over all of the seven time periods examined. Rainfall correlates strongly with all clusters except Clusters 4 and 7, which both exhibit negative correlations to rainfall.

Table 6.12: Percentage of shifts between groups derived from the dendrogram in Appendix O relating to a) fencing of the mine and municipal leases, and b) the 1989 rainfall events.
* value based on a very small sample from a single site.

Fencing of Mine and Municipal Leases

a)	Groups	
	Before Fencing	After Fencing
Current pastoral land	13	8
Undeveloped mine lease	40*	11
Developed mine lease	12	12
Town area	50*	13
All monitoring sites	14	11

1989 Rainfall Events

b)	Before 1989 Rain	After 1989 Rain
Current pastoral land	13	7
Undeveloped mine lease	27	9
Developed mine lease	23	8
Town area	31	10
All monitoring sites	21	8

6.4.1.5 Juvenile Shrubs

Twelve groups were identified from a PATN analysis of the Olympic Dam juvenile shrub count data at the Bray-Curtis 0.96 level of dissimilarity, with seven clusters at the 1.6 level of dissimilarity. The dendrogram from this classification is presented as Appendix T. The species composition and shrub density for each group is given in Table 6.13. Eight of the groups and five of the clusters are dominated by *Atriplex vesicaria*, while three groups and two clusters have *Maireana astrotricha* as the dominant shrub. One group contains relevés with *Senna artemisioides* and lesser densities of *Atriplex vesicaria* and *Frankenia serpyllifolia*. The differences between the groups is mainly in the mean density of the dominant species, rather than in different combinations of species. *Atriplex vesicaria dominates* Clusters 2, 4, 5, 6 and 7, while *Maireana astrotricha* dominates Clusters 1 and 3.

The significant environmental parameters ($p<0.05$) in relation to juvenile shrubs are the soil type, vegetation association, land use and rainfall over the previous three years. An ordination of these parameters and the 12 groups is shown in Figure 6.16.

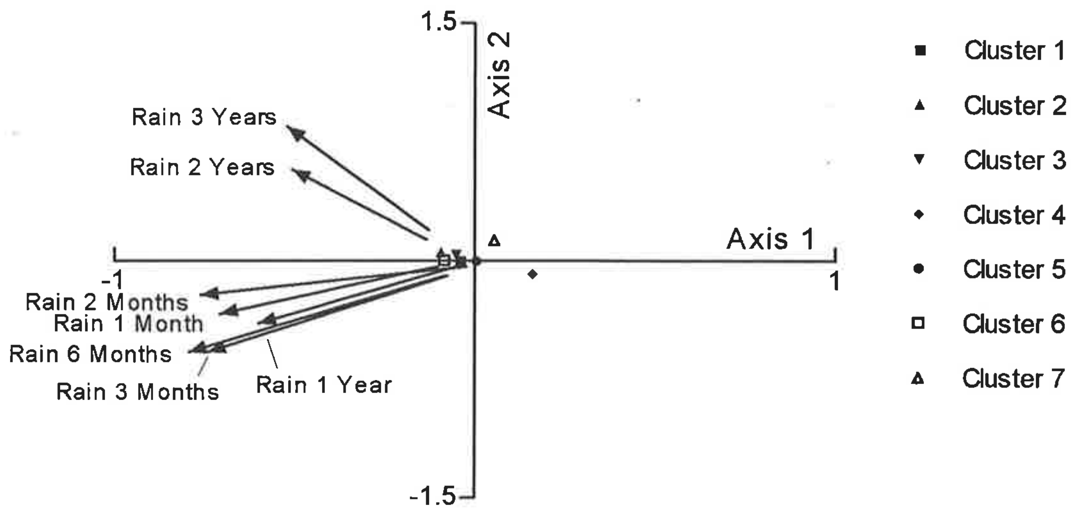

Figure 6.15: Plot of the first two axes of a PCC ordination of significant environmental parameters ($p<0.05$) superimposed on the seven clusters (Appendix S, Figure 6.14) from the classification of the Olympic Dam adult shrub count data.

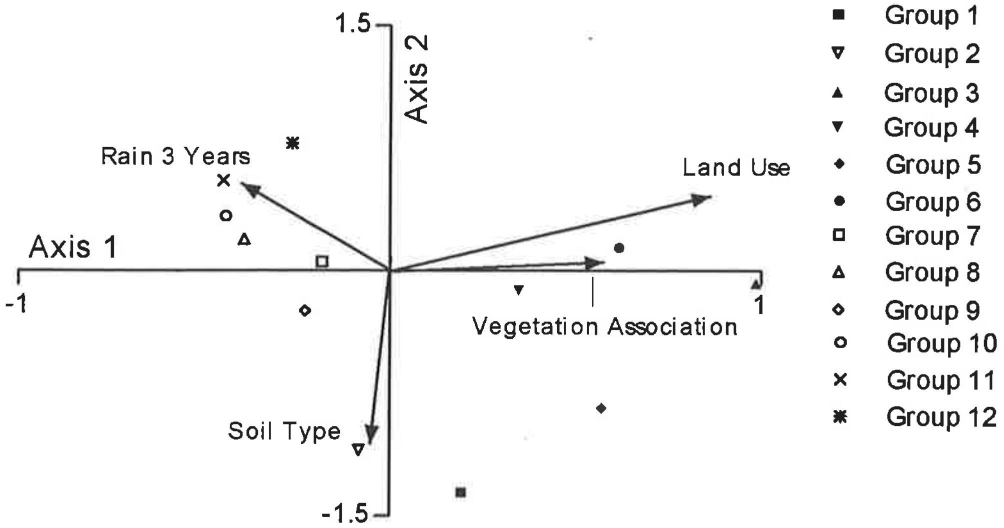

Figure 6.16: Plot of the first two axes of a PCC ordination of significant environmental parameters ($p<0.05$) superimposed on the 12 groups (from the dendrogram in Appendix T) from the classification of the Olympic Dam juvenile shrub count data.
Stress = 0.10.

Rainfall over the previous three years correlates most closely with Groups 11 and 10, and less closely with Groups 7, 8 and 12. Soil type correlates strongly and closely with Group 8 and the vegetation association with Groups 6 and 4. Group 5 has a negative correlation to rainfall over the previous three years.

Table 6.13: Floristic composition and mean densities of juvenile shrubs in the 12 groups and seven clusters derived from the PATN classification of the Olympic Dam juvenile shrub count data.

	No of Relevés	*Atriplex vesicaria*	*Maireana astrotricha*	*Senna artemisioides*	*Frankenia serpyllifolia*
Group 1	16	0.0	2.8	0.0	0.0
Group 2	16	0.0	1.0	0.0	0.0
Group 3	22	47.4	1.6	0.0	0.0
Group 4	41	14.4	0.1	0.0	0.0
Group 5	15	5.5	16.6	0.0	0.4
Group 6	8	0.1	0.0	4.6	1.8
Group 7	47	6.3	0.0	0.0	0.0
Group 8	17	4.0	0.0	0.0	0.0
Group 9	8	3.5	2.0	0.0	0.0
Group 10	23	3.0	0.0	0.0	0.0
Group 11	36	2.0	0.0	0.0	0.0
Group 12	33	1.0	0.0	0.0	0.0
Cluster 1	32	0.0	1.9	0.0	0.0
Cluster 2	63	16.0	0.0	0.0	0.0
Cluster 3	23	3.7	10.8	1.6	0.9
Cluster 4	72	5.4	0.2	0.0	0.0
Cluster 5	23	3.0	0.0	0.0	0.0
Cluster 6	36	2.0	0.0	0.0	0.0
Cluster 7	33	1.0	0.0	0.0	0.0

No data are available on the presence of juvenile shrubs prior to May 1986. Despite the obvious need for recent rainfall to produce germination of seeds, there is a general lack of correlation between the results shown in Table 6.13 and rainfall. Rainfall over the previous three years, as mentioned above, is the only significant rainfall period. The relationship between rainfall and seed germination and establishment is discussed in more detail in the next section.

6.4.2 DISCUSSION

Classification of the shrub count data has again highlighted the problem of distinguishing between the various age classes of chenopod shrubs. This issue was recognised in the Olympic Dam area during routine annual vegetation monitoring and reporting in 1989 (Fatchen and Associates 1990). This problem was discussed above in Chapter 1 and in Section 6.3.5. The analysis carried out during this study suggests that the best approach is to consider all shrubs other than juveniles in the one category. This removes the possibility of significant errors being introduced into the analysis, as has sometimes been the case in the past (Fatchen and Associates 1992).

As in other sections of this thesis, the majority of shifts in group affinities correlate to rainfall, particularly the heavy rainfall event of March 1989. Despite this, the heaviest rainfall event during the monitoring period, in May 1989, did not lead to the highest percentage of sites with juvenile shrubs. This suggests that recruitment may be seed limited: insufficient seed may remain in the soil for heavy rainfall events following long dry periods to result in large-scale recruitment of some species. A heavy rainfall event is likely to result in production of large amounts of seed that will germinate if a second suitable rainfall event occurs while viable seed remains in the soil. This is supported by the results of the ordination of juvenile shrub data and environmental parameters discussed in Section 6.4.1.5. As was the case with the exclosure sites discussed in Chapter 4, short-term rainfall was not significant in the establishment of shrubs, with rainfall over the previous three years being the only significant rainfall parameter. The only correlations between juvenile classification groups and rainfall are with those groups that have the lowest mean densities of *Atriplex vesicaria.* Negative correlations exist between the highest mean density groups with both *Atriplex vesicaria* and *Maireana astrotricha*, with the correlation weakening in those groups with lower mean juvenile shrub density.

The main rainfall events prior to each monitoring and the percentage of shrubby sites with juvenile shrubs present are shown in Appendix U. Juvenile shrubs were present at more than 50% of shrubby sites for 30% of monitoring events, and at less than 20% of sites for 35% of monitoring events. The common factor between monitoring events with high proportions of sites with juvenile shrubs is a combination of several successive wet days during warm, but not the hottest, months. Similar combinations of wet days during winter did not produce the same results. Cloudy conditions associated with rain assist in protecting emerging seedlings from the hot sun during summer. Mott (1972, 1973) demonstrated that many arid zone species require the soil to be moist for at least 24 hours in summer and 3-5 days in winter in order to attain 50% germination. Even though seeds may germinate under these conditions, the present data suggest that a longer wet period and/or a follow-up rainfall event are required to ensure the establishment of seedlings. Suitable conditions occur more frequently during the cooler months than during mid-summer, with large establishment of seedlings recorded on only two occasions following summer rainfall. Both occasions following extended wet periods with either a long initial rainfall event with a follow-up rain a month later (May 1987 monitoring) or an extended wet period with very high total rainfall (May 1997 monitoring).

Although it is impossible to conclude from the present data which rainfall events caused the germination of seedlings, the most commonly met conditions that produced seedling shrubs appear to be a combination of at least 3-4 days of wet weather in the warm months followed by a further extended rainfall event within about one month and possibly a third similar rainfall event. Because the viability of the seed of *Atriplex vesicaria* diminishes after two years under field conditions at

Olympic Dam (Badman 1992a), it would also appear that successful establishment of this species is also dependent on rainfall events sufficient to replenish the seed bank during the previous two years.

Another factor is that shrubs cannot increase indefinitely due to root saturation in relation to available soil moisture. Seedlings are essentially ephemeral in areas with high shrub densities.

The monitoring events with the lowest incidence of juvenile shrubs were preceded either by periods of very low rainfall, by heavy rainfall on only one or two days, by rainfall entirely during the cold months, by extended rainfall events with the largest fall coming at the end thus making the previous days' falls ineffective, or by extended rainfall events with a low total rainfall. The lowest recorded incidence of juvenile shrubs was in November 1994, following a single rainfall event of 71 mm over three days in June. This rainfall event met Mott's criteria concerning the time the ground remained moist (Mott 1972), but little recruitment occurred. This is likely to have been due to the cold weather and to the lack of a follow-up rainfall event, although seed predation may also have been a contributing factor.

The heavy rainfall of March 1989 could have been expected to produce a very large recruitment of shrub species, but this did not occur to the extent that might have been expected. Unlike *Callitris glaucophylla* (Read 1995), low shrub seedlings establish readily in this area, especially on formerly disturbed areas (Badman 1992a). They did so in 1989, but to a lesser extent than occurred following some lesser rainfall events. The most likely explanation for this may be that they were out-competed by faster establishing but shorter-lived species (Hall *et al.* 1964) especially the grasses that dominated the vegetation at this time (Badman 1995a, and see above), or all available resources were used by established trees. Hunter (1989) found that only 3% of shrub seedlings survived in undisturbed areas of the Mojave Desert because of competition with established plants, compared to almost 60% in disturbed areas where there was no competition.

Those groups containing the highest mean densities of both *Atriplex vesicaria* and *Maireana astrotricha* also have the closest correlations to vegetation association. The group with the lowest mean density of *Atriplex vesicaria,* and with the highest mean density of *Senna artemisioides* juveniles, is closely correlated with vegetation association and also with land use.

6.5 CONCLUSIONS

Few changes to the vegetation of the Olympic Dam area can be directly related to the effects of the mine and processing plant. At the current level of data collection and analysis, these effects are restricted to sites near the tailings retention system and the processing plant. Earlier effects of aerosol emissions, known to have been localised around a raise bore ventilation shaft, were not detected by this analysis. Remedial measures appear to have worked and to have halted this effect.

The removal of domestic stock has had little impact on the vegetation of the mine and municipal leases. Most major changes to the vegetation during the monitoring period correlated with seasonal conditions.

Apart from the direct effects of removal of vegetation during construction, the establishment of the town of Roxby Downs has had no effect on the local vegetation that could be distinguished at the present scale of monitoring and analysis.

The exclusion of domestic stock from the mine and municipal leases and of rabbits from the town area has not resulted in any large-scale increase in recruitment of perennial species. Establishment of seedlings was dependent on the occurrence of a suitable set of rainfall related events, with recruitment during the monitoring period sufficient only to maintain the status quo.

Major rainfall events correlated with many of the changes in vegetation associations during the study period. These shifts were rapid and sometimes long-lasting. Shifts that correlated to the onset of dry conditions took longer to occur and were sometimes temporarily halted or reversed by minor rainfall events.

CHAPTER 7 COMPARISON OF THE EXCLOSURE AND OLYMPIC DAM DATA

7.1 INTRODUCTION

The distribution and abundance of plants depends primarily on two factors: environmental conditions and immigration (Hagen 1989). Because both factors contain an element of randomness, no two environments are ever geographically distinct because environmental factors vary continually in space and time (Hagen 1989). In a more broad-ranging study than the present one, Brandle (1998) identified some floristic groups that occurred right across his study areas, an extension of more than 600 km. However, there is a need for care when classifying vegetation units only on the basis of habitat (Poore 1956).

Very long-term natural cycles, perhaps beyond the knowledge of the European settlers of Australia (Baker and Mutitjulu Community 1992), may be at play in the Australian arid zone. Even without such cycles, changes caused by natural seasonal conditions may be very slow, with the most rapid changes caused by unusually heavy rainfall events (Foran *et al.* 1982, Leigh *et al.* 1989, Stafford Smith and Morton 1990). Arid zone vegetation studies extending over periods as long as 30 years after changes in land use have not always been long enough to detect the return to a stable state (Gardner 1950, Hall *et al.* 1964, Robertson 1971, Dean and Milton 1995).

Differences in soil processes (Herrick and Whitford 1999), plant interactions (Callaway and Tyler 1999), landform (Daley and Hodgkinson 1996) and topography (Buckley 1982a, 1982b) operate at different scales but all can affect the type and quantity of vegetation that grows at a particular site.

7.2 AIMS

This chapter examines the relationship between the exclosure and Olympic Dam cover datasets, i.e. between the effects on vegetation of the different land uses of grazing and mining.. Therefore, the aim of the analysis of the combined datasets was to see whether there are similarities in relevé ordinations between data collected from the exclosure and Olympic Dam sites.

7.3 DATA ANALYSIS

The exclosure and Olympic Dam datasets were combined and a PCoA analysis was carried out as described in Section 3.11.2. Environmental parameters were not considered in this analysis because this had already been done for the two separate datasets.

7.4 RESULTS

7.4.1 CLASSIFICATION OF THE COMBINED COVER DATA

Twenty five groups (Appendix V) were identified from the dendrogram at the Bray-Curtis 0.96 level of dissimilarity. This is the same cut off point that was used to separate groups in the exclosure cover data analysis (Chapter 4) and clusters in the Olympic Dam cover data analysis (Chapter 6). The relationships between the 25 groups and the earlier groups for the exclosure and Olympic Dam datasets are shown in Table 7.1. This table also shows the relationships between groups from the exclosure and Olympic Dam classifications. Brief descriptions of group composition are given in Table 7.2. The classification of the combined data shows that two groups contain only relevés from exclosure sites, 14 groups contain only Olympic Dam relevés and nine groups contain relevés from both datasets (Table 7.1). A plot of the first two axes of a PCoA ordination of the combined data is shown in Figure 7.1.

Table 7.1: Composition of the 25 groups (Appendix V) derived from the classification of the combined exclosure and Olympic Dam cover data at the Bray-Curtis 0.96 level of dissimilarity.

Group	No. of Relevés	Equivalent Exclosures Cover Group(s) and Number of Relevés From Each Group	Equivalent Olympic Dam Cover Group(s) and Number of Relevés From Each Group
1	53	-	1 (53)
2	164	-	2 (153), 6 (10), 9 (1)
3	41	-	3 (41)
4	42	-	2 (3), 4 (29), 19 (10)
5	26	-	5 (26)
6	32	-	7 (32)
7	64	-	6 (7), 8 (51), 9 (6)
8	18	9 (6), 10 (8)	9 (4)
9	106	-	9 (38), 10 (31), 11 (37)
10	84	1 (24), 2 (15), 3 (4) , 4 (7)	10 (29), 12 (5)
11	24	1 (1)	12 (23)
12	23	-	15 (23)
13	26	12 (8), 13 (18)	-
14	12	14 (12)	-
15	47	-	8 (1), 14 (46)
16	90	12 (1)	17 (89)
17	12	-	18 (12)
18	12	-	16 (12)
19	49	-	20 (49)
20	96	3 (4)	19 (92)
21	73	-	19 (73)
22	90	5 (3), 6 (4), 8 (1), 11 (8)	9 (12), 21 (62)
23	204	6 (11)	9 (10), 14 (1), 21 (182)
24	60	5 (21), 7 (7)	13 (12), 21 (20)
25	42	8 (23)	15 (19)

Table 7.2: Descriptions of the 25 groups obtained from a classification of the combined exclosure and Olympic Dam cover data at the Bray-Curtis 0.96 level of dissimilarity.

Group	Description
1	Relevés from sandy sites at Olympic Dam with mid-range median cover and species richness and vegetation dominated by *Brassica tournefortii.*
2	Relevés from sandy sites at Olympic Dam with very low median cover and low species richness. Similar to Group 1 but not dominated by *Brassica tournefortii.*
3	Relevés from sandy sites at Olympic Dam with low cover and species richness and few perennial plants.
4	Relevés from sandy sites at Olympic Dam with very low median cover and species richness. *Salsola kali* and *Aristida holathera* are often dominant.
5	Relevés from sandy sites at Olympic Dam with mid-range median cover and species richness, but with more *Aristida holathera* than Group 1.
6	Mainly relevés from dune-base sites at Olympic Dam with low median cover and species richness and few or no perennial species but with some *Crotalaria eremaea.*
7	Relevés from clay sites at Olympic Dam with low median cover and species richness but with some perennial species, especially *Dodonaea viscosa.* Also *Sclerolaena diacantha* and *Chenopodium desertorum.*
8	Relevés from clay sites at Olympic Dam with *Atriplex vesicaria* and mid-range median cover and high species richness; relevés from sandy and clay sites from the April 1997 monitoring at Billa Kalina with high to very high median cover and mid-range to high species richness.
9	Relevés from clay sites at Olympic Dam with *Acacia papyrocarpa* and/or *Atriplex vesicaria* and with *Enneapogon avenaceus* dominant in the understorey, low to mid-range cover and mid-range to high species richness.
10	Relevés from clay sites at Olympic Dam with high grass cover of *Aristida contorta* and *Enneapogon avenaceus,* low to very high median cover and mid-range species richness; relevés from sandy exclosure sites with low to mid-range median cover and mid-range to high species richness, but with a grassy understorey dominated by *Enneapogon avenaceus* or less frequently by *Aristida holathera.*
11	Relevés from clay sites at Olympic Dam with *Atriplex vesicaria* and *Enneapogon avenaceus* and very high cover and mid-range species richness; one relevé from Billa Kalina Site 3 with high cover and species richness and dominated by *Aristida holathera.*
12	Relevés from clay sites on pastoral country near Olympic Dam with low to mid-range cover and species richness and vegetation dominated by *Sclerolaena brachyptera.*
13	All but one of the relevés from the Dulkaninna site.
14	All of the relevés from the Cowarie site.
15	Relevés from sandy sites at Olympic Dam, mainly with *Callitris glaucophylla* but one with *Dodonaea viscosa,* with very high median cover and high species richness.
16	Relevés from sandy sites at Olympic Dam with *Acacia aneura* and a grassy understorey dominated by *Aristida contorta* or less commonly *Aristida holathera,* high median cover and species richness; one relevé from the Dulkaninna rabbit-proof exclosure with high cover and species richness and dominated by *Aristida contorta.*
17	All of the relevés from Olympic Dam dune sites dominated by *Zygochloa paradoxa.*
18	All of the relevés from Olympic Dam dune site 46 (EV61), which is dominated by *Acacia ligulata.*

Table 7.2 (cont.): Descriptions of the 25 groups obtained from a classification of the combined exclosure and Olympic Dam cover data.

Group	Description
19	Relevés from dune sites at Olympic Dam dominated by *Dodonaea viscosa* with high median cover and low species richness.
20	Relevés from sandy sites at Olympic Dam that are dominated by grasses, especially *Aristida holathera,* with high median cover and mid-range species richness; four relevés from sandy exclosure sites dominated by *Aristida holathera* with high cover and species richness.
21	Relevés from sandy sites at Olympic Dam that are dominated by grasses, especially *Aristida holathera,* with mid-range to high median cover and low to mid-range species richness.
22	Relevés from swale sites at Olympic Dam with *Atriplex vesicaria* and *Enneapogon avenaceus* and mid-range median cover and low to mid-range species richness; relevés from clay exclosure sites with *Maireana astrotricha* and some with *Atriplex vesicaria,* mid-range median cover and low to mid-range species richness.
23	Relevés from clay sites at Olympic Dam with *Atriplex vesicaria* and mid-range to high median cover and low to high species richness; relevés from clay sites at Billa Kalina and Wilpoorinna with *Atriplex vesicaria* and high median cover and mid-range species richness.
24	Relevés from clay sites at Olympic Dam with *Atriplex vesicaria* or *Maireana astrotricha* and mid-range to high median cover and low to mid-range species richness; relevés from clay exclosure sites with *Maireana astrotricha* and sometimes *Atriplex vesicaria,* with mid-range to very high cover and mid-range to high species richness.
25	Relevés from clay sites on pastoral country near Olympic Dam with low to mid-range cover and species richness and vegetation dominated by *Sclerolaena brachyptera*; relevés from the clay soil Billa Kalina Site 2, with mid-range cover and species richness.

The ordination in Figure 7.1 shows a clear distinction between those groups that contain relevés from the exclosures, distributed along the negative x-axis and generally in groups that are close to each other, and those that do not contain exclosure relevés (distributed along the positive x-axis). The exceptions to this are the exclosure Group 14 which contains the Cowarie relevés and is located just on the positive site of the x-axis, and Group 16 (one exclosure relevé) and Group 20 (four exclosure relevés). Only 2% of exclosure relevés are located on the positive side of the x-axis, compared to 55% of Olympic Dam relevés. The groups that contain the Olympic Dam Cluster 2 relevés, the worst-condition dune relevés, do not contain any exclosure relevés.

Chenopod shrubland sites from both the exclosures and Olympic Dam are located on the negative side of the distribution and the Olympic Dam dune sites on the positive side. Chenopod shrubland sites often have an understorey dominated by the grass *Enneapogon avenaceus*, while *Aristida holathera* or *Aristida contorta* is usually dominant, at least in the understorey, in groups on the positive side of the ordination. Groups towards the centre of the ordination have either little or no shrub component (Groups 12 and 13), are dominated by the trees *Callitris glaucophylla* or *Acacia aneura* (Groups 15 and 16), or by tall shrubs (Groups 7, 14, 18, 19) the tree *Acacia papyrocarpa*

(Group 9) or the hummock grass *Zygochloa paradoxa* (Group 17). The remaining groups contain relevés with few shrubs. There is far less dissimilarity between exclosure sites on clay and sandy soils than between the Olympic Dam sites on these different soils. Several groups contain relevés from sandy exclosure sites and relevés from clay sites at Olympic Dam.

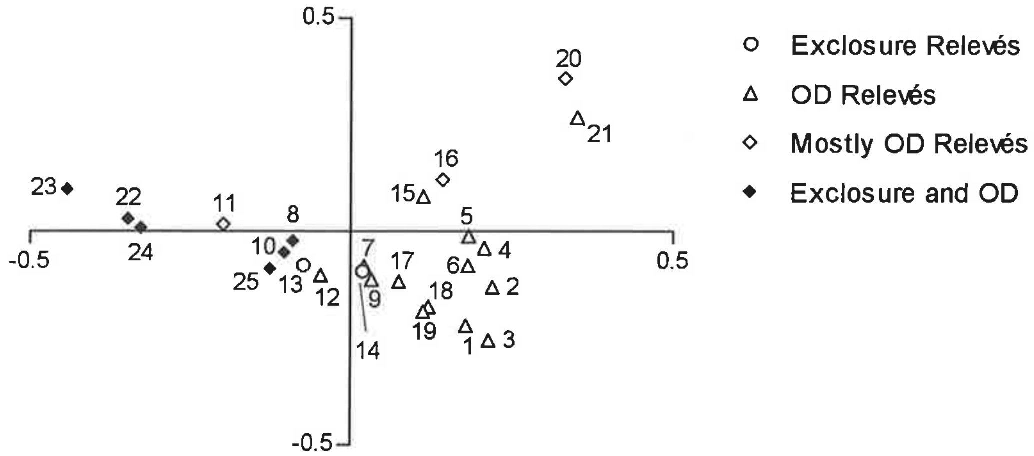

Figure 7.1: Plot of the 25 groups (Appendix V) from an ordination of the first and second axes of a PCoA analysis of the combined exclosure and Olympic Dam cover data.
Groups described as containing mostly OD relevés contain 1-4 exclosure relevés. See Table 7.1 for further explanation of the group relationships.

A single relevé from the Dulkaninna rabbit-proof exclosure was included in Group 16 in April 1997. Its presence in Group 16 correlates with domination by the grass *Aristida contorta* at this site following the February 1997 rainfall event.

Group 14 is the only group containing only exclosure relevés located on the positive side of the x-axis in Figure 7.1. This group contains all of the relevés from the Cowarie site and was the most dissimilar of all the exclosure groups identified in Chapter 4. Its location in the current ordination places it closer to Groups 7 and 9, which include relevés from Olympic Dam, than to other exclosure groups. Group 7 contains relevés dominated by the tall shrub *Dodonaea viscosa* and Group 9 those dominated by the tree *Acacia papyrocarpa.* Group 14 is also quite close in the ordination to Groups 17, 18 and 19. Group 19 is also dominated by *Dodonaea viscosa*, while Group18 is dominated by *Acacia ligulata* and Group 17 is made up entirely of relevés dominated by the hummock grass *Zygochloa paradoxa.* Even though the dominant shrub species is different, domination of the vegetation of exclosure Group 14 by *Chenopodium auricomum* places it closer in the ordination to these Olympic Dam sites than to any other exclosure sites.

The position of Group 14 in the present ordination maintains this group's position in relation to other exclosure cover groups as shown in Figure 4.5. Groups 7 and 9 also occupy a similar midway position in the ordination of Olympic Dam cover groups shown in Figure 6.3. This is a further indication of the dissimilarity of the dune relevés in groups along the positive x-axis of Figure 7.1 to the relevés of the exclosure groups.

Group 6 contains the majority of relevés from around the Olympic Dam process plant and tailings retention system that have a long history of low cover and species richness (Section 6.3.5).

7.4.2 VEGETATION COVER AND SPECIES RICHNESS

The mean cover for all relevés in the Olympic Dam dataset is 13.8%, while for the exclosure dataset it is 20.1%. The median cover value for the 21 Olympic Dam groups is 11.3%, while for the 14 groups of the exclosure dataset it is 14.8%. However, the main difference between the two datasets is in the median species richness of their groups: nine for the Olympic Dam groups compared to 17 for exclosure groups.

7.5 DISCUSSION

The periods covered by the exclosure and Olympic Dam datasets are greater than for many other studies of arid zone vegetation, but are probably still insufficient to detect the presence of any long-term trends or natural cycles in rainfall patterns (Section 7.1). None of the differences between the 11 years of cover data and the five years of exclosure site data can be ascribed to differences in the length of the two studies.

There were no large scale recruitments of any tree or tall shrub species that were sufficient to permanently alter the floristic composition at any of the sites, even in rabbit proof exclosures or within the rabbit-proof Roxby Downs town fence, following the major rainfall events that occurred during this study. Even the common and widespread *Acacia ligulata,* which was dominant at one site at Olympic Dam, did not greatly increase in cover at any other site. It's cover values at this site did increase following the major rainfall events, but returned to previous levels within a few years. With the larger trees, several consecutive wet years are required to sustain growth of the seedlings that do germinate following the large rainfall events (Read 1995) and this did not happen at any of the monitored sites. These findings suggest that the existing trees and large shrubs are already making optimal use of the available soil moisture in all but the very wettest years. Germination occurs during these years, but is not sustained through the drier years.

Sites that are close to each other in the same landform tend to be more similar than sites that are located further away, particularly in the way species hierarchies are affected. If there was an even distribution of groups in the ordination shown in Figure 7.1, the Olympic Dam dune-base sites, with their combination of dune and swale species, should be located somewhere towards the middle of the x-axis. This is not the case. These dune-base sites are generally similar in appearance and floristic composition to the sandplain sites at Billa Kalina, yet the ordination shows them to be quite dissimilar.

The grouping of relevés from sandy exclosure sites and from clay sites at Olympic Dam (Figure 7.1) is likely to be because of the higher incidence of chenopod shrubs on exclosure sandplain sites than on the sandy dune sites at Olympic Dam. The tighter clustering in the ordination of groups containing exclosure relevés is also partly due to the higher incidence of chenopod shrubs at some sandy exclosure sites. This is particularly the case at Wilpoorinna and at the Billa Kalina Site 1 second control site. However, it may also be due to the lack of any large dunes with tall shrubland vegetation at exclosure sites and to the absence of exclosure relevés in the groups containing the Olympic Dam Cluster 2 relevés. Groups that include relevés from exclosure sites on sandplains always have higher median cover and species richness than groups from Olympic Dam Cluster 2 and often a higher chenopod shrub cover than other Olympic Dam dune groups. The area that contains many of the Olympic Dam Cluster 2 relevés had unstable dunes and poor vegetation cover before any mining or processing activities commenced (Fatchen and Associates 1993). This is unlikely to be associated with prolonged heavy grazing pressure by domestic stock because of the lack of permanent water in this area until it was piped in by WMC Limited in the late 1980s.

The two groups that are most dissimilar to other groups on sandy soils are Groups 20 and 21. These are located at some distance from other groups in the ordination in Figure 7.1 and include relevés with high cover of the grass *Aristida holathera*. Group 20 has higher median cover and species richness values than Group 21. Only four exclosure relevés are included in Group 20 and none in Group 21. Although it was shown in Chapter 5 of this thesis that *Aristida holathera* recovers only slowly following heavy grazing, the fact that exclosure relevés are poorly represented here appears to be unrelated to grazing. Three of the four relevés from Group 20 are from a rabbit-proof exclosure where grazing did not occur and one is from a stock-proof exclosure. All are from early in the monitoring period (May and November 1993 and November 1994). The subsequent decline in cover of this grass, correlating with shifts to different groups, must therefore have been due to another factor. Dry seasonal conditions is the most likely cause. The heavy rainfall of February 1997 produced an increase in cover of *Aristida holathera* at some sites, but *Dactyloctenium radulans* was the dominant grass and this resulted in shifts to exclosure Group 10 (Tables 4.5 and 4.7).

The ordination in Figure 7.1 also shows that the Billa Kalina sandplain sites are often similar to dune relevés from Olympic Dam. The main differences are in median species richness values and in median cover, which are both lower at Olympic Dam sites. There is no domestic grazing on the Olympic Dam mine lease or on the Roxby Downs municipal lease and rabbit numbers during the period covered by this thesis were lower at Olympic Dam than at Billa Kalina (Figure 4.1, ODC 1998), so the differences cannot be caused entirely by grazing pressure. Therefore there must be one or more other factors, possibly ones that were not examined in the present study, that are responsible for the dissimilarity between these sites.

There are several possible explanations for these differences that involve landform, type of herbivore(s) present, total grazing pressure, previous history of both grazing and land use and the seasonal timing of surveys. The differences in landform are discussed above, particularly those concerning the apparently similar Billa Kalina sandplain sites and Olympic Dam dune-base sites. Evidence from later work carried out by myself at Mulka and Clifton Hills (Appendix W) also supports the contention that differences exist between exclosure and Olympic Dam sites.

Graetz and Wilson (1980) found that both sheep and cattle are generalist herbivores, with similar dietary preferences for grasses, annual forbs and saltbush which together made up more than 80% of their diets, although the quality of the diet in both nitrogen content and digestibility was different. They also found that cattle were forced to browse saltbush before sheep, which were able to obtain sufficient nutrition from perennial grasses for a longer period than cattle, although neither animal was placed under any grazing stress during their experiment. Sheep could be expected to eat some small ephemeral species that may be too close to the ground to be eaten by cattle, but this would not explain the low species richness at many of the Olympic Dam sites on the mine and municipal leases. These sites have not been grazed by domestic stock for more than a decade and had only a light domestic grazing history prior to this (Section 3.3.2). Absence of permanent water restricted grazing by sheep to the best seasons when ephemeral surface water was available, or when the original Olympic Dam held water. Less damage is done to the vegetation at such times than during drier periods (Chapter 2) and it is unlikely that any plant species would have become locally extinct at such times. In contrast, the area adjacent to the Birdsville Track, a former route for travelling stock, has a history of heavy grazing (MSCB 1997a). This is possibly reflected in the low cover values for the Dulkaninna site, although this site is on a gibber plain that, apart from gilgais, run-on areas and watercourses, may always have had naturally low cover values (MSCB 1997a).

The low cover values and species richness at Olympic Dam were present throughout the monitored period. They were therefore not due to better or more thorough distinction between species at different monitoring events. Differences in the damaging effects of the hard hooves of cattle and sheep is another possible factor. However, it was shown in Chapter 5 that trampling by cattle caused less damage to the cryptogamic cover than might have been expected, and possibly less than that caused by the hooves of sheep. Cattle trampling on dunes cannot be measured by its impact on cryptogamic cover because these organisms are not generally found on sand dunes with less than 4-5% clay and silt content (Danin 1983 - cited in West 1990).

Total grazing pressure may be a more important factor. It is widely recognised that the introduction of artificial watering points on pastoral land has led to large increases in kangaroo populations (Box and Perry 1971, Bennett 1997, James *et al.* 1998). Kangaroos are also known to move into areas that have been destocked of domestic livestock (Norbury and Norbury 1993, Norbury *et al.* 1993) Badman (1995a) found that kangaroo numbers at Olympic Dam are often up to 4.5 times higher than the long-term district average, while Caughley *et al.* (1980) found that kangaroo numbers inside the Dog Fence can be up to 166 times higher than those outside the fence. Olympic Dam is inside the fence and all exclosure sites except Wilpoorinna are outside the fence. Kangaroo numbers at Olympic Dam fluctuated after the period reported by Badman (1995a), reaching a peak of 17 animals per square kilometre in the northern part of the mine lease in late 1995 and lesser peaks of 15 animals per square kilometre in late 1996 and late 1997 (ODC 1998). The lowest kangaroo density in this area during this period was six animals per square kilometre (ODC 1998). Kangaroo numbers from April 1989 to February 1998 ranged from a low of near zero in mid 1992 to a high of 23 per square kilometre in May 1993 (ODC 1998).

Badman (1995a) suggested that lower cover values at Olympic Dam vegetation monitoring sites, compared to Olympic Dam rehabilitation control sites, may have been an artefact of the timing of the monitoring, with the May-June surveys at Olympic Dam sites being too early to record the peak of winter-growing species and the November-December surveys being too late. Rehabilitation monitoring was carried out in August-September for the majority of that study, when cover of winter-growing species is usually greatest. However, the practice at Olympic Dam and at exclosure sites of recording all standing plants, whether dead or alive, would remove most of this bias in relation to species richness, but not in relation to cover, as long as one plant of each species could be identified at each site. Observers at Olympic Dam necessarily become adept at identifying dead plants.

7.6 CONCLUSIONS

There are large differences between the vegetation on sandy soils at the exclosure sites and on sandy soils at Olympic Dam, including within areas that are fenced to exclude domestic stock. The exclosure sites have higher median cover and species richness values in all cases, including in most cases those that are still being grazed by domestic stock. The only possible difference that can be attributed to temporal scale is the possible identification of a transitional state from the exclosure data, while none could be identified from the Olympic Dam data. The time scale for the collection of both datasets, although both rank amongst the longest intensive studies, still appears to be too short to identify major changes in shrub or tree composition caused by the exclusion of herbivores.

Differences in landform may be partly responsible for some of the differences between sandy sites at exclosures and Olympic Dam. However, the differences in mean cover and species richness values appear to be too great to be caused by this factor alone. It is unlikely that the seasonal timing of Olympic Dam surveys had a significant bearing on species richness at those sites.

Available soil moisture is sufficient to maintain existing vegetation through most years. Even when there is large-scale recruitment following exceptional rainfall events, this is not being sustained through the subsequent dry years, even inside the rabbit-proof exclosures and in the town area.

Because domestic stock are not present on the mine and municipal leases at Olympic Dam and Roxby Downs and rabbits are present in parts of both areas, there may be another factor affecting both cover and species richness. This may be the higher kangaroo numbers at Olympic Dam sites compared to exclosure sites outside the Dog Fence.

CHAPTER 8 FINAL DISCUSSION AND CONCLUSIONS

8.1 INTRODUCTION

The primary finding of this study was that the effects of major rainfall events overshadowed all other factors that influenced change in vegetation communities in each of the three study areas (Chapters 4, 5 and 6). Changes caused by such episodic events can occur very quickly (Chapters 4 and 6). The next most important factors in vegetation change were grazing (Chapter 5) and desiccation of annual, ephemeral and biennial plants during dry periods (Chapters 4, 5 and 6). Heavy grazing has the ability to cause rapid shifts to worse-condition states (Chapter 5), while small rainfall events, light grazing or natural desiccation of the vegetation cause slower shifts in vegetation condition (Chapters 4 and 6). Combinations of light rainfall and light grazing events may cause shifts in either direction, depending on which factor has the greatest influence. Rainfall sometimes causes shifts to different condition states that cannot be classified as being either better or worse than the original state (Chapters 4 and 6).

There were no increases in cover or species richness in exclosures (Chapter 4) or in areas fenced to exclude domestic stock (Chapter 6) that were not mirrored at control sites. Control sites sometimes had higher species richness, although with less cover, than exclosure sites (Chapter 4). Species that are generally unpalatable to herbivores can sometimes take a very long time to recover when they are grazed because of a lack of more desirable forage plants (Chapter 5).

Vegetation of swale sites was found to be more stable than that of dune sites (Chapters 4 and 5), although changes were sometimes less well defined on sandy swale sites (Chapter 4). Swale vegetation also recovered more quickly following disturbance than did that of dunes (Chapter 5). The effects of rabbit grazing were found to be significant only at sandy sites (Chapter 4), but were not as pronounced as those recorded during some other surveys (Chapter 2).

Although recruitment and death of perennial species occurred in most years (Chapters 4 and 6), lengthy wet periods promoted major germination and sometimes establishment of perennial species (Chapter 6). However, even though several such events were recorded during the monitoring, recruitment was sufficient only to maintain original shrub numbers (Chapter 6).

Alien species are able to establish and sometimes dominate the vegetation following heavy winter rainfall after a long dry spell (Chapter 6). This does not occur following summer rainfall events[4] (Chapters 4, 5 and 6).

There was no evidence that the impacts of underground mining operations have had other than a minor impact on surrounding vegetation except in areas that are directly disturbed by development. The only place where the processing plant may be responsible for chronic changes in vegetation condition is near the Olympic Dam tailings retention system (Chapter 6), although the area has a long history of poor vegetation condition. This was the only place or occasion where vegetation changed to a worse-state condition following a major rainfall event. Establishment of the town of Roxby Downs has had little effect on surrounding vegetation (Chapter 6).

Use of data on the presence or absence of species, without accompanying cover data, did not answer all of the questions asked in this study or detect changes caused by heavy rainfall events (Chapter 4). The temporal duration of this study also appears to have been too short to answer some questions (Chapters 4 and 7).

High cryptogamic cover at the end of the grazing experiment is in contrast to most other studies (Chapter 5). Higher species richness at sites outside the Dog Fence (Chapter 7) could not be attributed to any of the factors examined in this study and may have been due to high kangaroo grazing pressure in certain land forms (Chapter 7).

A conceptual model of these changes is presented in Figure 8.1. The implications of different intensity and duration rainfall events and different disturbance factors are discussed below.

8.2 RESPONSES TO RAINFALL AND DISTURBANCE

8.2.1 RAINFALL

Rainfall is the principal physical and biological driving force in the Australian arid zone (Stafford Smith and Morton 1990), as well as in other arid or semi-arid areas (Jensen and Belsky 1989). Coughenour (1991) considered that even some of the South African changes from grassland to shrubland that were originally blamed on overgrazing may in fact have been caused by climatic change. Temporal variability of rainfall in Australia is high on a world scale for areas with similar

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[4] This statement assumes that *Salsola kali* is not an alien species (e.g. Jessop 1993) as was suggested by some earlier workers (e.g. Wilson 1986).

aridity (Stafford Smith and Morton 1990). Changes caused by seasonal differences in rainfall can be highly significant (Leigh *et al.* 1989) and can mask changes caused by other factors (Foran *et al.* 1982, Brady *et al.* 1989, Friedel 1994). Large rainfall events trigger the establishment of long-lived perennials (Griffin and Friedel 1985, Stafford Smith and Morton 1990). Smaller rains allow growth of shorter-lived species and sustain established populations of longer-lived plants (Noble 1977).

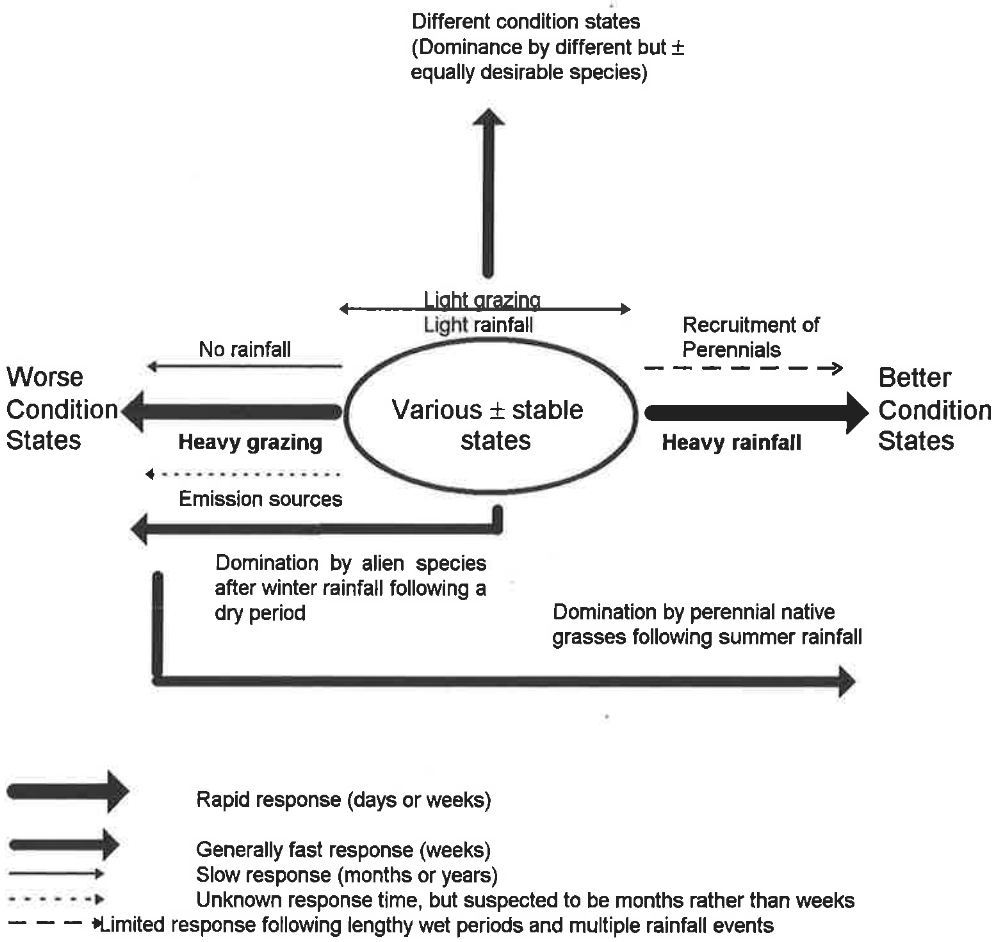

Figure 8.1: Conceptual model of direction and changes in vegetative states following different rainfall and disturbance events.

Davis (1986) considered climate to be inherently unstable, changing continuously on all time scales. Many changes in population size and geographical distribution of vegetation communities have been caused by decade- or century-long directional climatic trends (Davis 1986). Although both biomass and cover respond quickly to rainfall, the importance of species within the community may lag climatic change by at least several decades (Davis 1986).

The above comments on rainfall are supported by the findings of the present study. The heavy rainfall event of February 1997 correlated with more shifts in group affinities than any other factor at the exclosure sites (Chapter 4). The 1989 rainfall event correlated with more shifts in group affinities than any other single factor at Olympic Dam sites (Chapter 6). The February 1997 rainfall event also correlated with shifts at the grazing experiment site to states that were better, in all but one case, than the pre-grazing condition of these sites (Chapter 5). The exception was a control area that remained in the same group throughout the monitoring period. Smaller rainfall events maintained or improved the condition of vegetation, but did not correlate with transitions to different states. The effects of major rainfall events became obvious in days or weeks. With lighter falls of rain it took much longer, and usually more than one rainfall event, before changes in vegetation group alliances occurred. Changes to better condition states occurred following major rainfall events even when coupled with grazing. In contrast, a combination of light rainfall and light grazing could result in gradual changes to either a better or worse condition (Figure 8.1).

Successful regeneration of perennial species usually required lengthy wet periods, although the greatest recruitment did not always coincide with the heaviest rainfall events (Chapter 6). Timing of rainfall, in relation to both temperature and length of time that the soil remains moist, is also important. Despite the combination of fencing to exclude various species of herbivore and major rainfall events resulting in good germination of seed, recruitment during this study was generally not sufficient to increase the density of adult perennials. This supports the findings of Watson *et al.* (1997a, 1997b), who found that although the majority of recruitment of two arid zone shrubs was event-driven, there was also a continuous process of mortality and recruitment in all years.

8.2.2 GRAZING

8.2.2.1 Comparison Between Short-Term Intensive Grazing and Long-Term Conservative Grazing

The effects of heavy grazing pressure on the environment were discussed in Chapter 2. The worst of these effects were caused late in the 19th or early in the 20th Century by long-term grazing rather than by short-term intensive grazing. Although no quantitative data are available on the effects of these early grazing events, it is likely that the end result was often similar to that reached following the grazing pulses in the experiment described in Chapter 5. The main difference between these earlier practices and the intensive grazing experiment is that the former often did not allow a recovery period between grazing pulses. The overall effect of early grazing events on the present study areas, and on much of Australia, cannot be directly compared to what is happening today because of a lack of quantitative data.

The species composition of vegetation communities is often determined, in part at least, by past total grazing pressure. Even in cases where all domestic grazing has been removed, there are documented cases where no new species have been recorded on experimental plots after 10 years (Leigh *et al.* 1989). No loss of species was recorded during the grazing experiment described in Chapter 5. All long-lived perennial species returned to near or better than their pre-experimental grazing condition following the heavy rainfall event of February 1997. The condition of ephemeral species is always dependant on seasonal conditions as well as grazing. There was no major effect on either species richness or cover following this experiment. However, the biennial or short-lived perennial grass *Aristida holathera* did not fully recover following the grazing pulses and subsequent rainfall events. It is not known whether the generally good recovery that followed this experiment would have occurred without the major rainfall event of February 1997.

From the two grazing pulses it can be inferred that although partial recovery from intensive grazing follows smaller rainfall events, major growth pulses and near-original state recovery may occur only once or twice in each decade[5]. This is also the case with vegetative growth under the conservative grazing practices currently employed on cattle stations involved in the exclosure experiments (Chapter 4). There appear from this study to be no long-term differences between the two grazing practices, although the experimental period, particularly for the grazing experiment, may have been too short to allow a definitive conclusion to be drawn on this comparison.

Intensive grazing pulses, with adequate time and rainfall to allow recovery of the vegetation between pulses, does not appear, from the results of this experiment, to have the same long-term effects that were documented following the heavy continuous grazing practiced earlier in the 20th Century (Chapter 2). However, these results need to be treated with caution. John Read (pers. comm. June and September 2000) considers that up to 90% of shrubs in the grazed areas died following three dry years subsequent to the February 1997 rainfall event, compared to the death of about 50% of shrubs on control areas. Shrub mortality was greater for *Atriplex vesicaria* than for

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[5] Based on 114 years of records from Arcoona Station where annual rainfall >200 mm occurred twice in each 11 years and annual rainfall >250 mm has occurred about once in each nine years.

Maireana astrotricha. Some new growth was observed on apparently dead shrubs following a subsequent rainfall event, as was recorded in this study (Chapters 4 and 6), with the former species showing less recovery than the latter. This mortality on ungrazed control areas reported by Read is much higher than that reported by other workers in similar situations (Chapter 2), or following four years of drought at the Billa Kalina sites (Chapter 4). It would have been interesting to know the effects of a third grazing pulse on the perennial shrubs, given that the recovery following the second grazing pulse and a major rainfall event did not quite return the cover values for *Atriplex vesicaria* and *Maireana astrotricha* to their original level.

8.2.2.2 Rabbit Grazing

Rabbits are often considered to have caused the greatest degradation to arid ecosystems (Chapter 2). Although there are usually large increases in vegetation biomass following rabbit control, the cost of implementing such controls in arid areas is generally prohibitive (Foran *et al.* 1985). Even when rabbit control is carried out, the benefits can be masked by the effects of large rainfall events (Foran *et al.* 1985).

The effects of rabbit grazing at the exclosure sites (Chapter 4) showed close correlations to sandy sites at Billa Kalina but not to sites with clay soils or to sandy sites in the Marree district. Four very dry years at Billa Kalina sites, followed by the advent of RCD, reduced the local rabbit population to such an extent that they were not an important inhibiting factor in vegetation cover or composition at the end of the exclosure monitoring. Other herbivores also had insignificant effects on the vegetation of exclosure sites at this time. The heavy rainfall event of February 1997 was then the most important factor. No significant differences in vegetation cover or perennial density between sites where rabbits were excluded and those where they had unrestricted access were detected by this study (Chapter 4). This in no way detracts from damage the rabbit has undoubtedly done to arid zone vegetation in the past (Chapter 2), but rather shows the significance of exceptional rainfall events to the ecology of arid zone plants (Jensen and Belsky 1989, Friedel 1994), especially when total grazing pressure is light.

The results of exclusion of rabbits was not studied specifically at Olympic Dam, but several vegetation monitoring sites are located within the rabbit-proof fence around the township of Roxby Downs. Relevés from these sites did not form a distinct classification group, but were distributed amongst groups containing relevés from other land use areas. This may have been due to the fact that complete elimination of the rabbit was never achieved in this area. The low number of rabbits that remained may still have been sufficient to have an effect on vegetation (Section 2.5). The dominance of vegetation by two tree species that are not affected by grazing when mature, *Callitris glaucophylla* and *Acacia papyrocarpa*, is also likely to have been an important factor. These species are less dominant at sites around Olympic Dam.

8.2.2.3 Kangaroo Grazing

Kangaroos preferentially graze grasses and are often more selective in their diet than other herbivores (Leigh *et al.* 1989, Newsome *et al.* 1996). The latter trait can lead to degradation of their preferred habitat (Landsberg and Stol 1996). Although kangaroo grazing in general is sometimes considered to have insignificant effects on vegetation (Tiver 1994) and to be less than that of rabbits (Leigh *et al.* 1989), all native herbivores add to the total grazing pressure and their presence in inappropriate numbers can be just as harmful as any other herbivore (Parker and Graham 1971, Ssemakula 1983, Wilson 1991a). Adverse effects of kangaroo grazing have been recorded on rehabilitating rangelands (Norbury and Norbury 1993, Norbury *et al.* 1993) and have been implicated in failure of arid zone trees to regenerate (Hall *et al.* 1964, Auld 1995). Bailey and Alchin (2000) found that vegetative cover decreased more under kangaroo grazing than under cattle grazing at an experimental site in south-western Queensland and suggested that "*...the negative impacts of grazing are no worse for livestock than for kangaroos and may even be less impacting*". Oksanen and Oksanen (1989) considered that resource limited populations of native herbivores may be even more detrimental to some plants than either sheep or cattle.

Kangaroo grazing was not considered during the design of any of the monitoring programmes discussed in this thesis, although instances where kangaroos entered the Billa Kalina exclosures were recorded. Badman (1995a) showed that kangaroo numbers at Olympic Dam increased following exclusion of domestic herbivores from the Roxby Downs municipal lease and the Olympic Dam mine lease and that this increase maintained a similar total grazing pressure.

The evidence presented in Chapter 7 suggests that kangaroo grazing may be an important factor in the differences in vegetative cover and species richness between exclosure and Olympic Dam sites. With the exception of the Wilpoorinna site, this also represents a division of sites by the Dog Fence. The Wilpoorinna site is inside the Dog Fence but had a very light grazing history by all herbivores during the monitoring period. Following the study of Badman (1995a), it came as no surprise in the present study that there were no significant differences between the "ungrazed" Olympic Dam mine lease and Roxby Downs municipal lease sites and "grazed" sites on adjacent pastoral land. However, the finding that these sites had lower species richness and cover values than the majority of exclosure sites was completely unexpected.

Recently, Newsome *et al.* (2000), claimed that two different "*ecological universes*" occur on either side of the Dog Fence. This paper was concerned mainly with fauna on both sides of the fence, particularly kangaroos, but it is quite likely that the vegetation is also quite different because of the fence and the control of native herbivores by dingoes outside the fence, as suggested in Chapter 7 of this thesis.

8.2.3 MINING

Mining is a temporary land use. All mines eventually cease to be economically viable or the resource is exhausted. It is also a land use that disturbs relatively small areas of land (Section 2.7). Ideally, mining rehabilitation aims to leave a final landscape that is sympathetic to the local topography and is influenced by the objectives of biodiversity and aesthetic considerations (Rethman *et al.* 1999).

Fencing of the Olympic Dam mine and Roxby Downs municipal leases and removal of domestic herbivores was claimed to have resulted in the return of a number of un-named perennial species (WMC 1990). This claim is not supported by the results presented in Chapter 6, nor by my personal observations. The heavy rainfall events of 1989 had a far greater effect on the vegetation than the fencing of these leases and the exclusion of domestic stock (Section 6.3.3.2, Table 6.12).

Except for a small area around the tailings retention system (TRS) that has worse-condition vegetation than the surrounding country (Section 6.3.3.2), changes to vegetation on the mine and municipal leases have generally mirrored those on surrounding pastoral land. The small area around the TRS where the condition of vegetation appears to have deteriorated since 1989 should probably be regarded as an acceptable sacrifice area for an operation that is a major contributor to the State's economy. Recent extensions to the TRS are in country with better condition vegetation than the original ponds. Future analysis of data from monitoring sites on the new perimeters should confirm whether dust or aerosol emissions from the TRS or emissions from the processing plant in general are responsible for the poor condition of the vegetation surrounding the original ponds.

Total grazing pressure on these leases since fencing excluded them from the pastoral lease, except within the town rabbit-proof fence, has remained similar to that of surrounding pastoral country (Badman 1995a). This has been due to an increase in the number of kangaroos in the absence of competition from domestic herbivores, increased availability of water and release from the kangaroo culling programme. As discussed above, the major changes in these areas have correlated with the major rainfall events of 1989 and 1997. Many of the differences in vegetation between areas with different land uses at Olympic Dam and Roxby Downs were present throughout the monitoring and reflect natural differences in landform and vegetation communities. Many sites in the Roxby Downs township area are dominated by either *Callitris glaucophylla* or *Acacia papyrocarpa* and are therefore naturally different to sites around Olympic Dam where dunes are more widely spaced and these species are less common or absent.

Apart from the area around the TRS, there were no shifts between vegetation groups at Olympic Dam that can be related to mine development. Only minor developmental work had been carried out prior to the start of the cover data monitoring examined by this thesis. The deterioration in vegetation condition that appears to have occurred around the TRS did not appear in the analysis until 1989, well into the monitoring period covered by this thesis and more than a year after the official opening of the mine and processing plant and the start of full-scale production.

In Section 4.3.2.3 it was suggested that the sites at Olympic Dam where domestic herbivores have been excluded since 1987 could be used as reference areas for similar landforms in the region. However, in the light of the findings of this study, this may not be the case. Many grazed sites on pastoral land north of the Dog Fence have higher vegetation cover and species richness than these "ungrazed" sites at Olympic Dam. This fact did not become apparent until the two datasets were compared (Chapter 7) and so it was not investigated as part of this study. Further work is needed to determine whether these differences are maintained over a wider area in similar landforms on both sides of the Dog Fence.

8.3 ALIEN AND UNDESIRABLE SPECIES

Badman (1995a) found that a high incidence of alien species at Olympic Dam was dependent on winter rainfall at a time when available spaces were not occupied by native perennial grasses (Section 2.9 this thesis). This study confirms that finding (Chapter 6). High incidences of alien species at the start of monitoring, and classification groups that were based on these species, began to disappear from the analysis following the heavy rainfall of 1989 and these classification groups were completely absent after the heavy rainfall events of 1992. For the rest of the monitoring period, native grasses were sufficiently abundant to exclude alien species following winter rainfall (Chapter 6). Even at the heavily grazed pulse grazing site (Chapter 5), alien species never dominated because summer rainfall allowed the establishment of native grasses before sufficient winter rainfall occurred to allow the establishment of alien species (Badman 1995a).

Badman (1995a) suggested that heavy winter rainfall following another dry period might allow new increases in alien species, particularly the dominant *Brassica tournefortii*. Such conditions occurred during the winter of 1996, when *Brassica tournefortii* was very common, yet the present analysis shows that there was no resurgence of the group dominated by this species, presumably because there were still enough native species present to maintain the classification groups that replaced the one dominated by *Brassica* (Chapter 6). Timing of surveys is important in the detection of many annual and ephemeral species, however, in the case of *Brassica tournefortii,* this is less important. The stems of this species remain in the ground for long periods, at least until the following summer. They would still have been detected during the November monitoring at Olympic Dam, although with reduced cover as the leaves broke down. In any case, the Olympic Dam monitoring was carried out at the same times in each year.

8.4 THE STATE AND TRANSITION MODEL

The state and transition model (Section 2.12.3) has gained increased acceptance amongst rangeland ecologists, particularly in Australia (Watson *et al.* 1996). Changes in arid zone vegetation may be very slow: Omar (1991) established a correlation between rainfall over the previous 10 years and the amount of vegetation cover recorded during a survey. Release from grazing does not necessarily result in an immediate improvement in the vegetation (Turner 1971, Kleiner 1983, Brady *et al.* 1989, Omar 1991, Oba 1992). Once the transition has been made from one state to another, this may not be easily reversible, even if all contributing abiotic factors are removed (Collins and Barber 1985, Friedel 1991, Llorens 1995, Rapport and Whitford 1999). In the present study, it was sometimes difficult to determine whether certain conditions represent more or less stable "states", or the "transitions" between them (Chapters 4 and 6).

Transitions to a worse-state involving dry seasonal conditions and the natural breakdown of short-lived species may last for some time, while those involving shifts to a better-state condition occur more rapidly following heavy rainfall events (Chapters 4, 5 and 6). The time scale for the former may be measured in months or years and for the latter in days or weeks. Intensive grazing pulses result in rapid shifts between states (Chapter 5), which can also occur in a matter of days or weeks. Light grazing at exclosure control sites did not result in significant differences between the timing of changes to a worse-state condition between the control and exclosure sites (Chapter 4). Good-condition states may be relatively short-lived on sandy country with few perennial species unless there is continuing rainfall to maintain the annual species. Conversely, poor condition states may persist for long periods unless a heavy rainfall event occurs. Llorens (1995) also found that transitions caused by dramatic events such as very heavy grazing or fire occurred quite quickly, while those triggered by light grazing happened over a longer period.

At sites with a significant component of shrubs there is a longer time lapse before changed seasonal conditions result in shifts between states than is the case at grassland or herbland sites (Chapters 4 and 6). Such sites include most of the swale sites of this study and the main species are *Atriplex vesicaria* and *Maireana astrotricha*. Dune-base sites are the least stable, with changes in species composition, often determined by the timing of rainfall, causing the majority of shifts between states. The *Acacia aneura* or *Acacia papyrocarpa* overstorey changes little, but cool-season rainfall produces a large number of short-lived dune species and causes shifts to dune groups, while lack of these species often causes shifts back to swale groups dominated by chenopod low shrubs.

Very few transitions between states (classification groups) occurred at exclosure sites (Chapter 4). Those that did occur correlated with the natural decline of vegetation (slow shifts to a worse state), or by rainfall events (rapid shifts to a better state). Far more shifts (transitions) appeared to occur at Olympic Dam (Chapter 6). However, if the same cut-off point that was used for exclosure sites is applied to the dendrogram for Olympic Dam cover data, only four groups result. These are the four "clusters" described in Chapter 6. At this level there are also very few shifts between the four groups, showing that this area is also in a more-or-less stable condition. Shifts that occurred during the monitoring period correlated with either natural desiccation of the short-lived plants or with increases in cover and species richness following heavy rainfall events. Smaller rainfall events generally did not result in shifts to a different state. When grazing was also a factor, the direction of the shift was determined by the balance between rainfall and grazing and occurred over a long time span. The only shift that can possibly be attributed to the mining operation is the one discussed above involving sites around the TRS.

8.5 SPECIES RICHNESS

One of the unexpected findings of this study was the large difference in species richness between the exclosure and Olympic Dam relevés in similar land forms. Median species richness for all exclosure relevés used in the Chapter 4 analysis is 17, while for the Olympic Dam relevés it is nine. These figures are the same whether they are calculated on median species richness of the classification groups (Chapter 7) or on the individual relevés (Chapters 4 and 6). Mean species richness is approximately one species higher than the median value for both the exclosures and Olympic Dam. The comparisons are made on data from the 2 x 5 m quadrats, which was collected in the same manner in both cases.

Exclusion of grazing, even over several decades, has been found to have little effect on species richness (Gardner 1950, Putman *et al.* 1989). At Olympic Dam, swale sites had slightly lower median species richness than dune or dune-base sites with similar vegetation cover. This is thought to be due to the dominant chenopod shrubs using most available water in all but the very wettest years, thus preventing the recruitment of some short-lived species. Similar sites on pastoral country at Billa Kalina had higher median species richness values. Possible reasons for the differences between exclosure and Olympic Dam sites, including landform, past grazing history, the type of herbivore involved, seasonal timing of surveys and total grazing pressure, were discussed in Chapter 7.

Other possible reason for the differences in species richness could be differences in observer capability and taxonomic changes. However, the Olympic Dam data were mostly collected by Dr Tim Fatchen, a highly competent observer with many years experience in this area. It is inconceivable that he missed sufficient species at enough quadrats to cause the differences identified here. The effects of mining activities also cannot be blamed for these differences. The low species richness in the Olympic Dam area occurred from the beginning of monitoring, when mining and processing activities where at a very low level, and continued throughout the study. There was no decrease in species richness as mining activities increased.

Taxonomic changes, particularly the splitting of a single taxa into two or more taxa, may account for a small difference in species richness. The old taxonomy was generally maintained at Olympic

Dam while later revisions were used for the exclosures. However, this is likely to account for no more than one or two additional ephemeral species at some sites at some monitoring events.

Higher kangaroo numbers at sites south of the Dog Fence appears to be the most likely explanation for the lower species richness values at Olympic Dam (Chapter 7). However, relevés at the Wilpoorinna site, also south of the Dog Fence, had a median species richness of 18, one species higher than the median value for all exclosure relevés.

The findings from the Wilpoorinna exclosures do not necessarily detract from the above hypothesis on the effects of kangaroo grazing because kangaroo numbers are always much lower in this paddock and land system than in surrounding areas. The effects of high kangaroo numbers that occasionally occur here following local thunderstorms are analogous to the intensive grazing experiment described in Chapter 5, although the effect on vegetation is unlikely to ever be as severe as that achieved at the Andamooka Station grazing site. No long-term changes to the vegetation will occur providing it is allowed time to recover between grazing events. Because kangaroos do not normally favour this area, this will always be the case.

While kangaroo numbers at the Wilpoorinna exclosures are generally low, those in the Olympic Dam area, which lies mainly in the Roxby land system, are usually high. This land system appears to be a preferred habitat for red kangaroos (Keith Greenfield, Billa Kalina Station, pers. comm.). It is therefore subject to continuing high grazing pressure from these animals, with little chance for the vegetation to recover. The only time that kangaroo numbers are likely to be low is during a severe drought, when no recovery of the vegetation is possible. Prior to RCD, this area also had high rabbit numbers, which peaked in the same year as the rainfall event, while kangaroo numbers peaked in the following year (Badman 1995a). This combination gave the vegetation no chance to recover, even in the absence of domestic stock. At present there is no kangaroo culling programme on the Olympic Dam mine lease or on the Roxby Downs municipal lease. This is likely to be preventing any real improvement in vegetation compared to surrounding pastoral areas where culling programmes are in place.

8.6 COMPARISONS BETWEEN THE EFFECTS OF GRAZING AND MINING

Mining disturbs far less land than domestic grazing. The direct effects of exploration and mining at Olympic Dam, including the town area and all infrastructure, had disturbed only about 4% of the lease areas by 1996 (Section 2.7.2), the time covered by the vegetation cover data collection

(Chapters 3 and 6). Possible indirect effects of mining at Olympic Dam are restricted to areas near certain emission sources and add between 1% and 2% to the total disturbed area (Section 6.3.3.2). Most of these areas will be rehabilitated to some extent at mine closure. In contrast, almost all areas are accessible to native and feral herbivores. Domestic stock are able to graze all pastoral areas during wet periods when there is abundant surface water, and areas within 5-8 km of watering points at other times.

The Olympic Dam monitoring sites were set up to detect the effects of the mine and town on the surrounding vegetation. Similar sites were located on nearby pastoral land (Chapter 3). The analysis in Chapter 6 detected no significant differences between the various land uses. In Chapter 7 it was argued that there are differences between exclosure sites and sites in the mine and town areas, but that these differences are likely to have been caused by a factor that was not measured during this study. Kangaroo grazing is proposed as the most likely factor, a proposal that is supported by the recent papers of Newsome *et al.* (2000) and Bailey and Alchin (2000).

Apart from the larger area required for pastoralism, compared to what must be cleared for mining and processing infrastructure, no significant differences between the effects of grazing and mining were identified by this study. Even when domestic livestock were removed from the Olympic Dam Mine Lease and Roxby Downs Municipal Lease, the same total grazing pressure appears to have been maintained by other herbivores.

At Olympic Dam, the strongest correlations between land use and vegetation groups occurred in the vicinity of the Roxby Downs township. This was an artefact of the data, because the dominant trees in these groups, *Acacia papyrocarpa* and *Callitris glaucophylla,* are more common in this area than at Olympic Dam mine lease sites and occur in denser populations than on nearby pastoral sites. These species are not affected by grazing once they reach maturity.

8.7 RETROSPECTIVE COMMENTS ON DATA COLLECTION METHODS

The methods used to collect data would appear to be appropriate in answering questions posed by this study (Chapters 4, 5 and 6). Although considerable time and money could be saved by collecting data only on the presence or absence of species, this method did not provide sufficient information to answer all of the questions asked here. A particular shortfall of this type of information, when making temporal comparisons between the data, is its inability to detect changes relating to the abundance of species following major rainfall events, or during the subsequent drying off period. Many of the changes in group alliance following the 1989, 1992 and 1997 rainfall events (Chapters 4 and 6) and in the grazing experiment (Chapter 5) involved changes in cover values and dominance of various species, with little change in the actual species present. Presence or absence data would appear to be more relevant to broadscale studies involving a single monitoring event.

The temporal scale of this study still appears to be too short to answer all questions, particularly those relating to perennial species. Subsequent events at the grazing experiment site appear to suggest that the time frame for this experiment was too short, although it conforms to what is recognised by at least some other workers as being adequate (Green 1979). The results obtained after two years appear to be different to those that would have been obtained after five years. The recovery of perennial shrubs on swales may not have been maintained through the next major drought, a similar situation to that suggested for some native fauna populations (Morton 1990). In particular, the three-year time limit set on many Government grants, including that for the soil board exclosures, is far too short to provide meaningful results. Even time scales of 10 years would still appear to be too short to answer many questions concerning arid zone vegetation communities (Chapters 2 and 6).

The extreme patchiness of arid zone landscapes was highlighted in this study by the differences in classification groupings of exclosure and control sites located within a few metres of each other (Chapters 4 and 7). Ideally, each set of exclosures and its control site or sites would have started in the same classification group, as they were at Cowarie and at some Billa Kalina sites. To achieve this, it would have been necessary to mark out all exclosure sites, carry out the first reading of the quadrats and perform the first classification of the data before making the final decision on the site locations. This would add considerably to the cost of the experiment because of the distance between sites, their remoteness and the time required to set up the quadrats, and is probably impractical in most situations. The problem was somewhat alleviated by using comparisons of each exclosure or control site to itself over time, rather than to other sites. A more flexible approach to quadrat location could have allowed inclusion or exclusion of such features as gilgais, run-on areas, large bare patches or particular large trees or shrubs from quadrats. This approach was not favoured over the more rigid approach used here, where quadrat locations were determined by set distances from exclosure or control site corners, in order to remove the possibility of bias in site selection.

8.8 IMPLICATIONS FOR FURTHER RESEARCH

The role of kangaroo grazing in species richness and cover on opposite sides of the Dog Fence, and in different land systems, is in urgent need of further study. If there is a positive correlation between kangaroo numbers and species richness and cover, a hypothesis that is supported by the work of Newsome *et al.* (2000), it is a complete contradiction of the findings of Tiver (1994). Such a correlation would have major implications for the sheep industry and for management of biodiversity inside the Dog Fence, particularly in those areas that are preferred kangaroo habitat.

The differences between the trampling effects of sheep and cattle on soils and vegetation is another area that is in need of further study. Management decisions may need to be modified depending on which animal is present, rather than using the current practice of converting all domestic stock numbers to dry sheep equivalents. Ecologists should always mention which herbivores are present when grazing impacts are considered in their study.

Dune base sites presented problems with interpretation of data from all three study areas examined in this thesis. Whether this is a real problem, or simply an indication that vegetation cannot always be placed into convenient groups, may depend on what question is being asked.

8.9 SUMMARY AND FINAL CONCLUSIONS

This study analysed larger datasets over longer time scales than is usual for similar studies. Despite this, it appears that the length of the study was still insufficient for the exclosures to provide meaningful results relating to the abundance of plant species following the exclusion of various herbivores. At Olympic Dam, where the time scale was even longer, no significant improvement in the condition of vegetation occurred following exclusion of domestic herbivores. The temporal scale of the grazing experiment may have resulted in a recovery of the vegetation that could not be sustained through the next drought and therefore gave an incorrect result as far as the sustainability of such intensive grazing events is concerned.

The effects of exclusion of domestic herbivores were studied within exclosure sites, on the fenced Olympic Dam and Roxby Downs leases, and at the grazing experiment site. Exclusion of rabbits was studied at exclosure sites and within the Roxby Downs rabbit-proof fence. Native herbivores (kangaroos) were present at all sites south of the Dog Fence and periodically in very low numbers at the Billa Kalina sites. Ungrazed areas often had higher vegetation cover following rainfall, but this was often coupled with lower species richness. A small number of common species often dominated at fenced sites, while grazed sites had less cover but supported a larger number of species. No differences between grazing by domestic, feral or native herbivores were identified by this study. It did not matter which herbivore was involved, in the long-term the end result was the removal of vegetation and eventual shift to a worse-condition state unless this was prevented by further rainfall. No classification groups were identified that resulted from grazing by only a single species of herbivore.

As has been the case in many other arid zone studies from around the world, rainfall was found to be the most significant factor that correlated with shifts of vegetation communities from one state to another, particularly when the transitions were to a better-condition state. Such transitions to a better state often happened quite quickly. Very heavy grazing was also found to correlate with rapid transitions between states, but in the opposite direction. Transitions correlating with natural reductions in vegetation cover were usually much slower. Combinations of light rainfall and light grazing generally had little effect on the classification group, although shifts could be in either direction depending on which of the factors had the greatest influence. Major shifts in vegetation communities may have been caused directly by sheep or cattle grazing early in the 20^{th} Century, but no quantitative data are available on this. If this was the case in the present study areas, all vegetation communities have now gone through transitions and reached different and more or less stable states.

Recruitment of perennial species is mostly restricted to extended periods of above average rainfall, with present recruitment sufficient only to maintain the status quo.

The incidence of alien species was found to correlate with winter rainfall and the availability of spaces for the plants to grow. Summer rainfall promoted the growth of perennial native grasses and these prevented the establishment of the winter-growing alien species.

No significant differences were detected that could be directly attributed to the effects of either grazing or mining. A small area around the tailings ponds may have been adversely affected by the ponds, but no other classification group was found to correlate to any grazing or mining activity. It can be inferred from these findings that the effects of an underground mine on the surrounding arid zone vegetation, excluding areas directly disturbed by infrastructure and other development related activities, cannot be separated from those of grazing by native, domestic and feral herbivores.

Apart from the direct effects of vegetation clearing during construction, no changes in vegetation were detected that could be directly linked to the township of Roxby Downs. The present direct effects of the town are largely related to unauthorised off-road driving. Much of this is confined to the formation and use of new tracks. These are too few in number to have been detected by the present monitoring system, or to have had a significant impact on current vegetation monitoring sites.

The scale at which the majority of the monitoring was carried out would appear to be appropriate to this and similar studies. Data on the presence or absence of species was examined for Olympic Dam, but appeared to give less robust results than were obtained from the cover data. This type of data would appear to be more appropriate to studies over larger areas, particularly if temporal comparison of sites is not required.

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