Plant and soil indicators for detecting zones around water points in arid perennial chenopod shrublands of South Australia.

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Summary

Overgrazing has reduced the carrying capacity of chenopod shrublands, reduced biodiversity and increased the susceptibility to degradation in fenced paddocks. The piosphere is part of this grazed ecosystem, and therefore within it there are many mutually interacting, dynamic processes.

This study investigates several questions relating to the impact of continuous sheep grazing on the form, structure and botanical composition of chenopod shrublands. Specifically, which species are more sensitive to grazing in which zones around water points; and which plant and soil features are important for identifying the point of incipient change (threshold). The latter is important so that it can be used as an indicator for detecting the changes in chenopod shrubland communities. The "piosphere effect" was used as a framework for examining the effect of domestic livestock on ecological variables in detail in three arid chenopod shrubland paddocks of South Australian rangelands.

This project consisted of three components. The first aimed to describe the pattern of chenopod shrubland in terms of the foliage cover of the perennial species, using multivariate analysis. From the classification and ordination of these data, it was found that the plant patterns were patchy, rather than random and that five species could be considered dominant in the vegetation: *Atriplex stipitata* Benth (bitter saltbush), *Atriplex vesicaria* Heward *ex* Benth (bladder saltbush), *Maireana georgei* (Diels) Paul G. Wilson (satiny bluebush), *Maireana pyramidata* (Benth.) Paul G. Wilson (black bluebush) and *Maireana sedifolia* (F. Muell.) Paul G. Wilson (pearl bluebush).

The second component of the project specifically examined vegetation patterns based on these five dominant species. Five features (the percentage of canopy cover, density, total dry matter, average height and average width) of the above plant species were measured at 336 sites in

three paddocks separately. Three zones were distinguished (disturbed, sensitive and outer zones). Large and frequent *A. vesicaria* is the indicator of "outer" zone and wide and tall *M. pyramidata* indicate disturbed zones. The disturbed zone also had more abundant *A. stipitata* and *M. pyramidata*. The most important zones of the paddocks are the sensitive zones. The presence of narrow and small plants of *M. georgei* and *A. vesicaria* might be distinguished as the indicators for these zones.

The final component of the project examined to what extent soil features correlated with the vegetation patterns. At the same sampling sites used for collection of plant data, 23 soil based features were examined. Data were correlated with the plant attributes for three paddocks to give a classification of site attributes. High cryptogam cover, particularly of the lichen *Heppia polyspora* and a moderately hard soil crust (i.e. needing a plastic or metal tool to break the surface) may be a useful indicator, for soil infiltration, nutrient cycle status and soil stability in the outer zone. In contrast, destroyed cryptogam cover and an easily broken (with finger pressure), brittle, non-coherent sub-crust could be considered as indicators of degraded zones. Also, cryptogam cover, slaking performance, infiltration capacity, rate of nutrient cycle and soil stability were useful soil indicators for detecting different management zones. In contrast, results show that organic carbon might be not useful as an indicator for detecting zones for rangeland managers.

From an ecological point of view we might conclude that any form of grazing use by domestic livestock is likely to cause a shift in botanical composition. The longer term benefits (and impacts) of grazing needs to be weighed against the diminution of ecological values, including biodiversity.

Declaration

This work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best to 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.

Gholam Ali Heshmatti

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Chapter 1 General Introduction

1.1 Introduction

Rangelands represent one of the largest and most widespread terrestrial natural resources (Tueller 1988). They occur on almost every continent and are a major influence on the way of life of a large portion of humankind. These rangeland ecosystems occupy approximately 40% of global land surface (Johnson and Mayeux 1992) and have inherent value as well as the capacity to produce commodities. Rangelands are under extreme pressure, because they produce forage for many domestic and wild animals as well as food, water, fuel, fibre, and open space for an ever expanding human population. These increased demands carry risks of accelerated soil erosion and diminished biodiversity.

Many rangelands are dominated by shrubs and or trees. It is commonly accepted that shrublands have many unique features and that important uses and products can be obtained from shrubs under positive management practices (McKell 1989). A significant proportion of the arid and semi-arid rangelands of Australia is occupied by shrublands with a high proportion of species edible to livestock (Squires 1989). Much of the southern Australian arid and semi-arid native shrublands is dominated by plants of the family Chenopodiaceae, hence the name chenopod shrublands (Yan *et al.* 1996), and they form an important part of the resource base for the pastoral industries of these areas (Hacker 1987). Grazing by domestic stock on these arid perennial shrubs is known to impact upon related soil features, plant community and population dynamics.

1.2 Arid And Semi-Arid Australian Ecosystems

Like all countries with extensive arid and semiarid lands, Australia has a desertification problem (Ludwig and Tongway 1995). More than 70% of the total land surface of continent, some 5.5 x 10^6 km^2, is arid and semi-arid ecosystems (Parkinson 1986) and over 80% of South Australia is also covered by these areas (Osborn 1926). These ecosystems together with tropical rangelands are the main resources of forage for livestock animals of Australia. Pastoral lands or rangelands constitute 84% of the continent (Young *et al.* 1984) and are mainly used for extensive grazing by domestic sheep and cattle (Squires 1981). Arid land for South Australia was formally defined as follows: "they include all lands within South Australia which are considered too dry for agricultural cropping, and generally have a rainfall of less than 250 mm per year" (Anonymous 1990). These areas include the pastoral leasehold lands, National and other parks, and the Aboriginal lands.

1.3 Australian Rangeland Ecosystems

Rangelands are areas defined by a combination of climate, vegetation and land use parameters. They are generally native grasslands, shrublands and woodlands which cover a large proportion of the arid and semi-arid regions and also include tropical savanna woodland, and the slopes and plains of northern NSW and southern Queensland. The majority of the Australian mainland, particularly the arid and semi-arid zones, is rangeland (ABARE 1993).

Despite their harsh, rugged appearance, rangelands are fragile ecosystems which are susceptible to erosion and thus require careful management. Extensive areas have been severely degraded since human, mostly European settlement (Noble and Tongway 1987). About 42% of arid and semi-arid lands of Australia, (some 2 million km^2) is estimated to be either in a severe (26%) or very severe (16%) state of desertification (Christie 1986). In addition, it is estimated that about 8.2% of the arid area of Australia, some one-half million km^2, is in a 'severe' class of desertification (Dregne 1983). Newman and Condon (1969) estimated that about 14% of Australia's rangelands were 'severely degenerated'. These problems with severe and very severe degradation tend to be localised; for example, around watering points on pastoral lands

(Ludwig and Tongway 1995). Also, the shrub vegetation, which forms the basis of the arid zone pastoral industry, has been extensively damaged by grazing sheep (Jessup 1951).

1.4 Chenopod Shrubland Communities

Chenopod shrubland communities are distributed throughout different climates, soils and occupy many harsh environments of the world (O'Leary and Glenn 1994). These communities provide a substantial portion of the fodder consumed by domestic livestock, especially during seasons when grass forage is limited in volume or low in protein content. Le Houérou (1989) claimed that intensified browsing would cause changes in the composition of the woody-perennial assemblage.

Chenopod shrublands, principally those dominated by *Atriplex* and *Maireana*, occupy a significant proportion of the arid and semi-arid zones of Australia and the role these shrubs play in the stability, productivity and aesthetics of Australian rangelands is becoming increasingly recognized (Squires 1989). The distribution of these shrublands appears to be largely restricted to lands of low relief; the featureless plains or gently undulating lowlands where relief is generally less than 30 m (Mabbutt and Sullivan 1970). Those communities occupy approximately 6% of the total land surface area of Australia and extend in a large, discontinuous arc across the southern portion of the continent where the winter rainfall is most reliable and effective (Wilson and Graetz 1979), with rainfall varying from 125 to 350 mm (Wilson *et al.* 1988). These communities represent the main plant species which are growing in harsh environments and provide the main food for the herbivores in dry seasons. Sheep graze in these areas with density from one sheep to 1.5 ha in the high rainfall (400 mm) areas of the Riverine Plain of New South Wales, to one sheep to 25-30 ha on the western fringes in South Australia and Western Australia (Wilson and Graetz 1979). Improving current understanding of the effects of grazing livestock on chenopod shrubland in arid and semi-arid areas would be useful for effecting better management of these communities. This is because one of the impacts of grazing has been the elimination of the dominant *Atriplex* or *Maireana* shrubs and their replacement by less palatable or shorter-lived perennial chenopods, or a forb-grassland (Wilson 1990).

1.5 Microbiotic Soil Crusts

The term microbiotic or cryptobiotic (Belnap 1993) is synonymous with cryptogamic (Kleiner and Harper 1977), microfloral (Loope and Gifford 1972), biologic (Danin 1987) and microphytic (West 1990). These crusts develop at the soil surface through growth of algae (brown and green), bacteria, cyanobacteria, lichens, mosses, liverworts and fungi or some combination of these nonvascular microphytes (West 1990; Eldridge 1996). Microphytic crusts occur in open shrub and grass communities in arid and semi-arid environments around the world (Williams *et al.* 1995a), but in areas which are not extensively sandy, stony or cultivated (Eldridge 1996).

Australia has a rich lichen assemblage of about 2275 species from a global total of 20 000 currently recognised species (Rogers and Hafeneller 1992; Filson 1992). They occur on many different substrates in almost every natural environment involving terricolous (Rogers 1972a; Rogers 1972b; Rogers and Lange 1972), saxicolous (Orwin 1970, 1972), epiphyllous (Conran and Rogers 1983; Rogers and Barnes 1986; Rogers 1989) and corticolous (Rogers 1988; Griffin and Conran 1994). In some arid and semi-arid areas cover the soil surface (Rogers 1992) and may be important in soil stability. These biota have a major impact on physical and ecological processes such as nitrogen fixation (Rogers *et al.* 1966), infiltration, the resistance of soil surfaces to wind and water erosion (Williams *et al.* 1995b; Eldridge and Greene 1994a) and recruitment and survival of vascular plants (Eldridge 1996). In less disturbed areas, a well developed lichen crust forms on the soil surface in between the perennial vegetation. This crust is destroyed by sheep tracking and is absent in washes (Reid 1979).

1.6 Grazing Effects

Overgrazing is the fundamental problem in the management of rangelands. It reduces the production of forage, exposes the soil to sealing, baking, and erosion, reduces the infiltration of water into the soil, increases water run off and flooding, and induces unfavourable changes in the species composition of the native vegetation. Grazing shapes the composition of vegetation at the landscape level, (Oksanen and Oksanen 1989; Oksanen *et al.* 1995) whilst also influencing attributes of plant communities such as species composition, biomass and plant architecture (Manseau *et al.* 1996). It affects foraging areas by defoliating plants and trampling soil (Heitschmidt 1990; Matches 1992), leading to reduced macropore space and a reduction in infiltration, percolation, root growth, and overall plant production (Lull 1959; Bryant *et al.* 1972). Reviews by Heitschmidt (1990) and Matches (1992) have pointed out that in mesic grazing lands, plant communities may produce more herbage as a result of some degree of defoliation, whereas plant communities in arid situations may produce less herbage as a result of almost any amount of defoliation. Overgrazing has denuded vast areas of rangeland on nearly every continent, and this has lead to the desertification of many semi-arid regions (Hansson *et al.* 1994).

The effects of grazing are not only limited to changes in species composition, but can also affect the soil structure, nutrient distribution and microbiotic crusts. Overgrazing by sheep, goats and other livestock has also influenced the semi-arid rangelands of north eastern Iran, and greatly reduced the beneficial effects of rain because of increased runoff through compaction (Heshmatti, 1994). Graetz and Tongway (1986) found that grazing changed the distribution of nutrients from the upper 2 cm to a depth of about 10 cm. Also, microbiotic crusts, especially those formed by lichens, are generally thought to be susceptible to disturbance by grazing and trampling, particularly when the soils are dry (Marble and Harper 1989; Eldridge and Greene 1994b).

Intensity, frequency, seasonality and selectivity are the main factors of grazing impacts on plants (Heady and Child 1994). The degree of influence domestic herbivores have on plant communities depends upon the intensity, season, duration and frequency of grazing, level of selectivity and site characteristics. In a chenopod shrubland community, the impact of grazing is seen not only by a loss of shrubs, but through shifts in species composition from the more palatable to the less palatable shrub species (Wilson 1994). Some fluctuations such as selective grazing and wind direction will naturally cause temporal variability in factors such as plant density, phenology and physiology and subsequently a point of incipient change (threshold) and then patchiness in the chenopod shrubland community will develop.

1.7 The Concept Of Threshold

The threshold concept was first established by Lewontin (1969). Further work by Friedel (1991), Laycock (1991), Tausch *et al.* (1993) and others aided understanding of the dynamics of the interrelationships between vegetation and environmental changes. The threshold as defined by Friedel (1991) has three characteristics.

- It is the boundary in space and time between two stable states of a rangeland that is undergoing a succession or retrogression.
- It is crossed when severe environmental or management disorder occurs.
- It will not revert to its former state without substantial intervention by the range manager on a practical time scale.

In general, plant population parameters or other abiotic variables that might forecast impending transition thresholds should be identified and incorporated into rangeland management plans (Archer and Smeins 1992).

1.8 Patchiness Concept

Because of the incomplete vegetation cover, incoming rainfall strikes a considerable amount of bare soil, with the result that there is substantial run-off, leading to the redistribution of water and nutrients. This redistribution results in run-on patches which have moisture levels above those expected from the average rainfall for the area, and other patches which are correspondingly drier. This phenomenon occurs at a range of scales from kilometres (Pickup 1985) to tens of metres (Tongway and Ludwig 1990).

Patchy distribution of plant populations is a hallmark of arid and semi-arid ecosystems (Tongway and Ludwig 1994). Stuth (1991) pointed out that each landscape unit (pasture, paddock, block, allotment) is composed of a complex of different habitats or distinct groupings of plant species in communities. These habitats can be further delineated into patches which contain more homogeneous groupings of species. The presence and nature of habitats or "fertile patches" can be revealed by analysis of pattern in landscapes, using edaphic and vegetation variables (Tongway and Ludwig 1990).

Furthermore, ruminant livestock may lead to an orderly sequence of changes in habitats that are produced by the grazing of herbivores that, in turn, occupy an area in a seasonal succession of species dictated by food preferences (Bell 1970). When an animal selects and grazes in a landscape, a hierarchy of instinctive responses and behavioural actions has been taken by it that leads to the point of consumption (McNaughton 1987; Senft *et al.* 1987; Senft 1989). Livestock generally seek spatially scattered plants of nearly constant and high nutritional value. The least palatable of the plant species are shrubs, and a typical hierarchy of selectivity by sheep would be annual herbs > perennial grasses > dry herbage > chenopod shrubs (Wilson, 1994).

In a chenopod shrubland community, the most palatable species are consumed first, and unless the rangeland is destocked, eventually only the unpalatable plants remain. Therefore, the distribution of grazing across the landscape is uneven, being influenced by preferred plants (Low *et al.* 1973), proximity to cover (Hill, 1981) and above all, water supply (Wilson, 1990). The plant community consists of an array of patches, rather than individual plants, that are sensed by the grazing animal (Senft *et al.* 1987).

The grazers of chenopod shrublands have high water requirements because their fodder species are high in minerals, especially salts (Wilson and Graetz, 1980). Thus, livestock graze most closely to water points, and this leads to a gradient of grazing pressure. The result is a mosaic of denuded patches nearest to water, vegetated mainly by unpalatable species, in sharp contrast to more lightly grazed areas further from the water (Wilson, 1990). Such selective grazing pressure by domestic livestock usually leads to long-term changes in the composition of the native vegetation, and these changes are generally not reversed simply by removing the grazing pressure, at least in the short term (Westoby, 1980).

Sheep have traditionally been favoured in the arid southern rangelands of Australia (Noble and Tongway, 1987), with chenopod shrublands occupying large areas of southern Australia and providing the main fodder for livestock, especially during the dry season. During these dry seasons, the stock's need for drinking from troughs increases. Grazing thus become more concentrated around water points. It has been suggested that selective grazing pressure by domestic livestock combined with drinking behaviour usually leads to long-term changes in the composition of the native vegetation and more specifically, the development of a piosphere (Lange, 1969).

1.9 The Piosphere Pattern As A Framework

Drinking is a vital part of the activities of stock in any paddock and a feature of rangelands the world over is the peculiar zone of influence around the permanent watering points (Squires, 1982). The piosphere (Lange, 1969) is part of this ecosystem, and therefore within it there are many mutually interacting, dynamic processes.

Lange (1969) described the piosphere (from the Greek *pios* = to drink) as being the basic ecological unit in arid areas under grazing pressure, and is defined as the zone around a watering point. In the other words, it is a region resulting from the interaction that occurs between livestock, plants, soils and watering points. Squires (1982) called the piosphere an ecological system whose interactions are determined by the existence of the watering point and the capacity of the animal to forage away from it. The piosphere provides a good context for studying the ecological effects of large herbivores, and for applying ecological information to land management. The proliferation of artificial water points across much of Australia's rangelands means that piospheres associated with large grazing mammals (domestic, feral and native) are now widespread (Landsberg and Gillieson, 1996).

It seems reasonable to assume that when the paddock is first stocked, the initial change to its plant community will be a reduction in biomass, then a change in some population densities, eventually leading some species to disappear and others to take their place (Barker, 1979). Piosphere patterns have been reported for the following ecological variables (Andrew, 1988): the accumulation of livestock faeces and density of livestock trails (Lange, 1969; Andrew and Lange, 1986a), soil compaction and cover of the soil cryptogam crust or amount of bare soil (Andrew and Lange, 1986b; Rogers and Lange, 1971; Graetz and Ludwig, 1978; Eldridge and Greene 1994b), and biomass of herbage or degree of herbage defoliation (Graetz and Ludwig, 1978; Osborn *et al.* 1932; Fatchen and Lange, 1979; Andrew and Lange, 1986a). The piosphere concept is now widely accepted as the framework for the ecological variables and the effects of domestic livestock on ecological variables around watering points. Therefore, the piosphere framework seems appropriate for determining threshold and patch dynamics in chenopod shrubland in arid and semi-arid regions.

1.10 Framework For This Research

It is estimated that 16% of Australia's arid lands (including those regions with arid and semi-arid rangelands) are under threat of 'very severe' degradation (desertification hazard), with another 26% in a 'severe' hazard class (Christie, 1986). This points to the fact that the potential for further rangeland degradation in Australia is very serious. Ludwig and Tongway (1995) pointed out that most of the vast arid and semi-arid regions of Australia have undergone desertification in the form of conversion of grasslands and savannas to more desert-like barren lands and shrublands, although in most areas the severe impacts of soil erosion have been localised.

Chenopod shrublands cover a vast area of South Australia. Overgrazing has reduced the carrying capacity of these shrublands, with consequent decrease in bio-diversity and an increase in susceptibility to degradation. Management in these arid and semi-arid ecosystems should aim to achieve ecological sustainable development for the benefit of future generations. Consequently, indicators which quantify, simplify and communicate information, enable easier assessment of progress towards this fundamental goal. Indicators of ecosystem function are largely independent of historical biases: the indicator merely reflects how well an ecosystem is functioning based on current knowledge of the processes that affect water, nutrient and energy fluxes and distribution patterns.

Heavy grazing of the chenopod shrubland ecosystems and failure to manage these communities can lead to redistribution of plant species and eventually, degradation. Degradation is both very difficult and very expensive to reverse and rehabilitation is equally difficult, sometimes impossible, to achieve. The ability to detect the early signs of degradation in these communities is crucial for management practices.

Torrential rainfall can have a severe physical impact in arid and semi-arid region and can combine with heavy grazing in making the ecosystem cross the threshold from stable to degraded soil (Friedel 1991). Furthermore, cryptogam cover responds to grazing and trampling in these areas. Threshold or patch dynamics can be determined through the measurement of soil, vegetation attributes and cryptogam cover in chenopod shrubland vegetation.

The study of thresholds (the point of incipient change) and patchy features are necessary for determining the range dynamics of the chenopod shrublands ecosystem. There are some questions which we must answer. Soil-based attributes, plant characteristics and management factors are major factors which play a dominant role in thresholds and patchiness.

1.11 The Objectives Of The Study

There were four major aims of this thesis. They were as follows:

Data on vegetation and edaphic features should enable us to answer the following questions for chenopod shrubland management in arid and semi-arid regions of South Australia:

- What is the pattern of perennial chenopod shrubland in response to grazing around water points in arid and semi-area of South Australia?
- Are there any distinguishable areas (zones) in paddock grazing system for chenopod shrubland of South Australia?
- Which plant and soil features are most important as indicators of distinguished zones?
- How can these indicators be articulated in rangeland assessment and what is the outcome of this study for management practices, especially for chenopod shrubland of arid and semi-arid areas?

Chapter 2 Literature Review

2.1 The Ecological Theories Of Vegetation Dynamics

2.1.1 Introduction

Vegetation is the part of an ecosystem which can be most easily manipulated to reach certain management objectives. It we knew how plant species respond to climate, soils and herbivores, then we can read the effects of past environments.

The objective of this chapter is to describe the concept of range condition and review the literature on theoretical rangeland ecology. The role of these theories in furthering our understanding of rangeland ecosystems and their management will be discussed.

2.2 Range Condition And Trend In Rangeland Ecology

The concepts of range condition and trend are perhaps the most influential in range management (Smith 1978) and were developed to quantify the effect of grazing on native pastures (Friedel 1981). Trend is the directional change in kind, proportion and/or amount of plant species, or soil characteristics (S.R.M. 1989). The direction of trend is based on whether the changes in vegetation and soil conditions are desirable/improving, stable or undesirable/deteriorating for specific management objectives.

2.3 Ecological Theories

2.3.1 Clementsian Succession Theory

The conventional notion of range condition rests on "successional theory" (Westoby *et al.* 1989) or "plant succession theory" (Friedel 1991). Climax vegetation theory (Clements 1916; 1920) was initially developed to explain variation in vegetation types. From the viewpoint of Whittaker (1953, 1956, 1960), a climax community is best considered as a pattern of overlapping populations, fluctuating about some average structure and productivity. This climax vegetation has been considered to be resilient, and it is assumed that any change resulting from human utilization (eg. stock grazing) could return towards the climax through successional sequences.

The application of ecological science in range management had its origins in Clement's (1916) theory. He postulated a series of smooth, continuous and reversible changes along a gradient of ecological states. This theory was later developed by Dyksterhuis (1949) as the quantitative climax approach, based on comparison of the present status of range condition with the climax state. At the same time, the "site potential" approach based on productive potential for particular use was developed by Humphrey (1949). Succession theory and the application of these concepts to rangelands permeate the classical literature (Tainton 1981).

2.3.1.1 Important Assumptions Of Climax Theory:

Classical successional theory suggests that plant communities will "progress" through a series of stages toward a stable climax (Krebs 1985). As indicated by Walker (1993), the early model of rangeland dynamics is a simple, straightforward application of the Clementsian theory of ecological succession (1916). It holds that:

1) Any particular rangeland site has a single, persistent state, called the climax, which represents the end stage of a successional series.

2) The climax state is determined by the climate, and succession proceeds towards this stage in the absence of grazing or other disturbance.

3) Grazing pressure results in changes which are equal and opposite to the successional tendency; and a given stocking rate will result in an equilibrium state of the vegetation, giving a sustainable yield of livestock products (Westoby 1980; Walker 1993).

4) Interannual variation in rainfall causes vegetation to move up and down the successional gradient, and drought is assumed to influence vegetation change in the same direction as grazing.

5) All possible states of the vegetation can be arrayed along the continuum from early-successional, heavily-grazed, poor condition to climax, properly grazed, excellent condition. Any identifiable state of the vegetation is known as a sere in Clementsian theory, and the analogous applied range-management term is condition class.

6) The management implications of this theory include selecting a stocking rate that balances successional tendency and grazing pressure such that a desired condition is achieved (no erosion, palatable perennial grasses, etc) which yields a sustainable, economically viable livestock offtake. Under drought conditions stocking rates are reduced to compensate for the anti-successional tendency.

The assumption in succession theory is that, in the absence of disturbance, rangelands proceed to the 'highest' expression of the vegetation (the climax) that the prevailing climate permits (Heshmatti and Squires, 1997). In contrast, according to the equilibrium model, upon displacement by a disturbance, the rangeland state returns to its former equilibrium (Mentis *et al.* 1989).

2.3.2 Range Science And Succession Theory

Range condition assessment based on the principles of quantitative climax (Clements, 1916 1920; Dyksterhuis 1949) has been criticized for some time (Smith 1978 1989; Wilson 1989), but it is still in use in a wide variety of rangelands (Tainton 1986; Pendleton 1989).

Single, catastrophic events of weather, fire, grazing, or management action may change range ecosystems in ways not easily reversible and more consistent with the linear monoclimax succession model (George *et al.* 1992). There is a general recognition that 'pristine' states are only conceptual in nature and that multiple stable states exist as a result of interactions among climate, soils, grazing history, and management practices (Wilson 1986). Questions of appropriate application of succession theory arise on some shortgrass types, shrublands, and Mediterranean annual grasslands (Heady and Child 1994). Therefore, one relevant topic in the continuing debate surrounding rangeland succession theory is whether an equilibrium model or a non-equilibrium model of change is more appropriate.

2.3.3 New Approaches To Rangeland Dynamics

Multiple stable points exist and the interesting problem is why the system is at a particular stable state (Lewontin 1969). The concept of relatively stable states of vegetation is not new in the ecological literature (Holling 1973; Wissel 1984). The "domain of attraction" model was developed first by Lewontin (1969). It depicts a community as a ball or marble in a cup or trough. The boundaries of each cup represent the range of environmental conditions under which that community is stable (Hurd and Wolf 1974; Forman and Godron 1986; Krebs 1985).

A conceptual diagram of threshold changes in community structure from a grassland or savanna to a mesquite woodland as a function of grazing pressure was presented by Archer (1989). It was concluded that the conversion of mesquite savannas to woodlands in southern Texas has been recent and coincident with both heavy livestock grazing and shifts in precipitation.

At the same time, the state-and-transition model was proposed by Westoby *et al.* (1989). It was an attempt to provide a workable and an alternative model for Clementsian theory. This approach helps bring order to the complex body of knowledge and concepts describing vegetation dynamics in rangeland ecosystems (George *et al.* 1992). The model includes states that represent relatively stable vegetation assemblies, and transitions between states are caused by natural events such as drought and fire, or management practices such as changes in stocking rates. In other words, the forces that cause vegetation to cross a threshold and move toward another state are shown as transitions. In simple terms, "state" means a vegetation type, such as those of the condition classes on a range site, and "transition" indicates the direction of change from one state to another. Data are catalogues of different states of the vegetation and of the possible transitions among the states. The states have been illustrated as a series of boxes that describe different combinations of dominant plants. Arrows between the boxes suggest different transitions when factors such as fire, herbicides and grazing change the vegetation. Catalogues of both state characteristics and transition factors are made and revised as information becomes available. The model describes rangeland behaviour through catalogues of alternate states and transitions between states, each with a range of probabilities of occurrence and probabilities of reversal. The model can be applied in the field and used for planning managerial inputs (George *et al.* 1992). Managers are then able to concentrate on timely intervention, in the sense that intervention at some times is pointless, at others critical. The advantages of adopting the state and transition model approach for describing the processes involved in vegetation change in tropical rangelands of northern Australia were pointed out by Ash *et al.* (1994) as follows:

1). This approach provides a useful framework around which to organise information that is relevant to management and to focus on the key factors that drive vegetation change.

2). State and transition models are useful conceptual tools for research workers to identify gaps in knowledge.

3). State and transition models, if adopted by land managers as an aid for decision making, can be used to highlight "management windows" where opportunities can be seized and hazards avoided.

Friedel (1988, 1991) used the concept of thresholds of environmental change to help describe and explain anomalies in assessments of the condition of central Australia's arid rangelands. It was hypothesized that when a severe environmental or management disorder occurs, the threshold is crossed. Friedel (1991) stated that once a threshold is crossed to a more degraded state, improvement cannot be attained on a practical time scale without a much greater intervention or management effort than simple grazing control. Two such changes in threshold, from grassland to woodland, and from stable to degraded soil, were recognised on Australian rangelands.

Another model is that of multiple stable states (Laycock 1991). The basic theory is that there are multiple stable states of differing species composition with multiple, non-linear pathways between them as a component of range vegetation dynamics. It was concerned to identify possible stable states and the different forces driving a vegetation community from one stable state to another, as well as the impact of grazing and fire. A number of changes that have occurred in different grasslands of North America which did not correspond to a traditional model was summarized by Laycock (1991). According to this study, there are multiple stable states of differing species composition with multiple, non-linear pathways between them as a component of range vegetation dynamics. He was concerned with identifying possible stable states and the different forces driving a vegetation community from one stable state to another, as well as the impact of grazing and fire. Laycock (1991) pointed out that the recognition of stable states and models describing them are needed to develop new concepts about range condition assessment.

The concept of multiple stable states or domains has not received much attention in the range management literature. However, the importance of the threshold approach in assessment of range condition has been discussed as a new method in recent ecological literature by Laycock (1991) and Friedel (1991). The concepts of state-and-transition (Westoby *et al.* 1989), multiple stable states (Laycock 1991) and threshold concept (Friedel 1991), are helpful in understanding the dynamic interrelationships between vegetation, environmental changes and management practices.

2.4 The Ideas On Description Of Pattern In Chenopod Shrublands

Ecologically sustainable development requires proper management. Proper management requires the understanding of patterns and processes in biotic systems and the development of assessment and evaluation procedures which assure healthy patterns and processes in biotic systems (Bridgewater 1996). Sound management programs in rangeland areas start with a thorough evaluation of current rangeland resources. The range management practices aim at sustainable utilisation of the range with regard to full ecological understanding of range conditions. However, by utilising the wrong ecological models of rangeland dynamics, undesirable changes in rangelands have occurred (Walker 1993).

In the piosphere, stocking pressure attenuates linearly with distance away from the water point, creating an almost radial pattern of impact on the vegetation (Lange 1969; Barker 1979). The major changes to the vegetation involve a reduction in the density of the long-lived palatable perennial plants as proximity to water increases with a concomitant increase in less palatable or shorter-lived plants. Under the range succession model these changes have been interpreted as retrogression along the successional pathway (Westoby 1980). Hence, removal of grazing is expected to result in a reversal of these changes in the vegetation.

The abiotic environment, particularly climate, determines the dynamics of plant community (Noble 1986). Short-term fluctuations and episodic events such as occasional periods of heavy rainfall and long droughts are characteristic of the arid zone of Australia (Ludwig and Tongway 1997). These fluctuations will naturally cause temporal variability in factors such as plant growth rates, phenology and physiological states of the plant and will affect the amount of feed available for livestock. Consequently, these episodic events can play an important part in bringing about major changes to the vegetation, particularly in the long-lived perennial component (Griffin and Friedel 1985; Friedel *et al.* 1990). They are thus considered important in inducing transitions between states under the state and transition model.

In order to develop new concepts and models about range condition, we not only need to identify possible stable states, we also need to identify and understand the factors which can force a stable community across a threshold into a transitional phase, moving toward another stable state (Laycock 1991). It is significant that the changes we seek to measure have been fashioned by livestock grazing. On the other hand, one special focus for concern is the probability that wherever rainfall is low and soils are thin, threshold effects can confine vegetation within what is a clearly different and simpler ecosystem type (Laycock 1991). Therefore, in each plant community a series of plant and soil factors need to be identified so that they can be measured as key indicators for threshold values in each transition state.

2.5 Importance Of Indicators

Effective and sustainable usage of vegetation resources in dry areas requires avoidance of overgrazing and prevention of the destruction of the vegetation beyond the point recovery. Understanding the role of indicators for conserving scarce resources has important implications for sustainable management of drylands, and for the rehabilitation of areas which are already desertified or degraded. Rangeland sustainability is a concept and cannot be measured directly. Appropriate indicators must, therefore, be selected, tested, and validated to determine levels and duration of sustainable land management. An ideal indicator should be unbiased, sensitive to changes, predictive, referenced to threshold values, data transformable, integrative, and easy to collect and communicate (Liverman *et al.* 1988).

Methods for the selection of indicators for assessing ecosystem health are currently being developed and debated (e.g., Breckenridge *et al.* 1995; Herrick *et al.* 1996). Some criteria for the selection of indicators are rapidity and reliability of measurement, repeatability, and linkage to ecosystem function. Indicators must also be efficient, easy to understand tools to communicate information on sustainability issues to users from the range manager, to the policy maker. In general, research to identify indicators of sustainability needs to be integrated with research on land-use optimisation procedures (Walker 1996).

A set of indicators of incipient change (critical thresholds) from a stable/productive state to an unstable and less productive state is required. The National Research Council of the United States (NRC) (1994) pointed out that there must be an early warning phase between "healthy" and "at risk" states and a threshold between "at risk" and "unhealthy" states. The committee calls for integrated research and development of indicators of changes in state.

In arid chenopod shrubland, deterioration of the ecosystem may manifest itself in many ways. Although an increase in the size and frequency of bare patches may be intuitively and qualitatively linked to the deterioration of an ecosystem, other indicators may be even more sensitive to disturbance. The question of what constitutes an indicator of incipient change (threshold), and how to measure it, is important for rangeland management. What attributes are to be measured, how they are to be measured, and how are the measurements to be interpreted, are the subject of continuing debate (Friedel 1991).

2.6 Soil And Plant Features: Separately Or Together?

Change in rangeland ecosystems is a multivariate process; it should also be noted that this change also occurs in chenopod shrubland communities. Measurement of features of these ecosystems must reflect any change and, for effective assessment, it must be subdivided into several steps of field measurement and subsequent analysis (Wilson 1986).

Whilst the measurement of vegetation composition is important in the assessment of range condition, other attributes are required in order to understand better rangeland dynamics. Scarnecchia (1995) reported that most of the early methods of rangeland condition assessment explicitly or implicitly used plant community variables or simple soil variables as measurable indicators of the extent of these processes. Some scientists (Tainton *et al.* 1980; Vorster 1982; Mentis 1983; Heard *et al.* 1986; Bosch *et al.* 1989) pointed out that range condition is defined by indices of vegetation change based on vegetation composition measurements. The limitations of this practice are addressed by Wilson (1986). Because distribution and species composition of rangeland plant community are known to be related to specific soil properties such as soil texture, depth, structure, fertility, pH, salinity and climate (moisture and temperature) (Leonard *et al.* 1988), the soil attributes could be considered as surrogates for plant patterns.

In some cases, soil stability is considered to be of greater importance than productivity or vegetation change in range condition evaluations (Wilson and Tupper 1982). The NRC (1994) has even suggested that the concept of rangeland condition should be based on the "integrity" of the soil and the ecosystem processes in rangelands. As an interim measure, the committee recommends that all current inventory and monitoring systems should incorporate uniform indicators of soil surface condition as a matter of priority.

Wilson (1986) suggested that the combination of indices of soil and vegetation change are useful for measurement of range condition. Friedel (1988) also proposed that rangeland monitoring must be incorporated with the assessment of herbage and soil features. Furthermore, Wood (1958) suggested that both edaphic and climatic variables are important in controlling the distribution of plants in arid South Australia. The vegetation and soil surface attributes observed are known to be sensitive indicators of the condition of arid and semi-arid landscapes (Ludwig and Tongway 1992; Tongway and Smith 1989).

No single criterion will be sufficient to determine whether rangelands are healthy, at risk, or unhealthy (National Research Council 1994), and the sustainable management of grazing lands such as chenopod shrubland communities requires the consideration of a series of factors. These include an array of plant, soil features and cryptogam cover, because the state of a grazing system is usually assessed visually, often in terms of changes in herbage composition and cover and/or changes to soil surface characteristics (Tothill and Gillies 1992).

If only vegetation is monitored, it will not be clear whether any changes in composition are due to interactions between grazing animals and vegetation alone, or whether the soil, as a habitat for pasture plants, has been degraded. As a result, the measurement of soil and vegetation attributes and cryptogam cover could be suitable for determining the indicators in chenopod shrubland vegetation. The combined assessment of these features could provide more comprehensive understanding of disturbance effects, such as grazing, and could be a sound basis for management of a particular area. It will help to aim at sustainable utilisation of the plant community with regard to full ecological understanding of range condition.

The concept of range condition is used to denote the changes in vegetation composition, productivity, and land stability that occur when rangelands are grazed by domestic livestock (Wilson and Tupper, 1982). Rangeland ecosystems, after undergoing a disturbance, do not always return to their original state but may assume a new domain. Almost all of the arid and semi-arid rangeland types remain stable at one or more lower successional states for long periods of time, even when grazing is removed (Laycock 1994).

There is ample evidence that sites can be described and range condition determined (Wilson 1986; Watters *et al.* 1996). Ecosystem management for biodiversity in managed chenopod shrubland of southern Australia requires an understanding of the distribution and abundance of species in the landscape and an understanding of the responses of those species to changes in stand structure and disturbance.

Grazing is the major disturbing force on soil surface conditions (Greene *et al.* 1994). This is due not only to the direct effects on soil physical properties, such as compacting the soil (Lull 1959), reducing soil aggregate stability (Knoll and Hopkins 1959) and destroying cryptogamic crusts (Mücher *et al.* 1988), but also to the indirect effects of defoliation (Hodgkinson 1993).

The development of scientifically sound policies for maintaining species abundance and biodiversity of chenopod shrubland in arid and semi-arid areas of South Australia is likely to require an understanding of the effects of grazing on this community. Despite a number of studies on chenopod communities in this region, there is a small amount of available information on how grazing-gradient processes affect chenopod community changes. This aspect is poorly understood. Plant population parameters or other abiotic variables that might forecast impending transition thresholds at the paddock level must be identified and incorporated into management plans (Archer and Smeins 1992). Therefore, it is important to develop a set of indicator values that will signal the onset of a major change in these ecosystem before it becomes irreversible.

Chapter 3: Study Area And Methodology

3.1 Study Area

3.1.1 Location

The field sites for this research were located at Middleback Field Centre (32° 57′S, 137° 24'E), on the Eyre Peninsula, approximately 20 km north-west of Whyalla, South Australia (Figure 3.1). The neighbouring stations of the area are Myola/Iron Baron and Katunga in the west, Corunna, Pandurra and Roopena in the north and Tregalana and the Whyalla Conservation Park to the east, at the junction of the Iron Knob and Iron Baron railways. The vegetation is an arid chenopod shrubland, dominated by *Atriplex* spp. and *Maireana* spp. with a variable low woodland of *Acacia* spp., on undulating desert loams (Lange 1985).

The Middleback Field Centre near Whyalla is the only fully serviced complex in South Australia for studying arid zone ecology (Botany Department Report 1994) and was opened in 1979. It is the location for rangeland ecological training and is the leading venue for fundamental and applied research into chenopod shrubland ecosystems in Australia (Ferris 1994). Roopena Station, and more specifically Middleback, has been the site of considerable scientific research since the 1970's (Tothill and Kutsche 1993). A research facility has been set up at Middleback for use by students, scientists, pastoralists and others for the purpose of investigating the long term effects of stock on perennial shrub rangelands.

3.1.2 Abiotic Variables

3.1.2.1 Climate

The climate of the area is characterised by long, hot summers and short, cool winters, with low and erratic rainfall (Wotton 1993). Temperatures in Whyalla range from a mean daily maximum of 28.9°C in January (summer) to a mean daily maximum of 7.3°C in July (winter). At Middleback Station, the summer maximum is usually 4-5°C hotter and the

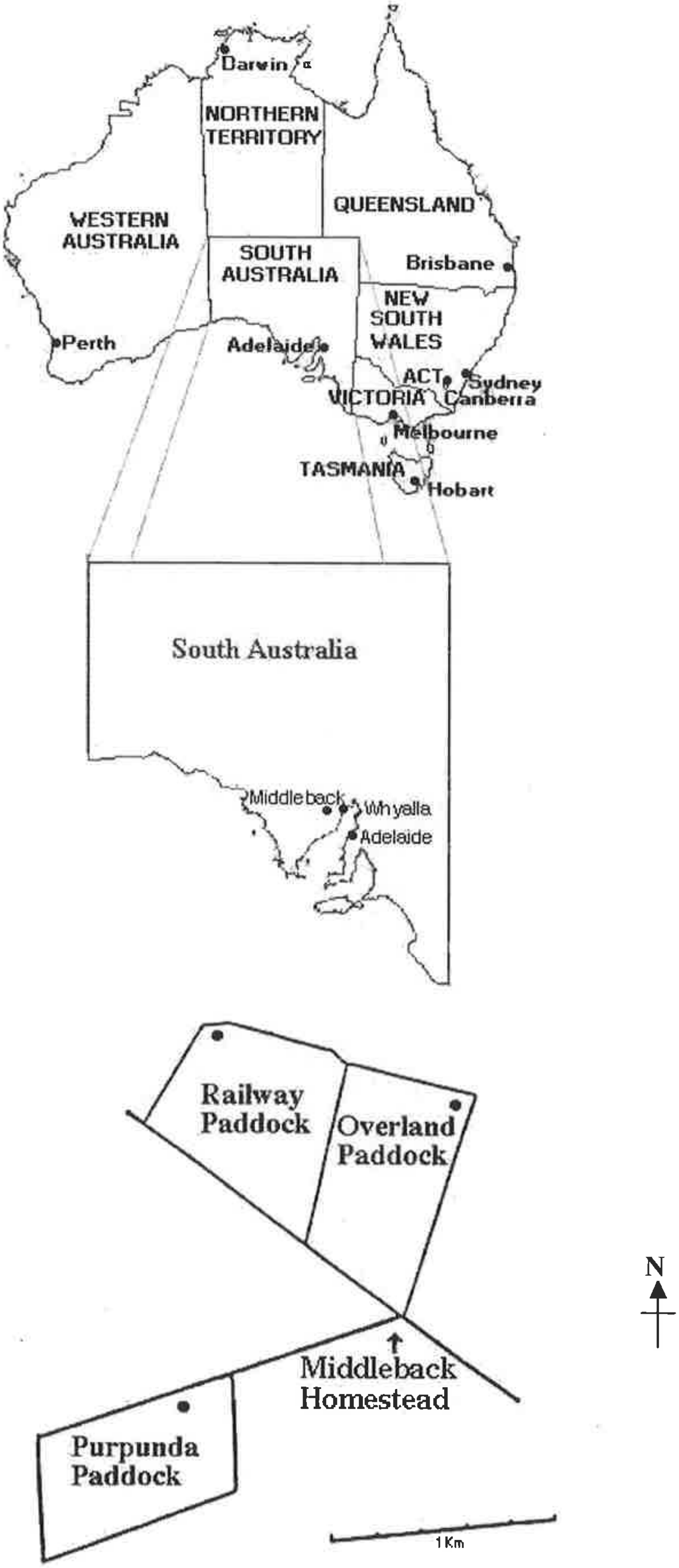


Figure 3.1 The location of Middleback Station and the location of three paddocks in which studies were conducted in South Australia.

winter minimum is 2-3°C colder due to its inland position (Reid 1984). Temperatures in the study area are predictable, being warm to hot in summer and cool in winter (Nicolson 1985).

Contrasting with the predictable, cyclic rainfall of the southern temperate region of South Australia, rainfall in the study area is unpredictable within and among years. Rainfall is low and irregular, averaging 218 mm for the period 1925-1996, but varying from 98 mm (1943) to 511 mm (1973) (Figure 3.2). Average annual evaporation in the region is high, being approximately 2200-2400 mm, or ten times the mean annual rainfall (Laut *et al.* 1977). Despite differences in summer and winter temperatures there is no distinct summer and winter flora (Barnes 1993). This is likely to be due to the unpredictable rainfall rather than the more constant temperature. This means that plants have to be opportunistic to take advantage of any rain regardless of season.

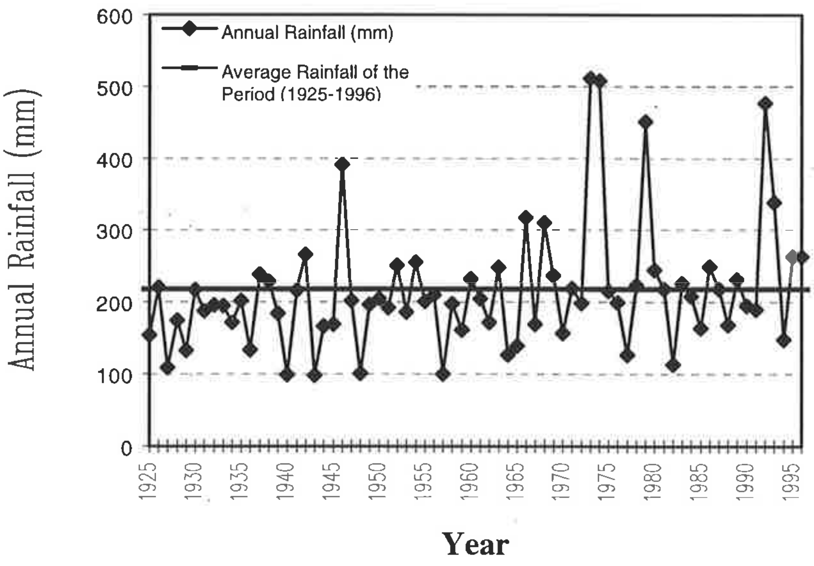


Figure 3.2. Annual and the average rainfall from 1925 to 1996 recorded at Middleback Station. The maximum rainfall is 511 mm for 1973, minimum is 98 mm for 1943 and average is 218 mm for this area.

3.1.2.2 Topography

Much of the structural geology of the region has been masked by fluvial and aeolian deposits of late Tertiary and Quaternary origin (Jessup and Wright 1971). These have given rise to the low undulating topography predominant in the area, a distinct system of interfluvial slopes and plains, washes and basins (Laut *et al.,* 1977; Johns, 1985).

The greater part of the region consists of gently undulating plains which rise gradually from sea level at Spencer Gulf to a maximum elevation of about 130 m in the west (Jessup and Wright, 1971).

3.1.2.3 Soils

The soils in the area are derived from alluvial and aeolian sedimentary parent material (Jessup and Wright, 1971) and are predominantly brown calcareous earths with a clay-loam texture (Northcote, 1968). Soil texture in the profile is gradational, with the clay fraction increasing with depth, and a marked layer of calcium carbonate nodules occurs at depths of between 20-50 cm (Northcote, 1968). Two minor soil types have been described by Northcote (1968) for the region; 1) where calcium carbonate is readily observable in the surface horizons and is at maximum concentration before a depth of 30 cm (Gc1.12), and 2) where an acid test is needed to detect $CaCO_3$ at the surface and the maximum concentration is at depths of at least 40-50 cm (Gc1.12).

Surface soils, commonly dark reddish-brown, range from sand to clay-loam in texture. These soils may be prone to scalding if the vegetation cover is removed as the lighter, and often more sandy top soil is easily removed by wind and water action.

3.1.3 Biotic Features

3.1.3.1 Vegetation

Three vegetation associations were present in the general area (Reid, 1984). These associations are:

a) Chenopod Low Open-Shrubland

These plant communities are generally dominated by *Atriplex vesicaria* (bladder saltbush) and *Maireana sedifolia* (pearl bluebush). The saltbushes dominate in low lying basins and washes, but both species appear together on the interfluvial slopes and plains. In areas subjected to heavier grazing pressure, washes and basins are dominated by *Maireana pyramidata* (black bluebush) and slopes and plains by *Maireana sedifolia*. Other shrub species, *Atriplex stipitata* (bitter saltbush) *Maireana georgei* (satiny bluebush) and *Rhagodia ulicina* (spiny goosefoot), are also common in these plant communities.

b) Western Myall Low Open-Woodland

This vegetation association dominates most of the region. It consists of a scattered but dominant overstory of *Acacia papyrocarpa* (western myall) over chenopod steppe. Tree density is higher in lower lying areas, where other tree and tall shrub species, such as *Alectryon oleifolius* (bullock bush), *Eremophila scoparia* (scotia bush) and *Myoporum platycarpum* (sugarwood) may also attain local dominance. Under the canopies of the larger trees (i.e. western myall and sugarwood) there are often two berry-fruited chenopods, *Enchylaena tomentosa* (ruby saltbush) and *Rhagodia spinescens* (thorny saltbush). The understoreys of this vegetation association are bluebush, saltbush and blackbush in varying proportions.

c) Black Oak Low Woodland

Due to its clonal nature, the black oak-low woodland association, comprised of quite dense groves of *Casuarina cristata* (black oak), is common in this area. Groves generally range in size from about one to one hundred hectares and are normally found on deeper sandier soils (Hunt, 1995). Black bluebush, bluebush and saltbush, as well as the berry-fruited chenopods (*Enchylaena tomentosa* and *Rhagodia spinescens*) are the usual understorey of this association.

These three community types form a mosaic of vegetation throughout the area. In all cases, the woodlands are sparse and the chenopod shrubland exists as a continuous system throughout, with or without an overstorey.

3.1.3.2 Lichen Cover

A systematic examination of lichens in soil crusts of arid and semi-arid landscapes in South eastern Australia was undertaken by Rogers (1970; 1972a; 1972b and 1974). Lichen populations on soil crusts around sheep watering places in this area; was studied by Rogers (1970) and he found twenty lichen taxa in Two-mile Paddock on Middleback Station. These lichen species are tabulated in Table 3.1

Table 3.1 The list of twenty lichen species which were distinguished by Rogers (1970) for study area. The name of some of species were changed and the new name were replaced by Filson 1986.

No.	Species	Climate	Habitat
1	*Acarospora ferdinandii* (Müll. Arg.) Hue	Arid, Semi Arid	Pebbles
2	*Aspicilia calcarea* (L.) Mudd (crustose)	Arid, Semi Arid, Humid	Soil, Rock
3	*Aspicilia calcarea* (L.) Mudd (fruticose)		
4	*Caloplaca sublobulata* (Nyl.) Zahlbr.	Arid	Soil
5	*Chondropsis semiviridis* (F. Muell. ex Nyl.) Nyl.	Arid, Semi Arid	Soil
6	*Cladonia foliacea* (Hudson) Schaerer	Arid, Semi Arid	Soil
7	*Collema coccophorum* Tuck	Humid	Soil
8	*Diploschistes ocellatus* (Vill.) Norman	Arid, Semi Arid	Soil
9	*Diploschistes scruposus* (Schreber) Norman	Arid, Semi Arid, Humid	Soil, Rock
10	*Endocarpon pusillum* Hedwig	Arid, Semi Arid, Humid	Soil
11	*Eremastrella crystallifera* (Taylor) G. Schneider	Arid, Semi Arid	Soil
12	*Fulgensia bracteata* (Hoffm.) Jatta	Arid, Semi Arid	Soil
13	*Heppia lutosa* (Ach.) Nyl.	Arid, Semi Arid	Soil
14	*Heppia polyspora* Truk.	Arid, Semi Arid	Soil
15	*Neofuscelia pulla* (Ach.) Esslinger	Arid, Semi Arid, Humid	Soil, Rock
16	*Psora decipiens* (Hedwig) Hoffm.	Arid, Semi Arid, Humid	Soil
17	*Toninia caeruleonigricans* (Lightf.) Th. Fr.	Arid, Semi Arid	Soil
18	*Trapelia coarctata* (Sm.) Choisy	Arid, Semi Arid	Soil
19	*Xanthoparmelia molliuscula* (Ach.) Hale	Arid, Semi Arid	Soil
20	*Xanthoparmelia amphixantha* (Müll. Arg.) Hale	Arid, Semi Arid	Soil

3.1.3.3 Fauna

As well as sheep, other herbivores such as western grey kangaroos (*Macropus fuliginosus*), red kangaroos (*M. rufus palidus*), rabbits (*Oryctolagus cuniculus*) and emus (*Dromaius novaehollandiae*) also inhabit the area. Numbers of these herbivores fluctuate from year to year, depending upon whether favourable or drought conditions prevail, whereas the number of sheep on the station does not vary greatly from one year to the next. There has been no attempt to interfere with the populations of these animals. The stations practice a no-shooting policy, and permit only the activities of those who hunt or trap vermin such as the introduced rabbit (*Oryctolagus cuniculus*). Lange *et al.* (1984) have described incidental features of the area and policy management.

3.1.4 Land Use

The main form of land use in the Whyalla region is the pasturing of sheep on the native vegetation. Sheep pastoralism in the area was introduced in 1868 but occurred only sporadically until 1919, when the Nicolson family took up the Roopena lease for wool production (Lange *et al.* 1984). The management principles are the Waite/Nicolson model (Lange *et al.* 1984) which has involved the close subdivision of the shrubland into small paddocks (2000 ha or less). Each paddock contains a permanent water source, and flock sizes are limited to 350 sheep, although 250 is preferable. Overall stocking is light at about 6 ha $sheep^{-1}$ (Lange *et al.* 1984). Destocking of paddocks is not carried out, even during drought, because of these conservative stocking rates.

An important part of the development of the Middleback and Roopena Stations, involved the construction of an extensive water piping system to distribute water from one major reliable well to other locations throughout the properties (Lange *et al.* 1984). In addition to underground water, pastoralism in the area relies on an extensive series of surface catchment dams which retain water for varying periods. Some properties also have access to water piped more than 200 km from the River Murray in the east of the State.

Land is occupied for sheep pastoralism in this area, as it is in the majority of the SA rangelands, under a leasehold system administered by the State Government. Lease agreements are initially issued for 42 years. They include covenants imposing maximum stock numbers for each lease and a requirement that the vegetation resources of the lease be maintained at least in the condition existing at the time of the granting of the lease (South Australia, 1989). A system of range condition monitoring and assessment is implemented by the government.

3.1.4.1 Paddock Management And Their Descriptions

The station is divided into fenced paddocks varying in area from 500 to 5,000 ha. Sheep are unshepherded, and set-stocked in these paddocks. The annual cycle of grazing management in the paddocks of this area is as follows. The sheep are allocated to the paddocks after shearing (March). Lambing occurs in June, lamb-marking in August, and the rams run with the ewes from late December until shearing.

This research was conducted in three paddocks of Middleback Station (Purpunda, Railway and Overland Paddocks). The paddocks usually have different grazing histories with different stocking rates of sheep. Sheep were usually of mixed sex and weaned between 8 months to 20 months. The climate and vegetation cover are approximately the same.

Overland Paddock

This paddock is in the vicinity of Railway Paddock (South) (Figure 3.1). The area of this paddock is 1270 ha and it was created in 1937. An average of 120-150 sheep run in this paddock. The paddock is also used at shearing time and may contain up to 2000 sheep for several weeks during February and March. The annual cycle of grazing management is the same as for the Purpunda and Railway Paddocks. It is serviced by a single permanent water point (tank + trough) and three dams (Carribie Dam, Overland Dam and Swamp Dam). The permanent water point (Yard Tank) was installed in 1975 in the north-west corner of paddock and water is supplied through a pipeline from the Carribie Dam.

Purpunda Paddock

Purpunda paddock is situated on the Middleback lease, approximately 7km from the Middleback homestead (Figure 3.1). It is a rectangular paddock of 1440 ha, set-stocked with an average of 250 sheep continuously since 1966 and serviced by a single watering-point (tank + trough) near the north-east corner.

Railway Paddock

This paddock is situated approximately 7.4 km north of the Middleback homestead and is easily accessible (Figure 3.1). The size of the paddock is 6.2 km along the longest (N.W.) axis and 4 km at its widest point and it was created in 1937 with 1280 ha area. An average of 200-220 sheep are grazed in this paddock. Occasionally up to 1,000 sheep are held [illegible] prior to shearing for approximately one week. It is serviced by a single watering-point (tank + trough), the same as Purpunda Paddock, and is installed in the north-west corner of the paddock. This trough is a permanent water point which was installed in 1938 and is supplied through a pipeline from the Railway Dam.

3.2 Methodology

3.2.1 Overview

The regional rangeland ecological dynamics of chenopod shrubland in response to grazing was considered within the landscape perspective. As a result, the soil and plant properties should be considered for this study. Therefore, the site selection and the precision of data collection are important.

3.2.2 Site Selection

The selection of a range monitoring site for the determination of vegetation dynamics, in response to grazing in rangeland ecosystems, is important for both managers and researchers as it is the basis of livestock and natural resources. Different natural features and various management characters should be considered in this unit and the interpretation of analysis is depend on the monitoring method and the features that are measured. Senft *et al.* (1987) hypothesised that animals often perceive relatively consistent assemblages of plant populations that are clustered in conjunction with soils or patterned by disturbance. The vegetation of particular areas differs in a characteristic way from that of other areas.

In rangeland ecosystems, the paddock is the grazing management unit and it is the pasture sites which have different management histories. Friedel (1990) suggested that a site can be chosen to represent the management history of a particular paddock, with the intention that it be compared with sites in other paddocks and other properties.

3.2.3 Precision Of Data Collection

Arid and semi-arid landscapes are highly variable through space and time in part because of landscape processes that redistribute resources (Ludwig and Whitford 1981). The grazing pressure on plant communities with the same stocking rate in different parts of the paddock is not equal (Friedel 1994). Fitzgerald and Burnside (1988) outlined a case in which 70% of sheep grazing time was spent in less than 12% of a paddock, resulting in over use of that particular portion, despite an overall conservative stocking rate.

Rangeland ecologists need to be able to explore spatial relationships of many species over many environmental features in relation to grazing effect. It is not adequate to monitor a single point in the landscape, because that point is influenced by processes occurring at points around it (Friedel 1990). Instead, it is better to monitor a series of points linked by resource redistribution processes within a landscape unit (Tongway 1989). The measurement of finer scales is more comprehensive for an ecologically sound rangeland management. In addition, precision is low when small data sets are used to estimate plant dynamics as a function of distance from watering points. On the other hand, random selection of monitoring sites might give misleading information (Ludwig and Tongway 1992).

3.2.4 General Method

Vegetation trends can be measured by various techniques. For example, vegetation can be inventoried at the time a plot is established and resurveyed every few years. A second approach is to measure vegetation inside and outside an exclosure at the time of construction and again at appropriate intervals. In this method a control is provided. However, both procedures require a period of several years to detect vegetation trend.

The inference technique of Tueller and Blackburn (1974) used in this study requires a much shorter time period. It is assumed that study areas have approximately the same site potential, i.e., if any one of the sites is given the proper use or degree of rest, it could attain a condition equal to or approaching the best condition. The "best" condition site can be defined as quantitative expression of "excellent" condition. The inference technique has both advantages and disadvantages (Tueller and Blackburn 1974). The advantage of this technique is that the results can be obtained at the end of any given field season. The principal disadvantage is inherent in the difficulty of interpretation brought about by seeming differences or similarities in site potential.

The paddocks (study sites) were determined to have a similar effective environments. Soil, topography and climate are homogeneous, and their soils belong to the same family (Brown calcareous earths with a clay-loam texture: Northcote 1968). These offer the best evidence that site potentials are equivalent. Where no differences occurred in elevation and aspect, it was judged that each paddock had the potential to produce the same vegetation.

Patterns in plant communities were examined across a grazing gradient within a large chenopod shrubland community. The plant features were examined and correlated with soil variables and cryptogam cover in the region. This is necessary because, to select the most informative ecological indicators, a field survey is conducted by sampling vegetation and soil attributes at regularly contiguous quadrats positioned intervals along the transect (Ludwig and Tongway 1992). The samples were collected from Purpunda, Railway and Overland Paddocks and these three paddocks were selected to have replication of data for generalisation of result for pattern of chenopod shrubland of these regions. These three paddocks were located close to each other to minimise differences due to climate and they were determined to have a similar effective environment. The soil and vegetation communities of these three selected paddocks are located at extensive areas of the arid chenopod shrubland of South Australia. These areas were defined as arid land which generally have a rainfall of less than 250 mm per year (Anonymous 1990).

A radiating transect sampling system was chosen as the best compromise between equal coverage of the paddocks and efficiency of time spent on data collection. The data were collected from contiguous quadrats along the transects at different distances from watering points in the three paddocks. Positioned in this way, the transects are set along a grazing gradient which should facilitate the recognition of different grazing pressure zones and represent vegetation in different stages of degradation due to grazing. The direction of the transect lines was determined by compass bearings, and the transects were also laid out to avoid the possible effects of other watering points within the same paddocks.

A preliminary study was carried out on the chenopod shrubland community in Spring 1994 to determine the species composition and significant plant species according to the statistical results and their importance to livestock grazing in the three paddocks. As a result of statistical analysis and palatability value for grazing, five chenopod shrubland species ranging from very low to moderate palatability (Wilson, 1994) were chosen for the main project. A series of measurements was carried out on these five perennial species as the target vegetation type and environmental data after the preliminary experiment.

A single-plot method closely examined the single limited area at different distances from the watering points at three paddocks. These plots were at least as large as the minimal area of the chenopod shrubland community. Minimal area is based on the premise that the true characteristics of a plant community need a minimum area for expression and any smaller areas examined would not fully represent the community characteristics. Plant and ground data were collected from these contiguous quadrats and were analysed with a high-precision level-surveying instrument. The details of the sampling design protocol for each study are explained in chapters 4, 5 and 6.

3.2.5 Data Analysis

Many ecological studies are descriptive and based on field surveys, as the complex levels of communities, ecosystems and landscapes are not readily investigated by manipulative and experimental techniques. The result is that complex and large data sets are generally produced (Jongman *et al.* 1996). The data analysis is also usually multivariate, in that each sampling unit is characterised by many attributes (Gauch, 1982; Jongman *et al.* 1996). For example, in this study each site is characterised by many plant features and a range of environmental variables. Descriptive ecological data therefore usually contain information which is only indirectly interpretable. The numerical techniques have a high degree of mathematical sophistication, so their use has been greatly facilitated by the availability of computers (Noy-Meir and Whittaker 1978). To advance research on the multiple relationships of livestock grazing, computer-based analyses using multiple variables are needed and can be used as indicator variables in simplified models for analysis and decision making (Scarnecchia 1994).

Extensive literature is now available on the theory and applications of multivariate methods in an ecological context (e.g. books and comprehensive reviews by Gauch 1982; Legendre and Legendre 1983; Greig-Smith 1983; Digby and Kempton, 1987; Gower 1987; Ludwig and Reynolds 1988; Ter Braak 1991; Jongman *et al.* 1996; Ter Braak and Prentice 1988; Shi 1993). Multivariate methods allow the data from community studies to be sorted without the investigator forcing in any preconceived ideas about which species tend to be associated with each other, or which environmental variables correlate most strongly with the species distributions. In other words, by using multivariate methods, range types could be classified, condition states identified and trends in vegetation change could be discerned (Friedel *et al.* 1988).

The development of multivariate analysis is useful in the assessment of condition: the comparison of each monitored location with all others, using classification and ordination of forage composition (Friedel 1991). This approach produces classes and orders of locations which can be interpreted according to known site factors. Ordination (indirect gradient analysis) and classification (cluster analysis) are among the most widely used techniques of multivariate analysis (Jongman *et al.* 1996). Shi (1993) has reviewed the multivariate data analysis and explained the cluster and ordination analysis as follows: Cluster analysis and ordination are similar techniques in the sense that they both serve to summarise large, complex, multidimensional data sets by reducing dimensionality and extracting major components of variation. The two differ, however, in strategy and outcome. Classification groups similar entities into clusters (Gauch 1982) and closely replicates the natural cognitive tendency of humans to group objects. Cluster analyses determine aggregations within landscapes and a dynamic model to determine stable states and probabilities of transitions within sites (Friedel 1994). Ordination arranges data in a low-dimensional space so that similar locations are near each other and dissimilar locations are far apart (Gauch 1982). Therefore, the relationships are identified and environmental interpretations can be made.

3.2.5.1 Numerical Analysis

Series of multivariate analyses in the PATN package developed by Belbin (1991) were carried out, incorporating both clustering and ordination analyses. This procedure was used for reducing the number of species and attributes to a small number of readily recognisable data sets from which interpretations can be easily made. The analysis of plant and soil-based attributes was independently carried out for each site.

The cluster analysis used (Bray-Curtis 1957) dissimilarity on range-standardized data. The Bray-Curtis coefficient was chosen because it was shown by Faith *et al.* (1987) to have a robust rank correlation with ecological distance. UPGMA (unweighted pair group mean association) clustering, was used as an agglomerative association method used to produce hierarchical dendrogram. The ordination used semi-strong hybrid multidimentional scaling (MDS). To rank sites along a series of axes which describe the major attribute variation. The results are displayed as a scattergram, from which continuity and disjunction of vegetation types can be determined. Indirect gradient analysis with principal canonical correlation (PCC) was used to determine if there were any correlated effects between the vegetation-derived ordination axes and the environmental parameters (Belbin 1991). The group definition and group statistic options (GDEF and GSTA) were used to assess significant character differences between dendrogram groups with the Kruskal-Wallis statistic.

Chapter 4 Species Composition And Significant Plant Species

4.1 Introduction

Understanding and predicting vegetation responses to grazing is an important step in preventing overgrazing, erosion and a loss of production. Plant features are inherently more sensitive to grazing pressure than soil features, because herbivores are able to alter quickly and drastically the density and basal cover of plants, and so change the effectiveness of management (Tongway and Ludwig, 1994).

Perennial vegetation serves two main important functions in rangeland ecosystems. Firstly, it is a soil stabiliser, which is essential for the germination and growth of ephemeral species (Moore 1962; Graetz and Tongway 1986). Secondly, it is a maintenance diet for animals in times of drought when ephemeral herbage availability is low or absent (Graetz and Wilson 1984). Hence shrubs are often regarded as the "haystack" of the rangelands (Yan *et al.* 1996).

The woodlands of semi-arid Australia are prone to degradation by the grazing of sheep and cattle (Mabbutt and Fanning 1987, Harrington *et al.* 1984). Degradation takes one or more of the following forms: 1) decreased occurrence of perennial grasses, 2) increased density of inedible shrubs, and 3) loss of soil productivity (Hodgkinson 1991).

In a paddock system, grazing pressures are variable and depend on different factors. The areas where sheep graze depend on a trade-off between the distance to water, vegetation-palatability, selective grazing behaviour, plus other factors such as wind direction and distance from water resource. Sheep will walk several kilometres from a water source for their preferred food species, ignoring unpalatable or less palatable species except in times of extreme drought (Squires 1981).

Investigation in different paddocks with different grazing histories is necessary to produce better results, because the collection of the data and their analyses have replication. These data may be generalised for the region. On the other hand, it is also not sufficient to monitor a single point in the landscape because that point can be influenced by processes occurring at points around it (Friedel 1990; 1994).

Decisions based on an assessment at only one or two points in a paddock or on areas only lightly utilised will not give a true indication of changes caused by livestock. It is necessary to consider spatial heterogeneity when investigating the causes of vegetation change, particularly under grazing by livestock. Grazing influences various attributes of a plant community, including species composition, individual plant productivity and the life form of each plant species.

This research was conducted on chenopod shrublands in South Australia because they are widespread in the winter rainfall zone (150-500 mm per annum) (Oxley 1979) and are important to pastoralism. Focus was placed on spatial structures and patterns arising directly from plant-herbivore interactions. An examination of the abundance, distribution and dominance attributes of these communities is important when assessing the population dynamics of these regions. By studying overstocked areas it may be possible to detect incipient changes in the vegetation to determine whether any thresholds can be defined, measured and analysed and the results used to establish standards for rangeland management.

4.2 Aims And Objectives

An initial survey was conducted on three chenopod shrubland paddocks with known grazing histories to meet the following aims:

1. To determine the species composition of chenopod shrublands in this region.

2. To identify significant plant species in this community with different responses to grazing pressure.

3. To identify 'increaser' and 'decreaser' species in response to grazing pressure.

4.3 Materials And Methods

The study was set up in three paddocks, all located at Middleback Station (see Chapter 3). The three paddocks; Purpunda, Railway and Overland Paddock were selected to represent the three grazing histories described in Chapter 3. It is necessary to investigate the species composition of these paddocks in order to describe vegetation changes caused by long-term grazing by sheep. Also, it is important to identify significant plant species which are sensitive to grazing pressure and are significant to sheep grazing trends in populations of chenopod shrubland communities and their values for livestock grazing in Australia.

Four radiating transects were used in each paddock at different angles (according to the situation of water resources in each paddock) (Figure 4.1). This method was chosen to cover a range condition gradient from areas with minimal effect from grazing to areas that were severely overgrazed. Distances to permanent water points were taken into account in order to select sample units with different grazing intensities. A base peg was established at each trough in each of the three paddocks. Four radial transects were made at 60° intervals out from the peg of Purpunda Paddock and Railway Paddock between 270° and 90°, 200° and 20° respectively. In the Overland Paddock, four transects were oriented at 30° intervals, between 180° and 90° (Figure 4.1).

A single-plot method was used to examine the vegetation along each transect at different distances from the watering points in each of the three paddocks. They were distributed along the radius from the troughs as quadrats. The quadrats were set at increasing distances from troughs in order to detect various degrees of degradation. A total of 120 quadrats were examined for chenopod shrub species in the three paddocks with a subset of 40 quadrats in each

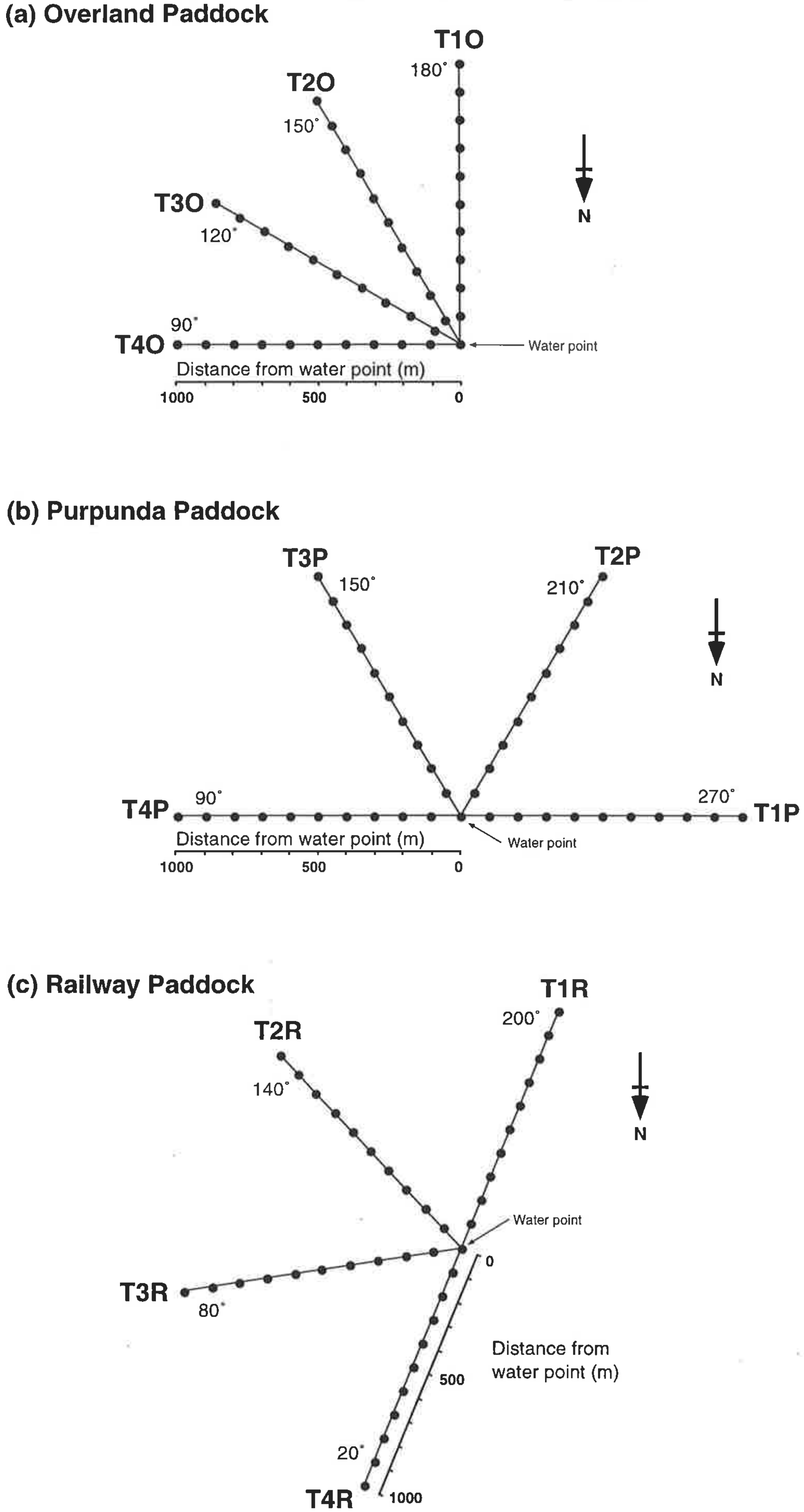


Figure 4.1. Position of quadrats in (a) Overland Paddock, (b) Purpunda Paddock and Railway Paddock. Transects radiated from the watering point at various compass bearings and are numbered accordingly. Along each, quadrats (●)were placed at 100-1000 m at 100 m intervals.

paddock. The sizes of these quadrats was determined using species area curve data; each quadrat was 16 m x 16 m. Ten quadrats were sampled along each transect at 100m intervals from the watering point. These distances were used on alternate transects to give better sample distribution, particularly close to the water points. The average width (diameter) of individuals of perennial chenopod plant species was measured in each quadrat. The projected canopy cover of each individual plant species was calculated from the field data. The percentage of this canopy was computerised for each individual plant. Because the measurement of percentage of canopy cover is believed to be strongly correlated with shrub density (Graetz and Ludwig 1978), this feature was calculated by individual for each plant species in the area. Annual species were excluded because their occurrence depends on recent seasonal events; their inclusion would therefore lower the repeatability of the results. The identity of all specimens was continually checked by means of a portable herbarium. Botanical nomenclature follows Wilson (1994).

4.3.1 Data Analysis

The data were analysed by cluster analysis using the Bray-Curtis agglomerative hierarchical dissimilarity measure on range-standardised data (Bray-Curtis 1957). Clustering was achieved with the average linkage method (Clifford and Stephenson 1975) or UPGMA (unweighted pair group mean association). Quadrats were grouped by cluster analysis according to similarities based on the percentage of cover of each species. The relationships between the quadrats based on their plant species frequencies were determined via Semi-strong Hybrid Scaling (Belbin 1991) using the SSH module in the PATN program (Belbin 1995). Varimax rotation was then used to improve the relative positions of the ordination relation to the primary axes. Principal canonical correlation analysis (PCC) with the species was performed to determine if there were any correlated effects (Belbin 1991). The group definition and group statistic options (GDEF and GSTA) in PATN were used to assess significant character differences between dendrogram

Table 4.1. List of the 20 chenopod plant species and their common names encountered in vegetation sampling units for three paddocks (Purpunda Paddock, Railway Paddock and Overland Paddock) at Middleback Station.

Plant species	Common names
Atriplex holocarpa F. Muell.	Pop Saltbush
A. stipitata Benth	Bitter Saltbush
A. vesicaria Heward. ex Benth	Bladder Saltbush
Chenopodium murale L.	Nettle-leave Goosefoot
Dissocarpus biflorus F. Muell.	Twin-horned Copperburr
D. paradoxus (R. Br) F. Muell. ex Benth	Cannonball, Ball Bindyii
Enchylaena tomentosa R. Br.	Barrier Saltbush
Eriochiton sclerolaenoides (F. Muell.) F. Muell. ex A. J. Scott	Woolly-fruit Copperburr
Maireana appressa Paul G. Wilson	a woolly bluebush
M. georgei (Diels) Paul G. Wilson	Satiny Bluebush
M. pyramidata (Benth.) Paul G. Wilson	Black Bluebush
Ma.sedifolia (F. Muell.) Paul G. Wilson	Pearl Bluebush
M. trichoptera (J. Muell.) Paul G. Wilson	
Rhagodia parabolica R. Br.	Old Man Saltbush
R. spinescens R. Br.	Thorny Saltbush
R. ulicina (Gand.) Paul G. Wilson	Spiny Goosefoot
Salsola kali L.	Prickly Saltwort/Buckbush
Sclerolaena diacantha (Nees) Benth	Grey Copperburr
S. obliquicuspis (R. Anderson) Ulbr.	Limestone Copperburr
S. patenticuspis (R. Anderson) Ulbr.	Spear-fruit Copperburr

It was clear from this clustering of quadrats and the distribution of grouped quadrats across the paddocks that the vegetation was likely to be heterogenous i.e. the percentage cover and identity of species depended not only on which paddock was being considered but also the location within the paddock. In order to describe the vegetation characteristics of these three groups of quadrats, group statistics of percentage cover were calculated and are presented in the next section.

4.4.2 Group Description

Table 4.2. shows, for each species, the mean percentage cover and associated standard deviation (SD) for quadrats within each dendrogram group. The Kruskal-Wallis test showed that of the 20 plant species considered, only ten showed significant difference in mean percentage cover between the three dendrogram groups. The remaining species were considered individually and a species is considered to be characteristic of a dendrogram group if it attained its highest mean percentage cover score in that group.

The G1 quadrats were characterised by the greatest percentage cover of *M. pyramidata* (64.53%), *A. stipitata* (1.92%), *R. parabolica* (5.27%) and *D. paradoxus* (1.05%). The plant species with the highest percentage cover in G2 quadrats were: *A. vesicaria* (31.02%), *M. georgei* (6.29%), *D. biflorus* (2.99%) and *E. sclerolaenoides* (1.82%). *M. sedifolia* and *R. ulicina* were dominant species in G3 quadrats with 72.27% and 9.48% percentage of cover respectively.

4.4.3 Ordination

Ordination of quadrats based on percentage of cover of 20 species was used to check the integrity of dendrogram groups. A scatter plot of quadrats on the first two ordination axes is given in Figure 4.3. The ordination indicates a clear distinction between groups obtained by the agglomerate cluster analysis. The G1 quadrats lie nearly on the middle and upper quadrants

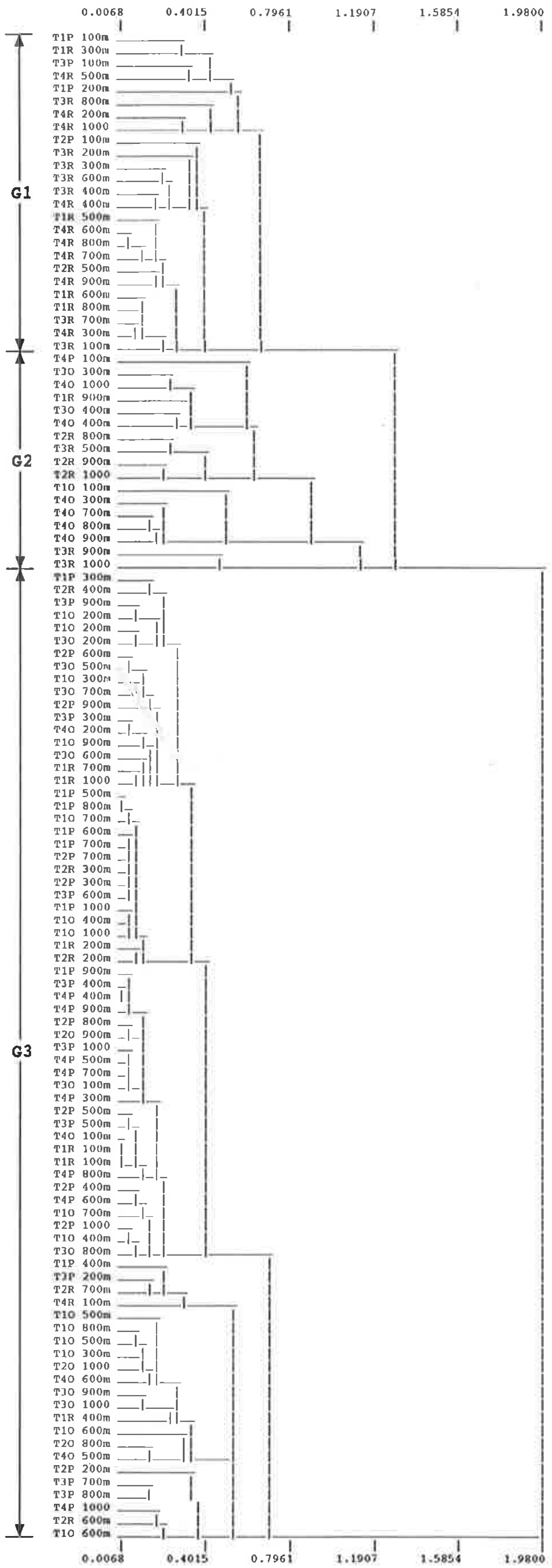


Figure 4.2. Cluster analysis of all 120 sampling units for the percentage of cover measured for 20 plant species at Overland Purpunda and Railway Paddocks.
The groups were also illustrated as labels. The labels used are alphabetical abbreviation and digit number, where the (G) is abbreviation of group and the digital numbers are unit of each group. For example; the label G3 represents group three. T1-4O are transect label of Overland, T1-4P are transect label of Purpunda and T1-4R are transect label of Railway Paddock. See Figure 4.1 for quadrat location.

and the G2 quadrats overlap with some part of the G1 quadrats. Three G1 quadrats of this group are well separated from the rest of the G1 quadrats along axis 1 and are located in the upper left quadrant. G3 quadrats are separated from other two groups along axis 2 and are mostly distributed on the middle lower quadrants.

4.4.4 PCC Analysis

For determining the correlation of percentage of cover of perennial plant species of three paddocks with the quadrat ordination, indirect gradient analysis with principal canonical correlation (PCC) analysis (Wilkinson 1990) was used. The results of this analysis are demonstrated in Table 4.2. and in Figure 4.4. Eleven plant species (*A. stipitata, A. vesicaria, Dissocarpus paradoxus, D. biflorus, Eriochiton sclerolaenoides, M. georgei, M. pyramidata, M. sedifolia, Rhagodia parabolica, R. ulicina* and *Sclerolaena obliquicuspis*) were significantly ($P<0.002$) correlated with the quadrat ordination (Table 4.2). Vectors representing increasing percentage of cover of these species are shown in Figure 4.4 and together with the quadrat groups (Figure 4.3). These show similar patterns of species correlation as were revealed by group statistics of dendrogram groups. *M. pyramidata* and *R. parabolica* showed increasing percentage cover in G1 quadrats. *M. sedifolia* and *R. ulicina* were highly correlated with G3 quadrats. G2 quadrats showed an interesting pattern of species composition, with the majority of quadrats having high percentage cover of *A. vesicaria* and *D. biflorus*, but three outlying quadrats (low axis 1 score) showing a different composition with high percentage cover of *M. georgei* and *A. stipitata*.

4.4.5 Vegetation Description

The classification dendrogram is summarised in Figure 4.5, along with the number of vegetation types, the list of plant species in each group, and the distribution of sampling units. The following descriptions are for the three major vegetation types of the area which resulted from the multivariate analysis.

Table 4.2. Summary of statistics of dendrogram groups for three paddocks (Overland, Purpunda and Railway Paddock showing the mean and standard deviation of the percentage cover of each plant species. Kruskal-Wallis test indicates whether there are significant differences between the groups ($p = 0.002$). Principal Canonical Correlation (PCC) analysis indicates which plant species are significantly correlated with the quadrat ordination (df = 118, r<0.280). Note: the data for Kruskal-Wallis test and PCC analysis were not range standardised.

No.	Species	Dendrogram Groups G1		G2		G3		Kruskal-Wallis test				PCC Correlation	
		Mean	*S.D.*	*Mean*	*S.D.*	*Mean*	*S.D.*	*H*	*d.f.*	P	Sig.	*R*	*Sig.*
1	*Atriplex spongiosa*	0.00	0.00	0.03	0.10	0.00	0.01	5.43	2	0.07	n.s.	0.188	n.s.
2	*A. stipitata*	1.92	3.48	1.29	3.00	0.00	0.00	22.74	2	0.00	***	0.301	***
3	*A. vesicaria*	5.99	7.09	31.02	19.24	8.77	10.34	23.66	2	0.00	***	0.655	***
4	*Chenopodium murale*	0.00	0.00	0.50	2.00	0.00	0.00	3.05	2	0.22	n.s.	0.248	n.s.
5	*Dissocarpus paradoxus*	1.05	3.65	0.68	1.64	0.05	0.27	19.14	2	0.00	***	0.399	***
6	*D. biflorus*	1.93	3.07	2.99	4.80	0.19	0.64	34.17	2	0.00	***	0.520	***
7	*Enchylaena tomentosa*	1.33	2.44	0.65	1.62	0.50	1.88	0.52	2	0.77	n.s.	0.159	n.s.
8	*Eriochiton sclerolaenoides*	1.47	5.02	1.82	3.33	1.49	3.22	8.66	2	0.01	***	0.716	***
9	*Maireana appressia*	0.00	0.00	0.05	0.19	0.02	0.17	1.53	2	0.47	n.s.	0.203	n.s.
10	*M. georgei*	4.96	5.38	6.29	11.69	1.68	2.66	12.77	2	0.00	***	0.524	***
11	*M. pyramidata*	64.53	17.55	13.06	17.56	2.00	5.46	76.85	2	0.00	***	0.788	***
12	*M. sedifolia*	5.62	11.11	18.88	16.75	72.27	14.83	81.68	2	0.00	***	0.774	***
13	*M. trichoptera*	0.00	0.00	0.00	0.00	0.17	0.54	5.33	2	0.07	n.s.	0.243	n.s.
14	*Rhagodia parabolica*	5.27	7.85	1.65	4.43	0.79	2.36	10.89	2	0.00	***	0.301	***
15	*R. spinescens*	1.02	5.00	0.00	0.00	0.06	0.49	0.52	2	0.77	n.s.	0.276	n.s.
16	*R. ulicina*	1.75	4.62	3.94	11.71	9.48	10.26	23.07	2	0.00	***	0.420	***
17	*Salsola kali*	0.00	0.00	0.00	0.00	0.01	0.05	1.24	2	0.54	n.s.	0.209	n.s.
18	*Sclerolaena obliquicuspis*	13.13	6.52	17.12	21.06	2.48	3.19	6.08	2	0.05	n.s.	0.733	***
19	*S. patenticuspis*	0.00	0.00	0.00	0.00	0.00	0.01	0.27	2	0.87	n.s.	0.165	n.s.
20	*S. diacantha*	0.05	0.15	0.02	0.07	0.02	0.16	3.09	2	0.21	n.s.	0.140	n.s.

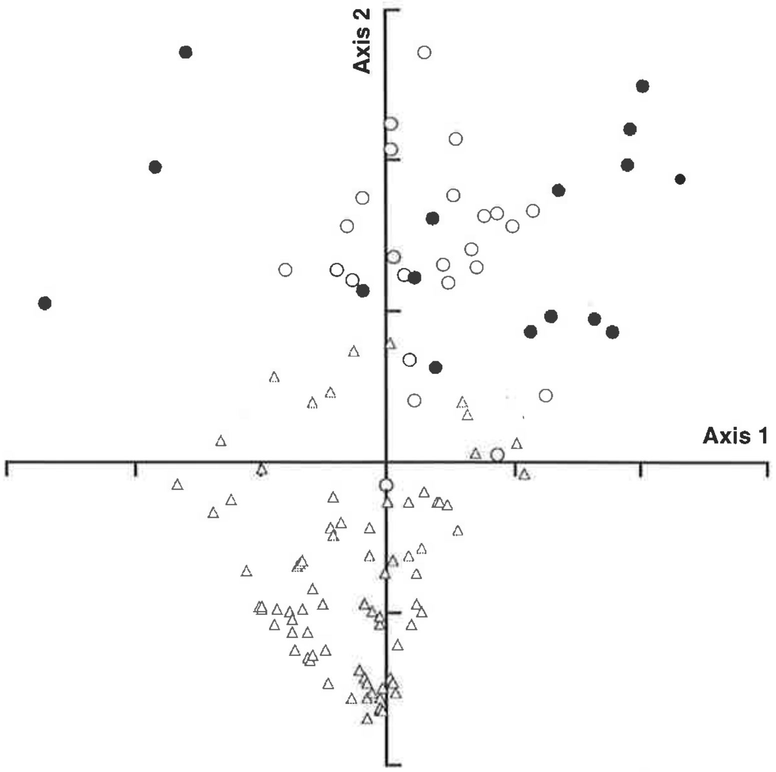


Figure 4.3. Plot of the first two axes from a semi-strong hybrid scaling (SSH) ordination of the 120 quadrats in three paddocks (Overland, Purpunda and Railway Paddocks) based on the percentage of 20 perennial plant species of chenopod shrubland. Stress = 0.08 Symbol represents dendrogram group (○ = G1, ● = G2 and Δ = G3).

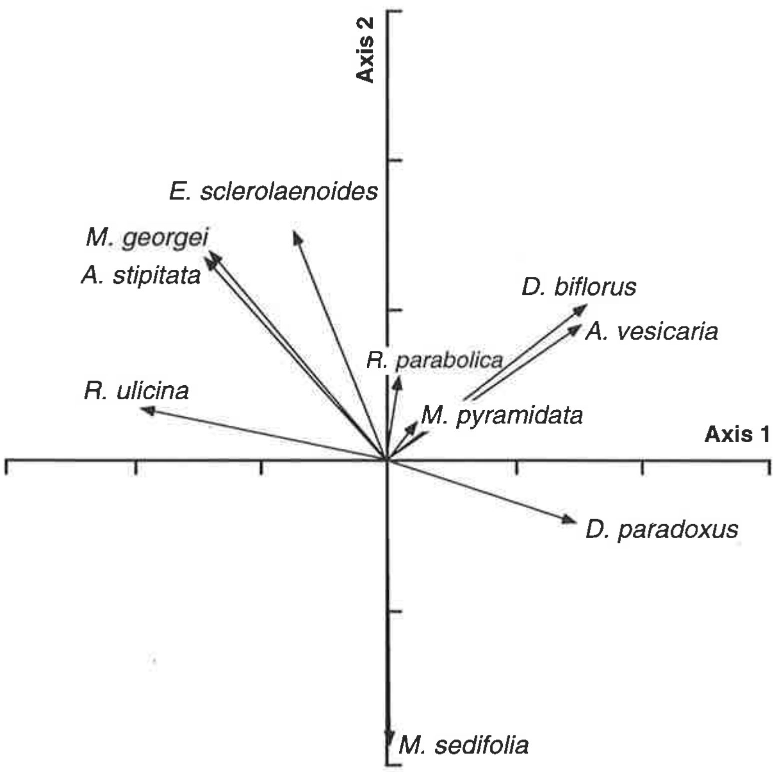


Figure 4.4. Principal Canonical Correlation (PCC) of the 20 plant species measured for three paddocks superimposed on the dendrogram group outlined plotted in Figure 4.3. The labels used are an actual name of each species which it was used for the eleven plant species. The percentage cover of these plant species was significantly (*P <0.002*) correlated with the dendrogram groups.

Vegetation type I: Of the perennial chenopod shrubs, *M. pyramidata* had the greatest cover (mean 64.53%) in this vegetation group (Table 4.2). The occurrence of *A. stipitata* and *R. parabolica* was significantly higher than in other group quadrats ($p<0.002$) based on Kruskal-Wallis and PCC analysis. These species also occurred together. Other major components of the shrub stratum were *D. paradoxus, M. georgei, A. vesicaria* and *M. sedifolia*, although *A. vesicaria* and *M. sedifolia* were relatively rare. The majority of G1 quadrats were in Railway Paddock.

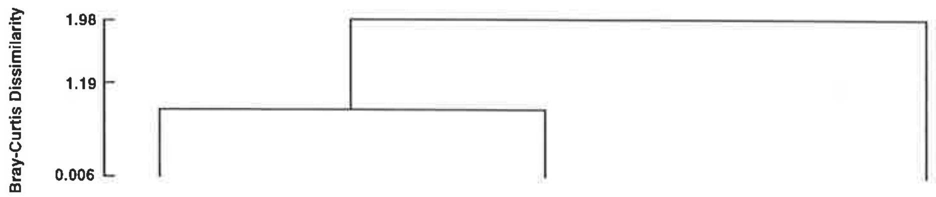
Vegetation type II: The major plant species of this vegetation type were *A. vesicaria, Dissocarpus biflorus, M. georgei, M. pyramidata* and *M. sedifolia*. The quadrats containing this vegetation type were patchily distributed in and mostly between 300-1000 m from the water points, mainly in Railway and Overland Paddocks. This vegetation group contain the lowest number of quadrat (17 out of 120 quadrats) (Figure 4.5).

Vegetation type III: These quadrats are dominated by *M. sedifolia, R. ulicina* and *A. vesicaria. M. georgei* commonly occurs, while *M. pyramidata* is less common. This vegetation type was composed of 30 quadrats in Overland, 34 quadrats in Purpunda Paddock and the remaining 13 quadrats found in Railway Paddock (Figure 4.2).

The statistical analysis showed that eleven of the 20 chenopod plant species displayed no difference in percentage cover between three quadrat groups. Of the remaining ten plant species, the percentage of each showed significant correlation with the ordination of quadrats and the percentage cover score was shown to differ between the quadrats. Vegetation types have been described on the basis of these ten important species.

4.5 Discussion

The multivariate analyses helped to identify potential functional species groups (Friedel *et al.* 1988). Also, the ability to distinguish groups from this data shows that the percentage of cover



Site group	G1	G2	G3
No. sites	25	17	78
Vegetation Type	I	II	III
Distinguishing species:	*M. pyramidata* *A. stipitata* *R. parabolica* *D. paradoxus*	*A. vesicaria* *D. biflorus* *M. georgei* *M. pyramidata* *M. sedifolia*	*M. sedifolia* *A. vesicaria* *R. ulicina*

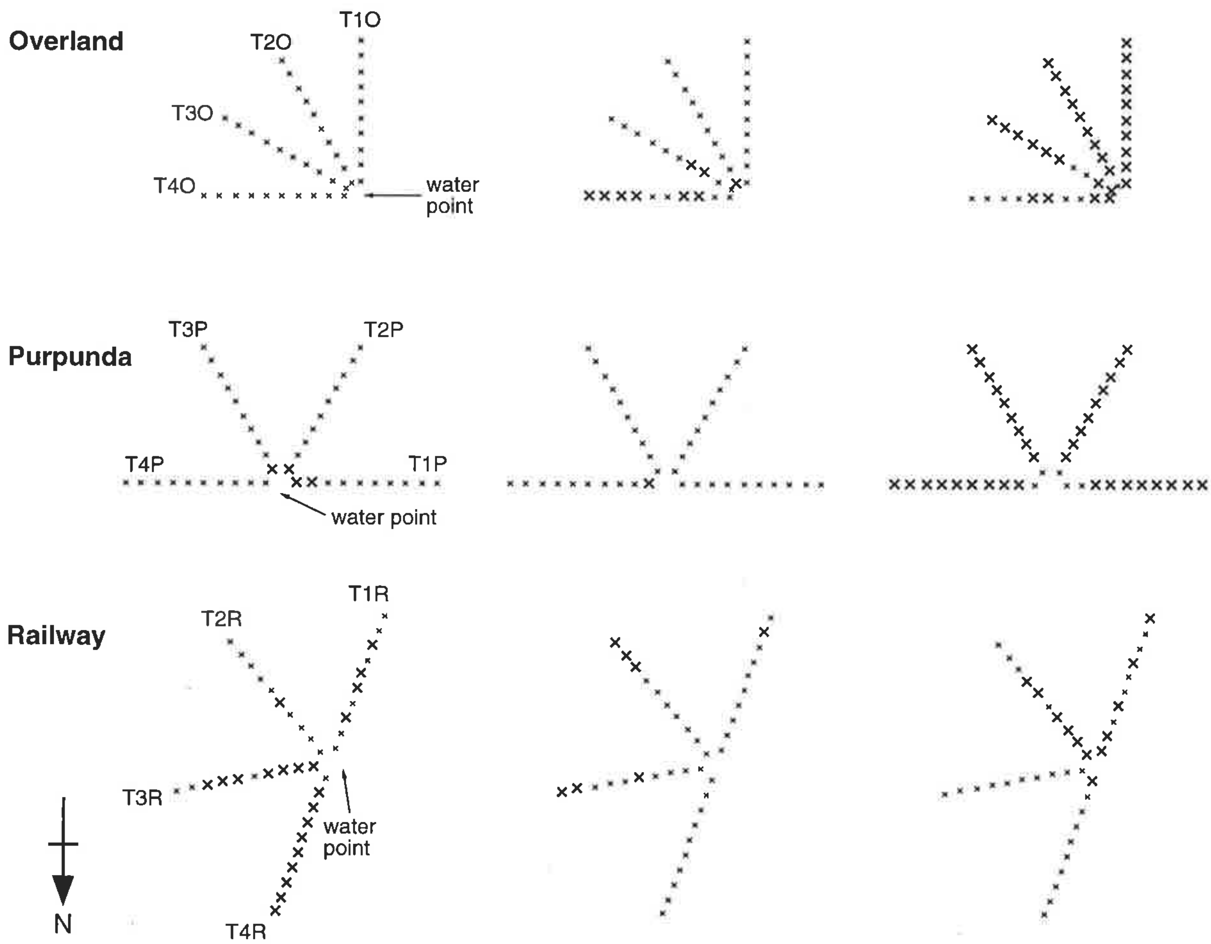


Figure 4.5. Classification quadrat groups (G1-G3), distinguishing species within each group, and the distribution of quadrats (X) and vegetation types in three paddocks.

of these plant species can be used to identify diagnostic groups along a grazing gradient. Three distinct vegetation types were observed from clustering and ordination analysis for the region. Changes in composition and cover percentage of chenopod plant species were observed along the main gradient, most likely reflecting vegetation response to grazing.

There is a common assumption that the dominance of undesirable plants on rangelands always serves as evidence for overgrazing by livestock (Laycock 1994). In other words, under continuous grazing, a decrease of palatable species and an increase in unpalatable species occurs. Also, it has generally been recognised that livestock grazing reduces desirable forage species around watering points (Lange 1969). The presence of two very low palatability plants *M. pyramidata* and *A. stipitata* (Wilson 1994) in G1 quadrats, suggests that these species are characteristic of overgrazed zones in this area and hence would be classified as 'increasers' (Dyksterhuis 1949). The high cover values of these unpalatable species together with low abundance of palatable plants *A. vesicaria, M. sedifolia* and *M. georgei* (Wilson 1994) were present around the water hole, extending into the direction of the prevailing wind at Purpunda Paddock. Most of Railway Paddock was characterised by this vegetation types, particularly areas furthest from the water point.

The presence of these shrubs of low palatability in Railway Paddock is likely be an important factor in their dominance in heavily grazed areas, which may be influenced by a long grazing history and high stocking rate of this paddock.

In general, the most unpalatable plant species were distributed around the watering point and extended along the wind direction of Purpunda Paddock. Also, the unpalatable plant species were found at the furthest point from the trough in Railway Paddock. This may be related to the longer grazing history of Railway Paddock in relation to two other paddocks and the high stocking rate of this paddock. The trough establishment of Railway Paddock is long (1937) and approximately twice as Purpunda Paddock (1966) even longer for Overland (1975) and its stocking rate (6 ha sheep^{-1}) was more than for either Purpunda (6.7 ha sheep^{-1}) or Overland Paddock (9 ha sheep^{-1}). Also, the lowest values of cover of *M. sedifolia* occur in G1 quadrats and particularly furthest away from the water point at Railway Paddock, probably because of the long grazing history and higher numbers of sheep in this paddock relative to Purpunda and Overland Paddocks. Nevertheless, although *M. sedifolia* is thought to be extremely long-lived (>300 years) (Wilson 1990), it may eventually become rare because of increased mortality and lack of recruitment in grazed areas (Lange and Purdie 1976; Crisp 1978; Lange and Graham 1983).

Overland Paddock was dominated by *A. vesicaria*, *M. georgei*, *M. pyramidata* and *M. sedifolia*, which were mostly distributed more than 400 m from the water point with patchy areas closer in. This result suggests that this paddock was moderately grazed by sheep and the grazing pressure was not excessively high.

The highest numbers of sampling units of vegetation cover of G3 quadrats were distributed more than 300 m from the water point of Purpunda Paddock. The main species of this vegetation type were *M. sedifolia* and *A. vesicaria;* this corresponds with the "chenopod low open-shrubland association" (*Atriplex vesicaria - Maireana sedifolia*) suggested by Reid (1984) for these areas (see Chapter 3). These species accounted for most of the forage production in undegraded areas which livestock can graze during the dry season and are recommended for the pastoral industry (Wilson 1994). These plants are dominant species in chenopod shrubland communities considered to be 'decreasers' under light to moderate grazing. The plant species of this group could be considered to be representative of ungrazed and/or selectively grazed vegetation.

From the chenopod plant species encountered in vegetation sampling (Table 4.1), five perennial species, *A. stipitata, A. vesicaria, M. georgei, M. pyramidata* and *M. sedifolia* were highly significant on the basis of principal canonical correlation (PCC) and non-parametric Kruskal-Wallis analysis (Table 4.2) and corresponded to Reid's (1984) vegetation association (a). These plant species were also classified by Wilson (1994) on their grazing palatability: *M. georgei* and *A. vesicaria* are considered to be moderately palatable; *M. sedifolia* and *A. stipitata* exhibit low palatability; and *M. pyramidata* very low palatability to sheep. The published diet data of Graetz and Wilson (1979) and Wilson (1994) also support the importance of these five plant species to domestic grazing in Australia. Because these five plant species are considered to be key species of chenopod shrubland communities and as they have significantly associated with the observed vegetation patterns in this pilot study, they formed the basis for subsequent studies.

Chapter 5: Pant-Based Vegetation Features

5.1 Introduction

Grazing management in chenopod shrubland communities is needed to ensure that these perennial shrubs are preserved. Sheep movement in paddocks is not random and even within a theoretically uniform pasture will be related to water distribution and wind direction (Stafford Smith 1984). Over time, the uneven distribution of animals produces, through grazing and trampling, a recognisable pattern within the vegetation centred around watering points (Lange 1969).

When herbivore numbers exceed the carrying capacity of the shrubland or woodland, damage occurs and some of the typical woody species are either removed or replaced (Platou and Tueller 1988). This means that the removal or reduction of stock at critical times is necessary and must be done before the vegetation structure crosses a threshold, when it may be irreversibly changed.

Grazing thresholds are critical in identifying those states beyond which further decline in the productivity of the rangeland is not easily reversed, and/or the cost of restoration becomes prohibitive (Hodgkinson 1991). To recognise a grazing threshold, we first need to know how much impact the grazing sheep have on different plant species of rangelands, and where the impacts occur.

It is not practical to monitor all species. Some species are insensitive to grazing and some are highly sensitive and therefore of little utility. Others are represented only by a few individuals, and estimating their abundance accurately and precisely is time-consuming and expensive. Similarly, species whose abundance changes little over range condition (i.e. the insensitive ones) might be ignored. Those species remaining can be ordered along a gradient of grazing intensity in terms of sensitivity.

5.2 Aims And Objectives

The aim of this study was specifically to address a number of topics relating grazing to vegetation pattern:

1. To examine the effect of grazing on the structure of important plant species of chenopod shrubland at different distances from a watering point.

2. To identify the spatial patterns of the important species of chenopod shrublands under continuous sheep grazing in paddock scale.

3. To identify the disturbed and sensitive zone and those "outer zones" from 1) above, beyond any obvious influence of grazing.

4. To develop a set of potential plant based indicators or signals of incipient change in chenopod shrublands which might forecast major changes in vegetation structure or productivity.

5.3 Materials And Methods

The research was set up at three paddocks: Purpunda, Railway and Overland paddocks at the Middleback Field Centre, north-west of Whyalla in the arid zone of South Australia. The study sites were described in Chapter 3.

Twelve compass bearing transects were used in Purpunda Paddock oriented at 15° intervals between 255° and 90° from the watering point. Similarly, eight transects, radiating at 25° intervals between 205° and 30°, and eight transects at 15° intervals between 190° and 85° were used in Railway and Overland Paddock respectively (Figure 5.1).

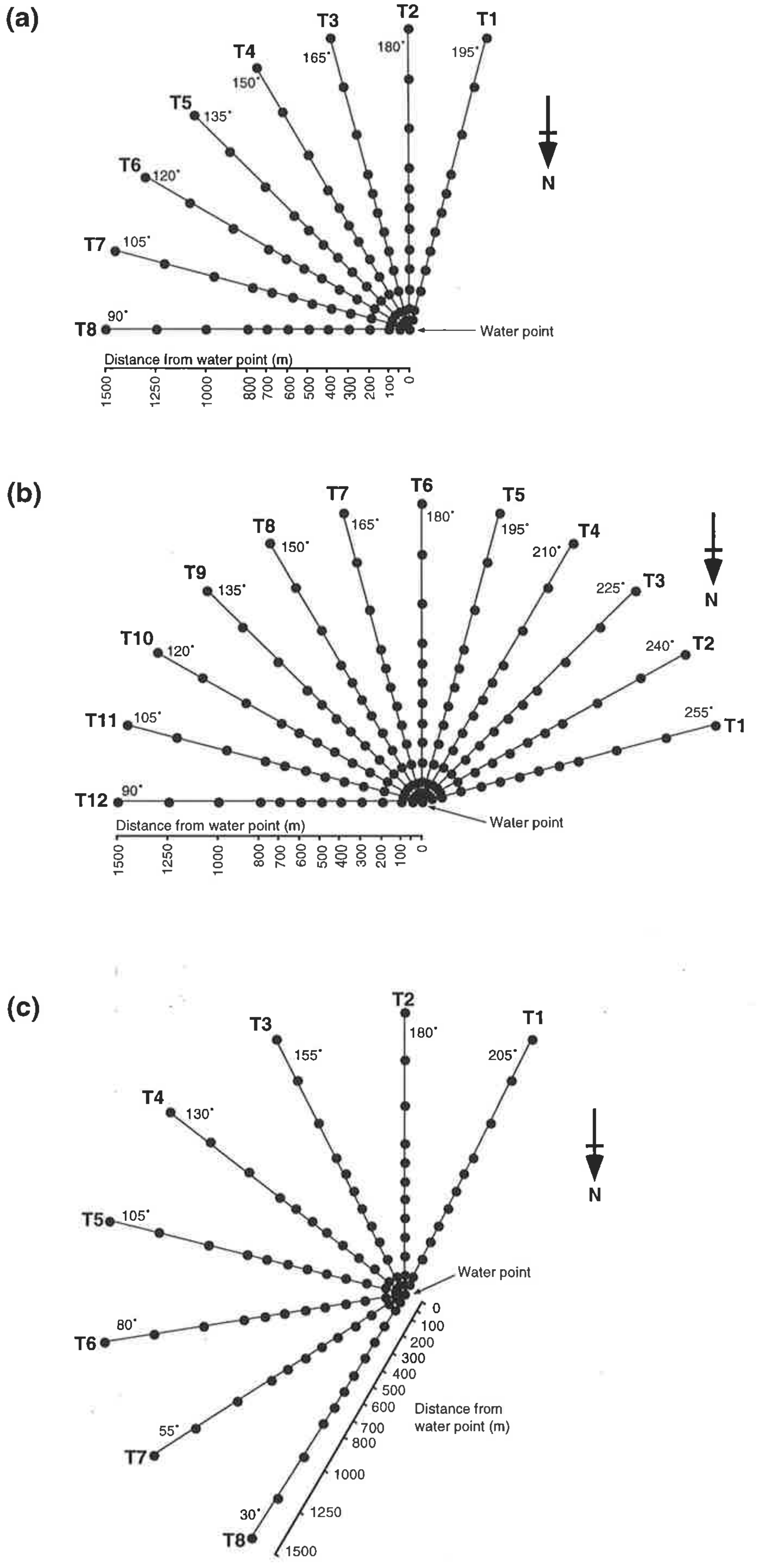


Figure 5.1. Position of quadrats in (a) Overland Paddock, (b) Purpunda Paddock and (c) Railway Paddock. Transects radiated from the watering point at various compass bearings and are numbered accordingly. Along each quadrats (●)were placed at 50 m, 100-800 m at 100 m intervals, 1000 m, 1250 m and 1500 m.

5.3.1 Quadrat Configuration

Each transect was 1500 m long. Quadrats of 5 m x 5 m were spaced along the transects, at distances of 50 m, 100 m, every 100 m up to 800 m, 1000 m, 1250 m and 1500 m from the watering point (Figure 5.1). These distances were used to represent the major zones of potential grazing influences on vegetation. Transects were terminated at 1500 m because this was the outer limit of the paddock. This gave a total of 144 quadrats in Purpunda and 96 quadrats in each of Railway and Overland Paddocks. Quadrat size was 16 x 16 m, based upon preliminary species area curve data for chenopod shrubland communities in three paddocks.

5.4 Plant-Based Measurements

In each quadrat the following features were measured; the percentage canopy cover, density (number rooted within the quadrats), total dry matter, average height and average width of each species. Five plant species were examined; *A. stipitata, A. vesicaria, M. georgei, M. pyramidata and M. sedifolia* (see following section).

5.4.1 Significant Plant Species

Of the 21 chenopod plant species which were analysed in Chapter 4, the following five perennial species which were statistically (PCC and Kruskal-Wallis analysis) and economically (grazing palatability) significant, were designated as target plants.

- *Atriplex stipitata* Benth
- *Atriplex vesicaria* Heward ex Benth
- *Maireana georgei* (Diels) P.G. Wilson
- *Maireana pyramidata* (Benth.) P.G. Wilson
- *Maireana sedifolia* (F. Muell.) Paul G. Wilson

A brief explanation of the characteristics of the five significant plant species:

Atriplex stipitata **(Bitter Saltbush)**

A small, grey perennial shrub growing about 60 cm in height with very little foliage compared to most saltbushes (Condon and Knowles 1952). Leaves are generally oblong in shape from 13-19 mm long and the fruiting body is easily recognisable, rounded on the back, flat and up to 13 mm across (Condon and Knowles 1952). This species resembles bladder saltbush (*Atriplex vesicaria*) in general appearance but can be distinguished from it by its bitter taste. It is widespread throughout the mallee country of South Australia, particularly on stony mallee soils (Jessup 1949). As *A. stipitata* is an invader, its unpalatability (Wilson 1994) to stock means that it is likely to persist despite heavy grazing. However, like *M. pyramidata*, it is not confined to the inner piosphere area.

***A.* vesicaria (Bladder Saltbush)**

Cunningham *et al.* (1981) described *A. vesicaria* as a perennial shrub, to 70 cm in height and diameter, with brittle woody stems. Leaves grey-green with a whitish scurfy surface, obovate to oblong, 1-2.5 cm long, occasionally toothed, rather thick, very shortly stalked. Flowers usually dioecious, the males in slender dense spikes at the ends of the branchlets, the females solitary or few in the leaf axils. Fruiting body more or less circular in outline, membranous, net-veined, entire or toothed, 8-15 mm long and about as broad, usually almost concealed by large spongy appendages which in some forms may be absent. Flowering is opportunistic, mainly spring and summer.

This species is a moderately palatable plant for grazing (Wilson 1994) and has the shortest life-span of the dominant perennial shrubs of these rangelands (Graetz and Wilson 1984).

***M.* georgei (Satiny Bluebush)**

M. georgei is a compact stout-stemmed subshrub, to 40 cm high, the branches bearing a close woolly covering. Leaves alternate, fleshy, slender, 8-15 mm long, 1-2 mm wide, almost hairless or covered with dense silky hairs. Flowers solitary in the leaf axils. Fruiting body large, hairless except for short lines of hairs in the wing centre; tube top-shaped, thick-walled, about 6 mm high and wide, wing horizontal, 15-20 mm diameter. Flowering throughout the year, mainly in the warmer months (Cunningham *et al.* 1981).

This species grows in red brown sands, loams and sandy loams, in a wide range of vegetation types, including belah, mulga and bluebush communities (Cunningham *et al.* 1981). *M. georgei* is relatively short lived species and in terms of sheep grazing, it was variously rated as palatable and preferred (Yan *et al.* 1996) or as moderately palatable (Wilson 1994).

***M. pyramidata* (Black Bluebush)**

Blue-grey perennial shrub, to 1.5 m high, with rigid, often spiny branches. Leaves spreading, fleshy with short, downy covering. Flowers are solitary in the leaf axils, the males and females frequently on separate plants (Cunningham *et al.* 1981).

This species grows on a range of soil types from sand to sandy loam to clay loams. It is a widespread plant of the arid zone but is confined to south of 26° 30' (Barker 1972) and it is often found growing with *M. sedifolia* (Wilson 1975). *M. pyramidata* was classed as one of the least palatable of the bluebushes, but does provide valuable feed during droughts (Leigh and Mulham 1965; Wilson and Harrington 1984; Wilson 1994).

***M. sedifolia* (Pearl Bluebush)**

M. sedifolia is a much-branched, native perennial shrub with thick woody stems, reaching a height and diameter of 1.2 metres. The soft, stalkless leaves are cylindrical in shape, about 2 mm in diameter and less than 13 mm long. This species has finely-veined fruits, 6 to 13 mm in diameter which are concentrated at the ends of the branches (Leigh and Mulham 1965).

M. sedifolia is typically formed on medium textured soils (Graetz and Wilson 1984). It is a deep rooted species with roots to more than 2 metres (Williams 1979). Establishment in this species is infrequent because the seed rapidly loses viability (Wilson 1994). *M. sedifolia* may establish only once every 50 years under natural conditions, but has a longevity in excess of 150 years (Crisp 1978). This species is reported by graziers to be acceptable to sheep in South Australia, but not in New South Wales (Graetz and Wilson 1979) and it was considered by Barker (1972) and Wilson (1994) as a moderately palatable species.

5.4.1.1 Plant Attributes

The following features were measured for each species.

The diameter of the top of each plant's canopy and the length of each plant were measured with a metre ruler stick and directly recorded in the field notebook, to allow more detailed subsequent analyses. A computer was used to calculate the crown cover from these diameter records assuming a circular area and using the formula area = πr^2, where r is the canopy radius. Numbers of each plant and subsequently the density (i.e. the absolute number of plants per unit area) were direct counts of individuals that had the centre of their basal stem within the quadrat.

Herbage Biomass Estimation

The above-ground biomass of the five perennial chenopod plant species was estimated using the Adelaide technique (Andrew *et al.* 1981). A sample outer branch unit was collected and the number of equivalent branches was counted on the shrub. Similarly for the larger inner branch units, a sample was collected and equivalents were counted. Both samples were taken for drying and weighing for subsequent calibration. Finally, the dimensions of all remaining main stems were measured for estimates of wood volume. Wood volume was subsequently converted to weight using the dimensions and dry weight of the inner branch units. The sample branch units were returned to the laboratory for dry-weight determination. Moisture content for dry weight determination was obtained from samples dried at 80° C for 48 hours. The relationship between assessed biomass and actual biomass was computed.

5.4.2 Statistical Analyses

Quadrats were grouped according to their similarities based on five features of five species for each of paddock. The data from all paddocks were analysed with the same techniques; cluster analysis using agglomerative hierarchical fusion (Bray-Curtis with UPGMA). The group definition and group statistic options (GDEF and GSTA) were used to assess significant character differences between dendrogram groups with the Kruskal-Wallis statistic. The ordination employed was semi-strong hybrid multidimentional scaling (SSH), and indirect gradient analysis with principal canonical correlation (PCC). PCC determines whether the abundance of any particular plant features significantly correlate with the placement of the quadrats on the ordination. Significance was Bonferroni adjusted to $\alpha = 0.002$ to allow for multiple comparisons (Wilkinson 1990). Only the significant features are shown on the PCC plots. All analyses were undertaken using the PATN package (Belbin, 1991). Data were range-standardised prior to analysis in order to even out the contribution of the different plant features to the analysis (Clarke 1993).

5.5 Results

The five features (percentage of canopy cover, density, total dry matter, average height and average width) of the five species (*A. stipitata, A. vesicaria, M. georgei, M. pyramidata and M. sedifolia*) were analysed for each site (Purpunda Railway and Overland Paddock). The results of the multivariate analysis are separately explained for each paddock.

5.5.1 Overland Paddock

5.5.1.1 Clustering Analysis

A total of 96 quadrats were clustered by UPGMA on the basis of 25 plant features from Overland Paddock. Five major quadrat groups were identified at the 0.67 level (Figures 5.2a). Their geographical locations are shown on Figure 5.2b. The area immediately around the water point was distinct from the other parts of paddock, with an area which included eight identical

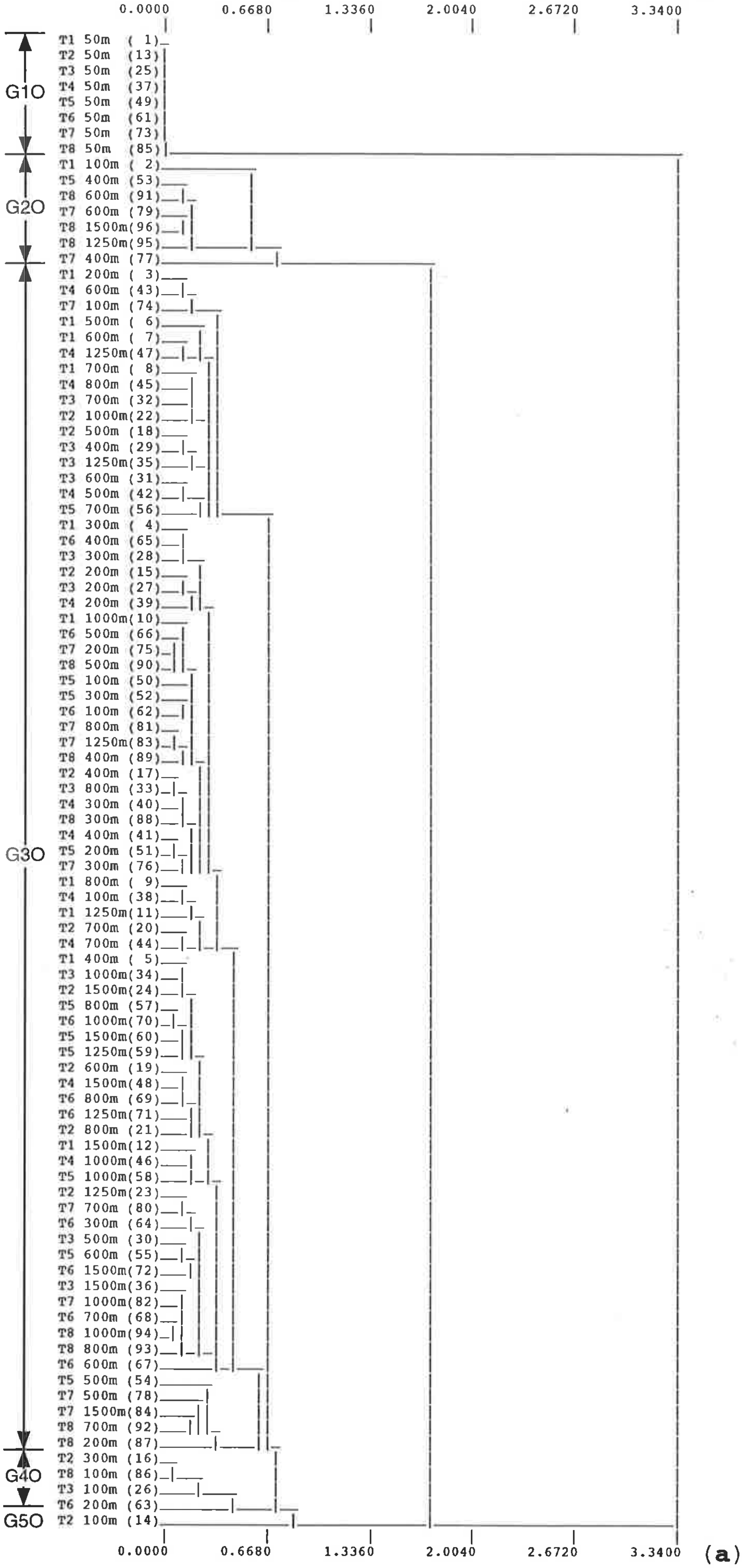
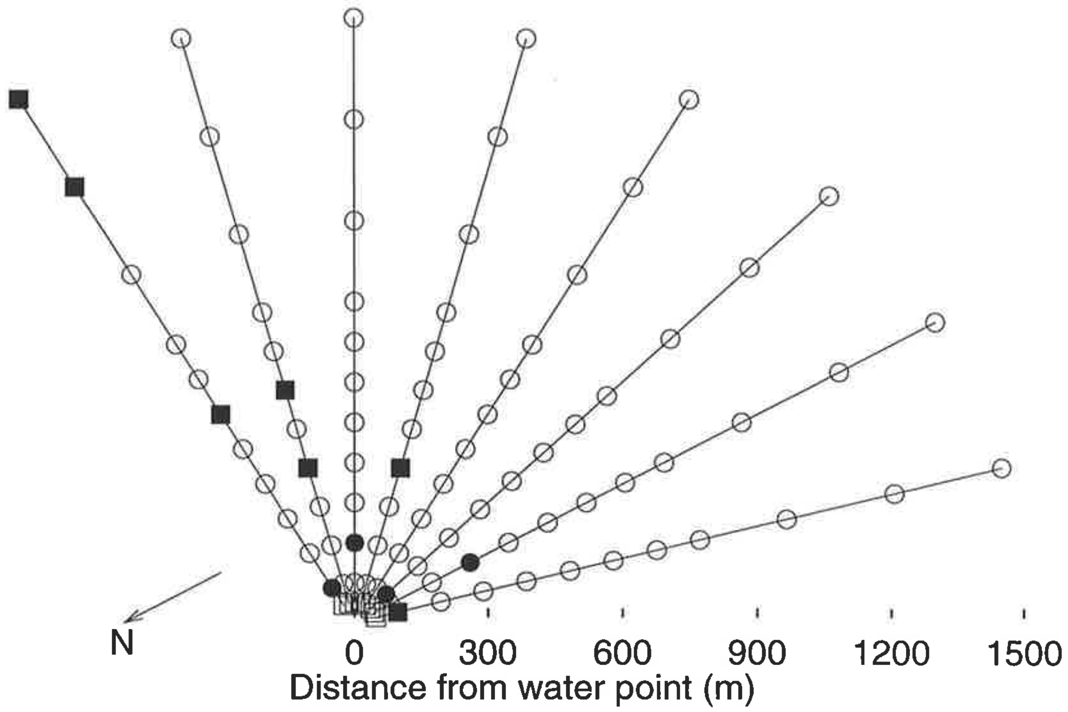


Figure 5.2a. Cluster analysis of all 96 sampling quadrats for the five features measured for five plant species at Overland Paddock. The five dendrogram groups were distinguished and are labelled as G1O-G5O (O = Overland Paddock).



(**b**)

Figure 5.2b shows the geographical locations of sampling quadrats for Overland Paddock where the □ = G1O, ■ = G2O, O = G3O, ● = G4O and Δ = G5O.

quadrats with very high dissimilarity (G1O quadrats) from the other four groups. These quadrats were those closest (50 m) to the water point. The highest percentage of quadrats (79%) were clustered as G3O quadrats. The fifth group (G5O) was widely separated from the four other groups, but consisted of only a single quadrat.

5.5.1.2 Non-Parametric Analysis

The results of non-parametric (Kruskal-Wallis) analysis of variance for the dendrogram group means for each character are presented in Table 5.1.

All features of four plant species (*M. pyramidata*, *A. vesicaria*, *A. stipitata* and *M. sedifolia*) showed significant differences between the five groups ($p<0.002$) in this paddock, but those of *M. georgei* did not. *M. pyramidata* with high values of all features (canopy cover 6.6% ± 3.(SD), density 4 plants/quadrat ± 2.4, dry matter 478 g ± 233.1, height 47.3 cm ± 22.3 and width 62.6 cm ± 29.1) and *A. vesicaria* with high density (10.6 plants/quadrat ± 4.9) were characteristic of G2O quadrats. G3O quadrats were recognised by the presence of *M. georgei* and also by high values for canopy cover (11.1% ± 4.8), density (5.6 plants/quadrat ± 2.4) and dry matter (496.1 g ± 211.7) of *M. sedifolia* and high values of canopy cover (5.4% ± 4.5) and width (43.7 cm ± 15.9) of *A. vesicaria*. G4O quadrats were dominated by relatively high values of all features of *M. sedifolia*. G5O was characterised by high values of dry matter (294 g) and height (45 cm) of *A. vesicaria* and high values of height (100 cm) and width (120 cm) of *M. sedifolia*. No measure of variance was possible as the group consisted of only a single quadrat. G1O quadrats lacked any of the five plant species assessed in this study (Table 5.1).

5.5.1.3 Ordination

The ordination of quadrats in Overland Paddock is presented in Figure 5.3 and shows a scatter plot of quadrats on the first two ordination axes. The relationships between the plant features can be seen from the ordination; is given in Figure 5.4. Below is a brief description of the patterns found in the paddock and the overall trend.

Table 5.1. Summary statistics of dendrogram groups for Overland Paddock showing the mean and standard deviation of each plant feature. Kruskal-Wallis test indicates whether there are significant differences between the group means ($p = 0.002$). Principal Canonical Correlation (PCC) analysis indicates which plant features are significantly correlated with the site ordination (df=94, r<0.33). Note: the data for Kruskal-Wallis test and PCC analysis were not range standardised.

		Dendrogram groups										Kruskal-Wallis Test				PCC Correlation	
Species	**Feature**	**G1O**		**G2O**		**G3O**		**G4O**		**G5O**							
		Mean	*S.D.*	*Mean*	*S.D.*	*Mean*	*S.D.*	*Mean*	*S.D.*	*Mean*	*S.D.*	**H**	**d.f.**	**P**	**sig.**	**R**	**sig.**
A. stipitata	*Canopy cover*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8	0.0	32.68	4	0.00	***	0.19	n.s.
A. stipitata	*Density*	0.0	0.0	0.0	0.0	0.1	0.4	0.0	0.0	1.0	0.0	30.68	4	0.00	***	0.22	n.s.
A. stipitata	*Dry matter*	0.0	0.0	0.0	0.0	0.1	0.4	0.0	0.0	12.0	0.0	24.77	4	0.00	***	0.18	n.s.
A. stipitata	*Height*	0.0	0.0	0.0	0.0	0.8	4.8	0.0	0.0	60.0	0.0	32.68	4	0.00	***	0.11	n.s.
A. stipitata	*Width*	0.0	0.0	0.0	0.0	0.6	3.9	0.0	0.0	75.0	0.0	24.77	4	0.00	***	0.15	n.s.
A. vesicaria	*Canopy cover*	0.0	0.0	4.8	2.3	5.4	4.5	0.1	0.1	2.0	0.0	32.51	4	0.00	***	0.59	***
A. vesicaria	*Density*	0.0	0.0	10.6	4.9	7.2	4.3	3.0	5.2	4.0	0.0	57.96	4	0.00	***	0.76	***
A. vesicaria	*Dry matter*	0.0	0.0	297.6	164.4	276.8	187.6	9.8	16.9	294.0	0.0	32.28	4	0.00	***	0.72	***
A. vesicaria	*Height*	0.0	0.0	25.6	11.2	44.0	15.6	2.0	3.5	45.0	0.0	45.39	4	0.00	***	0.56	***
A. vesicaria	*Width*	0.0	0.0	27.7	12.1	43.7	15.9	1.8	3.0	38.0	0.0	41.97	4	0.00	***	0.56	***
M. georgei	*Canopy cover*	0.0	0.0	0.0	0.0	0.4	1.4	0.0	0.0	0.0	0.0	5.53	4	0.24	n.s.	0.54	***
M. georgei	*Density*	0.0	0.0	0.0	0.0	0.8	1.9	0.0	0.0	0.0	0.0	10.25	4	0.04	n.s.	0.64	***
M. georgei	*Dry matter*	0.0	0.0	0.0	0.0	8.2	24.4	0.0	0.0	0.0	0.0	5.53	4	0.24	n.s.	0.57	***
M. georgei	*Height*	0.0	0.0	0.0	0.0	7.2	15.0	0.0	0.0	0.0	0.0	7.41	4	0.12	n.s.	0.68	***
M. georgei	*Width*	0.0	0.0	0.0	0.0	8.1	16.7	0.0	0.0	0.0	0.0	5.53	4	0.24	n.s.	0.70	***
M. pyramidata	*Canopy cover*	0.0	0.0	6.6	3.0	0.1	0.5	0.0	0.0	0.0	0.0	42.47	4	0.00	***	0.79	***
M. pyramidata	*Density*	0.0	0.0	4.0	2.4	0.1	0.3	0.0	0.0	0.0	0.0	79.63	4	0.00	***	0.75	***
M. pyramidata	*Dry matter*	0.0	0.0	478.7	233.1	10.1	44.0	0.0	0.0	0.0	0.0	45.83	4	0.00	***	0.78	***
M. pyramidata	*Height*	0.0	0.0	47.3	22.3	3.3	13.0	0.0	0.0	0.0	0.0	45.36	4	0.00	***	0.76	***
M. pyramidata	*Width*	0.0	0.0	62.6	29.1	4.3	17.6	0.0	0.0	0.0	0.0	38.18	4	0.00	***	0.75	***
M. sedifolia	*Canopy cover*	0.0	0.0	0.1	0.2	11.1	4.8	7.5	4.2	4.5	0.0	41.70	4	0.00	***	0.67	***
M. sedifolia	*Density*	0.0	0.0	0.1	0.3	5.6	2.4	4.3	2.3	1.0	0.0	107.77	4	0.00	***	0.73	***
M. sedifolia	*Dry matter*	0.0	0.0	10.6	25.9	496.1	211.7	395.5	185.3	147.0	0.0	41.69	4	0.00	***	0.72	***
M. sedifolia	*Height*	0.0	0.0	5.7	14.0	65.6	11.5	63.3	3.4	100.0	0.0	51.83	4	0.00	***	0.81	***
M. sedifolia	*Width*	0.0	0.0	5.7	14.0	76.7	19.2	69.5	6.1	120.0	0.0	44.53	4	0.00	***	0.76	***

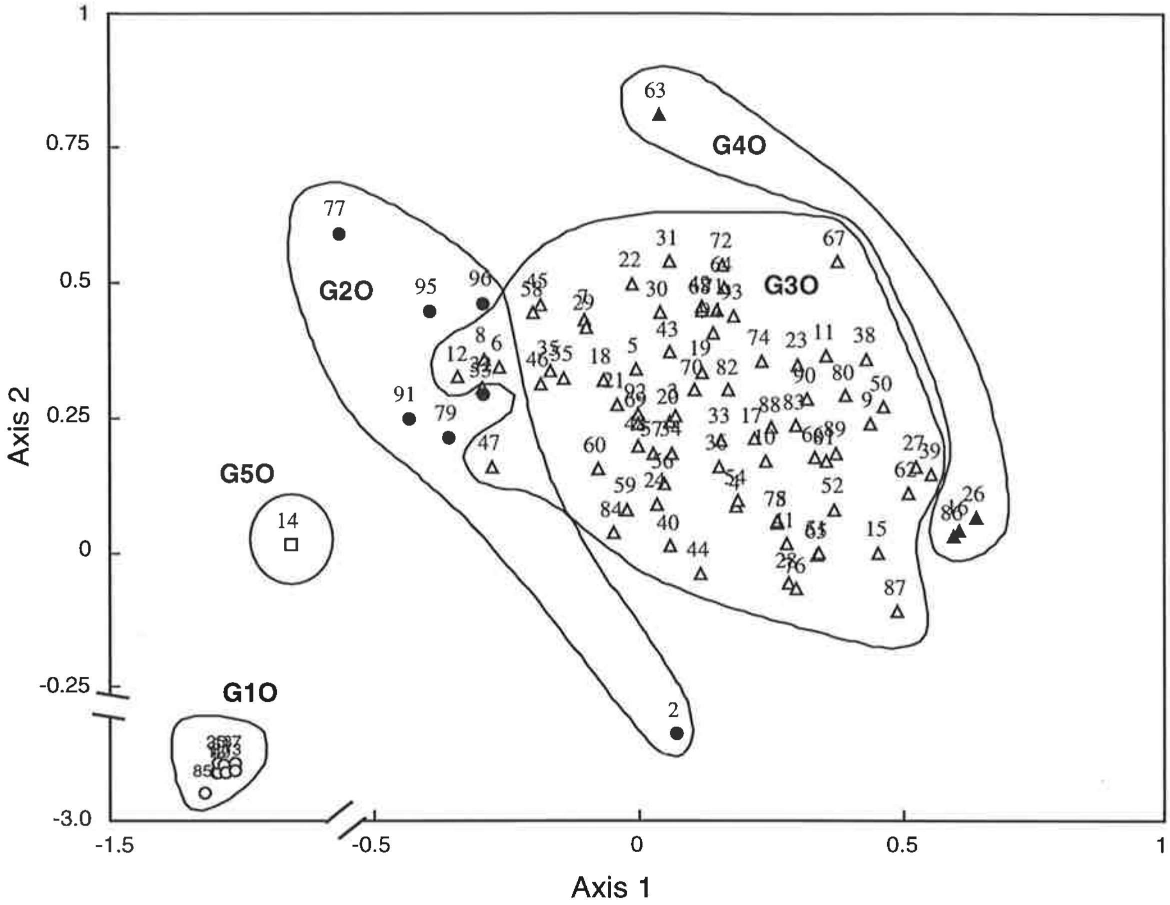
Figure 5.3. Plot of the first two axes from a semi-strong hybrid scaling (SSH) ordination of the 96 quadrats in Overland Paddock based on 25 plant-based features. Stress = 0.09

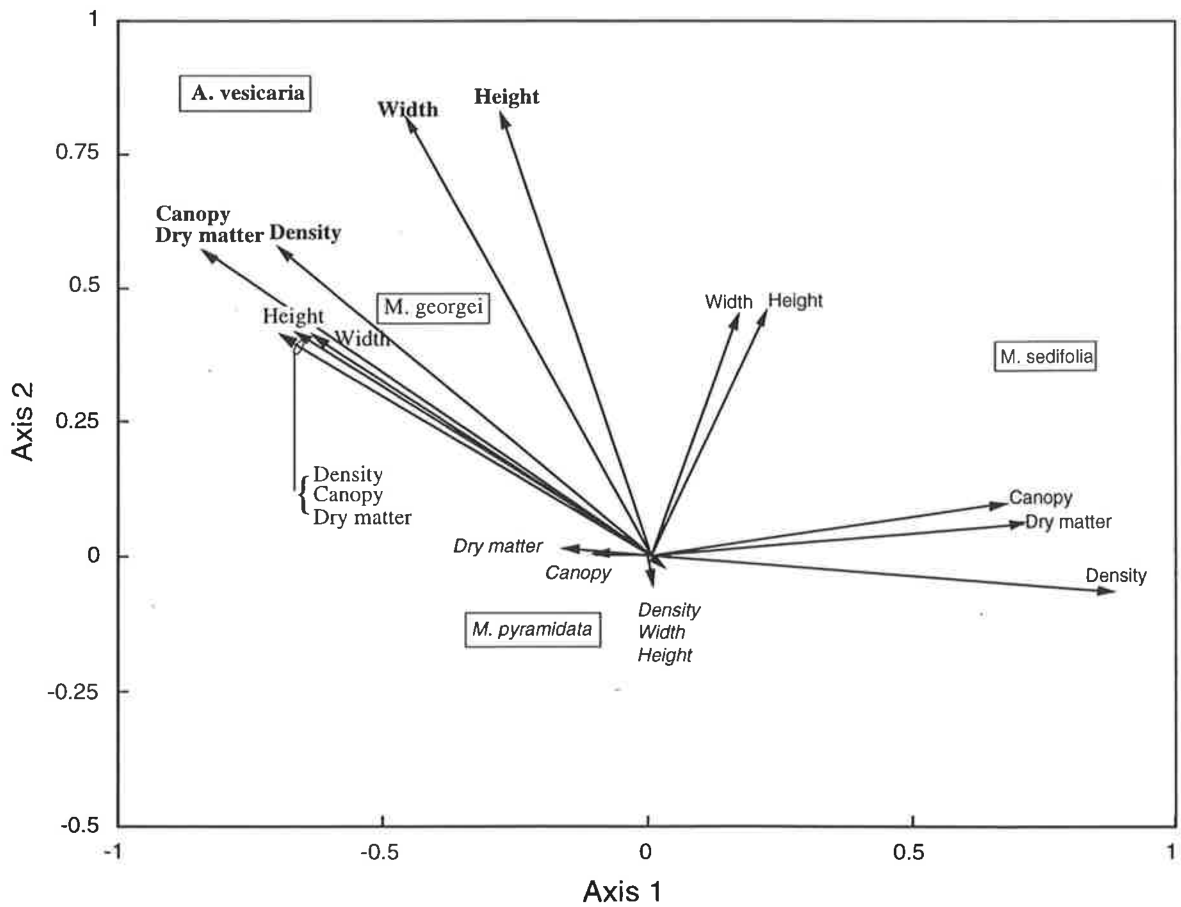
Symbol represents dendrogram group (○ = G1O, ● = G2O, Δ = G3O, ▲ = G4O and □ = G5O) and label represents sample no. (1-96). Sample numbers appear in the following transects: 1 - 12 = Transect 1 (195°), 13 - 24 = Transect 2 (180°), 25 - 36 = Transect 3 (165°), 37 - 48 = Transect 4 (150°), 49 - 60 = Transect 5 (135°), 61 - 72 = Transect 6 (120°), 73 - 84 = Transect 7 (105°), 85 - 96 = Transect 8 (90°).

Figure 5.4. Principal Canonical Correlation (PCC) of the 25 plant-based features measured for Overland Paddock superimposed on the dendrogram group outline plotted in Figure 5.3.

Species and their features are indicated by type face in the following way:

M. georgei (roman); *A. vesicaria* (bold roman); *M. sedifolia* (sans serif); *M. pyramidata* (sans serif italic). The features of *A. stipitata* showed no significant correlation with the site ordination and are not shown on this plot.


G1O
G2O
G3O
G4O
G5O
Axis 1
Axis 2
-1.5
-0.5
0
0.5
1
-3.0
-0.25
0
0.25
0.5
0.75
1


A. vesicaria
M. georgei
M. sedifolia
M. pyramidata
Width
Height
Canopy
Dry matter
Density
Height
Width
Density
Canopy
Dry matter
Width
Height
Canopy
Dry matter
Density
Dry matter
Canopy
Density
Width
Height
Axis 1
Axis 2
-1
-0.5
0
0.5
1
-0.5
-0.25
0
0.25
0.5
0.75
1

The five groups (G1O-G5O quadrats) are distributed from the lower left to the upper right of the ordination plot in Figure 5.3 with the exception of G5O quadrats. This group represents only a single quadrat. The G1O quadrats were distant from the other four groups and in the lower left quadrant. The ordination confirms that the dendrogram groups are distinct. G3O quadrats appeared in the centre of the ordination and overlapped with G2O quadrats. G2O includes 7 quadrats, of which quadrat 2 (100 m from the water point) is well separated from the others. G4O includes four quadrats and, as with G2O, one quadrat of this group (quadrat 63 = 200 m from water point) is separated from the others.

5.5.1.4 PCC Analysis

To determine if there was a correlation between plant features and the placement of quadrats in ordination space, indirect gradient analysis with principal canonical correlation (PCC) analysis (Wilkinson 1990) was used for Overland Paddock. The results of this analysis are presented in Table 5.1. Significance was Bonferroni adjusted to $\alpha = 0.002$ to allow for multiple comparisons (Wilkinson 1990).

All features (canopy cover, density, biomass, height and width) of *A. stipitata* showed no correlation with the site ordination. In contrast, the features of *M. pyramidata*, *M. sedifolia*, *M. georgei* and *A. vesicaria* showed a significant correlation.

Comparison of the sampling units with vectors representing the individual plant features and their correlation with the plotted quadrats (Figure 5.4) revealed that certain plant features were correlated with the five dendrogram groups in Figure 5.3. The wide and tall plants of *A. vesicaria* and *M. sedifolia* were associated with quadrats of G3O. High dry matter, canopy cover and density of *A. vesicaria* were associated together and correlated with 6 quadrats which are 400 m or more from the water point (quadrat numbers 77 = 400 m, 95 = 1250 m, 96 = 1500 m, 91 and 79 = 600 m and 53 = 400 m from the water point)of the G2O quadrats where scattered in patchy areas (Figures 5.3 and 5.4). High levels of three features of *M. sedifolia* (canopy cover, biomass and density) were correlated and associated with G3O quadrats and three quadrats (number 16 = 300 m, 86 = 100 m and 26 = 100 m from the water point) of G4O. The plant features of *M. pyramidata* were associated with G2O quadrats, particularly with one quadrat (number 2 = 100 m from the water point).

Figure 5.4 also shows that correlations occur both within and between species. Two features (width and height) of *M. sedifolia* were associated with each other and these same two features were negatively correlated with density, width and height of *M. pyramidata*. Canopy cover, dry matter and density of *M. sedifolia* were positively correlated with each other, but negatively correlated with dry matter and canopy cover of *M. pyramidata*. All five features of *M. georgei* and three features (canopy cover, dry matter and density) of *A. vesicaria* were strongly correlated with each other, whereas two other features of *A. vesicaria* (width and height) were positively correlated with each other, but negatively with density, width and height of *M. pyramidata*.

5.5.1.5 Description Of Vegetation Types

The major groups of vegetation which resulted from these analyses are as follows: bare ground (G1O quadrats); large and frequent *M. pyramidata* + frequent *A. stipitata* (G2O quadrats); large *M. sedifolia* + *A. vesicaria* (G3O quadrats); frequent *M. sedifolia* + *A. vesicaria* (G4O quadrats); and large *M. sedifolia* + *A. vesicaria* + *M. georgei* (G5O quadrats) (Figure 5.5). The features and distribution of these groups are described in turn, with summaries of their features given in Table 5.1 and Figure 5.5.

G1O Vegetation Type: No perennial chenopod shrubland species were present in this group. This group was close to the water point (≤100 m).

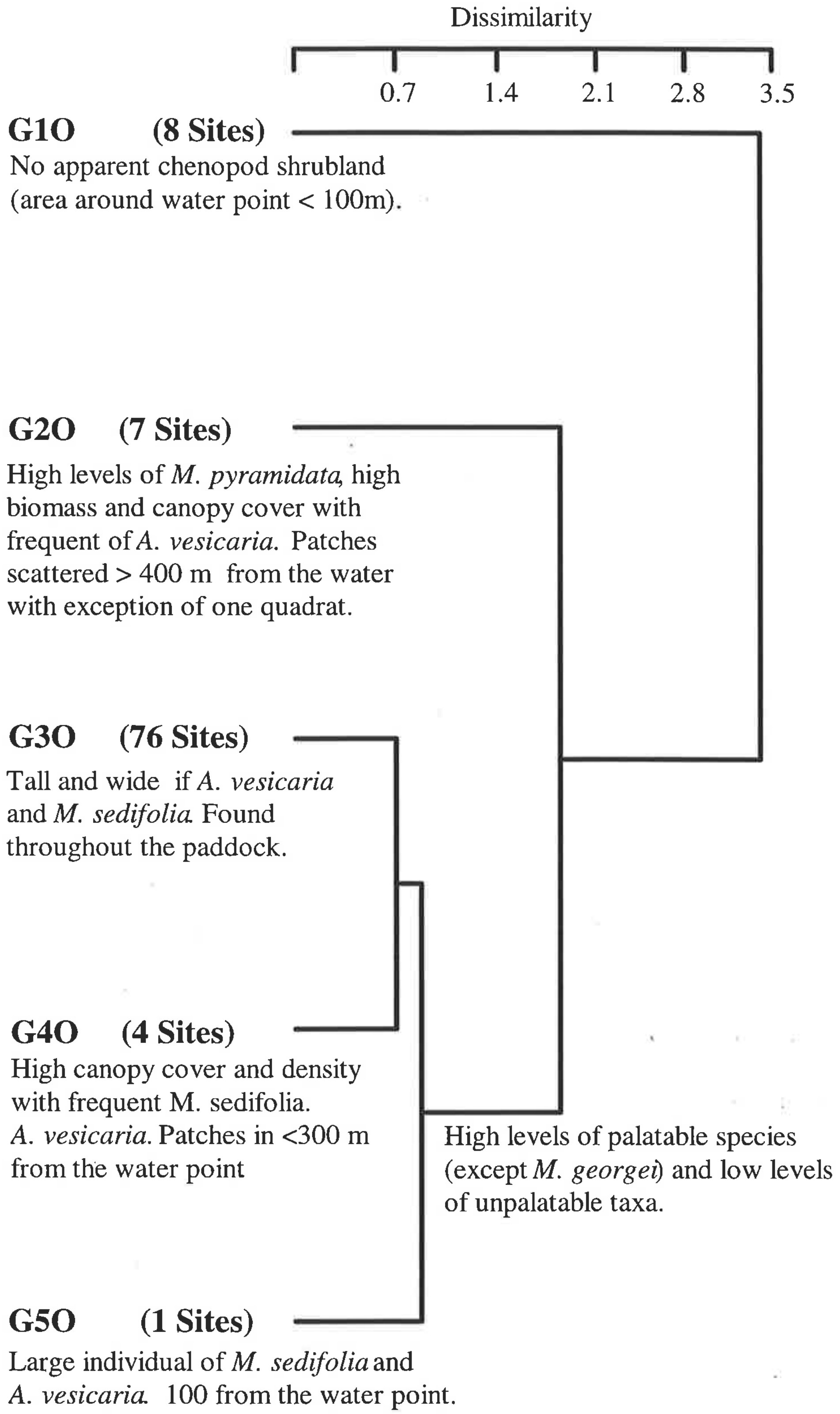


Figure 5.5. Stylized dendrogram group relationships with plant indicator features for group in Overalnd Paddock.

G2O Vegetation Type: High levels of all features of *M. pyramidata* were present in this vegetation type which tall, wide and high frequent of this species was in quadrat 2 (100 m from the water point). There were high numbers of *A. vesicaria* with high biomass in this vegetation type which they were located in most quadrats of this group (6 out of 7 quadrats) in patches scattered areas greater than 400 m from the water point.

G3O Vegetation Type: Plants with moderate palatability (*A. vesicaria* and *M. sedifolia*) were associated with G3O quadrats. Wide and tall plants of *A. vesicaria* and *M. sedifolia* were present in this area. *M. georgei* was common in this group. More than 50% of the paddock (76 quadrats) was represented by this vegetation type.

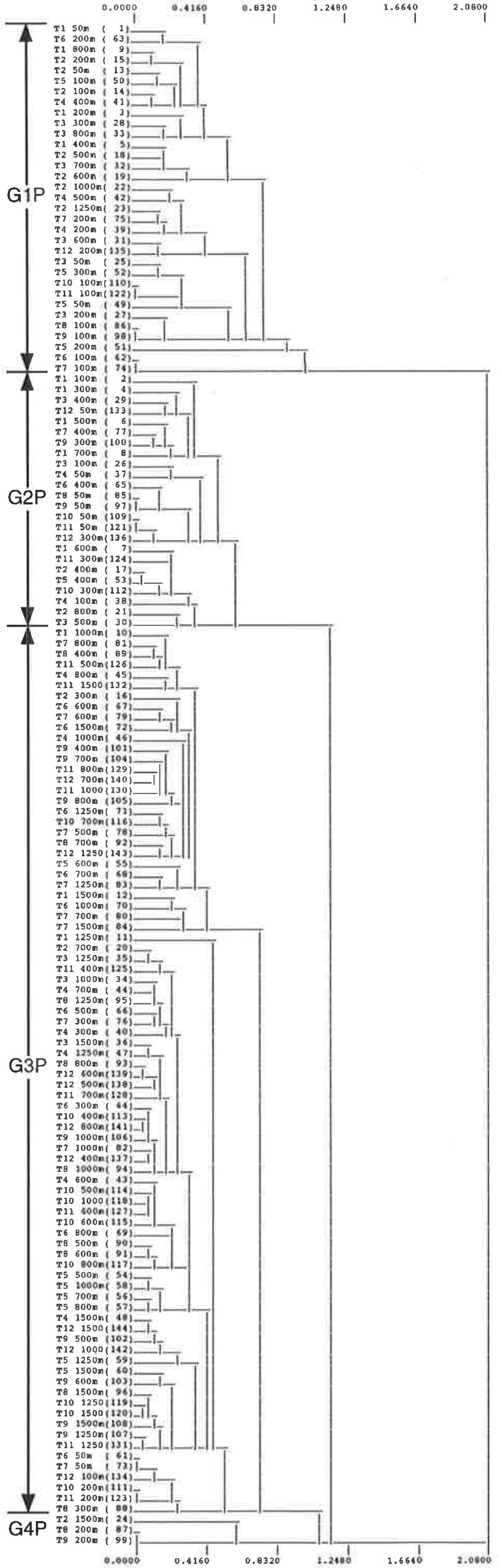
G4O Vegetation Type: Within the fourth vegetation group, three quadrats could be distinguished based on the high presence of features of *M. sedifolia* and absence of *A. stipitata*, *M. pyramidata* and *M. georgei*. The high canopy cover and dry matter with frequent of this species was widely distributed throughout the most quadrats (3 out of 4 quadrats)of this vegetation type. *A. vesicaria* was also present in this vegetation type.

G5O Vegetation Type: This vegetation type represented only a single sampling unit, where both *A. vesicaria* and *M. sedifolia* were tall and wide. This quadrat was located 100 m out from the trough on transect 2 (180°), but was under larger trees of mallee.

5.5.2 Purpunda Paddock

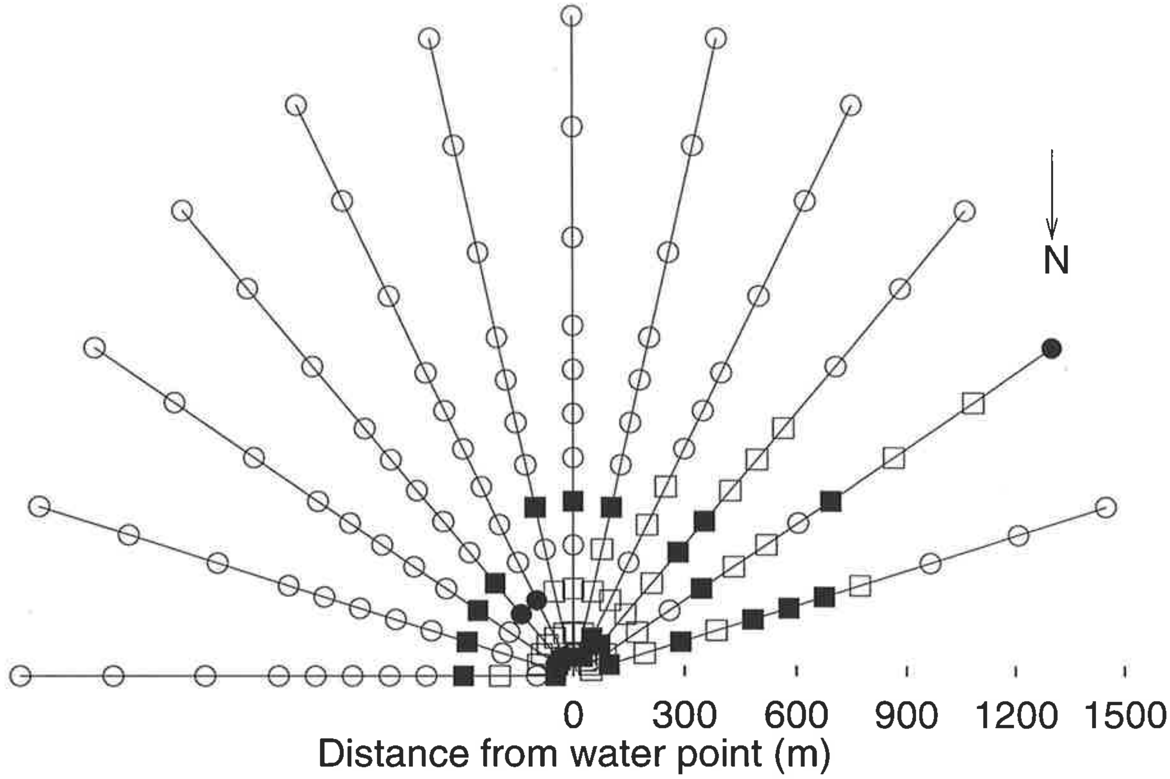
5.5.2.1 Clustering Analysis

The results of the cluster analyses are presented as a dendrogram of all 144 quadrats for plant-based features from Purpunda Paddock in Figure 5.6a. The quadrats were clustered in four major groups which the geographical distribution were shown in Figure 5.6b. These four quadrat groups were identified at the 1.0 level, one of which, G1P quadrats, was widely dissimilar from the other groups, only fusing with them at the 2.08 level (Figure 5.6a).



(a)

Figure 5.6a. Cluster analysis of all 144 sampling quadrats for the five features measured for five plant species at Purpunda Paddock. The four dendrogram groups were distinguished and are labelled as G1P-G4P (P = Purpunda Paddock).



(b)

Figure 5.6b shows the geographical locations of sampling quadrats for Purpunda Paddock where the □ = G1P, ■ = G2P, ○ = G3P and ● = G4P.

Based on the results obtained from cluster analysis, two geographical situations can be defined. The distances from the water point are labelled for each quadrat in Figure 5.6a. The first situation includes areas close to the water point (<300 m) and along the main wind direction (G1P quadrats) whilst the second encompasses areas of vegetation found greater than 300 m from the water point and away from main wind direction (G2P, G3P and G4P quadrats).

5.5.2.2 Non-Parametric Analysis

Non-parametric (Kruskal-Wallis) analysis of variance was used to test for significant differences between the means of each character in each dendrogram groups (Table 5.2).

The five features (canopy cover, density, dry matter, height and width) of *A. stipitata* and *M. georgei* showed no significant differences between dendrogram groups ($p<0.002$) based on this analysis (Table 5.2). In contrast, all features of *M. pyramidata*, *A. vesicaria* and *M. sedifolia* were significantly ($p<0.002$) different between at least some of the dendrogram groups in this paddock.

G1P quadrats were characterised by high values for all features (canopy cover 6.3% ± 3.6 (SD), density 3 plants/quadrat ± 2.6, dry matter 361.1 g ± 188.6, height 67.6 cm ± 22. and width 89.7 cm ± 26.1) of *M. pyramidata* (Table 5. 2). High values of canopy cover (8.2% ± 3.9), dry matter (678.7 g ± 395.9), height (71.1 cm ± 20.1) and width (77.8 cm ± 23.3) of *M. sedifolia* were the characteristics of G2P quadrats. Highest number of plants/quadrat (5.7 ± 2.8) and relatively high value canopy cover (8.1% ± 4.) of *M. sedifolia* were present in G3P quadrats. *A. vesicaria* with relatively high values of all features were common in this group. G4P quadrats were illustrated by highest values of all features (canopy cover 5.1% ± 3.4, density of plants/quadrat 5.3 ± 4.7, dry matter 206 g ± 126, height 67 cm ± 11.3 and width 60.3 cm ± 6.6) of *A. vesicaria*.

5.5.2.3 Ordination

The results of the SSH ordination are presented as a scatter plot of the first two axes for all 144 quadrats shown in Figures 5.7. This ordination explained the variation in the data set, and corresponded to the first major branching of the dendrogram, separating group one from the others. The G3P quadrats are similar to the /and G2P quadrats, because the members of these two groups overlap.

5.5.2.4 PCC Analysis

In order to determine the correlation of plant attributes with the placement of quadrats, principal canonical correlation (PCC) was carried out for this paddock. The results of indirect gradient analysis with PCC analyses are presented in Table 5.2. for this Paddock. Significance was Bonferroni adjusted to $\alpha = 0.002$ to allow for multiple comparison (Wilkinson 1990).

All features (canopy cover, density, biomass, height and width) of five plant species (*A. stipitata, A. vesicaria, M. georgei, M. pyramidata* and *M. sedifolia*) were significantly ($p<0.002$) correlated with the quadrat ordination.

The relationships between the plant features can also be seen from the SSH ordination of the first two axes (Figure 5.8), reflecting the same patterns seen in the GSTA Kruskal-Wallis analyses of the significantly associated plant features with the dendrogram groups. In the SSH ordination (Figure 5.8), the PCC correlation also reflects the strong association between the plant features and quadrat units. All features of the *M. pyramidata* and *A. stipitata* vectors aligned with G1P quadrats. Three features of *M. sedifolia* (dry matter, height and width) were correlated with G2P quadrats and, to a lesser extent, plant number and the percentage of canopy cover with both G2P and G3P quadrats. Most of the G3P quadrats were correlated with *M. georgei* features. *A. vesicaria* was associated with G4P quadrats for high values of all features, i.e., the *A. vesicaria* plants in G4P quadrats were tall, wide, frequent, heavy and had a high level of canopy cover.

Table 5.2. Summary of statistics of dendrogram groups for Purpunda Paddock. Showing the mean and standard deviation of each plant feature. Kruskal-Wallis test indicates whether there are significant differences between the groups (*p = 0.002*). Principal Canonical Correlation (PCC) analysis indicates which plant features are significantly correlated with the site ordination (df =142, r<0.33). Note: the data for Kruskal-Wallis test and PCC analysis were not range standardised.

Species	Feature	Dendrogram groups G1P		G2P		G3P		G4P		Kruskal-Wallis Test				PCC Correlation	
		Mean	*S.D.*	*Mean*	*S.D.*	*Mean*	*S.D.*	*Mean*	*S.D.*	H	d.f.	P	sig.	R	sig.
A. stipitata	*Canopy cover*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.77	3	0.08	n.s.	0.41	***
A. stipitata	*Density*	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	6.77	3	0.08	n.s.	0.41	***
A. stipitata	*Dry matter*	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	6.77	3	0.08	n.s.	0.41	***
A. stipitata	*Height*	1.2	4.8	0.0	0.0	0.0	0.0	0.0	0.0	6.77	3	0.08	n.s.	0.41	***
A. stipitata	*Width*	0.3	1.2	0.0	0.0	0.0	0.0	0.0	0.0	6.77	3	0.08	n.s.	0.41	***
A. vesicaria	*Canopy cover*	0.4	0.6	0.0	0.0	1.7	1.4	5.1	3.4	103.44	3	0.00	***	0.74	***
A. vesicaria	*Density*	0.9	1.6	0.0	0.2	3.4	2.8	5.3	4.7	319.50	3	0.00	***	0.72	***
A. vesicaria	*Dry matter*	19.3	36.3	0.3	1.4	105.6	98.2	206.0	125.9	109.98	3	0.00	***	0.70	***
A. vesicaria	*Height*	18.2	24.8	0.6	3.0	47.1	15.7	67.0	11.3	104.86	3	0.00	***	0.84	***
A. vesicaria	*Width*	14.5	19.6	0.8	4.0	41.1	12.8	60.3	6.6	137.03	3	0.00	***	0.84	***
M. georgei	*Canopy cover*	0.2	0.3	0.2	0.2	0.2	0.4	0.0	0.0	1.81	3	0.61	n.s.	0.71	***
M. georgei	*Density*	0.8	1.5	0.8	0.9	0.8	1.5	0.7	0.5	9.25	3	0.03	n.s.	0.68	***
M. georgei	*Dry matter*	6.1	20.7	2.1	2.7	2.5	6.1	0.0	0.0	5.07	3	0.17	n.s.	0.42	***
M. georgei	*Height*	6.2	10.5	10.6	11.7	9.5	15.0	13.3	9.4	4.78	3	0.19	n.s.	0.84	***
M. georgei	*Width*	7.7	13.3	11.5	13.6	9.4	15.7	10.0	7.1	3.70	3	0.30	n.s.	0.84	***
M. pyramidata	*Canopy cover*	6.3	3.6	0.1	0.4	0.0	0.0	0.2	0.2	138.53	3	0.00	***	0.80	***
M. pyramidata	*Density*	3.0	2.6	0.5	0.8	0.0	0.1	0.3	0.5	423.00	3	0.00	***	0.65	***
M. pyramidata	*Dry matter*	361.1	188.6	11.0	21.8	0.2	1.4	15.3	21.7	151.56	3	0.00	***	0.84	***
M. pyramidata	*Height*	67.6	22.1	10.5	17.8	0.3	2.7	13.3	18.9	186.54	3	0.00	***	0.92	***
M. pyramidata	*Width*	89.7	26.1	9.5	16.7	0.3	2.7	13.3	18.9	171.70	3	0.00	***	0.92	***
M. sedifolia	*Canopy cover*	2.5	3.6	8.2	3.9	8.1	4.0	0.0	0.0	46.64	3	0.00	***	0.63	***
M. sedifolia	*Density*	1.4	1.9	4.5	1.9	5.7	2.8	0.0	0.0	228.59	3	0.00	***	0.66	***
M. sedifolia	*Dry matter*	230.9	325.6	678.7	395.9	574.2	329.6	0.0	0.0	39.95	3	0.00	***	0.54	***
M. sedifolia	*Height*	36.3	37.2	71.1	20.1	65.6	16.8	0.0	0.0	26.20	3	0.00	***	0.69	***
M. sedifolia	*Width*	37.6	40.1	77.8	23.3	70.8	19.5	0.0	0.0	27.71	3	0.00	***	0.71	***

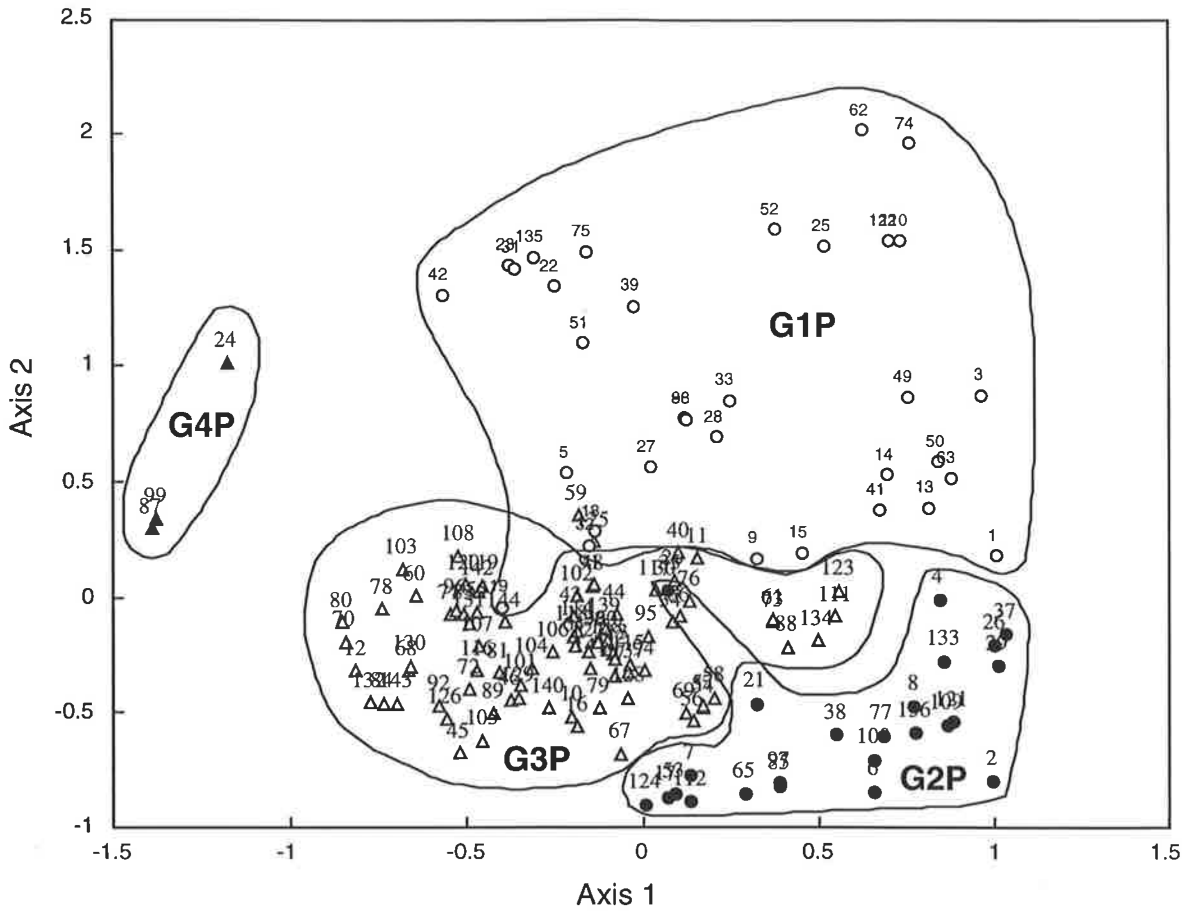
Figure 5.7. Plot of the first two axes from a semi-strong hybrid scaling (SSH) ordination of the 144 quadrats in Purpunda Paddock based on 25 plant-based features. Stress = 0.08

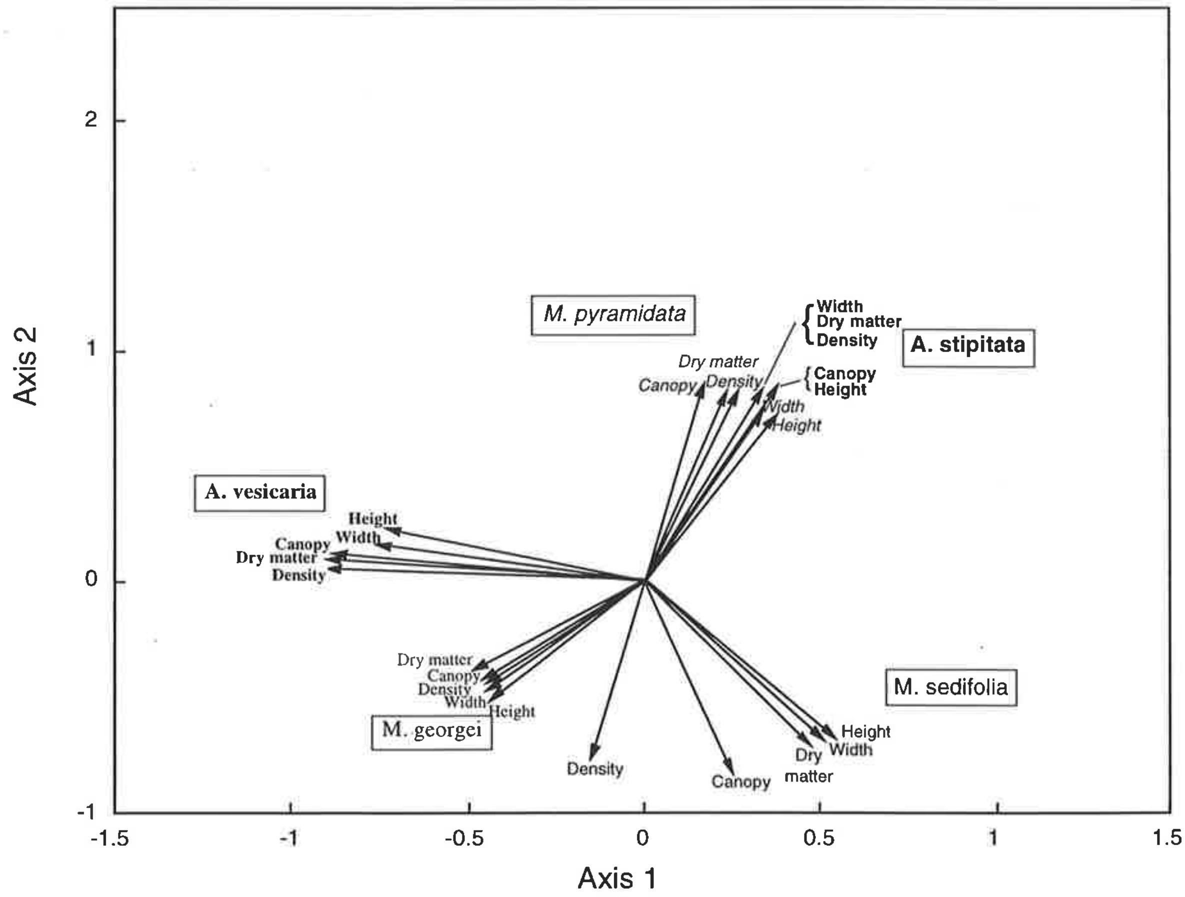
Symbol represents dendrogram group (○ = G1P, ● = G2P, Δ = G3P and ▲ = G4P) and label represents sample no. (1-144). Sample numbers appear in the following transects: 1 - 12 = Transect 1 (255°), 13 - 24 = Transect 2 (240°), 25 - 36 = Transect 3 (225°), 37 - 48 = Transect 4 (210°), 49 - 60 = Transect 5 (195°), 61 - 72 = Transect 6 (180°), 73 - 84 = Transect 7 (165°), 85 - 96 = Transect 8 (150°), 97 - 108 = Transect 9 (135°), 109 - 120 = Transect 10 (120°), 121 - 132 = Transect 11 (105°) and 133 - 144 = Transect 12 (90°).

Figure 5.8. Principal Canonical Correlation (PCC) of the 25 plant-based features measured for Purpunda Paddock superimposed on the dendrogram group outlined plotted in Figure 5.7.

Species and their features are indicated by type face in the following way:

M. georgei (roman); *A. vesicaria* (bold roman); *M. sedifolia* (sans serif); *A. stipitata* (bold sans serif); *M. pyramidata* (sans serif italic).


G1P
G2P
G3P
G4P
Axis 1
Axis 2


M. pyramidata
A. stipitata
A. vesicaria
M. georgei
M. sedifolia
Width
Dry matter
Density
Canopy
Height
Axis 1
Axis 2

Not only were plant features associated with quadrat groups, they also associated with each other. The Figure 5.8 shows that the all features of each plant are associated with each other and the different plant species are in different directions.

All features of *M. pyramidata* were correlated together the same direction and also all features of *A. stipitata* were correlated the same direction of *M. pyramidata.* The five features of *M. georgei* were strongly correlated with each other and negatively correlated with all features of *M. pyramidata* and *A. stipitata.* All features of *A. vesicaria* were strongly correlated each together and more weakly correlated with the features of *M. georgei.* Three features (Width, height and dry matter) of *M. sedifolia* were correlated with each other, but density of this species was separated from another features and the canopy vector was placed between these features.

5.5.2.5 Description Of Vegetation Types

From the analyses, four main plant-based feature types were recognised: large and frequent *M. pyramidata* + *A. stipitata* (G1P quadrats), large *M. sedifolia* (G2P quadrats), frequent *M. sedifolia* and large *M. georgei* (G3P quadrats), large *A. vesicaria* (G4P quadrats) (Figure 5.9). The plant features of each species and presence and absence of each plant species were different in these four vegetation groups which were explained as follows:

G1P Vegetation Type: All features of *M. pyramidata* with high level of all features occurred in G1P quadrats. Also, all features of *A. stipitata* recorded their highest values in this vegetation type whereas *A. vesicaria* recorded its lowest values. However, all features of *A. stipitata* and *M. georgei,* with the exception of density of *M. georgei,* were represent trends only in this paddock. This group is located predominantly around the water point, extending further out along the prevailing wind direction towards the southwest.

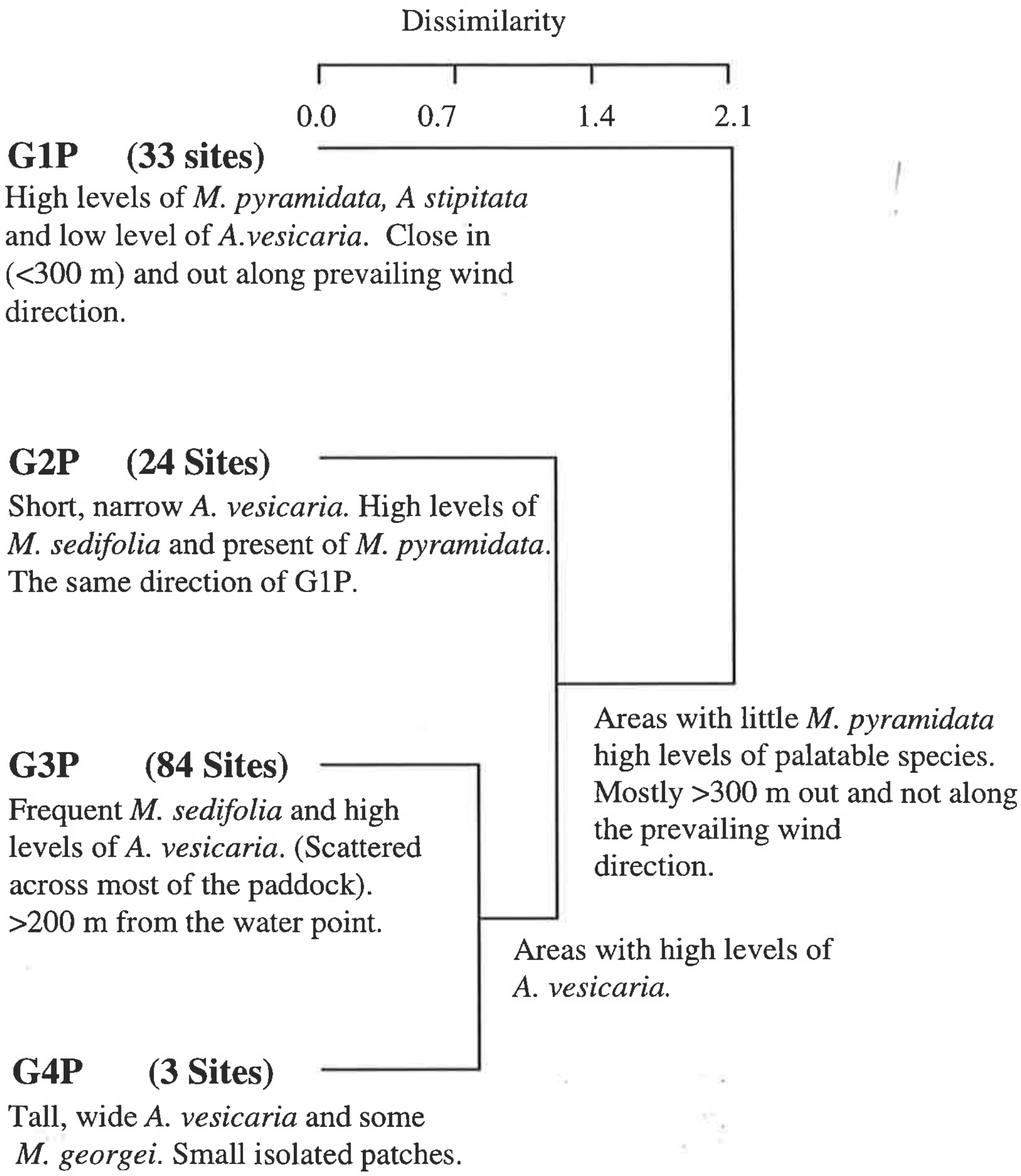


Figure 5.9. Stylized dendrogram group relationships with plant indicator features for each group in Purpunda Paddock.

G2P Vegetation Type: *M. pyramidata* was common in this group, but *A. stipitata* was absent. There were also high levels of *M. sedifolia*, and short, narrow individuals of *A. vesicaria* were found in G2P quadrats.

G3P Vegetation Type: Frequent *M. sedifolia* is characteristic of G3P quadrats. The other four features of this plant species and all features of *A. vesicaria* were found in this group and they were in the second grade in relation to all four groups. Also, *M. georgei* was common in this group. This group was distributed through 58% of the paddock.

G4P Vegetation Type: The largest *A. vesicaria* plants occurred in this vegetation type. *M. georgei* was also common, but *M. sedifolia* was absent. This group was distributed in only 2% of the paddock (three sampling points) and represents patchy areas both far from the water point along main wind direction, and close to the water point away from main wind direction. These patterns were similar for all the features measured for each species, and are represented statistically and schematically in Table 5.2, Figure 5.9 respectively.

5.5.3 Railway Paddock

5.5.3.1 Cluster Analysis

The results of cluster analysis from 96 quadrats of plant-based features from the Railway Paddock are presented in Figure 5.10a. Four quadrat groups were distinguished at the 0.8 dissimilarity level (5.10a) and the geographical distribution of these four groups were illustrated in Figure 5.10b. G1R quadrats were widely separated from the other three groups, with fusion occurring at 1.88 dissimilarity level. This quadrat group was distributed from adjacent to the water point to c. 300 m from the water resource in the direction of the prevailing wind. Distribution of these groups was heterogeneous and they were grouped in patchy areas, not radially (Figure 5.10b). The G2R quadrats were distributed in patchy areas between 300-800 from the water point. Geographical distribution of G3R quadrats were in the areas between 400

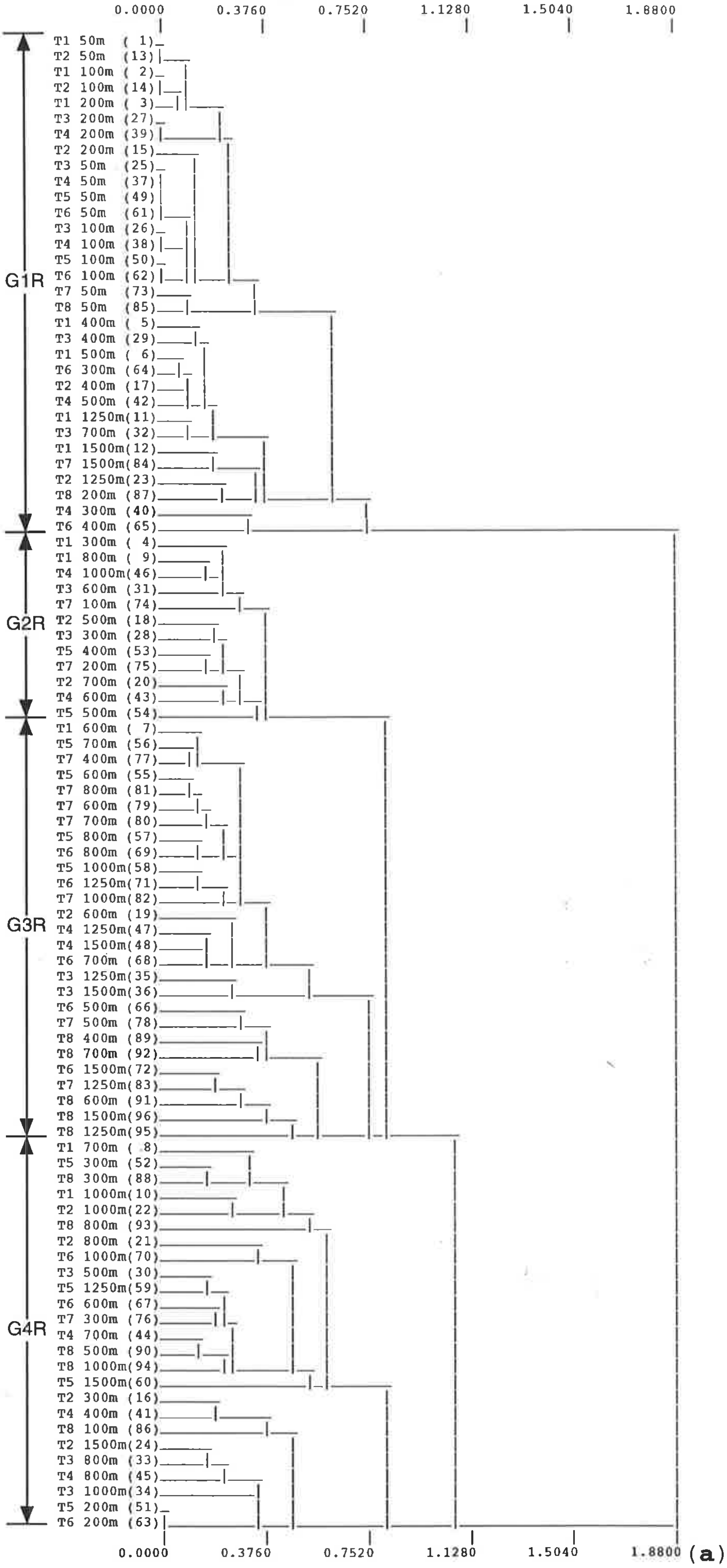
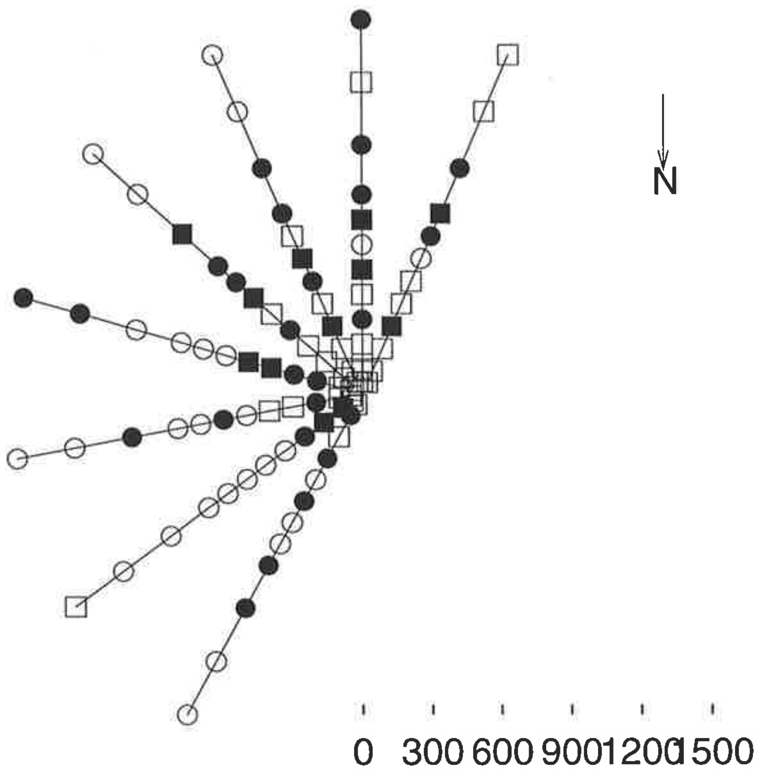


Figure 5.10a. Cluster analysis of all 96 sampling quadrats for the five features measured for five plant species at Railway Paddock. The four dendrogram groups were distinguished and are labelled as G1R-G4R (R = Railway Paddock).



(b)

Figure 5.10b shows the geographical locations of sampling quadrats of Railway Paddock where the □ = G1R, ■ = G2R, ○ = G3R and ● = G4R.

m and 1500 m from the water point, whilst the G4R quadrats were distributed between 300-1500 from the water point, but not into the prevailing wind direction.

5.5.3.2 Non-Parametric Analysis

The results of non-parametric (Kruskal-Wallis) analysis are presented in Table 5.3. The analysis of variance for the mean character differences was used to test for significant difference between the dendrogram groups.

All features of all five plant species (*M. pyramidata*, *A. stipitata, A. vesicaria, M. georgei* and *M. sedifolia*) show strongly significant ($p<0.002$) differences between the quadrat dendrogram groups in this paddock. High values of three features (canopy cover 8.5% ± 3. (SD), density 6.1 plants/quadrat ± 2.1 and dry matter 792.1 g ± 370.5) of *M. sedifolia* were characteristic of G1R quadrats. G2R quadrats were typified by high values of canopy cover (4.8% ± 4.), dry matter (172.1 g ± 159.7) and width (41.2 cm ± 22.2) of *A. vesicaria*, high width values for *M. sedifolia* (66.4 cm ± 21.4) and *A. stipitata* (10.5 cm ± 19.1). Four attributes of *M. pyramidata* (canopy cover 8.5% ± 3.8, density 5.2 plants/quadrat ± 3.5, dry matter 368.1 g ± 249.1 and height 56.5 cm ± 20.6), three features of *M. georgei* (canopy cover 1.6% ± 1.2, density 3.8 plants/quadrat ± 3 and dry matter 26.8 g ± 27) and three features of *A. stipitata* (density 2.1 plants/quadrat ± 3.9, dry matter 5.1 g ± 11.3 and height 13.3 cm ± 20.8) were the major plant features in G3R quadrats. The fourth group was characterised by canopy cover (9.5% ± 6.1), height (68.7 cm ± 9.3) and width (88.8 cm ± 20) of *M. sedifolia*, density of *A. vesicaria* (7.1 plants/quadrat ± 8.7) and width (39.8 cm ± 16.4) and height (30.6 cm ± 3.9) of *M. georgei.*

5.5.3.3 Ordination

The four quadrat groups were ordinated in Figure 5.11 which were the results of the SSH ordination are presented as a scatter plot of the first two axes for all 96 quadrats in Purpunda Paddock. G1R quadrats were distributed in the upper right corner and G3R quadrats were distributed from the upper left to the lower left quadrant and overlapped with G4R quadrats

Table 5.3. Summary of statistics of dendrogram groups for Railway Paddock showing the mean and standard deviation of each plant feature. Kruskal-Wallis test indicates whether there are significant differences between the groups ($p = 0.002$). Principal Canonical Correlation (PCC) analysis indicates which plant features are significantly correlated with the site ordination (df=94, r<0.33). Note: the data for Kruskal-Wallis test and PCC analysis were not range standardised.

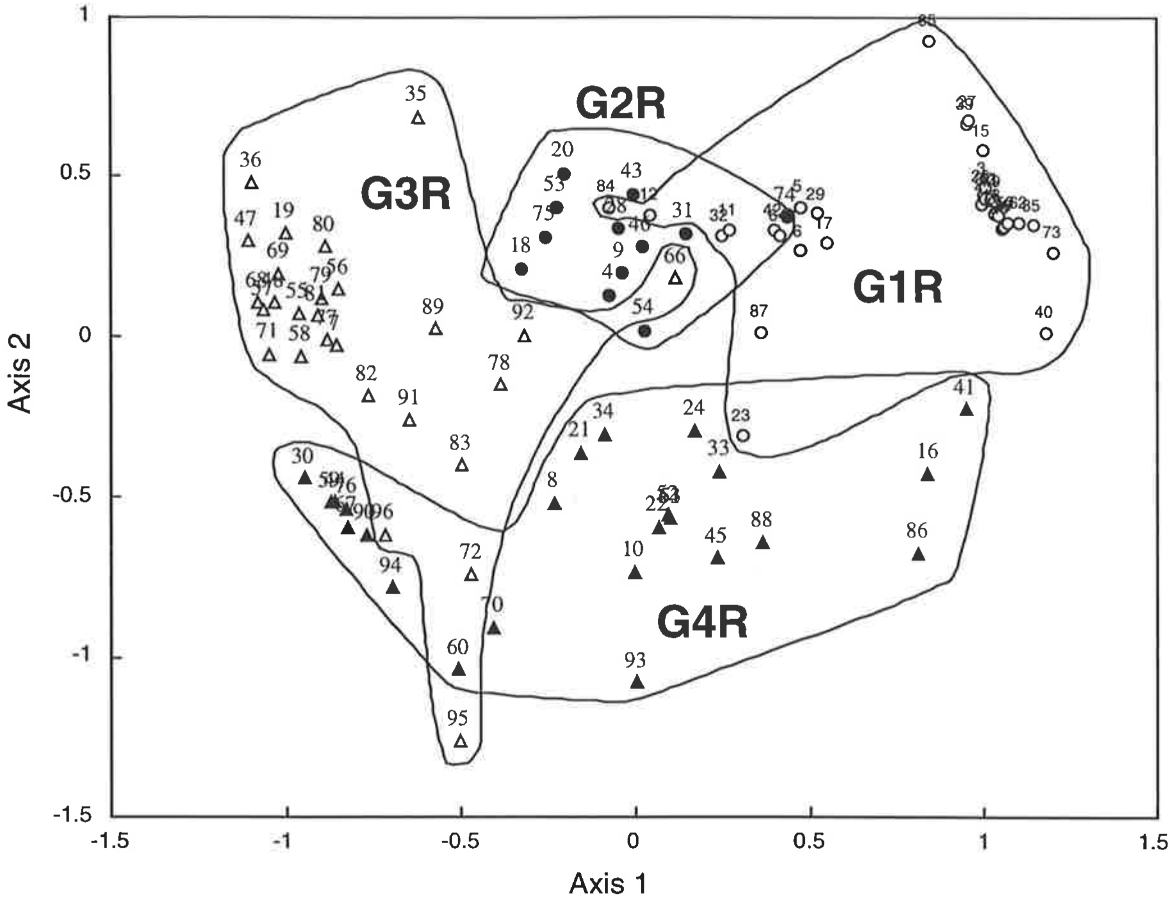
		Dendrogram groups													
Species	**Feature**	**G1R**		**G2R**		**G3R**		**G4R**		**Kruskal-Wallis Test**				**PCC Correlation**	
		Mean	*S.D.*	*Mean*	*S.D.*	*Mean*	*S.D.*	*Mean*	*S.D.*	**H**	**d.f.**	**P**	**sig.**	**R**	**sig.**
A. stipitata	*Canopy cover*	0.1	0.6	0.8	2.3	0.7	1.5	0.0	0.0	8.86	3	0.02	***	0.51	***
A. stipitata	*Density*	1.0	3.8	1.6	3.6	2.1	3.9	0.0	0.0	8.11	3	0.00	***	0.61	***
A. stipitata	*Dry matter*	1.0	4.4	3.6	7.9	5.1	11.3	0.0	0.0	8.79	3	0.01	***	0.63	***
A. stipitata	*Height*	2.0	6.2	11.7	20.1	13.3	20.8	0.0	0.0	9.48	3	0.01	***	0.74	***
A. stipitata	*Width*	1.4	4.7	10.5	19.1	9.3	14.2	0.0	0.0	9.45	3	0.02	***	0.70	***
A. vesicaria	*Canopy cover*	0.9	1.7	4.8	5.0	3.9	4.9	4.6	5.7	24.16	3	0.00	***	0.54	***
A. vesicaria	*Density*	1.5	2.8	7.1	9.0	5.5	5.9	7.1	8.7	22.31	3	0.00	***	0.57	***
A. vesicaria	*Dry matter*	34.4	53.8	172.1	159.7	147.4	166.7	113.8	117.6	8.79	3	0.00	***	0.57	***
A. vesicaria	*Height*	19.5	25.8	42.3	22.1	45.2	20.9	27.1	21.5	14.36	3	0.00	***	0.71	***
A. vesicaria	*Width*	14.7	20.0	41.2	22.2	35.4	19.0	24.3	19.4	20.83	3	0.00	***	0.72	***
M. georgei	*Canopy cover*	0.0	0.0	0.0	0.0	1.6	1.2	1.4	1.1	82.47	3	0.00	***	0.70	***
M. georgei	*Density*	0.1	0.4	0.1	0.3	3.8	3.0	3.3	3.9	78.69	3	0.00	***	0.68	***
M. georgei	*Dry matter*	0.2	0.7	0.1	0.6	26.8	27.0	25.9	46.1	76.87	3	0.00	***	0.57	***
M. georgei	*Height*	0.9	3.8	1.0	4.4	28.6	6.7	30.6	3.9	81.93	3	0.00	***	0.86	***
M. georgei	*Width*	0.8	3.1	0.8	3.5	35.6	10.2	39.8	16.4	82.48	3	0.00	***	0.82	***
M. pyramidata	*Canopy cover*	0.0	0.0	5.6	3.8	8.5	7.4	0.0	0.1	70.86	3	0.00	***	0.72	***
M. pyramidata	*Density*	0.0	0.0	3.5	2.0	5.2	3.5	0.1	0.3	71.18	3	0.00	***	0.73	***
M. pyramidata	*Dry matter*	0.0	0.0	250.8	157.1	368.1	249.1	1.4	4.1	71.44	3	0.00	***	0.73	***
M. pyramidata	*Height*	0.0	0.0	55.6	14.5	56.5	20.6	3.3	9.4	70.64	3	0.00	***	0.87	***
M. pyramidata	*Width*	0.0	0.0	66.4	21.4	62.0	26.2	3.3	9.4	70.87	3	0.00	***	0.86	***
M. sedifolia	*Canopy cover*	8.5	3.0	2.2	4.1	1.6	2.5	9.5	6.1	47.71	3	0.00	***	0.77	***
M. sedifolia	*Density*	6.1	2.1	0.9	1.9	0.7	1.0	3.8	2.3	60.02	3	0.00	***	0.86	***
M. sedifolia	*Dry matter*	792.1	370.5	147.7	267.2	122.9	183.9	740.4	426.7	55.35	3	0.00	***	0.81	***
M. sedifolia	*Height*	59.0	12.7	27.3	38.7	33.9	45.2	68.7	9.3	15.06	3	0.00	***	0.67	***
M. sedifolia	Width	64.4	13.3	31.2	43.6	30.1	41.6	88.8	20.0	19.01	3	0.00	***	0.68	***

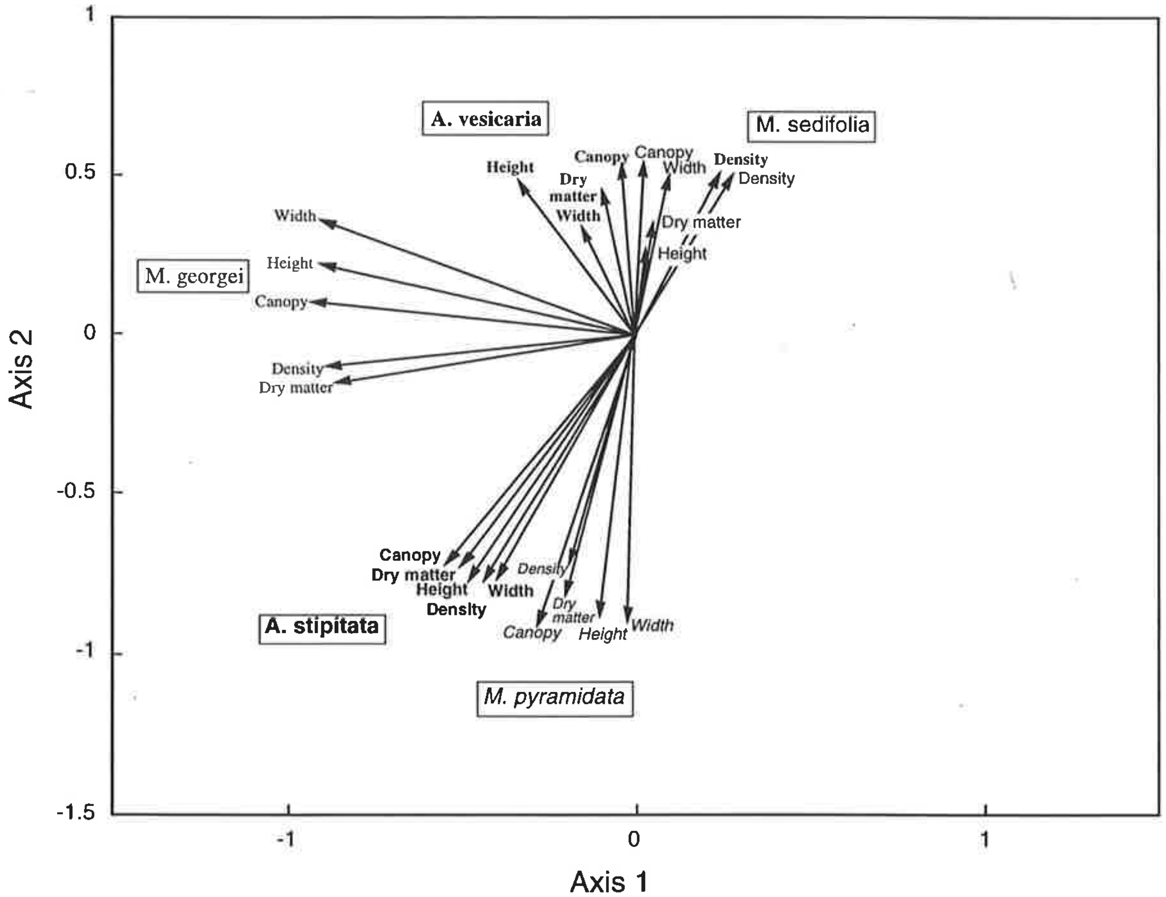
Figure 5.11. Plot of the first two axes from a semi-strong hybrid scaling (SSH) ordination of the 96 quadrats in Railway Paddock based on 25 plant-based features. Stress = 0.08 Symbol represents dendrogram group (○ = G1R, ● = G2R, Δ = G3R and ▲ = G4R) and label represents sample no. (1-96). Sample numbers appear in the following transects: 1 - 12 = Transect 1 (205°), 13 - 24 = Transect 2 (180°), 25 - 36 = Transect 3 (155°), 37 - 48 = Transect 4 (130°), 49 - 60 = Transect 5 (105°), 61 - 72 = Transect 6 (80°), 73 - 84 = Transect 7 (55°), 85 - 96 = Transect 8 (30°).

Figure 5.12. Principal Canonical Correlation (PCC) of the 25 plant-based features measured for Railway Paddock superimposed on the dendrogram group outlined plotted in Figure 5.11.

Species and their features are indicated by type face in the following way:

M. georgei (roman); *A. vesicaria* (bold roman); *M. sedifolia* (sans serif); *A. stipitata* (bold sans serif); *M. pyramidata* (sans serif italic).


G1R
G2R
G3R
G4R
Axis 1
Axis 2
-1.5
-1
-0.5
0
0.5
1
1.5


A. vesicaria
M. sedifolia
M. georgei
A. stipitata
M. pyramidata
Height
Dry matter
Width
Canopy
Density
Axis 1
Axis 2
-1.5
-1
-0.5
0
0.5
1

(Figure 5.11). However, G2R quadrats were between these two groups (G1R and G3R quadrats) and it overlapped them. The G4R quadrats were scattered from the left end-point to the right end-point of the quadrant.

5.5.3.4 PCC Analysis

Indirect gradient analysis with principal canonical correlation (PCC) analyses (Wilkinson, 1990) was used to determine the correlation of plant features with the site ordination. The results of PCC analyses are presented in Table 5.3 and relationships between the 25 plant features with the quadrat groups are illustrated in Figure 5.12 for this paddock. Significance was Bonferroni adjusted to $\alpha = 0.002$ to allow for multiple comparison (Wilkinson 1990). All features of five plant species were significantly ($p<0.002$) associated with quadrat positions.

Comparison of these quadrat groups, with vectors representing the contribution of plant species features to the position of the groups in the paddock (Figure 5.12), revealed that all five plant attributes of *M. sedifolia* were associated with G1R quadrats, whereas all features of *M. pyramidata* were absent in this group. The G2R quadrats and G3R quadrats share similar plant features of *A. vesicaria*. The plant features of *M. pyramidata* and *A. stipitata* were correlated with some quadrats of G3R quadrats. Five features of *M. georgei* were associated with G3R quadrats.

The plot shows that there were an association between the features of individual species and there was also a correlation between each individual species. All features of *A. stipitata* were strongly correlated with each other and they were correlated with all features of *M. sedifolia*. All features of these two species were negatively correlated with another two species (*A. vesicaria* and *M. sedifolia*) of this paddock. Whereas, all features of *M. sedifolia* and four features (density, canopy cover, dry matter and width) *of A. vesicaria* strongly correlated with each other, and height of *A. vesicaria* more and less correlated with them. All features of *M. georgei* were separated from other four species but correlated with each other.

5.5.3.5 Description Of Vegetation Types

According to the multivariate analysis, the four vegetation dendrogram groups were distinguished which the quadrats were approximately equally distributed between the groups G1R, G3R and G4R (32, 27 and 25 quadrats respectively) (Figure 5.13), with a smaller number of quadrats in G2R (12 quadrats). The vegetation features of these groups were as follows:

G1R Vegetation Type: The vegetation features of this group were characterised by high frequency and biomass of *M. sedifolia* with relatively tall and wide individuals of this species, the tallest and widest of which occurred in G4R quadrats. Also, *A. stipitata* was present at low levels and there was no sign of *M. pyramidata* (Table 5.3).

G2R Vegetation Type: The characteristic plant features of this group were high levels of some features (canopy cover, dry matter and width) of *A. vesicaria*, relatively wide *A. stipitata* and *M. pyramidata,* and with the second highest rankings for canopy cover, density, dry matter and height of this plant. This group was patchily distributed in this paddock.

G3R Vegetation Type: The most important plant attributes of this group were four features (canopy cover, density, dry matter and height) of *M. pyramidata* and three features (density, dry matter and height) of *A. stipitata*. Also, three plant features (canopy cover, density and dry matter) of *M. georgei* and tall and wide (large) *A. vesicaria* were the characteristics of this group. The plant features of *M. sedifolia* had the lowest values in G3R quadrats.

G4R Vegetation Type: High frequency and canopy cover of *A. vesicaria* with high values of four features (canopy cover, dry matter, height and width) of *M. sedifolia* occurred in this vegetation type. *A. stipitata* was absent from this group.

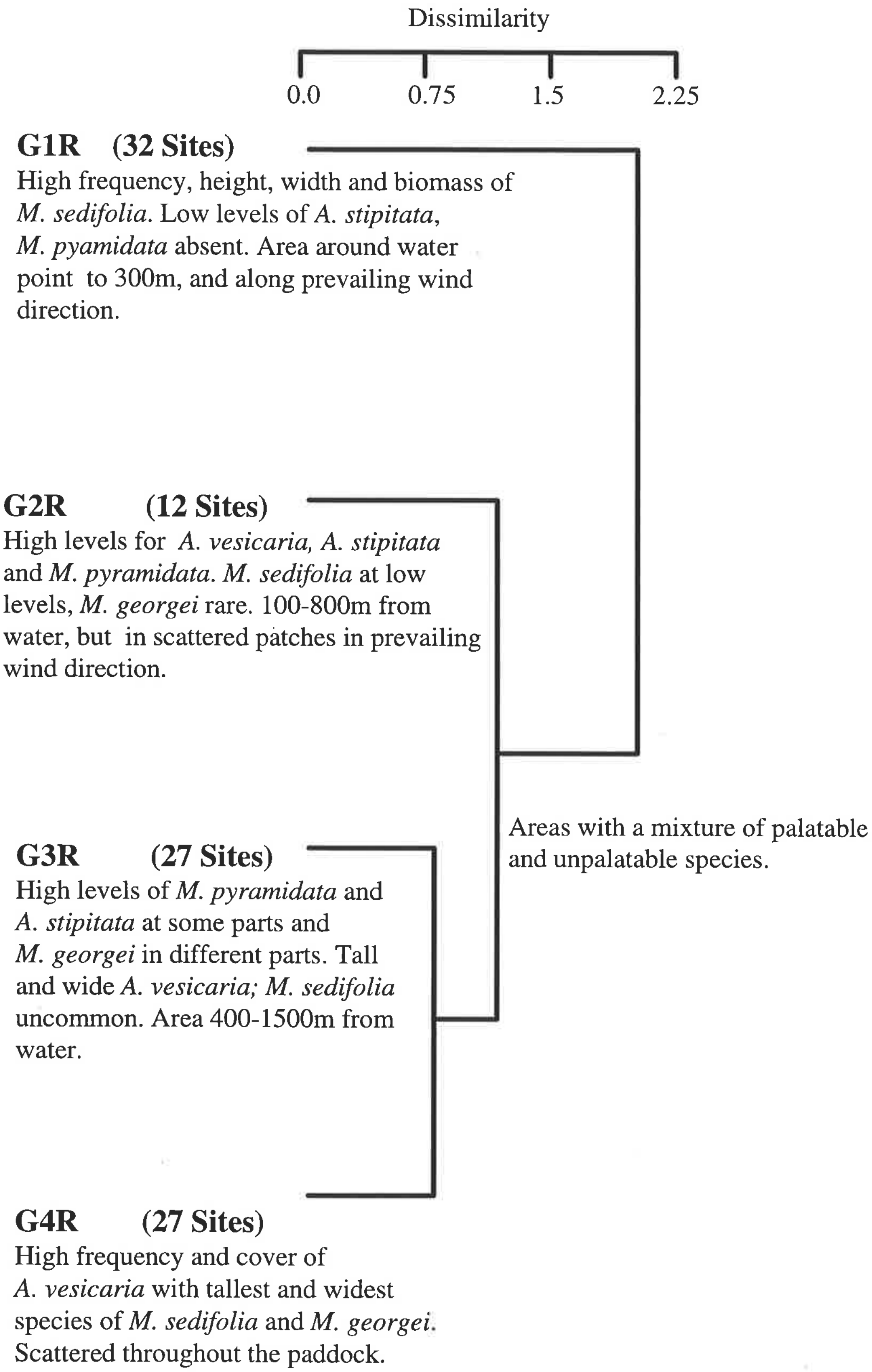


Figure 5.13. Stylized dendrogram group relationships with plant indicator features for each group in Railway Paddock.

5.5.4 Comparison Of Vegetation Form Of Three Paddocks

The results of the multivariate analysis based on twenty five plant-based features showed that different vegetation types were grouped at different geographical situations with different structures in each of the three paddocks. Four groups were classified each in Purpunda and Railway and five groups in Overland Paddock.

With the exception of the area immediately surrounding the water point at Overland Paddock, which was heavily degraded, the vegetation of this paddock closely resembles that of Purpunda Paddock. In contrast to the other two paddocks (Overland and Purpunda), the pattern of vegetation observed in Railway Paddock was different.

There was a bare zone around the water point only in Overland Paddock (Figure 5.2), whereas the two highly unpalatable species (*M. pyramidata* and *A. stipitata*) were frequently found near the water point, along the axis of the prevailing wind direction and in the patchy zones of Purpunda and Railway as well as adjacent to the bare zone of Overland Paddock. Plants of the moderately palatable species (*A. vesicaria* and *M. sedifolia*) were commonly short and narrow in this area, particularly the latter species, with higher levels for all features recorded in Railway Paddock. The low grazing value plant (*M. pyramidata*) and the more preferred grazing plant (*A. vesicaria*) were grouped as vegetation group G2O and scattered throughout the paddock in a patchy distribution. The highest densities of the moderately palatable plant species (*A. vesicaria* and *M. sedifolia*) were present in G5O quadrats, but were found in only 1% of this paddock. Tall and old mallee (*Eucalyptus* spp.) trees are more abundant on this part of paddock, therefore these areas might possibly indicate a combined response to shading and increased moisture availability. The greater percentage of this paddock (79%) was relatively dominated by large plants of *A. vesicaria* and *M. sedifolia*.

The unpalatable *M. pyramidata* was concentrated closest to the water point (<300 m) and along the main wind direction in Purpunda Paddock (G1P quadrats), whereas the largest palatable plants (*A. vesicaria and M. georgei*) were in small scattered patches (G4P quadrats). *A. vesicaria* and *M. sedifolia* were widely distributed throughout most of the paddock (58%) with particularly high density levels for *M. sedifolia* (G3P quadrats). In general, low value plants (*M. pyramidata* and *A. stipitata*) were in G1P quadrats, whereas higher value plants (*A. vesicaria*) are more representative of G4P quadrats.

The unpalatable *A. stipitata* was associated in Railway Paddock with large specimens of the moderately palatable *M. sedifolia* in G1R quadrats, and *M. pyramidata* was absent. This contrasts with the composition of Overland and Purpunda Paddocks, both of which contain this latter unpalatable species close to the watering points. The geographical position of G1R quadrats are the same as G1P quadrats and G2O quadrats (around of water point and along the axis of main wind direction). In addition, G4R quadrats mirrored G4P quadrats and G5O quadrats, as it was dominated by valuable plants, the only difference being that G4R quadrats were distributed over a larger area (26% of the paddock), because the G4P quadrats and G5O quadrats were in small parts of the paddocks (2% and 1% respectively). The G2R quadrats were distributed in patchy areas with a smaller number in Railway Paddock (12 quadrats). Distribution of this group was heterogeneous and it was grouped in patches, not along a radius.

5.6 Discussion

5.6.1 Observed Spatial Pattern And Possible Causes

The vegetation types of three paddocks were heterogeneous and exhibited considerable patchiness throughout the paddocks. Overgrazing around water troughs often results in an increased density of inedible shrubs and a decrease in, or disappearance of, more palatable perennial shrubs (Lange 1969; Squires 1978; Andrew 1988 and Thrash *et al.* 1993). Due to a greater concentration of livestock near the water point, a bare zone around the water hole (G1O quadrats) could be expected. Similarly, two unpalatable plants (*M. pyramidata* and *A. stipitata*) were frequently found near the water point, along the axis of the prevailing wind direction zones of Purpunda and adjacent to the bare zone of Overland Paddock. In contrast, in Railway Paddock, *M. sedifolia* was commonly found in G1R quadrats. Although *A. vesicaria* was also present in this area, the plants were few, small, and narrow, with low foliage cover and low biomass. The x-axis of the SSH ordination for this paddock could be considered to represent a gradient of grazing intensity (Figure 5.5). Plant features were ordinated from left to right along a direction which represents lightly grazed areas to heavily grazed areas. The ordination along the y-axis reflected palatability of plant features (low to high). Surprisingly, *M. pyramidata* was not found in G1R quadrats and *A. stipitata* was not common in this area of Railway Paddock, but the latter, where present, was significantly associated with groups G2R and G3R quadrats. On the other hand, some plant features of valuable plants (*A. vesicaria* and *M. georgei*) were better represented in the patchy areas both close to the water points (G2O and G2R quadrats) and at furthest areas from the water points (G5O, G4P and G4R quadrats). Patchy vegetation distribution of palatable species of the area might be a function of "fertile patches" (Tongway and Ludwig 1994) but, distribution of unpalatable species in the area might be related to selective grazing behaviour of livestock (Heady and Child 1994). They may also represent areas where the sheep have not yet grazed either by chance, or as part of their grazing behaviour i.e. avoiding grazing near trees.

5.6.2 Distinguishable Zones

It is likely that plant features undergo changes when subjected to management treatments that can degrade the paddock. Relative species frequency and gross morphology changed relatively quickly from numerous, large palatable species to more common and larger unpalatable taxa. *A. vesicaria* was most abundant in lightly grazed and selectively grazed vegetation, declining rapidly along the grazing pressure gradient (Osborn *et al.* 1932). It appears as low quality vegetation around the water point, and along a line into the predominant wind direction and in patchy areas. The presence of wide and tall *A. vesicaria* and/or *M. sedifolia* was therefore probably a good indicator of the "outer" zone. The wide, tall plants and high foliage cover of *M. pyramidata* and *A. stipitata*, plus narrow and small plants of *A. vesicaria*, could represent a disturbed (degraded) zone. Therefore, three zones could be distinguished from plant features; the disturbed (degraded) zone; a sensitive zone (the boundary region between them); and an "outer" zone, found at increasing distance from the watering point. The behavioural patterns of livestock might also lead to the development of the heavily grazed and semi-grazed patches such as those seen in G2P, G4O and G3R quadrats, because the sheep do not graze uniformly around the water point, tending instead to graze into the wind, and selectively preferring some fodder species over others (Squires 1981).

The changes in the plant composition of the shrubland community are illustrated by two unpalatable plants (*M. pyramidata* and *A. stipitata*), which increased noticeably in patchy areas (G2R and G3R quadrats), around water points and along main wind direction (G1P and G2O quadrats). The proportion of moderately palatable plants was patchy and distributed at further points of the paddocks.

The highly unpalatable plant species *M. pyramidata* is most common around the water point, extending outward along the predominant wind direction. *A. stipitata* was distributed in three groups (G1R, G2R and G3R quadrats) at Railway Paddock, albeit with low values of all features and it showed a trend toward higher values in G3R quadrats. It was only present in small areas (G1P, G3O and G5O quadrats) with low frequency at Overland and Purpunda Paddocks.

The presence of *M. sedifolia* in G1R quadrats might be also related to soil attributes, as *A. vesicaria* and *M. sedifolia* often grow in different soil types (Carrodus and Specht 1965) and *M.*

sedifolia does not occur in swamp or some creeks. However, the isolated G2P quadrats near the water point may also reflect its reduced palatability relative to *A. vesicaria* and *M. georgei* or a combination of these factors. The palatability rating or preference index for a particular species depends on the relative abundance of that species in the local flora, the intensity of grazing and the presence of other forage species (Cook 1962). The lowest values of all features of *M. sedifolia* occur in G1P and G2O quadrats. Nevertheless, although *M. sedifolia* is extremely long-lived (>300 years) (Wilson 1990), it may eventually become rare because of increased mortality and lack of recruitment in grazed areas (Lange and Purdie 1976; Crisp 1978; Lange and Graham 1983).

M. georgei was so rare that it was not significantly associated with any group in either Overland or Purpunda Paddock, although there was a non-significant trend toward higher values in G4P and G3O quadrats. All features of this species appeared in all four groups of Railway Paddock, albeit with low values for all features and with a trend toward higher values in G4R quadrats.

A. vesicaria is most abundant away from the water point, declining rapidly along the transect, and appears as low quality vegetation around the water point, and into the predominant wind direction in Purpunda Paddock. This species was abundant in G3O and G2R quadrats of Overland and Railway Paddock.

5.6.3 Vegetation Indicators

It seems that large and frequent *A. vesicaria* is the best indicator of "outer" zones and wide and tall *M. pyramidata* is an indicator of disturbed zones. The most important zones of the paddocks are the sensitive zones, as these are where management attention should be focused because those areas may still be capable to recovery, or, at least, where degradation may be prevented by appropriate management strategy. Indicator species need to identify areas that are at risk and provide a measure of the severity of that risk, to enable management to focus its attention most effectively. The presence of narrow and small individuals of *M. georgei* and *A. vesicaria* might be distinguished as the indicators for sensitive zones. From these plant features, indicators might be used to detect sensitive zones in chenopod shrubland.

The inference that selective herbivory is the dominant mechanism of species replacement within communities dominated by *A. vesicaria* is supported by observations that intensive herbivory is required to shift community dominance from "outer" to sensitive zone and finally to the degraded zone. The defoliation of *A. vesicaria* by sheep grazing in Koonamore, South Australia (Osborn *et al.* 1932), the Riverine Plain in N.S.W. (Wilson *et al.* 1969) and in Middleback (Barker 1972, Andrew and Lange 1986a and Hunt 1995) increased after intensive herbivory and substantially reduced the abundance of this species. This suggests that threshold levels of population degradation of *A. vesicaria* potentially precede large-scale changes in species composition (Archer 1989, Friedel 1991, Laycock 1991). If threshold levels were identified within the species replacement process, they could potentially alert rangeland managers to impending compositional changes prior to their occurrence. Grazing management practices could then be modified to reverse large-scale shifts in community composition.

However, as it is possible that other factors besides the plant features, such as soil characteristics, are responsible for the changes of vegetation community, because they are linked to landscape processes (Ludwig and Tongway 1992), or at least can be considered as an indication of the state of the paddock (Greene and Tongway 1989), comparisons of these plant based results with soil based analyses are necessary, and are the subject of the next chapter.

Chapter 6: Vegetation Associated Edaphic Features

6.1 Introduction

The Chenopodiaceae occupy a diverse range of habitats in Australia as a result of widespread, radiative evolution (Graetz and Wilson 1984). It has been suggested that are sorted into communities primarily on the basis of edaphic factors and only secondarily by climate. Furthermore, it has been hypothesised that soil factors (such as depth of wetting, salinity and texture) control plant/water regimes and determine species distribution rather than chemical characteristics of soils such as nutrients (Noy-Meir 1974; Eldridge 1988). The physical, chemical, and biological processes that occur in rangeland soils supply plants with nutrients and water. The texture, structure and porosity of soil determine how much rain is captured and how much runs off during a disturbance. Soils are reservoirs of water and nutrients for plants to draw on.

In the context of rangeland ecology, the interaction of climate and soil factors determines the vegetation type and quantity, and an understanding of the geomorphological structure and soil conditions of a site provides the key points for the identification and classification of plant communities (Heshmatti 1994). Soil condition information can augment and complement plant-based condition assessments, especially when plant densities are low due to drought or grazing. If only vegetation is monitored it will not be clear whether any changes in composition are due to interactions between grazing animals and vegetation alone, or whether the soil as a habitat for pasture plants has been degraded. Because overgrazing influences the plant community indirectly by its effects on soil characteristics (Tueller 1973), changes in site variables such as soil structure and nutrients may mean that grazing and vegetation change are nonlinearly related (Graetz and Tongway 1986). Site descriptions must contain information on soils and other environmental factors that adequately distinguish between each individual site's capability to produce a characteristic potential natural plant community even in the absence of that community (Leonard *et al.* 1992).

Soil degradation has profound effects on rangeland ecosystems. Wilson and Tupper (1982) suggested that there are four classes of rangelands based on whether the soil is stable or unstable and whether vegetation productivity is good or diminished. Smith (1989) concluded that site degradation occurs mainly through deterioration of the soil's capacity to capture and store water, loss of the ability of the soil to supply nutrients, or the accumulation of salts or other toxic substances in the soil. Friedel (1991) wrote that site deterioration is best indicated by irreversible change in the soil, and concluded that assessment of the soil surface is a critical element in the identification of thresholds of change on rangelands. Rangelands in severe environments are exposed to varying degrees of soil degradation. Soil deterioration affects not only soil attributes but can also degrade other ecological processes. Loss of organic matter in the soil reduces nutrient stores and interrupts nutrient cycles (National Research Council 1994). Accelerated soil erosion reduces the total organic matter and total nitrogen contents of soils and the capacity of rangeland soils to hold moisture (Croft *et al.* 1943). Microbiotic crusts provide the only biological form of soil cover during dry periods in many arid areas and overgrazing markedly reduces crust cover and composition within these areas (Eldridge and Greene 1994a).

A number of basic studies have been carried out on soil edaphic variables in recent years. These studies have linked terrain, soil, and plant patterns to landscape processes and have given rise to generic models of semi-arid landscape function (Tongway and Ludwig 1990, 1996; Tongway 1991; Ludwig and Tongway 1993, 1995). Protocols to assess rangeland condition have been developed (Tongway and Smith 1989; Tongway 1994), and soil surface condition and cover of biological soil crusts are major components of this system.

6.2 Aims And Objectives

The aim of this chapter is relate soil conditions to the observed vegetation patterns. The objectives of this work are as follows:

1. To measure a range of largely soil-based environmental variables likely to be important in influencing plant distribution in grazed chenopod shrubland ecosystems.

2. To correlate soil features with the previously defined plant-based quadrat groupings.

3. To determine whether the impacts of grazing by sheep near watering points can be detected by measuring soil attributes.

4. To determine which soil attributes are important as potential indicators of distinguishable zones of chenopod shrubland communities

6.3 Materials And Methods

In order to identify useful environmental indicators, a variety of soil surface descriptors devised by Tongway (1994) was used (see also Appendix A). In addition, the percentage cover of major cryptogam species and related chemical attributes were also measured. A number of soil surface microtopographic features was measured in the field with a high-precision level-surveying instrument. This suite of environmental features were examined and correlated with plant variables in Overland, Purpunda, and Railway Paddocks.

These soil surface attributes are known to be sensitive indicators of the condition of arid and semi-arid landscapes (Ludwig and Tongway 1992, Tongway and Smith 1989). They were measured in contiguous 25 m^2 quadrats (5 x 5 m) along the transects using the same quadrats as were used for plant features (Chapter 5). Thus, twelve quadrats were sampled along each transect line at intervals of 50m, 100m, 200m, 300m, 400m, 500m, 600m, 700m, 800m, 1000m, 1250m and 1500m. Transect length was determined by the fence of each paddock, which usually limited length to 1500m.

6.3.1 Soil Surface Condition

6.3.1.1 Field Assessment

The soil surface condition criteria were measured according to the methods outlined by Tongway (1994). At the fine or quadrat scale, observations were focused on the effect of processes that impinge upon the surface of the soil. Eleven features were observed using strict criteria and each was addressed separately.

- Soil cover in relation to interception of raindrops or soil cover (rain)
- Soil cover in relation to features which obstruct or divert overland flow or soil cover (flow)
- Crust brokenness
- The percentage of cryptogam cover
- Erosion features
- Eroded materials
- Soil microtopography
- Litter cover
- Surface nature
- Slake test
- Surface texture

Each individual feature was assigned to a class and this was a quadrat-based observation system. The features are fully described in Appendix A and are coded following Tongway (1994).

Abiotic Soil Features

Soil cover has two functions: interception of raindrops (rain) and interception of overland flow (flow). The first soil function (rain) was measured in order to assess the degree to which surface cover resists rainsplash erosion and the second function (flow) was measured to assess the cover of features which obstruct or divert overland flow. These two features were classed into 6 categories based on the percentage of soil cover by plants and any soil protective materials. Class 1 has nil (<1%) and class 6 has very high surface cover (>50%).

Crust brokenness was measured to assess to the degree to which surface, crust materials are broken, or loosely attached and available for erosion. These features, when present, were classed into 4 categories based on brokenness and slaking performance with class 1 being least stable and class 4 most stable.

The aim of measuring cryptogam cover was to assess the total cover of cryptogams and this was classified from 1 for zero cover to 4 for cover > 50%.

Erosion features are visible signs of active, current loss of soil material from the quadrats such as sheet and rill erosion, and evidences of smooth, rounded edges and colonisation by cryptogam cover and were classified in 4 categories: 1 for extensive and 4 for no visible erosion.

The objective of measuring eroded materials was to assess to what degree materials are being eroded from one place in the landscape and deposited in another. This feature was also classified into 4 categories in which class 1 included extensive eroded materials and class 4 was nil.

Litter cover assesses the availability of organic materials for decomposition and nutrient cycling and on the basis of degree of cover was categorised by 6 classes from 1, (nil, <1%) to 6 for very extensive cover (100%).

Soil microtopography was assessed for soil features which impede water flow on the quadrat between the time the surface becomes wet and the time water actually runs off the quadrat area.

This feature was classified from 1 (nil) to 5 (very high) on the basis of surface water detention capacity.

Surface nature observation was assessed on the basis of the robustness of the surface, or the degree to which the surface has the capacity to withstand stress (e.g. trampling), or to reform after rain. This feature was divided by 5 classes from 1 (weak) to 5 (hard).

The slake test examined for crust stability when the surface soil is wet and was classified from very unstable (1) to stable (4). The stability of soil crusts as measured by this test is a function of physical and biological processes that cement soil particles together. Also, this test measures the resistance of the soil surface to dispersion and detachment by raindrop impact and overland flow.

Soil texture was tested to rate the permeability of the soil body, as opposed to the crust, and in the field it was assigned to a class from 1 to 4 based on decreasing clay content.

The individual observations of the soil surface were condensed into three categories and their class values were summed for each category as follows:

- Stability: crust brokenness, surface nature, slake test, erosion features, eroded materials, cryptogam cover, soil cover (rain), and litter cover.
- Infiltration: microtopography, surface nature, litter cover (simple), soil cover (flow) and soil texture.
- Nutrient cycling status: litter cover (origin and incorporation), cryptogam cover and microtopography.

The above information and the range of scores for each class of each soil surface feature and their codes are summarised in Table A.11.

Biotic Soil Features

The lichen crust involves many species (Rogers and Lange 1971) which are difficult to identify in the field. Therefore, four of the most abundant and easily recognisable lichen species (*Heppia polyspora* Truk., *Xanthoparmelia amphixantha* (Müll. Arg.) Hale, *Acarospora ferdinandii* (Müll. Arg.) Hue and *Psora decipiens* (Hedwig) Hoffm.) were chosen from the list of lichens which were found in this area by Rogers (1970) (see Table 3.1). One unidentified moss in the soil crust which was also abundant and easily recognisable was also chosen for the study. The measurements for these five taxa were made on a single randomly placed 0.2 x 0.2 m subquadrat located within the larger 5 x 5 m quadrat used to score the other characteristics. The percentage of cover was calculated for each taxon, and expressed as a semi-quantitative score, using an adaption of the cover scale of Braun-Blanquet (1932) (Table 6.1).

Table 6.1. Semi-quantitative scores expressing percentage cover of lichens and moss (adopted from Braun-Blanquet 1932).

Lichen cover score	Percentage cover
0	absent
1	1-5%
2	6-25%
3	26-50%
4	51-75%
5	76-100%

6.3.1.2 Laboratory Assessments

In addition, the following soil-based chemical attributes were measured for each quadrat ;

- Percentage of soil moisture content
- Percentage of organic carbon
- Soil electrical conductivity (E.C.)
- Soil pH

Soil samples were taken from four cores each of 5 cm in diameter and 6 cm in depth taken randomly within each sample quadrat. The percentage of air-dry moisture content was measured (Rayment and Higginson, 1992).

Unfortunately, total nitrogen content could not be accurately measured because of the rapid vaporisation of ammonia and nitrates at temperatures above 25° C (Brower *et al.* 1990). Because of the remoteness of the study area, soil samples could not be refrigerated. Thus, the nitrogen present was likely to be the organic form because, in desert soils, nutrient concentration, especially nitrogen, is correlated with soil organic matter content (Greene and Tongway 1989). This value for nitrogen is directly proportional to the organic carbon content of the soil, so organic carbon content was calculated instead of nitrogen content because it is a much less labour-intensive analytical technique. Phosphorus values were not measured because Friedel (1981) found no correlation between range condition and phosphorus availability.

Soil samples were air-dried and passed through a 2 mm sieve prior to chemical analyses. Total oxidisable organic carbon content was estimated using the Walkley and Black rapid titration method (Allison 1965).

Soil electrolytic conductivity (E.C.) was measured in saturation extracts and used to evaluate the degree of topsoil salinization. This feature was measured on 1:5 soil:water suspensions and the estimation of soil pH was carried out in 1:5 soil:water extract (Loveday 1974).

6.3.2 Statistical Analysis

The indirect gradient analysis using principal canonical correlation (PCC) was carried out for soil-based features. This analysis was used to assess how well these features compared the plant features at the placement of the quadrats on the ordination. In ecological terms, the question is whether the vegetation patterns based on the plant species data correlate in any systematic way with the environmental attributes (Belbin 1995).

PCC determines whether the abundance of any particular soil features significantly correlate with the quadrat axis scores on the ordination. Data were range-standardised prior to analysis in order to even out the contribution of the different soil features to the analysis (Belbin 1991; Clarke 1993). The PATN package (Belbin 1991) was used for this analysis and significance was Bonferroni adjusted to $\alpha = 0.002$ to allow for multiple comparisons (Wilkinson 1990).

In the previous chapter, different vegetation groups were identified by multivariate analysis and in this chapter the soil feature will be analysed using PCC analysis (indirect gradient analysis) based on these vegetation-defined ordination axis scores. Indirect analysis was preferred for these soil features rather than using either cluster or gradient analysis because it has a number of advantages over these techniques (Jongman *et al.* 1996) Firstly, species compositions are easy to determine, because species are usually clearly distinguishable entities, whereas soil conditions are often difficult to characterise. There are many environmental variables and even more ways of measuring them, and one is often uncertain to which (if any) edaphic variables the species are responding. Secondly, the actual occurrence of any individual species may be too unpredictable to discover the nature of its relationship with soil conditions by direct means and therefore more general patterns of coincidence of several species are of greater use in detecting species-environment relations.

In contrast to direct gradient analysis approaches, the ordination space used for the PCC analysis is independent of the environmental data, which are then compared and correlated with the summarised vegetation data in order to detect possible environmental gradients (Kent and Coker 1992). This method is preferable in situations where the underlying environmental gradients are unknown or are unclear (such as this study), although both methods are equally applicable where the environmental gradients are known (Whittaker 1967).

6.4 Results

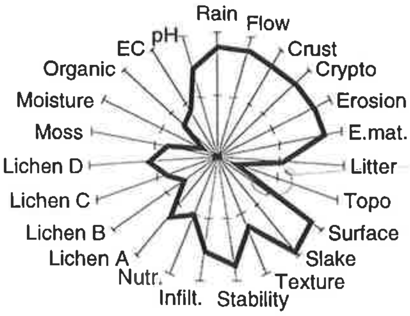
6.4.1 General Features

Figures 6.1 shows an overall view of the levels for each of the 23 soil surface features in the three paddocks (Overland, Purpunda and Railway). The lowest and the highest measured soil scores were used to range standardise the values for all three paddocks. The mean values of these standardised data were then used to illustrate the soil features of each paddock. The mean soil characteristics of Overland Paddock (Figure 1.1a) generally contained the highest scores and those of Purpunda Paddock (Figure 6.1b) contained the lowest, with those of Railway Paddock (Figure 6.1c) closer to but lower than Overland Paddock. The classes for interception of raindrops and overland flow were the same for Overland and Railway Paddock but low in Purpunda Paddock. Values of crust brokenness, cryptogam cover, erosion features, eroded material, litter cover, surface nature and slake performance in Railway Paddock were lower than in Overland Paddock but they were higher than Purpunda Paddock. Also, the cover of moss and lichens was high in Overland and low in Purpunda Paddock, although Lichen B (*X. amphixantha*) had low cover in this paddock and Railway paddock. Soil stability, infiltration rate and nutrient cycle status were highest in Overland and lowest in Purpunda Paddock. Soil moisture was low in all three paddocks and organic carbon was similar for the three paddocks and also low. EC and soil pH in Overland and Railway paddock were the same, but soil pH low in Purpunda.

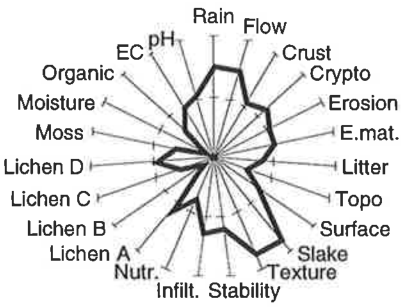
Table 6.2 shows, for each paddock, which of the 23 soil-based attributes were significantly correlated with the site ordination based on plant features, and Tables 6.3-6.5 show the maximum, minimum and mean values of these features in each dendrogram group for the three paddocks. The soil features are overlaid as vectors in Figures 6.2-6.4 which show the site ordinations on the first two axes for the three paddocks (Overland, Purpunda and Railway

Table 6.2. Summary of PCC analysis of soil features for Overland, Purpunda and Railway Paddock, showing whether or not the soil features are significantly correlated with the quadrat ordination on the basis of plant features.

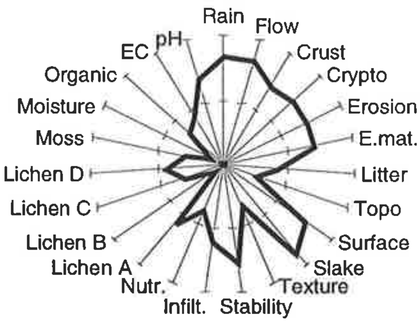
Soil Codes	Overland		Purpunda		Railway	
	R	Sig.	R	Sig.	R	Sig.
Rain	0.8855	***	0.4129	***	0.5175	***
Flow	0.8855	***	0.4129	***	0.5175	***
Crust	0.8704	***	0.6556	***	0.7452	***
Crypto	0.8704	***	0.6642	***	0.7312	***
Erosion	0.8704	***	0.6099	***	0.7415	***
E.mat.	0.8704	***	0.5471	***	0.7378	***
Litter	0.7445	***	0.6571	***	0.7002	***
Topo	0.5812	***	0.1631	n.s.	0.5929	***
Surface	0.3881	***	0.2503	n.s.	0.5741	***
Slake	0.1003	n.s.	0.2955	***	0.5981	***
Texture	0.6603	***	0.154	n.s.	0.2348	n.s.
Stability	0.8803	***	0.6843	***	0.7437	***
Infilt.	0.8635	***	0.4971	***	0.5655	***
Nutr.	0.7643	***	0.6448	***	0.684	***
Lichen A	0.7779	***	0.6331	***	0.7446	***
Lichen B	0.3736	***	0.1843	n.s.	0.3113	n.s.
Lichen C	0.6856	***	0.569	***	0.5292	***
Lichen D	0.7464	***	0.6777	***	0.6939	***
Moss	0.4682	***	0.5526	***	0.5813	***
Moisture	0.2987	n.s.	0.2528	n.s.	0.1578	n.s.
Organic	0.4107	***	0.2859	***	0.341	***
EC	0.2845	n.s.	0.4753	***	0.3194	***
pH	0.3355	***	0.5246	***	0.6039	***



(a)



(b)



(c)

Figure 6.1a, b and c show the soil characteristics for three paddocks (a = Overland, b = Purpunda and c = Railway Paddock). The data for each soil character were range standardised to range between 0 (lowest measured value) and 1 (highest measured value).

The key symbols of soil features in this figure are:

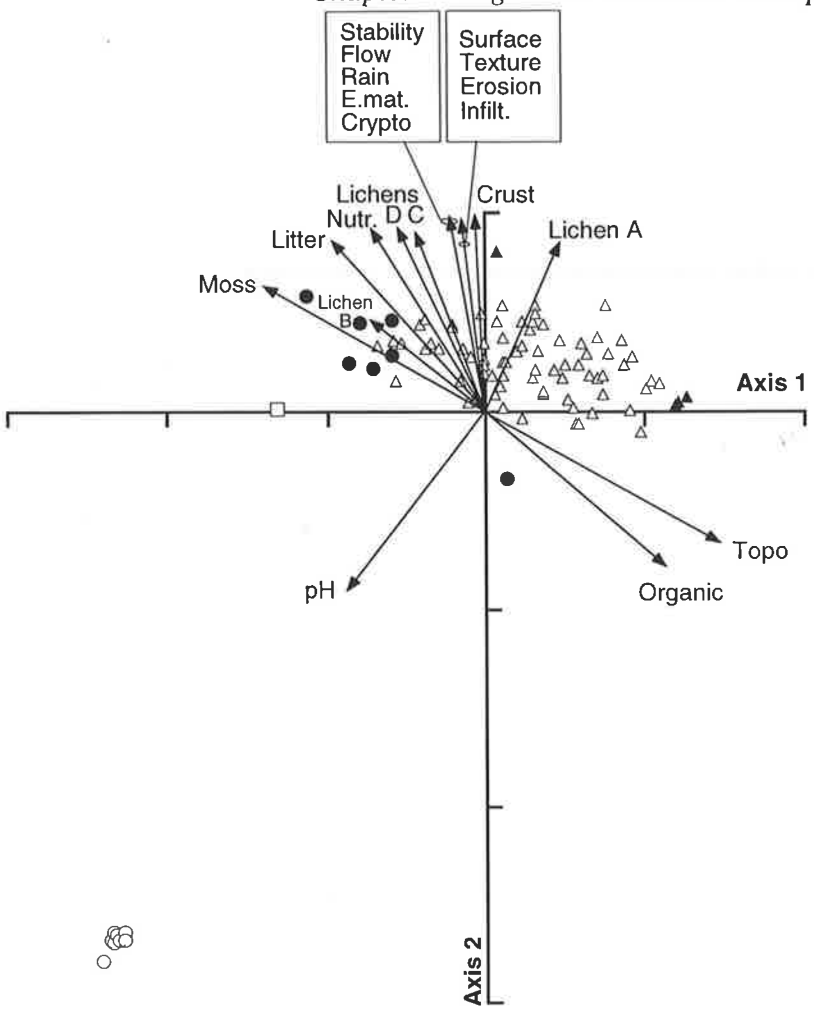
Rain = Soil cover in relation to interception of raindrops,
Flow = Soil cover in relation to features which obstruct or divert overland flow,
Crust = Crust brokenness, Crypto = The percentage of cryptogam cover,
Erosion = Erosion features, E. mat. = Eroded materials,
Litter = Litter cover, Topo = Soil microtopography,
Surface = Surface nature, Slake = Slake test,
Texture = Surface texture, Stability = Soil stability,
Infilt. = Infiltration, Nutr. = Nutrient cycling status,
Lichen A = %Cover of lichen *H. polyspora*,
Lichen B = %Cover of lichen *X. amphixantha*,
Lichen C = %Cover of lichen *A. ferdinandii*,
Lichen D = %Cover of lichen *P. decipiens*,
Moss = %Cover of moss, Moisture = %Soil moisture content,
Organic = %Soil Organic Carbon, EC = Soil electrical conductivity and
pH = Soil pH,

Figure 6.2. Plot of the first two axes from a semi-strong hybrid scaling (SSH) ordination of the 96 quadrats on the basis of 25 plant features. Principal Canonical Correlation (PCC) of the 20 significant soil features measured for Overland Paddock are superimposed on the dendrogram group in this paddock. Axes tick marks are shown at intervals of 0.5. Stress = 0.08

Symbol represents dendrogram group (○ = G1O, ● = G2O, Δ = G3O, ▲ = G4O and □ = G5O).

Character abbreviations are shown in Figure 6.1a.

Table 6.3. Summary of minimum, mean and maximum values of 23 soil features on the basis of 96 quadrats for five quadrat groups of Overland Paddock. The soil feature numbers 1-19 were measured as classes which are described in Tables A1-11. Also Table 6.1. shows lichen cover scores. The minimum, mean and maximum values of the remaining features were calculated from the actual data in the laboratory.



No.	Features	Possible Range	G1O Min.	G1O Mean	G1O Max.	G2O Min.	G2O Mean	G2O Max.	G3O Min.	G3O Mean	G3O Max.	G4O Min.	G4O Mean	G4O Max.	G5O Min.	G5O Mean	G5O Max.
1	Rain	1-6	1	2	2	4	5	5	4	5	5	3	4	4	4	4	4
2	Flow	1-6	1	2	2	4	5	5	4	5	5	3	4	4	4	4	4
3	Crust	1-4	1	1	1	2	4	4	3	4	4	2	3	4	2	2	2
4	Crypto	1-4	1	1	1	2	4	4	3	4	4	2	3	4	2	2	2
5	Erosion	1-4	1	1	1	2	4	4	3	4	4	2	3	4	2	2	2
6	E. mat.	1-4	1	1	1	2	4	4	3	4	4	2	3	4	2	2	2
7	Litter	1-6	1	1	1	2	3	4	2	3	4	2	2	2	2	2	2
8	Topo	1-5	2	2	2	1	1	2	1	1	2	2	2	2	2	2	2
9	Surface	5-1	2	2	3	2	3	3	2	3	3	2	3	3	3	3	3
10	Slake	1-4	3	3	3	2	3	3	2	3	3	3	3	3	3	3	3
11	Texture	1-4	1	2	3	2	3	3	1	3	4	2	3	3	2	2	2
12	Stability	7-36	11	12	13	20	29	31	23	29	31	19	24	28	20	20	20
13	Infilt.	5-25	9	10	11	14	15	16	13	15	16	13	14	14	14	14	14
14	Nutr.	3-27	5	5	5	7	12	15	8	13	14	7	8	9	7	7	7
15	Lichen A	0-5	0	0	0	1	2	2	1	2	3	1	2	2	1	1	1
16	Lichen B	0-5	0	0	0	0	1	1	0	0	1	0	0	0	0	0	0
17	Lichen C	0-5	0	0	0	0	1	1	0	1	1	0	1	1	0	0	0
18	Lichen D	0-5	0	0	0	0	2	2	0	2	2	0	1	2	0	0	0
19	Moss	0-5	0	0	0	0	1	2	0	1	2	0	0	0	0	0	0
20	Moisture%	%0.03-0.11	0.03	0.07	0.09	0.04	0.06	0.07	0.03	0.07	0.11	0.03	0.06	0.07	0.07	0.07	0.07
21	Organic%	%0.4-1.59	0.72	1.10	1.57	0.40	0.80	1.07	0.11	0.68	1.59	0.69	0.77	0.88	0.65	0.65	0.65
22	ECµS cm-1	0.71-1.1	0.88	0.93	1.10	0.81	0.89	0.95	0.71	0.87	1.04	0.77	0.88	0.93	0.94	0.94	0.94
23	pH	6.9-7.7	7.40	7.50	7.60	6.90	7.29	7.60	6.90	7.25	7.60	7.20	7.40	7.70	7.70	7.70	7.70

Paddock) respectively. The results of the multivariate analysis are explained separately for each paddock.

6.4.1.1 Overland Paddock

Figure 6.2 shows the site ordination based on plant features where the plot symbol represents the dendrogram group of Overland Paddock. Overlaid on this are vectors representing increasing levels of soil features which were shown by PCC analysis to be significantly correlated with the site ordination (Table 6.2). The geographical distribution of these five quadrat groups is as follows: the G1O quadrats were closest (50 m) to the water point. G2O were patchily distributed across a range of distances from the water point. The highest percentage of quadrats (79%) were clustered as G3O and they were also distributed in different parts of the paddock, but always more than 200 m from the water point. G4O had four quadrats and G50 had only a single quadrat all of which were located between 100 m to 400 m, but in the opposite direction to the prevailing wind.

All individual observations of the soil surface (crust brokenness, surface nature, erosion features, eroded materials, cryptogam cover and soil cover (rain) and litter cover), from which soil stability was calculated, were correlated with the G3O quadrats and a single quadrat of G4O. These quadrats were characterised by highly stable soils (mean score 29 out of maximum of 36). In contrast, G1O quadrats (closest to the water point) has the least stable soils (mean score 12, where the lowest possible is 7). Nutrient cycling status was calculated from litter cover, cryptogam cover and soil microtopography and was also correlated with G3O quadrats and the G4O quadrat. The highest class of nutrient cycling status for these areas was 13 (range 5-15) (Table 6.3). Infiltration was also correlated with these quadrats where the highest class for this feature was 15 (range 9-16). The highest cryptogam cover (>50%) was correlated with these areas and the lowest (<1%) was negatively correlated with G1O quadrats (Table 6.3). In addition, G3O quadrats contained the highest mean percentage cover of three lichen species (*H.*

polyspora (Lichen A), *A. ferdinandii* (Lichen C) and *P. decipiens* (Lichen D)) with mean cover scores of 2 (6-25% cover), 1 (1-5%) and 2 (6-25%) respectively. These lichens, particularly *H. polyspora* (Lichen A) were strongly negatively correlated with G1O quadrats. G2O quadrats were positively correlated with higher percentage cover of moss and *X. amphixantha* (1-5%) compared with other groups.

Increasing organic carbon in the quadrats was mainly correlated with one quadrat of G2O (100 m from the water point). On the other hand, there was an apparently contradictory result for G3O quadrats which had a maximum level of organic carbon of 1.59% (mean 0.68%), compared with G1O quadrats which had a maximum level of 1.57% (mean 1.1%) (Table 6.3). Microtopography was also correlated one quadrat of G2O (quadrat 2 refers to Figure 5.3) with mean of class 2 (3-8 mm depressions) from Table A8.

High soil pH was strongly correlated with G1O quadrats in the lower left quadrant of the ordination plot where the mean value was 7.5. (Table 6.3). This was in the upper range of soil pH values in this paddock (6.9-7.7). The remaining three features (slaking performance, soil moisture and EC) showed no significant ($p<0.002$) correlation with the ordination of sites in this paddock (Table 6.2).

6.4.1.2 Purpunda Paddock

Figure 6.3 shows the ordination of quadrats based on plant features. Dendrogram group is indicated by plotting symbol and vectors represent increasing levels of soil features which were shown by PCC analysis to be significantly correlated with the quadrat ordination. From this figure, the four quadrat groups on the basis of the plant features are seen to follow a cyclic pattern from the left to right, where quadrats of G1P were distributed in the top right quadrant. G1P quadrats were found close to the water point (<300 m) and along the main wind direction. G2P quadrats were found in patchy areas of this paddock. Over half of the sampled quadrats

(58%) were clustered into the G3P group which was patchily distributed throughout the paddock. G4P quadrats were also patchily distributed in the paddock.

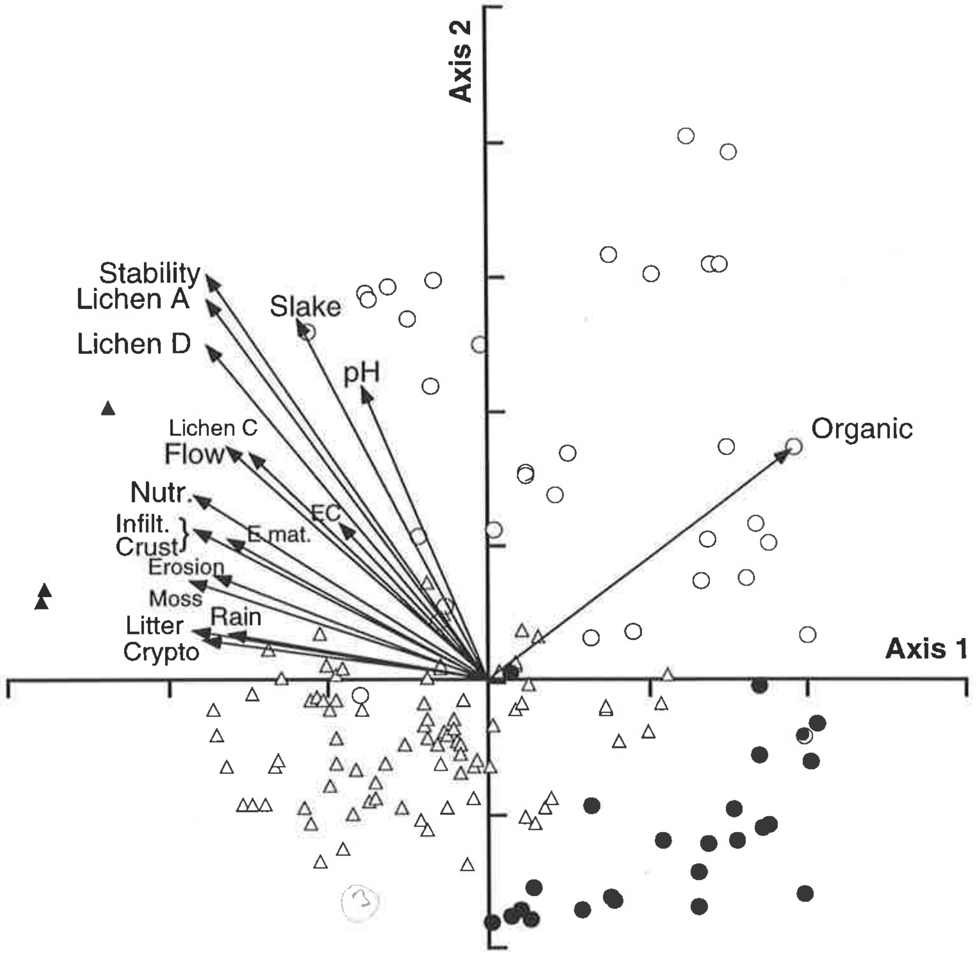
PCC analysis showed that all of the soil features were negatively correlated with G2P quadrats, with the exception of percentage of organic carbon (Figure 6.3). The presence of a cohesive crust and high cryptogam cover (mean class 2 = 10-50% cover) were correlated with G4P quadrats and some G3P quadrats. The highest percentages of *H. polyspora* (Lichen A, 6-25%), *A. ferdinandii* (Lichen C, 1-5%) and *P. decipiens* (Lichen D, 6-25%) and the moss were also positively correlated with these quadrats and negatively correlated with G2P quadrats. Similarly, slight erosion features, low eroded materials and in general, low degree of litter cover (mean class 3= 10-25%) with moderate interception of raindrops and projected cover to divert overland flow were correlated with the G4P quadrats and some G3P quadrats. These quadrats were also characterised by the highest electrolytic conductivity (EC), which reflects concentrations of soluble salts, with a mean value of 0.83 $\mu S\ cm^{-1}$ (range 0.77-1.1 $\mu S\ cm^{-1}$). Nutrient cycle status, infiltration rate and soil stability were also correlated with these quadrats. The slake test was correlated positively with some quadrats of G1P, G3P and G4P for which the average class for this feature was 3 (moderately stable) in these areas, but the highest class were in G3P and G4P quadrats which were between 2 and 3 (Table 6.4).

The percentage of soil organic carbon was correlated with G1P quadrats, but Table 6.4 shows more and less equal mean values for G1P, G2P and G3P quadrats (0.65%, 0.68% and 0.67% respectively). The highest percentage of soil organic carbon was in G3P quadrats with a maximum of 1.69% and a range of 0.16-1.69%. High soil pH was correlated with some quadrats of G1P. The remaining four soil features (microtopography, surface nature, texture and soil moisture) and the lichen *X. amphixantha* were not significantly ($p<0.002$) correlated with the quadrat ordination (Table 6.2).

Figure 6.3. Plot of the first two axes from a semi-strong hybrid scaling (SSH) ordination of the 144 quadrats on the basis of 25 plant features. Principal Canonical Correlation (PCC) of the 18 significant soil features measured for Purpunda Paddock are superimposed on the dendrogram group in this paddock. Axes tick marks are shown at intervals of 0.5. Stress = 0.08

Symbol represents dendrogram group (○ = G1P, ● = G2P, Δ = G3P, ▲ = G4P). Soil labels as for Figure 6.1.

Table 6.4. Summary of minimum, mean and maximum values of 23 soil features on the basis of 144 quadrats for five quadrat groups of Purpunda Paddock. The soil feature numbers 1-19 were measured as classes which are described in Tables A1-11. Also Table 6.1. shows lichen cover scores. The minimum, mean and maximum values of the remaining features were calculated from the actual data in the laboratory.



No.	Features	Possible Range	G1P Min.	G1P Mean	G1P Max.	G2P Min.	G2P Mean	G2P Max.	G3P Min.	G3P Mean	G3P Max.	G4P Min.	G4P Mean	G4P Max.
1	Rain	1-6	3	4	5	3	4	4	3	4	5	3	4	5
2	Flow	1-6	3	4	5	3	4	4	3	4	5	3	4	5
3	Crust	1-4	1	2	3	1	2	3	1	3	4	1	2	3
4	Crypto	1-4	1	2	4	1	2	4	1	3	4	1	2	4
5	Erosion	1-4	1	2	4	1	2	4	1	3	4	1	2	3
6	E. mat.	1-4	1	2	4	1	2	4	1	3	4	1	2	3
7	Litter	1-6	1	2	3	1	2	3	1	3	5	1	2	3
8	Topo	1-5	1	2	3	1	2	3	1	1	2	1	2	2
9	Surface	5-1	1	2	2	1	2	2	1	2	3	1	2	2
10	Slake	1-4	1	3	3	1	3	3	2	3	3	2	3	3
11	Texture	1-4	2	4	4	2	4	4	2	4	4	4	4	4
12	Stability	7-36	8	17	26	11	18	25	13	24	30	13	17	25
13	Infilt.	5-25	8	13	16	11	13	16	9	14	17	11	13	15
14	Nutr.	3-27	4	7	13	4	8	14	4	12	20	4	8	13
15	Lichen A	0-5	0	1	3	0	1	2	0	2	3	1	1	2
16	Lichen B	0-5	0	0	1	0	0	1	0	0	1	0	0	0
17	Lichen C	0-5	0	0	1	0	0	1	0	1	2	0	0	0
18	Lichen D	0-5	0	1	2	0	1	3	0	2	3	1	1	2
19	Moss	0-5	0	0	2	0	0	2	0	1	2	0	0	1
20	Moisture%	%0.02-0.1	0.02	0.04	0.06	0.02	0.05	0.08	0.02	0.05	0.10	0.02	0.03	0.06
21	Organic%	%0.16-1.69	0.18	0.65	1.45	0.33	0.68	1.42	0.16	0.67	1.69	0.40	0.46	0.57
22	ECμS cm^{-1}	0.77-1.07	0.77	0.85	0.98	0.80	0.90	1.05	0.81	0.93	1.07	0.81	0.83	0.84
23	pH	6.1-7.5	6.10	6.77	7.50	6.40	6.96	7.30	6.40	7.03	7.30	6.70	6.77	6.80

6.4.1.3 Railway Paddock

The pattern of the four dendrogram groups of quadrats for Railway Paddock resembled that of Purpunda Paddock (cyclic pattern), except that plotted from right to left, and G1R quadrats were at the top right quadrant. The results of PCC analysis of 23 soil features were superimposed on the ordination plots (Figure 6.4). Table 6.2 shows the significant differences between the soil features and the site ordination based on plant features. Three out of 23 soil surface features (soil texture, soil moisture and lichen cover for *X. amphixantha*) were not significantly ($p<0.002$) correlated with the scatter plot of the ordination. The remaining characters were correlated with different quadrats within the paddock.

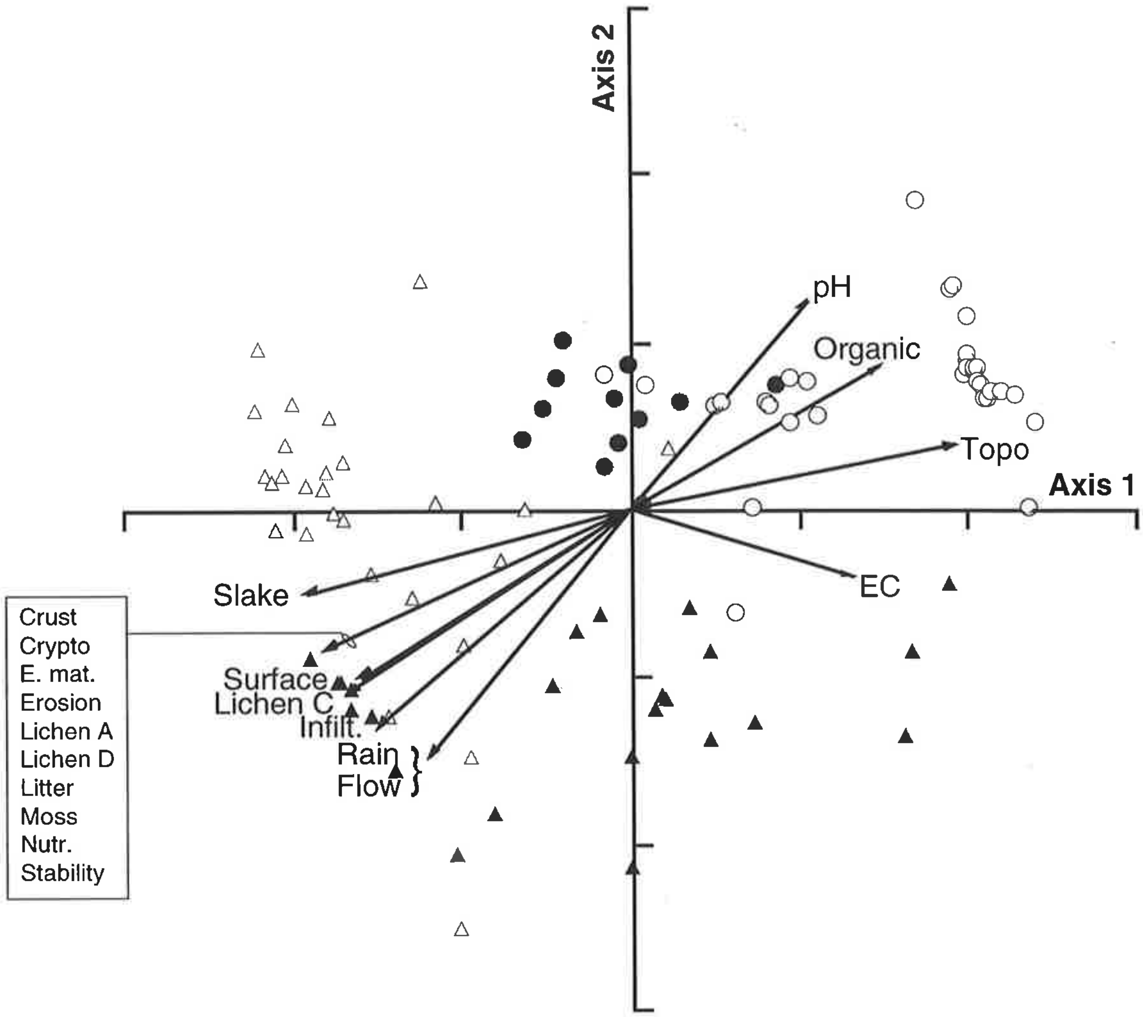
The quadrats were more or less equally distributed in the four groups and the groups were heterogeneous and patchy in this paddock. The G1R quadrats were situated adjacent to the water point and up to c. 300 m from the water point in the direction of the prevailing wind direction. G2R quadrats were patchily distributed in areas 300-800 m from the water point. G3R quadrats were found between 400-1500 m from the water point and G4R quadrats were found 300-1500 m from the water point, but not into the prevailing wind direction.

G4R quadrats, particularly seven quadrats of this group (quadrats 30, 59, 44 which overlayed on 59, 76, 67, 90, and 94; refer to Figure 5.12) and some quadrats of G3R were typified by an area with high soil resistance to erosion (stable soil), infiltration and dynamic range of nutrient cycling. The highest cover of the lichen species *H. polyspora* (Lichen A with a mean class 2 = 6-25%), *A. ferdinandii* (Lichen C with a mean class 1 = 1-5%), *P. decipiens* (Lichen D with a mean 2 = 6-25%) and moss (1-5%) (Tables 6.1 and 6.5) were also correlated with these quadrats and negatively correlated with G1R quadrats. The surface nature of the soil in these areas correlated with a high capacity to withstand stress, with low levels of crust brokenness and high cryptogam cover was evident. Slight erosion features and eroded material with somewhat moderate litter cover (10-25%) were also correlated with these quadrats, as were

Figure 6.4. Plot of the first two axes from a semi-strong hybrid scaling (SSH) ordination of the 96 quadrats on the basis of 25 plant features. Principal Canonical Correlation (PCC) of the 20 significant soil features measured for Railway Paddock are superimposed on the dendrogram group in this paddock. Axes tick marks are shown at intervals of 0.5. Stress = 0.08

Symbol represents dendrogram group (○ = G1R, ● = G2R, Δ = G3R, ▲ = G4R).

Table 6.5. Summary of minimum, mean and maximum values of 23 soil features on the basis of 96 quadrats for five quadrat groups of Railway Paddock. The soil feature numbers 1-19 were measured as classes which are described in Tables A1-11. Also Table 6.1. shows lichen cover scores. The minimum, mean and maximum values of the remaining features were calculated from the actual data in the laboratory.



No.	Features	Possible Range	G1R Min.	G1R Mean	G1R Max.	G2R Min.	G2R Mean	G2R Max.	G3R Min.	G3R Mean	G3R Max.	G4R Min.	G4R Mean	G4R Max.
1	Rain	1-6	3	4	5	4	4.5	5	4	4.6	5	4	4.3	5
2	Flow	1-6	3	4	5	4	4.5	5	4	4.6	5	4	4.3	5
3	Crust	1-4	1	2	4	1	3.7	4	2	3.8	4	1	3.1	4
4	Crypto	1-4	1	2	4	1	3.7	4	2	3.8	4	1	3.1	4
5	Erosion	1-4	1	2	4	1	3.7	4	2	3.8	4	1	3.1	4
6	E. mat.	1-4	1	2	4	1	3.7	4	2	3.8	4	1	3.1	4
7	Litter	1-6	1	2	4	1	3.0	4	2	3.1	4	1	2.6	4
8	Topo	1-5	1	2	2	1	1.3	2	1	1.4	2	1	1.6	2
9	Surface	5-1	1	2	3	1	2.8	3	2	2.8	3	2	2.6	3
10	Slake	1-4	1	2	3	3	3.0	3	3	3.0	3	2	2.8	3
11	Texture	1-4	2	2	3	2	2.0	3	2	2.0	2	2	2.0	2
12	Stability	7-36	13	20	31	13	28.1	31	19	28.7	31	15	25.3	31
13	Infilt.	5-25	10	13	15	10	13.6	15	12	13.9	15	12	13.4	15
14	Nutr.	3-27	4	8	14	5	11.6	14	7	12.0	14	5	10.0	14
15	Lichen A	0-5	0	1	2	1	2.2	3	1	2.3	3	1	1.9	3
16	Lichen B	0-5	0	0	1	0	0.1	1	0	0.2	1	0	0.0	0
17	Lichen C	0-5	0	0	1	0	0.8	1	0	0.9	1	0	0.7	1
18	Lichen D	0-5	0	1	2	0	1.7	2	1	1.8	2	0	1.3	2
19	Moss	0-5	0	0	1	0	0.9	2	0	0.8	2	0	0.6	2
20	Moisture%	%0.02-0.36	0.02	0.05	0.12	0.03	0.06	0.36	0.03	0.06	0.09	0.04	0.08	0.27
21	Organic%	%0.37-1.33	0.37	0.76	1.15	0.37	0.65	1.33	0.40	0.59	0.99	0.45	0.72	1.15
22	ECμS cm^{-1}	0.71-1.1	0.79	0.90	1.10	0.78	0.87	1.04	0.79	0.88	0.98	0.71	0.85	0.93
23	pH	6.9-7.7	6.90	7.38	7.70	6.90	7.15	7.40	6.90	7.14	7.40	6.90	7.22	7.40

correlations between these quadrats and increasing degree of surface cover, resistance to rainsplash erosion and the features which divert overland flow. The slake performance test which grades surface crust from unstable increasing toward intact and stable crusts was correlated with G3R and G4R quadrats. There was also a correlation between increasing soil EC and two quadrats of G4R, but approximately the opposite of the slake test.

There were contradictory percentage of soil organic results, the same as in the other two paddocks. The highest carbon content in relation to other groups (mean 0.76%) was correlated with the G1R quadrats and one quadrat of G2R in this paddock, but the G4R quadrats also had the same maximum organic carbon as G1R quadrats (1.15%), although the mean value of these quadrats somewhat less than G1R quadrats (0.72%).

The highest soil pH values in the paddock were correlated with the G1R and some G2R quadrats, and particularly two quadrats of this group (range soil pH 6.9-7.7). The highest level of soil microtopography (3-8 mm) depressions, were also correlated with these areas.

6.4.2 Edaphic Features And Vegetation Correlation In Three Paddocks

The various classes of soil surface condition occurred in different vegetation types within three paddocks, and their vegetation types were described with respect to their geographic situations in Chapter 5. Ordination analysis indicated a correlation between the numerical order of classes of soil features and the placement of properties on the basis of plant features for the paddocks, the various variables of surface soil condition occurring in different geographic positions. High cryptogam crust cover, soil stability, infiltration and nutrient cyclic status tended to occur mainly where the Group 3 and 4 vegetation types (outer zone) of the three paddocks were situated, whereas low potential of these categories was correlated with Group 1 and 2 vegetation types (around the water point, along the prevailing wind direction and in scattered patches).

The visual impression from the ordination (Figure 6.2) and tabulation in Table 6.3 for Overland Paddock is that the distribution patterns of the five vegetation groups correlate well with soil quality. Figures 6.5a-e show the relationship between five important soil features (soil stability, infiltration, nutrient cycle status, cryptogam cover and percentage of organic carbon) and distance from the water point. The geographical distribution of the five vegetation groups is shown in Figure 6.5f. These results show a high resistance to erosion (soil stability), water capture (infiltration) and dynamic range of nutrient cycling correlating with the soils at the most parts of the paddock (79%) (G3O quadrats). Soil stability in these areas indicates an ability of the soil to withstand erosive forces. Cryptogam cover was high in the outer zone and lower close to the water point (Figure 6.5b). The vegetation cover of the outer zone was characterised by significantly high frequencies of the palatable plant species (*A. vesicaria* and *M. sedifolia*), and a position trend for *M. georgei*. In contrast, the lowest soil stability was in the bare zone close to the water point (≥50 m or G1O quadrats) and this area also had high soil pH and no cryptogam cover. Nevertheless, the lichen *X. amphixantha* was correlated with patchy areas across a range of distances from the water point and which were dominated by high levels of *M. pyramidata*. As Figures 6.5a-e show higher soil stability, nutrient cycle, infiltration and cryptogam cover were in G3O quadrats with most of paddock represented by these areas. Lower values of these features were in group 1 which was in close to the water point. In contrast, the percentage of organic carbon was high in G1O (close to the water point) and low but equally distributed in other groups.

The soil surface of the furthest points in Purpunda Paddock was characterised by high stability, nutrient cycling, infiltration and cryptogam cover (Figures 6.6a-d). These areas were dominated by the highly palatable *A. vesicaria* and some *M. georgei*. High cryptogam cover, particularly for three lichens (*H. polyspora, A. ferdinandii* and *P. decipiens*), the moss and a moderately stable for slake test were also characteristics of these areas (G4P quadrats and some

G3P quadrats). Subsequently, high ability of the soil to withstand erosive forces, water capture by the surface soil (infiltration) and nutrient cycling status was correlated with these quadrats, supporting the system. The high soil pH and low percentage cover of lichens and moss were the characteristics of quadrats around the water point and along the prevailing wind direction of this paddock. Also, the high percentage of organic carbon in the soil surface was correlated with the areas close to the water point of this paddock (Figure 6.6e), but in the rest of this paddock having more and less equal levels of organic carbon. The vegetation characteristics of these areas were defined by the presence unpalatable plant species such as *M. pyramidata* and *A. stipitata*.

The results of the ordination analysis (Figure 6.4) and visual interpretation (Figure 6.7a-e) for Railway Paddock show that high soil resistance to erosion (stable soil), soil infiltration and nutrient cycling status were characteristic of the areas between 400-1500 m from the water point and in 300-1500 m from the water point, but not into the prevailing wind direction (G4R and some quadrats of G3R). High cryptogam cover, crust brokenness and consequently, a high capacity of the soil surface to withstand stress were also characteristics of these areas. *H. polyspora, A. ferdinandii, P. decipiens* and the moss had highest cover in these quadrats and also high surface cover resistance to rainsplash erosion and projected cover to divert overland flow was correlated with these areas. The vegetation of G4R quadrats was characterised by high frequency and cover of *A. vesicaria,* plus the tallest and widest individuals of *M. sedifolia*. High levels of *M. pyramidata*, *A. stipitata*, *M. georgei* and tall and wide *A. vesicaria* were the dominant features of G3R quadrats, but *M. sedifolia* was uncommon.

Low cryptogam cover and weak soil surface with eroded and unstable soils were typical of areas around the water point to 300 m, and along the prevailing wind direction (Figure 6.7b). The highest mean percentage of soil organic carbon content was in these areas, but the maximum level of this feature was the same as G4R quadrats which shows a contradictory

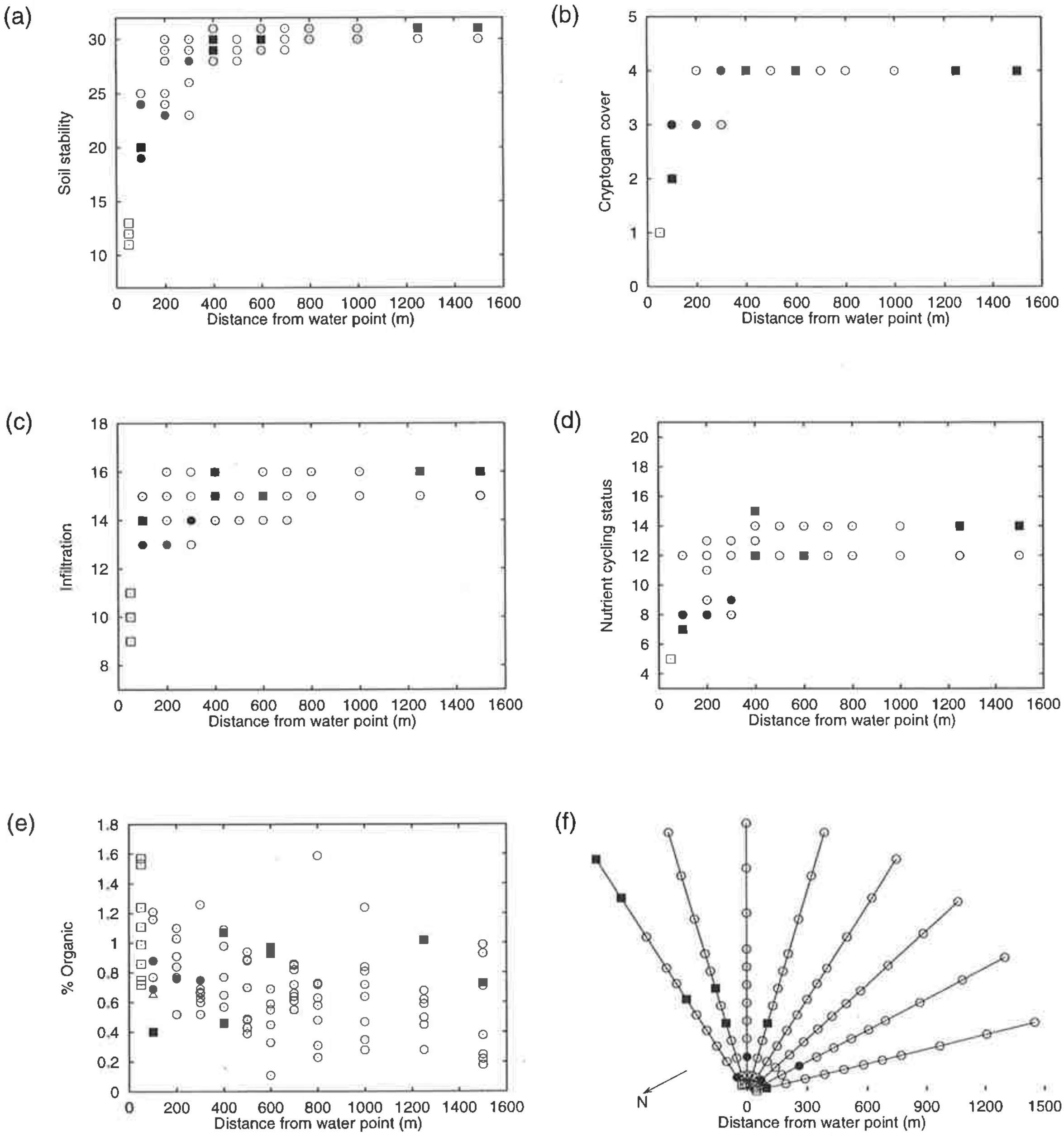


Figure 6.5. The relationship between various features and distance from water point are showed in Overland Paddock (Figures a-e). Figure (f) shows geographical distribution of the quadrats in the paddock. In each figure, the plotting symbols represent the dendrogram groups to which the quadrats belong, where the □ = G1O, ■ = G2O, O = G3O, ● = G4O and Δ = G5O.

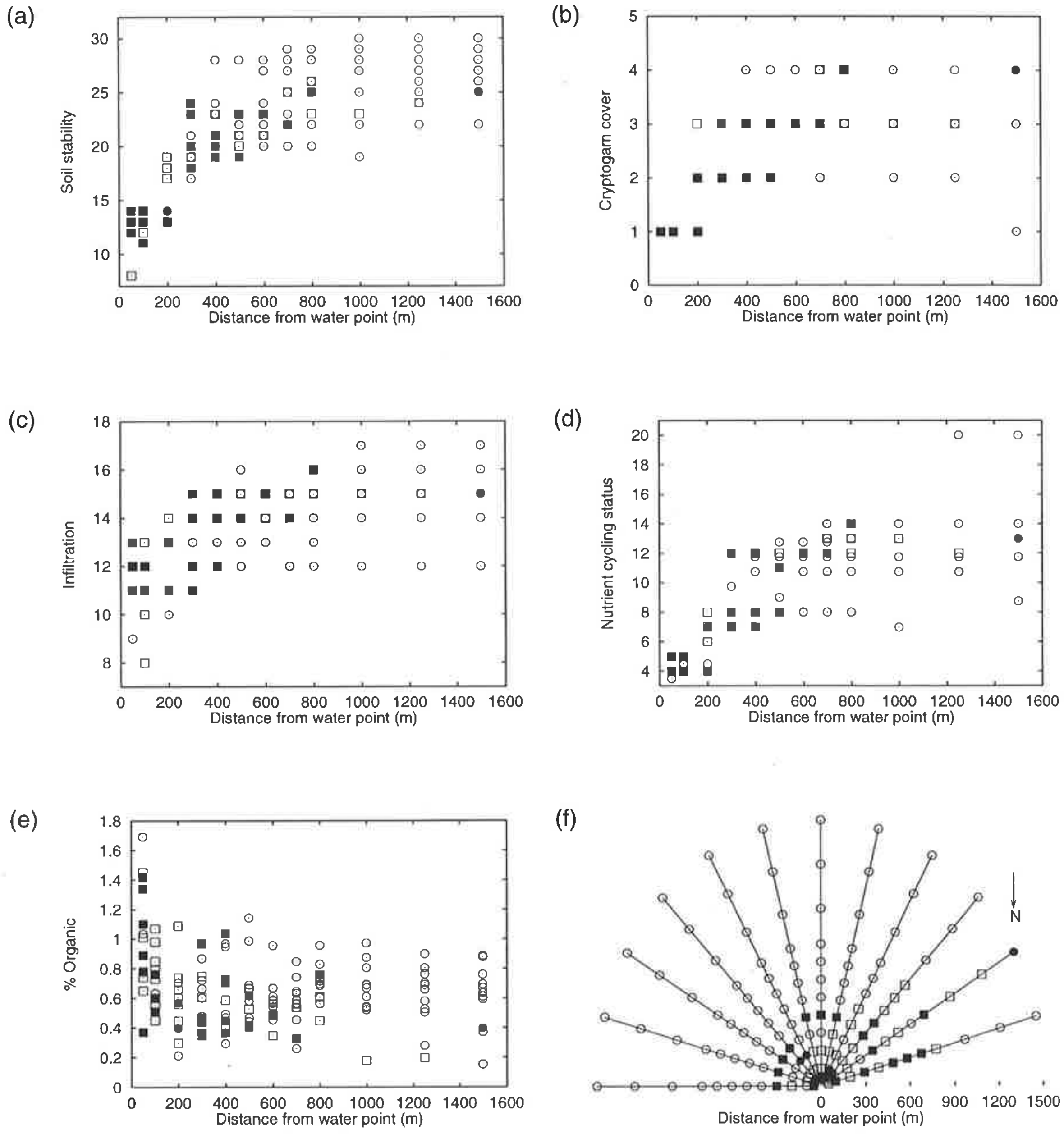


Figure 6.6. The relationship between various features and distance from water point are showed in Purpunda Paddock (Figures a-e). Figure (f) shows geographical distribution of the quadrats in the paddock. In each figure, the plotting symbols represent the dendrogram groups to which the quadrats belong, where the □ = G1P, ■ = G2P, ○ = G3P and ● = G4P.

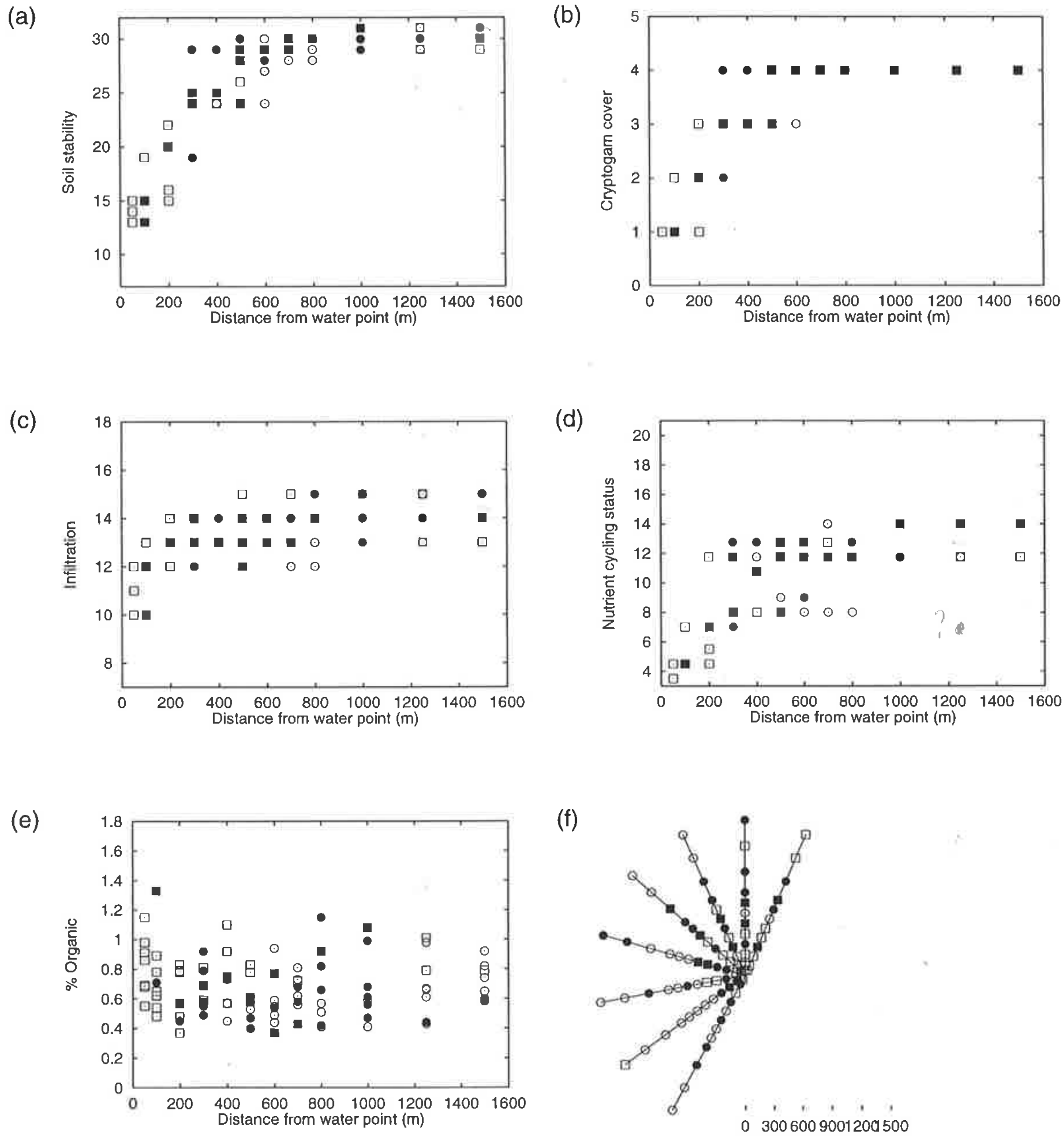


Figure 6.7. The relationship between various features and distance from water point are showed in Railway Paddock (Figures a-e). Figure (f) shows geographical distribution of the quadrats in the paddock. In each figure, the plotting symbols represent the dendrogram groups to which the quadrats belong, where the □ = G1R, ■ = G2R, ○ = G3R and ● = G4R.

result for these two quadrat groups. The highest soil pH and soil microtopography depressions were the characteristics of the areas adjacent to the water point and along the prevailing wind direction of these paddocks. The vegetation of these areas was characterised by high level of *M. sedifolia* and low level of *A. stipitata*. Surprisingly, the unpalatable *M. pyramidata* was absent in these areas. It might be related to habitat of growing of this species, because it is naturally growing in run-on areas (Lange pers. comm.) and the water point was not installed in this landform.

In general, as Figures 6.5a-e, 6.6a-e and 6.7a-e show, the variability of soil stability, cryptogam cover, infiltration and nutrient cycling status were similar in the three paddocks and follow as an arch distribution from low to high in relation to distance from water, but they are more variable in Purpunda Paddock. The variability of percentage of organic carbon content was also similar in all three paddocks, but generally speaking it follows a gradient away from the water point.

6.5 Discussion

6.5.1 Detected Soil Surface Changes

The importance of edaphic variables in this study was found to be related to distance from the water point and the prevailing wind direction, concurrent with findings by Andrew and Lange (1986b) for these areas. However, unlike their studies, the relationships here are not only radial, but are also patchy and heterogeneous. Soil features were patchily distributed in all paddocks, with the exception of areas close to the water point and along the prevailing wind direction, both of which are generally considered to be subjected to higher grazing pressures (Andrew and Lange 1986b). Most of the discussion involves a comparison of the properties of these areas. Because, soil moisture was approximately the same for all vegetation groups within this ecological type, this factor was considered not as important as management practices in causing the vegetation and zone degradation which was observed.

Distribution of cryptogam cover in the present study seems to be affected by sheep grazing of shrubs and the consequent trampling pressure of animals. The lowest percentage cover of lichens the *H. polyspora, A. ferdinandii* and *P. decipiens* and the moss occurred in Groups 1 and 2 in the three paddocks, suggesting that grazing by sheep has markedly reduced cryptogam cover. Eldridge and Greene (1994a) concluded that overgrazing reduced crust cover and composition, and that heavy traffic by stock in these areas breaks up the surface cryptogam crust. Another study from the semi-arid chenopod shrublands of South Australia by Crisp (1975) showed that this has two consequences: (1) the nitrogen-fixing action of the cryptogams is disrupted; and (2) the soil surface is loosened, allowing wind and water erosion to remove surface layers; consequences also predicted by Williams *et al.* (1995a) and Eldridge and Greene (1994b) respectively.

This is in contrast to the soils of the outer zone (Group 4 and some parts of Group 3), which have well developed lichen crusts that help to protect the underlying soil surface against water and wind erosion. These biological soil crusts have a major impact on physical and ecological processes such as nitrogen fixation (Rogers *et al.* 1966), infiltration, erosion, and recruitment and survival of vascular plants (Eldridge 1996). Eldridge (1993) showed that there were strong negative relationships between cryptogam cover and vascular plant cover, and increases in pasture biomass were associated with decreases in cryptogam cover. However, although a contradictory study from North America showed that the areas covered by mosses increased as forbs and grasses were progressively eliminated by overgrazing (Schofield 1985).

6.5.2 Soil Sensitive Indicators

The present results indicate that soil stability, water capture or infiltration and nutrient cyclic status were patterned according to livestock grazing pressure. There was a series of soil sensitive indicators for chenopod shrubland community of these areas.

Other studies have reported an increase in soil compaction through trampling as measured by increased resistance to a penetrometer (Crisp 1975) and a decrease in infiltration rate (Rauzi and Smith 1973). One of the major direct impacts of grazing on soils close to the water point, along the prevailing wind direction and in patchy areas was the effect of hoof activity, which increased erosion by causing detachment, or pulverization, of soil particles from the surface of bare soils. Andrew and Lange (1986b) showed that with an increase in stocking rates in chenopod shrubland of arid areas of South Australia, the greater hoof activity caused more particle detachment at the surface soil and hence more erosion.

The process of thickening plant canopy and restricted crusting and sealing in outer zone (Groups 3 and 4) are linked, and have acted to promote infiltration. On the other hand, destroying the cryptogam cover has been shown to prevent the soil particles binding together and influences hydrologic properties of the soil and soil stability which will reduce long term water absorption by the soils (Dunkerley and Brown 1995). Lichens, particularly *H. polyspora,* and mosses protect the soil surface from drop impact in "outer zones" away from the water points. This was considered to be a function of the physical and biological processes that cement soil particles together (de Soyza *et al.* 1997). The microphytic crusts stabilise fine particles at the soil surface (Williams *et al.* 1995b) and also potentially contribute to soil stability by enhancing aggregate structure (Belnap and Gardener, 1993). Consequently, this can enhance the infiltration capacity, soil stability and nutrient cycle status of the soil surface. Other studies showed that stocking pressure caused a differential removal of lichen species at distances out from the watering point (Rogers and Lange 1971). As the concentration of sheep for drinking water around troughs and in patchy areas influences the soil infiltration and soil hydrology and potentially reducing it by lowering cryptogam cover. The reduced abundance and diversity of soil biota results in fewer macropores (Eldridge 1993), thereby reducing infiltration (Bevan and Germann 1982). During droughts under low to moderate stocking levels, the soil crust lichens are often the only form of biological covering on the soil surface (Eldridge 1996). Therefore, high cryptogam cover, particularly of *H. polyspora,* may be a useful indicator for soil infiltration, nutrient cycle status and soil stability. Eldridge (1996) in western New South Wales considered that lichens are indicators of a healthy land condition where they have a positive role in regulating infiltration, soil 'stability, soil nutrition and vascular plant regeneration.

The soil surface stability or the 'last defence' (de Soyza *et al.* 1997) of a soil system against soil and water resource losses were different in each of the paddock zones. Presumably in the case of bare surface, the failure of rills to evolve may relate to the flow mixing caused by direct raindrop impact (Moss, 1979), enhanced by the lack of a plant canopy, which restricts the occurrence of flow concentration. The protection of the soil from rainsplash erosion is one factor for soil stability (Tongway 1994). Degraded zones have very low potential resistance to soil erosion relative to outer zones, because of the low projected soil cover. The diversion of overland flow through fallen logs which prevent soil erosion, results in higher infiltration rates and nutrient status than in surrounding soils (Tongway *et al.* 1989), leading to the development of nutrient-rich 'fertile patches' (Tongway 1990) in outer zones. On the other hand, the resistance of the soil surface to dispersion and detachment by raindrop impact and overland flow was high in degraded areas and low in patchy and outer zones. Plants also trap nutrients and soil particles by acting as barriers to wind and water. Prolonged grazing reduces plant cover and prevents plants from acting as nutrient traps or softening the impact of rainfall. Also, the nutrients and plant litter that collect under the shrubs and cryptogam cover of these areas are washed away, leaving the soil unprotected against evaporation. The loss of water and nutrients accelerates the loss of seedlings and consequently the plants. The sudden appearance of bare ground also accelerates the erosion cycle. Erosion becomes more severe and the sediments end up far away from their source. Hence, the presence of features which obstruct and divert overland water flow so as to slow down the overall flow-rate, might act as a potential indicator for soil stability, infiltration and nutrient cycle status of the outer zones.

The slake test was measured by de Soyza *et al.* (1997) in the Jornada Basin of the Chihuahuan Desert in southern New Mexico for grassland rangeland. They found that the slake test for soil surface stability was extremely sensitive to disturbance and may serve as an early-warning indicator of soil degradation for the coarse-textured soils. The results of the slake tests in this study indicate that crust surfaces were generally non-coherent sands. The soil surface was susceptible to dispersion, detachment by raindrop impact and overland flow around the water point and along the prevailing wind direction. These soils slake easily and encrust readily, thereby reducing water infiltration, increasing susceptibility to erosion and detachment and transport by water in these areas. In this stage, if a crust is created, then it is easily broken with finger pressure, being brittle with a non-coherent sub-crust. In contrast, the crust surface in outer zones was moderately hard, needing a plastic or metal tool to break it. This comparison suggests that the slake test is very sensitive to the early stages of disturbance for the degraded areas, but is relatively insensitive to later stages of disturbance for outer zones. This feature is therefore a useful potential indicator of soil stability in chenopod shrubland and may also be useful for detecting early changes in rangeland condition.

The contradictory results for organic carbon suggest that there are possibly two sources. The highest organic carbon levels were close to the water point, along the prevailing wind direction and in some patchy areas of all three paddocks. This may be related to sheep gathering to drink water (Squires 1978) as evidenced by dung accumulation and sheep track density (Lange 1969). Also, Weir (1971) and Perkins and Thomas (1993) pointed out that the accumulation of dung and urine from grazing mammals close to the water point is a major nutritive input to soils. Smoliak *et al.* (1972) reported that when the sheep grazed native *Stipa-Bouteloua* prairie for 19 years at 2.5 ha AUM^{-1} (compared to 1.7 ha AUM^{-1}), there was increased manure deposition and consequently, increased soil carbon content. These accumulations from grazing animals are inversely proportional to the distance from permanent water and this correlation has been shown for a number of systems including sheep in Australian chenopod shrublands (Lange 1969; Lange and Willcocks 1978; Lange 1985; Andrew and Lange 1986b).

In contrast, the second area which had high organic carbon was the outer zones. These zones were covered by high levels of cryptogam cover which is another recognised source of organic carbon because the most nitrogen that is available to plants is held in the top 10 cm of soil as a result of breakdown of organic matter (Charley and Cowling 1968) and nitrogen fixing algae in cryptogam crusts (Rogers *et al.* 1966). This feature therefore may not be as useful as a potential indicator for early warning for two reasons: 1) The difficulty of measurement and lack of a simple field based test; 2) The conflicting results brought about by two different and diametrically opposed organic carbon sources.

In conclusion, a range of soil features were measured and analysed with previously defined vegetation groups of this area. Some of these soil features were detected the grazing affects around the water point and they are useful tool for determining distinguishable zones in each paddock. Three important soil features of soil (soil stability, infiltration and nutrient cycling status)were highly correlated with the outer zone and negatively correlated with the degraded zone. Cryptogam cover was destroyed around the water point, in the prevailing wind direction and in the patchy areas of three paddocks. The slake performance of the crusts, cryptogam cover was might be good an indicator for soil stability, infiltration capacity and nutrient cycling back into the soil. The results show that the organic carbon might be not use as an indicator for rangeland manager as discussed on the above.

Chapter 7 General Discussion

7.1 Introduction

The main objective of the rangeland manager is to minimise disturbance but maximise sustainable productivity. The idea behind ecologically sustainable development is to have rangeland systems that remain both economically viable and which do not degrade the land. Because of these disturbance pressures, there is concern among rangeland managers about what is happening to their rangelands and to their most precious resource, the soil.

In order to maximise sustainable productivity in rangelands, the aim of grazing management should be the restriction of overgrazed patches. Managers should have a working knowledge of key ecological processes but they need indicators for critical decision-making points and to serve as the basis for developing and interpreting monitoring systems.

As discussed in the general introduction (Chapter 1), chenopod shrublands are a major rangeland type in southern Australia (Yan *et al.* 1996) and provide forage for livestock (Noble and Tongway, 1987). It is necessary to know the governing spatial processes from the interactions between plants and herbivores. The usual management unit in Australia's rangelands is the paddock, although sometimes the 'sphere of influence' of one watering point can be managed independently of others (Pickup and Stafford Smith 1993). In either case, at the typical scale of management units in the rangelands, grazing impact is never even and often varies by an order of magnitude within a paddock (Lange and Willcocks 1978; Stafford Smith 1988; Pickup and Chewings 1988). Since grazing at a given point can alter the vegetation pulse and decay function at that point, and since some of these alterations result in materials such as soil moving across the landscape, uneven grazing can increase landscape heterogeneity (Stafford Smith and Pickup 1990).

7.2 Reliability Of Results

There have been a number of studies of grazing impact on chenopod shrubland community, but none has sought to develop a set of the indicators for this community or examine the spatial patterns of the main plant species which result from the uneven use of paddocks by sheep. This study has gone some way to improving our understanding of the spatial pattern of chenopod shrublands and provides detailed information on plant-and soil-based features and their interactions. This may facilitate the development of management practices appropriate for long term persistence of the chenopod shrubland community under sheep grazing in arid areas of South Australia.

Interspecific competition has been studied in experimental plots in woody rangelands, Terpstra and Wilson (1989) found that kangaroos were more selective than sheep in their choice of grazing areas, whereas sheep are generally found to graze at random (Landsberg and Stol 1996). Andrew and Lange (1986c) also thought that the spatial dissociation they observed between kangaroos and sheep was more likely to have resulted from a preference by kangaroos for areas ungrazed by sheep, rather than any direct antagonism between the species or any displacement of sheep by kangaroos.

This study did not address the issue of whether competition between species contributed to the variations which were observed in distribution of grazing activities. Also, this study did not consider the different grazing between sheep and other species such as kangaroos and goats or a mix of them, because the main form of land use in these regions is sheep pastoralism (Lange *et al.* 1984).

Nevertheless, I do not feel these limitations detract from the value of this study, particularly in view of the strength of determining the zones, detecting the changes between them and their indicators. These indicators will be useful keys for the purpose of managing chenopod shrubland in the paddock grazing system. Also, it is important that results were obtained from several paddocks to allow detection of generalised patterns of grazing response rather than just local effects. The generality of these results to grazing throughout the chenopod shrubland will be discussed below.

7.3 Vegetation Patterns

The impact of livestock on the vegetation and soil of this area is expected to be proportional to the herbivore use intensity. If stocking rate exceeds the potential of the rangeland it generally results in a change of vegetation composition to one that is less productive or of lower value as livestock forage. This occurs because selective grazing places preferred plants at a competitive disadvantage to other plants in the community (Briske 1991). It is thus a useful parameter with which to interpret vegetation pattern and soil in response to grazing.

From the multivariate analysis of chenopod plant species encountered in the vegetation sampling study (Chapter 4), five perennial species (*A. stipitata, A. vesicaria, M. georgei, M. pyramidata* and *M. sedifolia*) were highly significant for the percentage cover in Middleback area, in particular, *A. vesicaria* and *M. sedifolia*. This vegetation type corresponds with the "chenopod low open-shrubland association" (*Atriplex vesicaria - Maireana sedifolia*) suggested by Reid (1984) for these areas (see Chapter 3, vegetation association (a)). These species accounted for most of the forage production in these areas which livestock can graze during the dry season and they are highly valued fodder species for the pastoral industry (Wilson 1994). Furthermore, they provide cover for the soil and have a general role in ecosystem functioning. These plant species were ranked by Wilson (1994) on their grazing palatability: *M. georgei* and *A. vesicaria* are considered to be moderately palatable; *M. sedifolia* and *A. stipitata* exhibit low palatability; and *M. pyramidata* very low palatability to sheep.

7.4 Definition Of Zones

The multivariate analysis procedure which produced a few simplified groups was appropriate to chenopod shrubland. These groups or vegetation types and their correlated soil features would assist interpretation of responses to grazing in different zones of paddock from palatable to unpalatable plants.

The results of this study indicate that the vegetation types vary markedly in different parts of paddock, and that the difference was greatest when comparing different distances from the water point (Chapter 5). It has generally been recognised that livestock grazing reduces desirable forage species around watering points (Lange 1969), along the prevailing wind direction (Andrew and Lange 1986b) and in patchy areas of the paddocks, creating different vegetation types. The magnitude and direction of that difference varies by species, with variable palatability responses to grazing observed for individual shrub species. Some of these vegetation types are desirable for grazing purposes and some of them undesirable. The undesirable plants on rangelands serve as evidence for overgrazing by livestock (Laycock 1994) and were generally found in heavily grazed areas which were degraded by sheep. Overgrazing has undoubtedly reduced the carrying capacity of chenopod shrublands, reducing biodiversity and increasing susceptibility to erosion. Having identified the important zones of the paddocks it is then appropriate to determine the nature of the critical thresholds in chenopod shrublands.

By plotting plant and soil features against distance from water, the grazing gradient method distinguished three common grazing gradient zones. These three zones were: the disturbed (degraded) zone; sensitive zone (the boundary region between them); and "outer" zone; located from closest to the water point to furthest from the water point respectively. The behavioural patterns of livestock might also lead to the development of the heavily grazed, semi-grazed and low or ungrazed patches, because sheep do not graze uniformly around the water point, tending instead to graze into the wind, and selectively preferring some fodder species over others. The plant and soil characteristics of these zones will be explained in the following section.

7.5 Soil And Vegetation Of Defined Zones And Indicators

7.5.1 Soil and vegetation characteristics

7.5.1.1 Degraded zone

Degradation occurs when ecological characteristics or processes are changed and the integrity of an ecosystem is threatened or lost. It is related to the changes in land and vegetation which make it less capable of meeting its desired uses, and results from the interaction of vegetation type and soil. An inverse rangeland quality gradient away from the water point is evident and palatable shrubs decrease or disappear at distances close to the water point and in heavily grazed patches. This zone is associated with heavy grazing near the water point and in patchy areas, leading to an increase in the proportion of the more unpalatable species and a lack of diversity at these sites. A composite gradient may also be associated with a build-up of unpalatable herbaceous species close to water points and in patches throughout the paddock. Two important unpalatable species of chenopod shrublands (*M. pyramidata* and *A. stipitata*) also increase in degraded areas.

Unpalatable plants begin to replace palatable and moderately palatable plants through grazing pressure but if pressure continues unabated, this can even create a bare zone or sub-degraded area as a 'severely degraded zone' around the water point (Overland Paddock). The abundance of two very low palatability plants (*M. pyramidata* and *A. stipitata*) and a bare zone (severely degraded zone) suggests that these species and the bare zone are characteristics of overgrazing, which was also noted by Wilson (1990) as a stage of degradation. This is due to the relative palatability of the shrubs, selective behaviour of sheep, grazing history and distribution of the livestock in the paddocks, while distribution of unpalatable species in the patchy areas might be related to selective grazing behaviour of livestock (Heady and Child 1994).

Herbivores select nutrient-rich sites more frequently than less productive sites in heterogeneous habitats. To do this, they alternate among sites in homogeneous habitats. Spatial memory allows herbivores to select among patches and feeding sites and should improve foraging efficiency, especially at large scales. Empirical studies indicate that large herbivores have accurate spatial memories (Bailey *et al.* 1996), and can both remember and avoid locations with little or no food and can remember patches that have been depleted recently. In addition, grazing pressure depends not only the density of grazing animals, but also upon how their grazing activities are distributed among different vegetation types (Coughenour 1991).

Overgrazing in the degraded zone can lead to a decrease in palatable plants (*A. vesicaria* and *M. georgei*), moderately palatable plant (*M. sedifolia*) and also create the patchy zones of these species (Chapter 5). The presence of *M. sedifolia* (in G2P) might in part be related to soil attributes, as *A. vesicaria* and *M. sedifolia* often grow in different soil types (Carrodus and Specht, 1965), but the isolated G2P quadrats near the water point may also reflect its reduced palatability relative to *A. vesicaria* and *M. georgei*. The lowest values for *M. sedifolia* occur in degraded zones of two paddocks (Purpunda and Overland Paddocks). Although *M sedifolia* is long-lived (Wilson, 1990), it can become rare because of increased mortality and/or lack of recruitment in grazed areas (Lange and Purdie, 1976).

In other studies, Crisp (1978) considered that under continuous grazing an increase in unpalatable species and a decrease in palatable species occurs, although these palatable plant species may be lost by excessive browsing. McConnell and Smith (1977) reported an increase in foliage production of bitterbush (*A. stipitata*) which had previously been heavily grazed.

Osborn *et al.* (1932) reported grazing-induced vigour in *A. vesicaria*, and this was supported by Leigh's (1974) of studies at Deniliquin, New South Wales. Osborn *et al.* (1932) concluded that moderately heavy stocking was good for the vigour of the shrubland. Leigh (1974) stressed that severe defoliation results in high mortality of *A. vesicaria*, a view supported by Andrew and Lange (1986a) and Hunt (1995). Barker (1979) also studied arid and semi-arid areas of South Australia and documented an increase in *M. pyramidata* close to water points (suggested to have occurred because of the accumulation of dung and urine), but a corresponding decrease in *A. vesicaria* near water.

The unpalatable plant species *M. pyramidata* and *A. stipitata* have a greater biomass and abundance in degraded zones than palatable plants like *A. vesicaria* and *M. georgei*, and they also have a more clumped morphology, might be resulted from a less attractive habit for grazing by sheep (Lynch *et al.* 1992). The low palatability of these species has probably been important in the establishment of these vegetation types. An abundance of unpalatable *M. pyramidata* and *A. stipitata* relative to palatable *A. vesicaria* and *M. georgei* contributes to resource loss for production which leads to deterioration of the chenopod shrubland ecosystem.

Soil properties in the topsoil were progressively depleted towards the watering point and in the patchy area (Chapter 6). Central to this change is the destruction of the soil surface by sheep moving towards the water point. Soil cryptogam cover was reduced and erosion was more severe, the litter cover was greatly reduced or even absent around the water point, extending toward the prevailing wind direction and in patchy areas. The soil infiltration and consequently soil hydrology was probably reduced by deleterious effects on cryptogam cover in these areas (Eldridge and Greene 1994b). The intercepted raindrops and the diversion of overland flow and hence the derived soil stability and nutrient cycling status were very low and weak.

However, it seems that prolonged overgrazing, in combination with low infiltration, nutrient cycling and soil stability can cause a shift to a patchy mix of unpalatable plants and bare spots. In addition, as the overgrazing of palatable plants (*A. vesicaria* and *M. georgei*) accompanied by the elimination of crust organisms, the seeds of these plants cannot germinate because of insufficient nutrient-rich soil and lack of recruitment (Eldridge 1996). Also, the degraded zone would have less moisture available for plant growth due to poor infiltration of water (Greene and Tongway 1989).

7.5.1.2 Outer Zone

The other end of the degradation gradient was the 'outer zone', where sheep grazing was less intensive and palatable species gradually increased with distance from the water point. Notwithstanding the more or less radial piosphere pattern, there were also distinctive patches separated by open spaces at a range of scales. At the widest scale, groves of tall and wide *A. vesicaria* and *M. sedifolia* were distributed further away from the water points (Figures 5.2b and 5.5b and 5.5, G3O for Overland and Figures 5.6b and 5.9, G3P for Purpunda Paddock). This type of landscape organisation appears to be a distinctive characteristic in other arid and semi-arid regions of the world, such as patch disturbance at the *Larrea divaricata* and *Stipa* spp. steppe in NE Patagonia, Argentina (Bisigato and Bertiller 1997), the vegetation 'patches' in the Serengeti of East Africa (Belsky 1989) and vegetation 'strips' in the Chihuahuan Desert of Mexico (Cornet *et al.* 1992). At smaller scales it was found that all three paddocks had individual patches with *A. vesicaria*, *M. sedifolia* and some *M. georgei* at high values were identifiable within the paddocks (Figures 5.2b and 5.5, G4O for Overland, Figures 5.6b and 5.9, G4P for Purpunda and Figures 5.10b and 5.13, G4R for Railway Paddock).

Among the identified vegetation types, palatable plants such as *A. vesicaria* and *M. georgei* were better represented in the patchy areas from close to the water points to the furthest distance from the water points. Patchy vegetation distribution of palatable species of the area might be a function of 'fertile patches' (Tongway and Ludwig 1994). Also, the areas furthest from the water points and those not along the prevailing wind direction were characterised by these palatable and moderately palatable species which are representative of infrequent grazing areas. *A. vesicaria* is most abundant far away from the water point, declining rapidly along the transect, and appeared as low quality vegetation around the water point, into the predominant wind direction and also in some isolated patchy areas. The greater abundance and better condition of palatable plants in the outer zones versus degraded zones suggest that the deterioration of vegetation in degraded areas is not due to soil features alone and the grazing by livestock has played a major role in exacerbating the effects of edaphic features.

Cryptogam crusts are well developed in the outer zone, and help to protect the underlying soil surface against water and wind erosion. These biological soil crusts, particularly *H. polyspora* and mosses protect the soil surface from drop impact, enhancing the infiltration capacity, soil stability and nutrient cycle status of the soil surface. The diversion of overland flow by logs and some long-lived features was also high in this area, and this can lead to the development of 'fertile patches' (Tongway 1990). The soil stability, infiltration capacity and nutrient cycling status were high in outer and in some patchy areas of the paddocks. Tongway and Hindley (1995) have developed a method for assessing soil condition on arid shrublands and tropical grasslands. Important indicators used in their study were vegetation basal cover, soil cover, litter, cryptogam cover and erosion features. They stated that soil in good condition is able to absorb and store rainfall, store and cycle nutrients, and provide appropriate habitat for growth of plants and resist erosion.

7.5.1.3 Sensitive Zone

The most important zones of the paddocks, especially from the perspective of a manager, are the sensitive zones, as these are where management attention should be focussed because those areas may still be capable of recovery, or where at least, further degradation may be prevented by the implementation of appropriate management strategies. Substantial changes in the abundance and life form of palatable and unpalatable plants and also soil surface conditions at different distances from the water point indicate that the grazing by sheep is a major factor influencing vegetation type and soil surface conditions in this region. There was an area between the outer zone and degraded zone where the rangeland condition was different from other two, and this area was called the sensitive zone.

It is obvious that by further increase in grazing intensity, there will be a level of grazing pressure beyond which the vegetation and soil cannot maintain stability, and will begin to decline. This is the beginning of the sensitive zone. Depending on the intensity of grazing pressure and the climatic conditions, the status of vegetation and soil may resonate somewhere between 'outer' and 'degraded' within the sensitive zone. However, if this decline continues, the recovery potential of the vegetation and soil can diminish and eventually lead into degraded or even 'severely degraded' (bare) zones. The sensitive zone is therefore a transitional stage which can potentially move in either direction (degraded or stable) depending on how the paddock is managed.

Vegetation And Soil Indicators For Zones

Megateli *et al.* (1997) stated that indicators of degradation should not describe the endpoint of desertification, but should instead indicate when a dryland is at risk of reaching a threshold of severe degradation. The participants at an International Symposium on Desertification in Tucson, Arizona in 1997 suggested that the indicators should be simple and easily measurable. In terms of effectiveness for early warning, the presence of nitrogen fixers and vegetation cover were recommended as the best criteria for this purpose (Megateli *et al.* 1997). A useful indicator must identify areas that are at risk, and provide a measure of the severity of that risk, thus enabling managers to focus their attention more effectively.

Monitoring the complex impact of the disturbances associated with the provision of a water point also requires useful indicators of change. In general, vegetation type appears to be the most useful indicator of rangeland condition. An early response to disturbance appears to be a shift in vegetation type from palatable perennial shrublands to unpalatable plants. These plants are preferentially grazed by domestic livestock and appear to be the most severely affected. As an indicator of chenopod shrublands, the abundance of palatable plants appears to be a sensitive and direct measure of rangeland condition. It seems that large and abundant *A. vesicaria* and *M. georgei* are the best indicators of 'outer zones' (Chapter 5). The diverted flow, cryptogam cover (particularly lichen cover of *H. polyspora*) and slake performance were good indicators for soil stability, infiltration capacity and nutrient cycling status. The organic carbon content was not a useful indicator for chenopod shrublands because it has two possible and conflicting sources (Chapter 6).

Wide and tall *M. pyramidata*, *A. stipitata,* and few or narrow *A. vesicaria* were found to be vegetation indicators of degraded areas. Low cryptogam cover, unstable crusts and low infiltration capacity were good soil indicators of this area. The presence of narrow and small individuals of *M. georgei* and *A. vesicaria* might be useful as the indicators for such sensitive zones, but there were no obvious correlated soil features to define this zone. The signs of improved cryptogam cover, soil condition and the high ratio of palatable to unpalatable plants are the best indicator that the sensitive zone is improving toward to the outer zone. In contrast, the increase rate of less palatable plants to palatable and start of reducing cryptogam cover and also soil stability are the best indicators for changing the direction of sensitive zone to degraded zone. In other word, the sensitive zone can be called 'Site Conservation Threshold' (Smith *et al.* 1995). This concept is based on the most important and basic resource on each ecological site which is the soil. The direction of this zone shows the potential of the site.

7.6 Piosphere Pattern

The nature, degree and robustness of resource regulation processes and grazing behaviour of livestock in a paddock grazing system created a heterogeneous pattern as one moves from highly palatable to mixed and through to unpalatable plants in different locations within the paddocks. The systematic sampling of many locations within each paddock can be useful and provides a comprehensive map of the condition of the vegetation within each paddock: no single location within a paddock can be considered representative, because sheep do not graze uniformly. The results of analysis of both soil and plant features showed that the decline in vegetation quality and cryptogam crust cover was associated with areas found progressively from the outer zone to the degraded zone. The results of this study also suggest that grazing pressure played a leading role in the distribution and abundance of the plant species and the life form spectrum of the different vegetation types.

The replacement of palatable plant species *A. vesicaria* and *M. georgei* by less palatable plants *M. pyramidata* and *A. stipitata* resulted from overgrazing by livestock in degraded areas of three paddocks and even in severely degraded area (Overland Paddock). As the replacement palatable species by less palatable species which resulted from this study shows, the grazing was high close to the water points, along the prevailing wind direction and in patchy areas, and grazing pressure declined towards the outer zone where more palatable plants were present in high levels. However, the zones were neither geographically contiguous nor concentric around the water point as the traditional piosphere pattern would predict but instead were rather scattered in a more patchy and heterogeneous pattern. At the broadest scale, however, the overall trend of a piosphere could still be discerned.

Considerable disagreement exists concerning the importance of grazing as a driving force in vegetation structure. For example, Yorks *et al.* (1992) found that communities undergoing no special management activities in Western Utah's Pine Valley experienced considerable recovery as a probable consequence of the reduction in grazing. Conversely, Norton (1978), using data from the same locality argued that community recovery was primarily a response to "climate or some other overriding environmental factor, not the grazing treatment."

7.7 Threshold Level

On the basis of this study, the point at which replacement of palatable plant species such as *A. vesicaria* by unpalatable species like *M. pyramidata* and *A. stipitata* within these paddocks could be identified as a threshold. Once palatable vegetation types collapse, the chance of rehabilitation is low as rainfall suitable for recruitment from the soil seed banks is rare (Hodgkinson 1996). Furthermore, native herbivores such as kangaroos are more selective than sheep (Terpstra and Wilson 1989) can impede the regrowth of pastures from which sheep have removed (Grice and Barchia 1992; Norbury *et al.* 1993). These vegetation changes could potentially warn rangeland managers of impending compositional changes prior to their occurrence. Grazing management practices could then be modified to reverse or ameliorate large-scale shifts in community composition before the thresholds are crossed.

The exposure of subsoil by pulverization of the soil crust in degraded areas and the beginning of soil loss helps to define the threshold state. These conditions may be induced by inappropriate management practices or in concert with overgrazing. In either case, the manager must recognise the risk and where possible, reduce the stocking pressure. If overgrazing continues, formerly productive surfaces may be progressively stripped, leaving large areas of unproductive rangeland, and reversing the process would be virtually impossible. The challenge is to develop simple methods for rangeland managers to read the signs of this approaching collapse and to gain knowledge as to when it is safe to graze these rangelands or not.

7.8 Management Implications

The results of this study have implications for the general understanding of change in rangeland condition. It is clear that rangeland condition cannot be simply related to animal production (O'Reagan and Mentis, 1990) but using vegetation and soil condition as the only criteria in a range monitoring program is likely to have little management impact unless changes in land condition are linked to livestock production. For example, where productive rangeland pasture is replaced by largely inedible shrubs, animal production and profitability declines (Harrington *et al.* 1984). In contrast, where productive rangeland pasture is replaced to a large extent by less desirable perennial rangeland, as in this study, the effect on animal production may be less certain. If botanical composition is unstable there is a greater risk of irreversible degradation. The state-and-transition approach of Westoby *et al.* (1989) may offer a more appropriate framework for linking changes in rangeland condition to animal production, though it has spatial limitations (Ash *et al.* 1994) which need to be recognised. Ultimately, quantifying the link between land condition and livestock performance will be an important step in improving the adoption of more sustainable grazing practices in rangeland environments (Ash *et al.* 1995).

7.9 State And Transition Model For Chenopod Shrublands

On the basis of this study, three zones were distinguished. Each of these zones had some definitive soil and vegetation indicators. Knowledge of these indicators would be a useful tool for rangeland managers who could use this information to organise for better management and decision making about chenopod shrublands in this region.

In particular, this could be achieved through the use of a conceptual model of vegetation change including a state and transition approach of Westoby *et al.* (1989) and the Site Conservation Threshold (Smith *et al.* 1995). This state and transition model provides an opportunity to simplify vegetation and soil patterns, providing an understanding of native pasture management.

State and transition models have not been applied previously to chenopod shrubland communities of arid areas of South Australia, although Hunt (1995) developed a state and transition model for *A. vesicaria* from a spatial variation analysis of the dynamics of this species under sheep grazing within a single paddock. However, as he did not consider edaphic features in his model nor interspecies relationships between the shrubs in the paddock the results are difficult to extrapolate. This is also complicated by the problem that his study relied on data from a single paddock, further limiting the ability of his model to be generalised.

A simplified version of a state and transition model for the results of the present study is presented in Figure 7.1. This conceptual model presents possible hypothetical mechanisms for transitions between states of chenopod shrubland community in the arid zone of South Australia. Each state represents a combined series of indicative plant physiognomic features and soil surface characters that were readily identifiable in the field. These plant and soil characteristics for each state in the model may be viewed as defining the stable states of this approach (Westoby *et al.* 1989). Transitions between these states occur following changes in the management practices.

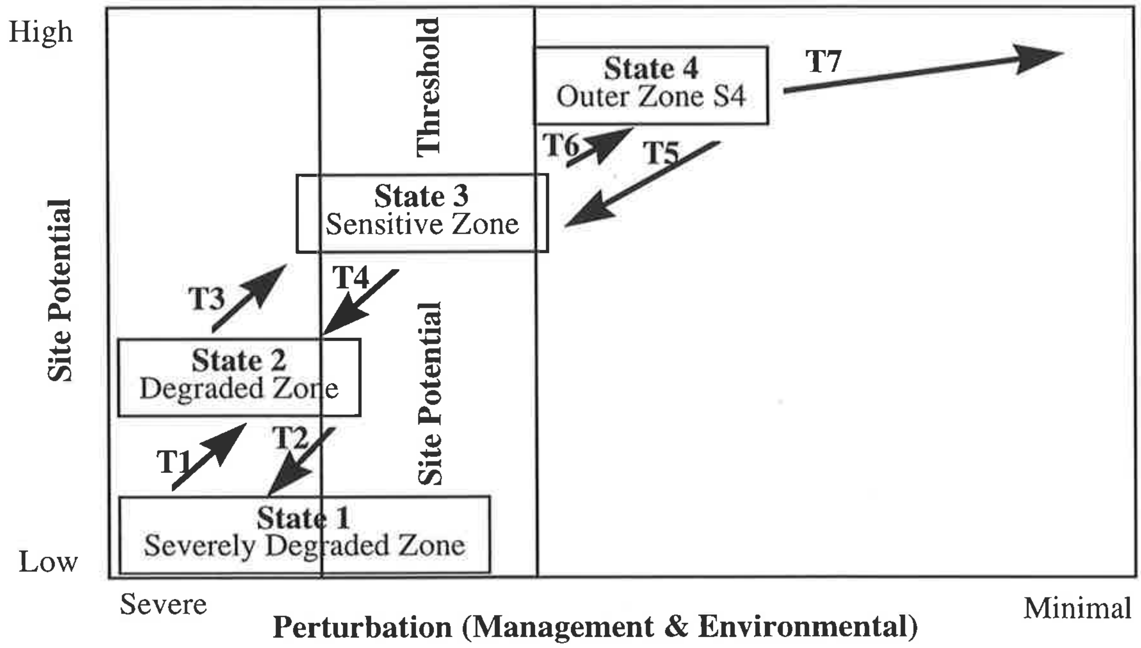
State 1- Severely degraded zone: The severely degraded zone is the most disturbed state with little or no recovery potential, and protection from grazing should cause no recovery. Following the loss of all perennial shrubs, erosion can remove the topsoil leaving a scald which is more or less permanently devoid of vegetative cover. This is obviously the most undesirable management state.

State 2- Degraded zone: Recognisable by increased areas of bare soil and an increase in the frequency of soil compaction, reduced perennial herbaceous vigor, reduced rates of infiltration, soil stability and nutrient cycling status which appear to be precursors for an increase in the abundance of unpalatable plants in these areas. This suggests that the level of damage to those plants at the end of a dry period is such that they could not recover fully. If stocking intensities similar to those of the last year continue during any forthcoming dry period, the condition of the plants at the end of this period may drop below that of the previous year's level because of their lower vital vigor.

State 3- Sensitive zone: The vegetation and soil surface conditions at the sensitive zone can go either way - towards the outer zone if livestock are excluded or towards the degraded zone if grazing pressure is high and prolonged. This focus is on the sensitive zone because, it represents the transition point; resting allows it to return to the outer zone; while further pressure pushes it into the more difficult to manage degraded zone. The sensitive zone is unstable and allows little or no flexibility in its management, as this zone is on the 'knife-edge' and can quickly deteriorate until unpalatable plants dominate the vegetation, bare ground is common. In these areas, water and nutrients are precious commodities, and existing plant species have adapted to exploit them when they occur together. When this area deteriorates, nutrients become widely distributed by erosion and water flows out of the system, leaving the area without well-watered, nutrient-rich patches where plants can grow. This probably coincides with the Site Potential Threshold as described by Smith *et al.* (1995).

State 4- Outer zone: The stable state where grazing has no long term effect on the development or maintenance of the vegetation and soil condition status. This model suggests that a perennial chenopod shrubland, with a mixture of palatable and unpalatable shrubs of similar age could be transformed to a shrubland where the majority of species were represented by plants of different ages. If the condition of the plants at the beginning of the next recovery period was similar to the previous time, this will provide assurance that the paddock is being used in a sustainable manner.

Conceptual field model for South Australian chenopod shrublands under paddock grazing systems



Catalogue of states	Catalogue of transition
State 1: Bare zone, close to water point. Unstable soil, no cryptogam cover, high organic carbon.	***T1:*** Reduced stocking intensity and heavy grazing especially during the dry period.
State 2: Tall and wide unpalatable perennial shrubs *M. pyramidata* and *A. stipitata*. Low and short *A. vesicaria* with *M. sedifolia*. In general, low grazing capacity. Very unstable crusts, low cryptogam cover, infiltration, soil stability,	***T2:*** Continued heavy grazing pressure above recommended stocking rates, exacerbated by extended drought. Soil surface degraded and cryptogam cover destroyed and exposing subsoil by pulverization of soil by hooves. ***T3:*** Resting or much reduced level of utilization by removing livestock particularly in dry season. Improved soil surface condition and cryptogam cover.
State 3: Mix of palatable and unpalatable plants with the presence of *M. georgei*. Unstable crusts and intermediate infiltration, soil stability, nutrient cycling status and cryptogam cover relative to the other two zones. Between two zones (outer and degraded zones).	***T4:*** Reduced herbaceous vigor by continuing moderate to heavy grazing. With winter drought and palatable plants will continue to decline. Cryptogam cover will be damaged and infiltration capacity and nutrient cycling back will slowed. ***T5:*** Reduced grazing pressure or Rotational grazing at recommended stocking rates. Improved cryptogam cover and soil condition.
State 4: Dominant tall and wide *A. vesicaria* and *M. georgei* with *M. sedifolia*. Moderately stable crusts with high cryptogam cover, infiltration, soil stability and nutrient cycling status. In patches and areas away from the water points.	***T6:*** Rotational grazing at recommended level with dry year, seedlings will be damaged and cryptogam cover will decline. ***T7:*** Lightly livestock grazing, rangeland towards stable condition and edaphic features at best situation.

Figure 7.1. State and transition model for chenopod shrublands of South Australia. States (1-4) are described in the text and transitions are shown with T1-T7.

Chapter 8: Conclusion

The main purpose of this study was to determine plant and soil indicators for detecting the distinguishable zones around the water point in perennial chenopod shrubland of arid rangelands of South Australia. Therefore, there were four major aims of this thesis. They were as follows:

1. To determine the patterns within a chenopod shrubland in response to grazing around water points in arid and semi-area of South Australia?

2. To determine if are there any distinguishable areas (zones) within paddock grazing systems on chenopod shrublands of South Australia?

3. To determine which plant and soil features are most important as indicators of distinguished zones?

4. To assess how these indicators can be articulated in rangeland assessment and what is the outcome of this study for management practices, especially for chenopod shrubland of arid and semi-arid areas?

Each will be discussed in turn.

8.1 Aim 1.

To determine the patterns within a chenopod shrubland in response to grazing around water points in arid and semi-area of South Australia?

The results of analysis of both soil and plant features showed that there was a decline in vegetation quality and cryptogam crust cover in areas closer to the watering point. There was an inverse relationship between proximity to water and the quality of vegetation and the associated cryptogam crust. Areas near the water point were devoid of cryptogams and showed a distinct lack of abundance and/or vigour of palatable species such as satiny bluebush (*Maireana georgei*) and bladder saltbush (*Atriplex vesicaria*). Values for both cryptogams and the abundance of palatable species increased progressively as the outer zone was reached. The results of this study suggest that grazing pressure played a leading role in the distribution and abundance of the plant species and the life form spectrum of the different vegetation types. The replacement of palatable plant species by less palatable plants resulted from overgrazing by livestock in degraded areas of three paddocks and even in a severely degraded area (Overland Paddock). From the replacement of palatable species by less palatable species (which this study shows) it is inferred that grazing pressure was high close to the water points, along the prevailing wind direction and in the patchy areas. Grazing pressure probably declined towards the outer zone where more palatable plants were present in high levels. However, the zones were neither geographically contiguous nor concentric around the water point as the traditional piosphere pattern would predict but instead were rather scattered in a more patchy and heterogeneous pattern. At the broadest scale, however, the overall trend of a piosphere could still be discerned. This study shows that five perennial plant species could be considered as dominant plant species in this area as follows: *Atriplex stipitata* (bitter saltbush), *Atriplex vesicaria* (bladder saltbush), *Maireana georgei* (satiny bluebush), *Maireana pyramidata* (black bluebush) and *Maireana sedifolia*.

8.2 Aim 2.

To determine if are there any distinguishable areas (zones) within paddock grazing systems on chenopod shrublands of South Australia?

On the basis of results of this study, three major zones were distinguished in paddock grazing systems of the area. These three zones were: the degraded zone; sensitive zone (the boundary region between them); and "outer" zone, located from closest to the water point to furthest from the water point respectively and in patchy areas of the paddocks.

The detectable zones within the three paddocks were clearly and quantifiably different but, the boundaries between them are not sharp and like all ecological boundaries there is fuzziness (similar to an ecotone). The aim of the rangeland manager should be to avoid disturbing this boundary thus preventing encroachment of the degradation which is associated with the zones closer to the watering point. Perturbations in the form of grazing pressure at the critical times of the year or drought act like the wind on the boundary layer around a leaf. If the perturbation is too severe the plant community can do something akin to wilting i.e. it goes into shock and this may impair its ability to recover fully.

8.3 Aim 3.

To determine which plant and soil features are most important as indicators of distinguished zones?

What the range manager is looking for an indicator of whether the disturbance to the "boundary layer" has occurred. From the present study it is seen that the large and frequent *A. vesicaria* is the indicator of the "outer" zone and wide and tall *M. pyramidata* is an indicator of disturbed zones. The degraded zone had more *A. stipitata* and *M. pyramidata*. The presence of narrow and small plants of *M. georgei* and *A. vesicaria* might be also act as indicators for this zone. High cryptogam cover, particularly of *H. polyspora* and moderately hard crust (i.e. needing a plastic or metal tool to break the surface) may be a useful indicator for soil infiltration, nutrient cycle status and soil stability in outer zone. In contrast, destroyed cryptogam cover and an easily broken (with finger pressure), brittle, non-coherent sub-crust could be considered as indicators of degraded zone.

Also, cryptogam cover, slaking performance, infiltration capacity, rate of nutrient cycle and soil stability were defined as a series of soil indicators for detecting different management zones. The results show that the organic carbon might be not useful as an indicator for detecting zones for rangeland manager as discussed in Chapter 6.

8.4 Aim 4.

To assess how these indicators can be articulated in rangeland assessment and what is the outcome of this study for management practices, especially for chenopod shrubland of arid and semi-arid areas?

This study has pointed to some far-reaching implications for rangeland managers. The first, and most obvious is that grazing-induced change in botanical composition is detectable and quantifiable even in well-managed and conservatively stocked chenopod shrublands. As was indicated in Chapter 3 p.7 the properties in and around the Middleback Centre have been managed in way that most would regard as near to the optimum i.e. small flocks in relatively small, paddocks with decentralised watering. Even so, distinguishable zones were detected in the three paddocks studied (Chapter 5).

The other important implication is in terms of how and where to monitor the rangelands to detect incipient change. Indicators are usually most readily identified after the event once the threshold has been crossed. What can we say about early warning of change in soil or plant features? Longer term studies might be required which can take account of the season to season variability and the infrequent, but critically important "co-occurrence of favourable events" (Walker, 1988). These infrequent events lead to recruitment of new perennials to the rangeland. It is unlikely that they can be predicted or even managed for, although it is also likely that recruitment occurs regardless of management.

The role of rangeland management in either maintaining or restoring chenopod shrublands needs to be seriously thought about. If we take the Middleback area as an example, we see near optimum management (see above) and yet there are detectable zones of use within the three paddocks. It is likely that any form of grazing by sheep will effect a change in botanical composition. Even if thresholds could be established and reliable indicators found it is a doubtful whether the rangeland manager can adjust stocking rates, or patterns of grazing in a way that can make any meaningful difference.

Another important point relates to the effect of a change in botanical composition (even loss of some shrub species) on animal production. Again looking at the Middleback situation, there has been no detectable decline in wool production per head or per hectare over the past 30 years even though sophisticated analyses can demonstrate a shift in botanical composition. Wilson (1986) makes the point that range condition assessment, to be successful and credible with pastoralists, needs to take animal productivity into account.

From an ecological point of view we might conclude that any form of grazing use by domestic livestock is likely to cause a shift in botanical composition. The longer term benefits (and impacts) of grazing need to be weighed against the diminution of ecological values, including biodiversity.

From this study and from the review of the relevant literature (Chapter 2) I would suggest a number of propositions for consideration. These are set out in Table 8. 1.

8.5 Implications For Range Management

The results of this study have implications for the general understanding of change in rangeland condition. It is clear that rangeland condition cannot be simply related to animal production (O'Reagan and Mentis 1990) although this is important (Wilson *et al.* 1988b). Similarly, using vegetation and soil condition as the only criteria in a range monitoring program is likely to have little management impact unless changes in land condition are linked to livestock production. For example, where productive rangeland pasture is replaced by largely inedible shrubs, animal production and profitability declines (Harrington *et al.* 1984). In contrast, where productive rangeland pasture is replaced to a large extent by less desirable perennial rangeland, as in this study, the effect on animal production may under certain conditions be positive or neutral but the long-term stability of the vegetation may be altered and at greater risk of degradation.

The state-and-transition approach of Westoby *et al.* (1989) may offer a more appropriate framework for linking changes in rangeland condition to animal production, although it has spatial limitations which need to be recognised (Ash *et al.* 1994). Ultimately, quantifying the link between land condition and livestock performance will be an important step in improving the adoption of more sustainable grazing practices in rangeland environments (Ash *et al.* 1995).

Table 8. 1. Some propositions for rangeland managers to consider.

Proposition 1. Any form of grazing of chenopod shrublands by sheep will inevitably lead to shifts in botanical composition. Some of these will be benign but most will lead to serious compromise of ecosystem stability.
Proposition 2. Even careful range and livestock management will do some damage to chenopods. Therefore, the long-term impact of pastoralism must be carefully weighed against the biodiversity and other ecological values.
Proposition 3. Shifts in botanical composition *per se* do not necessarily mean reduced animal productivity but may be early warning of long-term damage.
Proposition 4. Many methods of range condition assessment do not accurately reflect the changes in animal productivity. Therefore, range monitoring techniques and procedures should be more oriented to the pastoralist's perspective.
Proposition 5: Plant-based attributes alone cannot serve to characterise range sites and states or trends. Soil factors, including microtopography and cryptogam cover relationships should also be assessed.

8.6 Future Research

The uneven distribution of sheep in large areas of chenopod shrubland and in small highly improved paddocks suggest that this is a general phenomenon. The reasons for such variation in stocking intensity over the landscape, other than the high use of some areas related to eating preferred plants, drinking and day or night resting, remain to be determined. It is clear there are aspects of grazing behaviour of sheep related to feeding and the utilization of the habitat which require further study.

Similarly, the nature of patch dynamics in chenopod shrublands is far from fully understood. The mechanism of contagious distribution, the factors affecting recruitment and the thorough study of survival and longevity of the key chenopod species via life table studies would yield valuable insights.

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Appendix A

Soil surface condition individual features
1a. Interception of raindrops (rain)

The objective is to assess the degree to which surface cover resists rainsplash erosion. Using the classification scheme shown in Table A.1 estimates are made of the projected percentage cover of perennial grasses and perennial shrubs to a height of 0.5 m, rocks, sticks and any relatively immovable and long-lived object that will intercept raindrops and protect the soil from rainsplash erosion. Soft annual herbage is excluded. "Gravity drops" falling from foliage drip-rings have a high erodibility when falling from heights of more than 0.5 m, so foliage at heights greater than 0.5 m are ignored in this section. Litter is assessed separately (see below). Soil with more protection has a lower potential for future erosion, even if in the form of a layer of stones caused by previous erosion.

Table A1: Interception of raindrops and divert overland flow

Projected cover		Class
nil		1
very low	(<2%)	2
low	(2-5%)	3
moderate	(5-15%)	4
high	(15-50%)	5
very high	(>50%)	6

1b. Soil cover, divert overland flow (flow)

The objective is to assess the cover of features that obstruct or divert overland flow using the classification scheme shown in Table A1. These are long-lived features that project at least 1 to 2 cm above the soil surface (e.g. plant tussocks or stems, rocks, wood) and obstruct and divert overland water flow so as to slow the overland flow rate, increase the depth of flow and thus reduce the transporting capacity of the flow for soil and organic matter. Soft annual herbage is excluded. Many small features can be more effective than a few large ones. The key question to ask is the following: To what extent will the observed features reduce the erosive power of overland flow?

2. Crust brokenness

This observation assesses to what degree surface crust materials are broken or loosely attached and available for erosion. Crusts in this context consist of thin layers of fine-textured soil overlaying the soil proper. Soils in good condition have a crust that is smooth and conforms to gentle undulation in the soil surface. The crust also commonly has polygonal cracks. As long as they do not curve upwards at their edges, these cracks do not count as broken. Smooth, unbroken crusts will yield less material than crusts that are already partially broken into fragments and are mechanically fragile. Typically, as crust brokenness increases, the crust becomes discontinuous, with sharp edges and somewhat loose crust fragments, marking the "pocket" where the crust has been lost.

Where a quadrat has more that 75% cover of eroded material (Table A2), crust brokenness does not apply. Excluded are soils without natural crusts, such as self-mulching surfaces and loose sands on dunes and sandy banks.

Sandy textured soils that do have a thin cohesive crust are assessed under this heading.
Animal tracks and vehicle tracks are excluded from consideration.
The degree and extensiveness of the crust brokenness needs to be considered and quadrats that are judged to be outside the scope of this section should be scored as zero and the total score adjusted accordingly.

Table A2: Crust brokenness

Crust brokenness	Class
extensively broken	1
moderately broken	2
slightly broken	3
intact	4

3. *Cryptogam cover*

The aim is to assess the cover of cryptogams. "Cryptogams" is a term that includes algae, fungi, mosses and liverworts, plants that can exist on stable (i.e. nonshifting) surfaces that have access to light. Cryptogams are often early colonizers of recovering soil and are positive indicators of surface stability (see also notes on the slake test below). They are useful in open situations (i.e. not under litter beds) in assessing surface soil stability and are assessed as percentage cover (Table A3).

Soil crusts with cryptogams are often flexible and resist pulverization (see also crust nature). If a cryptogam-crusted soil "plate" is detached from the surface by a paint scraper or chisel and gently broken, one can see across the break fine roots or hyphae, which contribute greatly to the robustness of the soil crust.

Analysis of soil beneath cryptogam crusts usually finds higher concentrations of nitrogen and carbon in the immediate soil surface, implying that these crusts help establish a healthy nutrient profile shape. Even where liverworts are growing on sandy deposits, their presence is a positive indication of the surface stability.

Table A3: Cryptogam Cover

Cryptogam cover		Class
nil	(<1%)	1
slight	(1-10%)	2
moderate	(10-50%)	3
extensive	(>50%)	4

4. *Erosion features*

Erosion features are visible signs of active, current loss of soil material from the quadrat. Erosion features are used to assess how the surface soil responds to the erosive forces of wind and water. An erosion feature may be an incised channel or rill, a terracette, pedestalling around a plant, or sheet erosion. (A stony pavement on a smooth slope implies sheet erosion.) Observers must be careful not to confuse soil accumulated around grass butts with signs of pedestalling. In the case of accumulation hummocks, the soil in the hummock in unconsolidated and, if sectioned with a paint scraper, the hummock reveals layers of accumulated soil. Pedestals will be much more coherent and fine textured and have no sign of layering.

In the soil-surface method, these features will be small. Otherwise they would have been dealt with in step 2. The severity of the nature is more important than percent cover *per se*. A feature may occupy a small area but be severe or serious. It is important to note the severity so as to flag a potential problem. Sometimes spontaneous improvement in formerly active erosion scars will be evidenced by smooth, rounded edges and colonisation by cryptogams. In such a case, reduce the assessment by one class.

Table A4. Erosion features

Erosion features	Class
extensive	1
moderate	2
slight	3
nil	4

5. Eroded materials

The objective is to assess the degree to which materials are being eroded from one place in the landscape and deposited in another. These deposits may take the form of sand and gravel splays or hummocks. Because these materials are unconsolidated, they can be easily remobilised by an event and carried away. The deposition of these materials around the landscape rather than in streambeds implies that although materials are being eroded, there is potential for stabilisation.

Sometimes erosion deposits can be quite productive. However, until they have stabilised to the extent that they are no longer recognizible as erosion features, they need to be flagged as remaining potentially erodible.

Three sizes classes of materials can be seen: sand, less than 2 mm; gravel, 2 to 10 mm; and stone, greater than 10 mm. The percent cover is evaluated to classify this feature. Litter is treated separately (see below) (Table A5).

Table A5: Eroded materials

Eroded materials	Class
extensive	1
moderate	2
slight	3
nil	4

6. Litter cover

The object is to assess the availability of organic materials for decomposition and nutrient cycling. Litter refers to such organic matter as detached leaves, stems, twigs, fruit and dung. The position of litter in the overall landscape also helps define fertile patches.

Litter may be local, i.e. accumulates and decomposes where it falls (e.g. under a tree or shrub), or it may be transported by wind or water and dispersed or concentrated depending on the nature of the landscape and the zones of potential accumulation.

Copious accumulation protects against rainsplash erosion and serves as a seed trap as well as source of organic matter for cycling. Transported litter is clearly more mobile and its value to the system more uncertain.

Litter has three easily recognisable forms of decomposition value:

- Loosely strewn on the surface (nil)
- In intimate contact with the surface (slight)

- Partially or wholly covered with soil (extensive)

These categories reflect the likelihood of litter being incorporated in the soil *in situ*.

The cover is assessed first, then whether the litter is local (L) or transported (T) and finally whether the degree of incorporation is nil (N), slight (S) or extensive (E). A recording could therefore be 3LS.

These data are used in a calculation to modify the simple cover value *viz*.

- transported and nil incorporation, multiply by 1 (i.e. no change to simple cover)
- local and/or slight incorporation, multiply by 1.5
- extensive incorporation, multiply by 2.

Therefore, in the above example, 3LS, the score is 3 x 1.5 x 1.5 = 6.75.

Table A6: Litter cover

Degree		Class
nil	(<1%)	1
very low	(1-10%)	2
low	(10-25%)	3
moderate	(25-50%)	4
extensive	(50-100%)	5
very extensive (but several cm thick)	(100%)	6

7. Soil microtopography

Soil microtopography refers to soil surface features that detain water on the quadrat between the time the surface becomes wet (ponded) and the time water actually runs off the quadrat area (runoff). Soils that can absorb and store rainfall will have higher biological activity than those from which this water runs off or is evaporated. Typically, soil microtopography consists of a series of unconnected micro-depressions which are often associated with cryptogam crusts or mats buckling at the edges so as to form embayments.

A second role for microtopographic features is providing safe seed sites because of their accumulation, retention and protection characteristics.

Macro structures such as Gilgai s and depressions larger than the quadrat are excluded and should be addressed in step 2. The assessment estimates the volume of the detention as shown by the depth criteria in Table A7.

Sheep or cattle foot impressions should not be included because their persistence is unknown and not necessarily related to the processes that naturally produce shallow depressions.

Table A7: Soil microtopography

Surface water detention capacity		Class
nil, smooth	(<3 mm)	1
Slight, few shallow depressions	(3-8 mm)	2
Moderate, Deeper depressions	(8-15 mm)	3
High, deep, extensive	(15-25 mm)	4
Very High e.g. sink holes	(>25 mm)	5

8. Surface nature

This observation assesses the robustness of the surface, or the degree to which the surface can withstand stress (e.g. trampling) or reform after rain. The features assessed are crust flexibility, brittleness and hardness and also the coherence of subcrust soil.

This test can be conducted only when the soil crust is air-dry. This is the only moisture content at which the test is informative because clearly all soils are soft and non-brittle when wet or moist.

Hoof action easily breaks soils with weak or fragile crusts, releasing sub-crust material to erosion. Flexible crusts indicate that fine roots or fungal hyphae are holding the soil particles together (like a sticky string bag) and that biological activity is high on the surface.

Very hard soils resist detachment by mechanical means but indicate that infiltration rates may be very low and organic carbon levels depleted. Crust hardness is not a linear indicator of condition. Soil crusts are more likely to be performed after disturbance in the medium hardness/flexible scale.

Table A8: Surface nature

Surface Nature	Class
Crust shows some flexibility when pressed with pen or finger pressure, or surface is self-mulching clay. Sub-crust soils is coherent or strong crumb structure	5
Crust is very hard (needs metal tool to break surface), but is brittle, breaking into amorphous fragments or powder. Sub-crust soils is hard and coherent	4
Crust is moderately hard (needs metal tool to break surface), but brittle breaking into amorphous fragments or powder. Sub-crust soils is coherent	3
Crust is easily broken with finger pressure and is brittle. Sub-crust soils is noncoherent, e.g. sandy.	2
Surface is loose-sandy, over noncoherent sand.	1

9. Slake test

The slake test is a test for crust stability when wet. The ability of stable crusts to maintain their cohesion when wet enables them to resist the erosive effects of flowing water and to maintain a good physical structure after a wetting-drying sequence.

The test involves immersing fragments of surface soil (approximately 6 mm cubes) in a beaker of rainwater (saline waters are unsuitable) and observing the response of fragments over several minutes (Table A9).

The test should be performed on each of the landscape strata soils, e.g. under trees and between trees. At least three fragments are used per test. One quadrat from each stratum is sufficient for testing unless soil crust brokenness and/or cryptogam cover differs markedly along the transect.

Table A9: Slake test

Observed behaviour	Class
Fragment collapses completely in <2 seconds with myriad of air bubbles, into a shapeless mass. **Very unstable**	1
Fragment substantially collapses over about 5 seconds, a thin surface crust remains, but >50% of the sub-crust material slumps to an amorphous mass. **Unstable**	2
Surface crust remains intact, some slumping of sub-crust material, but <50%. **Moderately Stable**	3
Whole fragments remains intact over periods of 1 hr or more. **Stable**	4

10. Soil texture

The objective of this test is to rate the permeability of the soil body as opposed to the crust. Permeability is rated with a pedologist's moist blue test, a 0.5 cm sample and a simplified four-point scale (Table A10).

Table A10: Soil texture

Texture	Class
Silty clay to heavy clay (very slow infiltration rate)	1
Sandy clay loam to sandy clay (slow infiltration rate)	2
Sandy loam to silt loam (moderate infiltration rate)	3
Sand to clayey sand (high infiltration rate)	4

The individual observations of the soil surface are condensed into three categories, which have distinct significance for each monitoring site:

1. Stability: The ability of the soil to withstand erosive forces and to reform after disturbance.

2. Infiltration/Runoff: How the soil partitions rainfall into soil-water (water available for plants to use) and runoff water that lost from the local system or may carry materials away.

3. Nutrient cycling status: How efficiently organic matter is cycled back into the soil.

These categories are useful at both the quadrat and site scale:

Because the location of quadrats are fixed, changes in their assessed condition over time can be objectively used for assessing improvement or degradation.

Soil condition can also be compared directly with plant data and so build up a cause and effect understanding.

At the site scale an overall frequency distribution of quadrats in different conditions gives an overall site value. Because there are three categories, the strength and the weakness of a given site will be determined more accurately.

The class values for each observation are summed for each category to give a value reflecting the status of a quadrat or site with respect to the category. The scales vary as follows:

Soil stability

- Crust brokenness (1-4)
- Surface nature (1-4)
- Slake test (1-4)
- Erosion features (1-4)
- Eroded materials (1-4)
- Cryptogam cover (1-4)
- Soil cover (rain) (1-6)
- Litter cover (simple) (1-6)

(If all features are present, the scale ranges from 7 to 36.)

Note: simple litter cover only in this category.

Infiltration/Runoff

- Microtopography (1-5)
- Surface nature (1-4)
- Litter cover (simple) (1-6)
- Soil cover (flow) (1-6)
- Soil texture (1-4)

(If all features are present, the scale ranges from 5 to 25.)

Note: simple litter cover only in this category.

Nutrient cycling status

- Litter cover, origin and incorporation (1-18)
- Cryptogam cover (1-4)
- Microtopography (1-5)

(If all features are present, the scale ranges from 3 to 27.)

Note: simple litter cover only in this category.

If any feature does not apply to a given site, it should be recorded as zero and the scale of the category adjusted accordingly. For example, on a sandy site the soil may be loose and the slake test is impossible to perform. Score slake as 0 and adjust the category scale for stability to 6-26.

The final assessment for each category should be converted to a percentage value.

Table A 11. The summarised information of soil surface features and the scores of each soil features which was used for measurement and the direction of them.

No.	Features	Classes	Direction
1	Soil cover (rain)	1-6	Nil-very high
2	Soil cover (flow)	1-6	Nil-very high
3	Crust brokenness	1-4	Extensively broken
4	Cryptogam cover	1-4	Nil-extensive
5	Erosion features	1-4	Extensive-nil
6	Eroded materials	1-4	Extensive-nil
7	Litter cover	1-6	Nil-very extensive
8	Microtopography	1-5	Nil-very high
9	Surface Nature	5-1	Self-mulching surface over non-coherent sand
10	Slake test	1-4	Very unstable-stable
11	Texture	1-4	Very slow infiltration rate-high infiltration rate
12	Stability	7-36	From low ability of the soil to withstand erosive forces to high ability
13	Infiltration	5-25	From low infiltration to high infiltration
14	Nutrient cycling status	3-27	From low level organic matter cycling back into the soil to high level

Additional Publications And Award

Heshmatti, G.A. (1994) Ecological approach on plant communities: A site potential approach. The Australian Rangeland Society 8th Biennial Conference. June 21-23, Katherine, Northern Territory.

Heshmatti, G. A., Conran, J. G., and Facelli, J. M. (1996). Identifying the sensitive zone in a chenopod shrubland in semi-arid South Australia. In '9th Biennial Australian Rangeland Conference.' (Eds. L. P. Hunt and R. Sinclair) pp. 237-238. (Australian Rangeland Society: Port Augusta, South Australia 24-27 September, 1996.)

Heshmatti, G.A. and Squires, V.R. (1997) Geobotany and Range Ecology: A convergence of thought? *Journal of Arid Environments* **35**: 395-405.

Heshmatti G.A., Conran J.G., Facelli J.M. And Squires V.R. (In press.) Indicators of incipient change (critical thresholds) in chenopod shrubland ranges in arid areas. The International Conference on Desert Development, Kuwait 23-26 March, 1996.

Heshmatti, G.A., Conran, J. G., and Facelli, J. M. (In Press). Determination of pater structure of chenopod shrubland in semi-arid plain landform rangelands. In 8^{th} International Conference on Rainwater Catchment Systems, Tehran 21-25 April 1997.

Award:

1996 The Peter Martin Prize for Scientific Communication, Certification and award ($250.00).

Heshmatti, G.A. (1994) Ecological research on plant communities in the north of Iran: a site potential approach.
Presented at: The Australian Rangeland Society 8th Biennial Conference, 21-23 June, Katherine, Northern Territory

NOTE:
This publication is included on pages 170-172 in the print copy of the thesis held in the University of Adelaide Library.

Heshmatti, G.A., Conran, J.G. & Facelli, J.M. (1996) Identifying the sensitive zone in a chenopod shrubland in semi-arid area in South Australia.
Presented at: The Australian Rangeland Society 9th Biennial Conference, 24-27 September, Port Augusta, South Australia

Heshmatti, G.A. & Squires, V.R. (1997) Geobotany and range ecology: a convergence of thought? *Journal of Arid Environments, v. 35(3), pp. 395-405*

NOTE:
This publication is included on pages 177-187 in the print copy of the thesis held in the University of Adelaide Library.

It is also available online to authorised users at:

http://doi.org/10.1006/jare.1995.0144

Heshmatti, G.A., Conran, J.G., Facelli, J.M. & Squires, V.R. (1998) Vegetation indicators of incipient change in chenopod arid shrublands: a case study for grazing management.
In: Sustainable Development in Arid Zones, pp. 421-434

NOTE:
This publication is included on pages 188-211 in the print copy of the thesis held in the University of Adelaide Library.

Heshmatti, G.A., Conran, J.G. & Facelli, J.M. (1997) Determination of pater structure of chenopod shrubland in semi-arid plain landform rangelands.
Presented at: The 8th International Conference on Rainwater Catchment Systems, 21-25 April, Tehran, Iran

NOTE:
This publication is included on pages 212-223 in the print copy of the thesis held in the University of Adelaide Library.

The University of Adelaide

DEPARTMENT OF BOTANY

The Peter Martin Prize for Excellence in Scientific Communication

awarded to

GHOLAM ALI HESHMATTI

19 January 1996

Anthony Cheshire

Anthony Cheshire
Head of Department

THE UNIVERSITY OF ADELAIDE
Department of Botany

19 January 1996

Mr Ali Heshmatti
DEPARTMENT OF BOTANY

Dear Ali

The Peter Martin Prize for Scientific Communication

On behalf of the Assessment Committee, I write to congratulate you on winning the poster competition for Excellence in the Communication of Scientific Research. The Committee recognises the very high standard of your entry and wishes to extend to you its thanks for the time and effort you have put in to participating in this research competition.

You will be awarded the amount of $250.00 together with a certificate in early February. Once again, congratulations on an excellent entry!

Yours sincerely

Anthony Cheshire

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