Vegetation, soils and management of 'Zara': a sandhill remnant on the Riverine Plain

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Stafford, M.J.[1,3] and Eldridge, D.J[2]. ([1]School of Geography, University of NSW, Australia 2052. [2]Department of Land and Water Conservation, Centre for Natural Resources, c/- School of Geography, University of NSW, Australia 2052. [3]Current address: Australian Water Technologies, 51 Hermitage Rd, West Ryde, NSW, 2114, Australia) 2000. Vegetation, soils and management of 'Zara': a sandhill remnant on the Riverine Plain. Cunninghamia 6(3): 717–746. The 'Zara' exclosure (approximately 35°10'21''S, 144°41'59''E) is on a source-bordering dune on the Riverine Plain north of Deniliquin. The vegetation of this sandhill closely represents the original vegetation that once covered sandhills of the south-west Riverina prior to European occupation. Three vegetation communities comprising six associated Map Units were defined by cluster analysis within the 60 ha exclosure. These were the Callitris Mixed Woodland (Map Units 1, 2, 3, and 6), the Black Box Woodland (Map Unit 5) and the White-top Grassland (Map Unit 4). Seventy-seven taxa were recorded during the survey, and the vegetation was dominated by species from the families Chenopodiaceae and Poaceae. Three shrubs, the exotic weed *Lycium ferocissimum* and the natives *Rhagodia spinescens* and *Enchylaena tomentosa* occurred at more than 75% of sites. The distribution of vegetation communities was strongly associated with attributes of the soil (e.g. soil texture and organic carbon) and plant and litter cover. Vegetation communities occupying remnant sandhills such as the 'Zara' exclosure are some of the most vulnerable communities on the Riverine Plain.

Introduction

Sandhill remnants scattered across the Riverine Plain support restricted and vulnerable plant communities. Their small size, narrow shape and distance from other natural areas render them vulnerable to weed and pest invasion, and continued disturbance by livestock and feral herbivores. Grazing and disturbance and clearing and cultivation for agriculture result in declining recruitment and/or higher mortality of understorey species, and eventually loss of native vegetation cover (Porteners 1993). These sandhill remnants are becoming increasingly valuable for the survival of diminishing plant communities and their associated species (Eardley 1999). Maintenance of these sandhills as 'conservation islands' within a modified landscape depends on our knowledge of the current pressures and threats to these communities.

Only a few remnants, including the 'Zara' exclosure, closely represent the vegetation that once covered the sandhills of the south-west Riverina prior to European occupation.

The 'Zara' source-bordering dune (sandhill), has been recognised for its high biodiversity and conservation value. Brickhill (1985) recommended that the *Callitris*-dominated community at 'Zara' be given high conservation priority, and Porteners (1993) subsequently recommended that regeneration of the site be initiated. The Southern Riverina Naturalists also recognised the conservation value of the 'Zara' sandhill, and it was eventually fenced off from surrounding grazing land in May 1997. The fencing of the 60 ha sandhill site was supported by station owners F.S. Falkiner and Sons, with funding provided through the Drought Landcare Program of New South Wales National Parks and Wildlife Service. Greening Australia, Conservation Trust Volunteers, Windouran Shire Council and the Deniliquin Rural Lands Protection Board also provided support.

Previous work on vegetation communities on sandy soils on the Riverine Plain has been limited to species inventories, or general discussions of the sandhills in the context of the plain. Little is known about the relationships between plants and soils on these sandhill remnants, and there has been no attempt to quantitatively describe the links between the structure of the communities and the components of the soils and landforms.

Broad regional studies, species lists, management and technical reports, rangeland reviews and literature surveys have been undertaken by the Soil Conservation Service of NSW (Department of Land and Water Conservation), the National Herbarium of NSW, and by individuals such as Moore (1953), Leigh and Mulham (1977) and Cunningham et al. (1981). Porteners (1993) mapped the vegetation of the 'Hay Plain' which covered an area of 4.5 million hectares at a scale of 1: 250 000. Benson et al. (1997) also provide a recent and detailed description of the grasslands of the Riverine Plain.

The objective of this study was to describe the vegetation and soils, and their interrelationships, within the 'Zara' exclosure, and to provide base-line information against which future changes to the vegetation and soils could be compared. The ultimate aim is to provide objective information on which to support the management of the exclosure.

Study area

The study site is located on the Riverine Plain in south-western New South Wales. The Plain is a large expanse of flat alluvial landscape bordered by Narrandera and Balranald, and Ivanhoe and Bendigo. The exclosure is located within 'Zara', a grazing property located approximately 40 km north of Deniliquin, or 10 km east of Wanganella (35°10'21''S, 144°41'59''E) (Fig. 1). The principal land use in the area is sheep grazing on native pastures. The surrounding vegetation is typical of the Riverine Plain with annual grasses such as barley grass (*Hordeum leporinum*) and ryegrass (*Lolium rigidum*) comprising substantial proportions of the pasture. Smaller areas are used for irrigation and dryland cropping.

Isolated sandhills supporting the *Callitris glaucophylla* assemblage occur throughout the region. Those that occur within State Forests, as well as being subject to logging, are often leased out to landholders, and suffer intensive grazing pressure with little or no generation of tree species (Porteners 1993).

While the 'Zara' exclosure is by far the best remaining example of the *Callitris*-dominated community present in the region, it cannot be considered pristine. 'Zara' has been managed as a typical sheep grazing property for the past 150 years. The homestead is located approximately 500 m west of the sandhill, and consequently the

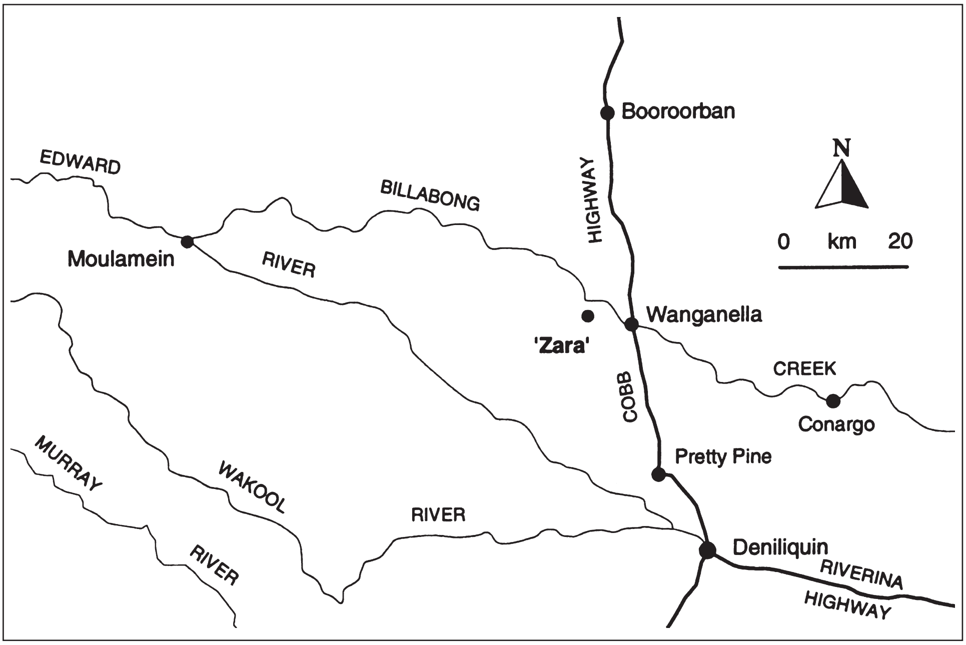

Fig. 1. Location of the 'Zara' exclosure in south-western New South Wales (adapted from Semple 1990).

sandhill would have formed part of the horse paddock surrounding the homestead. Grazing by sheep and cattle would have been intermittent, probably for short periods, as most managers tried to encourage a buffer strip around their homesteads to lessen the impact of dust storms. Ms Officer, the wife of one of the owners in the early part of the century was a keen naturalist, and collected many plant species from the sandhill. Some of her collection is housed at the National Herbarium of NSW. In the 1930s and 1940s the sandhill was apparently used as a golf course, suggesting that shrub cover would have been much less than it is today. Fencing, to exclude rabbits and domestic animals but not kangaroos, was carried out in 1997 using rabbit-proof netting.

The importance of the 'Zara' exclosure cannot be underestimated for several reasons. The exclosure, as well as officially recognising the conservation importance of the sandhill vegetation, encourages future and longitudinal studies of this sandhill. There is already evidence that the rabbit- and sheep-proof fencing has enhanced the regeneration of tree species such as rosewood (*Alectryon oleifolius*) and sugarwood (*Myoporum platycarpum*). Fencing has also enabled the Riverina Field Naturalists to strategically control african boxthorn (*Lycium ferocissium*) within the exclosure and within a buffer strip around the exclosure. Rabbit control has also been initiated with the use of 1080 baiting and warren ripping.

Climate

The climate of the Riverine Plain can be classified as semi-arid, with very hot summers, mild winters and a winter dominant rainfall (Edwards 1979). For the months of January and February, the average daily maximum is approximately 32°C and the average daily minimum for July is about 4°C for the whole of the Riverine Plain (O'Halloran 1995). 'Wanganella', east of 'Zara', has a mean annual rainfall of 337 mm and an average of 53 rain days (Bureau of Meteorology 1998). January and February are the driest months at 'Wanganella', while peak rainfall occurs in May and September (Benson et al. 1997).

Evaporation rates are high, especially in summer and autumn when rainfall is largely ineffective (O'Halloran 1995). Frosts are common between May and September (Cunningham et al. 1981). The most common wind directions are from the south and south-east, although in winter and spring a westerly influence is common. Wind is an important factor in the formation of landforms such as sand dunes which are common on the Riverine Plain.

Landforms and soils

The area surrounding the 'Zara' sandhill consists mostly of alluvial and lacustrine deposits of clay, silt, sand and gravel (Semple 1990). Geomorphically, the sandhill can be described as a source-bordering sandhill which has been derived from the redistribution of coarse stream bed deposits of prior streams and, to a lesser extent, ancestral rivers (Butler et al. 1973). The sandhill is gently sloping, orientated west-east, and was stabilised by vegetation prior to European settlement.

The soils of the 'Zara' sandhill consist of a mixture of siliceous and earthy sands which have a relatively uniform profile with only small changes in colour and texture with depth (Eldridge 1990). The sands are also low in fertility and are highly susceptible to wind erosion once the stabilizing vegetation is removed. Red and brown texture contrast (duplex) soils occur at the margin of the sandhill and the plain. Their surface textures are generally coarse sandy to loamy sands, grading to clayey subsoils often with carbonate at depth. Texture contrast soils are susceptible to windsheeting and scalding (Eldridge 1990).

Vegetation

Much of the Riverine Plain, particularly in the western section, supports chenopod shrubland dominated by *Atriplex vesicaria* and *Maireana aphylla*, and to a lesser extent *Atriplex nummularia* (Porteners 1993). To the east this shrubland has been replaced by a grassland dominated by *Notodanthonia caespitosa* and other perennial and annual grasses. Much of the Riverine Plain has been modified by grazing which has led to a change in vegetation community from *Atriplex vesicaria* to *Sclerolaena* spp. and annual *Atriplex* spp. Grazing pressure has also encouraged the dominance of *Nitraria billardieri* and annual grasses such as *Hordeum leporinum*. On rangelands which are periodically inundated, *Atriplex vesicaria* is often replaced by *Maireana aphylla*.

The Southern Riverina Naturalists compiled a list of 129 species from 44 families from the 'Zara' Exclosure (Mulham, unpublished data). Whilst this study provided a valuable initial assessment of the conservation value of the exclosure, no attempt was made to rate the abundance, importance, or uniqueness of the species within the exclosure or to relate these species to the underlying environmental attributes that determine species distribution.

Field Methods

Establishment of permanent grid points

Sixty permanent grid points were marked out at regular intervals of 30 m by 30 m across the exclosure. The points were identified on a 1: 10 000 black and white aerial photograph before being marked permanently in the field with numbered steel pegs.

Vegetation measurements

At each point a circular plot of 10 m radius was established for the collection of plant and soil data. Cover and abundance of each plant species were assessed during summer (January 1998) at each site using a modified Braun-Blanquet scale where: 1 = < 5% cover and < 5 individuals, 2 = < 5% cover and > 5 individuals, 3 = 5–25% cover, 4 = 25–50% cover, 5 = 50–75% cover, and, 6 = > 75 % cover (Mueller-Dombois and Ellenberg 1974). The botanical names used in this report follow Harden (1990–1993).

Soil surface condition assessment and soil sampling

At each site, attributes of the soil surface were measured in two 0.25 m^2 quadrats placed on opposite sides of the 10 m radius plot. Methods for assessing soil surface condition (Table 1) were adapted from Tongway (1995).

Table 1. Environmental variables used in the Canonical Correspondence analysis.

Variable	Code	Range of values	Description
slope	SLOPE	(1–5)	0% (1) to > 10% (5)
microtopography	MICRO	(1–5)	< 3 mm (1) to > 100 mm (5)
crust coherence	COHER	(1–5)	sand (1) to non-brittle or self mulching (5)
cracking	CRACK	(1–4)	extensively broken (1) to intact (4)
firmness	FIRM	(1–4)	very loose (1) to firm (4)
cryptogams	CRYPT	(1–4)	< 1% (1) to > 50% (4)
erosion amount	SHEET	(1–4)	extensive (1) to insignificant (4)
soil cover	PCOV	(1–5)	< 1% (1) to > 50% (5)
basal cover	BCOV	(1–4)	< 7 mm (1) to > 140 mm (4)
simple litter cover	LCOV	(1–6)	< 10% (1) to 100% (several cm thick) (6)
litter source	SOURCE	(1–2)	transported (1) to local (2)
litter incorporation	LCORP	(1–3)	low (1) to extensive (3)

Slope within the site was classified as 0%, 1–3%, 3–5%, 5–10% or > 10%. **Surface microtopography**, defined as the vertical difference between the highest and lowest point at the site, was recorded. Increases in this vertical difference, increases the soil's potential to retain and store rainfall, leading to potentially higher biological activity. The five classes were; < 3 mm, 3–8 mm, 8–25 mm, 25–100 mm and > 100 mm.

Crust coherence gives a measure of the crust's resistance to disruption, and is assessed as the resistance of the soil surface to an object equivalent to the diameter of a pencil. The 'resistance' indicates the ability of the surface to resist stress immediately upon wetting, or to reform after wetting (Tongway 1995). Crust coherence classes were ranked as: sandy (single grained), easily broken, moderately hard, very hard, non-brittle or self mulching (clay aggregates). Increasing number corresponds to the soils increasing predisposition to hardsetting.

Soil firmness or stability when subject to raindrop impact was estimated in the field. The categories were ranked as firm, moderately firm, loose or very loose. The less firm a soil the more potential there is for erosional loss of fines and greater impermeability on drying (Tongway 1995).

Relative cracking was measured by estimating the percentage of the soil surface covered by cracks. This relates to what degree the surface material is loosely attached and therefore its capacity to disintegrate and erode. It may also be related to the potential for microsites and consequently seed lodgement. Four categories were used: extensively broken, moderately broken, slightly broken and intact.

The cover of cryptogams, grass butts and understorey plants was measured to indicate the degree of cover on the soil at each site and therefore to determine the soil's ability to resist erosion. **Cover of cryptogams** (microphytic crusts; Eldridge & Greene 1996) was classified as: < 1 %, 1–10 %, 10–50 % or > 50 %. As cryptogams are a positive indicator of stability, increasing cover equates with a more stable soil (Tongway 1995).

The **grass basal cover** was estimated in the following classes: 7 mm, 7–70 mm, 70–140 mm or > 140 mm. These values indicate the contribution that the underground biomass (roots) is making to the nutrient pool (cycling). The **plant cover** values indicate the degree to which foliage cover of perennial grasses and any perennial shrubs, less than 0.5 m above the ground, protects the soil surface from rainsplash erosion. Because of the greater potential of gravity drops falling from the foliage of trees and shrubs taller than 0.5 m to erode soil, only foliage of vegetation < 0.5 m was included (Tongway 1995). The cover was estimated as: < 1 %, 1–15 %, 15–30 %, 30–50 % and > 50 %.

The percentage of **soil covered by litter** was recorded, along with an assessment of whether this litter was local or transported, and the degree of incorporation into the soil. The percentage of litter cover was represented by six classes: < 10%, 10–25%, 25–50%, 50–75%, 75–100% or 100% but several centimetres thick. The litter was either transported (material originated elsewhere and can be more easily lost) or local. The incorporation of this litter was assessed to be either low, moderate or extensive.

The **degree of erosion** at a site was classed as extensive, moderate, slight or insignificant. This gives an indication of the severity of active or current loss of soil material (Tongway 1995). If evidence of erosion existed, then the type (sheeting, scarping, scalding, terracing, hummocking, rills or gullies) was noted, and the eroded material (sand, gravel or clay) was recorded. The types recorded are defined in Tongway (1995).

Four soil samples were collected from a depth of 10 cm from within each circular plot and bulked for an assessment of soil chemical properties.

Organic carbon (OC) was determined using the modified Walkley-Black method (Colwell 1969). Replicates of a 1:5 soil and water solution were used to measure the hydrogen ion concentration (pH) and electrical conductivity (EC) after shaking. Soils were assigned to six texture (TEXT) classes (sands, sandy loam, loams, clay loam, clay) using the bolus method of Northcote (1979).

Data analysis

Vegetation relationships

A species-by-site matrix was constructed to examine groupings of the 60 sites based on cover-abundance of the vascular plants. Of the 77 species recorded, 37 were eliminated from the analysis as they occurred in < 7 (10%) of the sites. The aim of this reduction was to increase the clarity and simplicity of the interrelationships between sites and species, and to reduce the impact of locally 'rare' or infrequent species upon this interpretation.

The reduced data matrix of 60 sites by 40 species (including exotic species) was classified using an hierarchical agglomerative cluster analysis using the Bray-Curtis dissimilarity measure and the Ward's Incremental Sum of Squares (WISS) grouping strategy (Belbin 1990). This analysis produced a grouping of sites that were relatively 'similar' to each other but relatively 'different' to all sites in other groups based on the cover-abundance of species. Unweighted pair group method using arithmetic averages (UPGMA) was also used to cluster the sites in order to determine the robustness of the clusters. An optimal number of groups (Map Units) was determined by examining the point of inflection on a plot of the number of possible groups by dissimilarity level.

Correlations between the number of species and the number of exotics recorded for each Map Unit were determined using Pearson's correlation coefficient (r). Species richness (the average number of species within each Map Unit) was calculated. A measure of diversity, the Shannon-Wiener index, was calculated to account for the varying patterns of species abundance.

Relationships between vegetation and environmental variables

Canonical Correspondence Analysis (CCA) using CANOCO Version 2.1 (ter Braak 1991) was used to examine relationships between the measured environmental variables and the distribution of species within the exclosure. The environmental variables are represented by vectors whose length indicates the relative importance of each variable in determining the axes. The angle between a vector and an axis is an inverse measure of their correlation. The location of species scores relative to the environmental variables indicates those species or groups of species which have the greatest affinity with the measured environmental variables (ter Braak 1986).

Of a total of 24 environmental variables, nine were omitted from the CCA either to increase the clarity of the relationship between soil variables and species distribution or because the values for some variables did not change across the 60 sites. An environmental data set matrix was constructed using 120 rows (60 sites by 2 quadrats per site) by 15 environmental variables. The environmental variables include the 12 listed in Table 1, as well as soil texture (TEXT), organic carbon (OC) and electrical conductivity (EC). The significance of the environmental variables was tested using a Monte Carlo simulation in the CANOCO package (ter Braak 1991). Accordingly, all insignificant environmental vectors were omitted from the CANOCO biplots. Relationships between the environmental variables and the 60 sites were examined by projecting the 60 site locations, coded for Map Unit, onto the first two axes of the CCA biplot.

Statistical analysis

Data were tested for normality and homogeneity of variance and transformed where necessary (log_{10}, reciprocal, y^3) to meet parametric assumptions. Differences in richness and diversity were tested using one-way analysis of variance (ANOVA) and significant differences determined using Tukey's H.S.D. test. Data which were not normally distributed, or which had unequal variances, were tested using the non-parametric Kruskal-Wallis test (Minitab 1989).

Results

Floristics of the 'Zara' exclosure

Seventy seven taxa (species and subspecies) representing 32 families and 65 genera were recorded in our study (Appendix 1). Together with those species recorded by the Southern Riverina Field Naturalists (Mulham, unpublished), a total of 144 taxa (43 families, 110 genera) have been recorded in the exclosure (Appendix 1). The ROTAP species (*Ptilotus extenuatus*) and a Schedule I species under the Threatened Species Act (*Calotis moorei*) both recorded from the sandhill, were not found during the current survey or by the Riverina Field Naturalists.

As the survey of the 'Zara' exclosure was made at only one point in time, i.e. a hot summer with below average rainfall, a large number of species normally found in the area were not encountered. As a large number of annuals in the Riverina are winter growing (Leigh & Mulham 1977), only summer growing species and the main drought tolerant or drought avoiding plants were recorded. This may explain why only 20 of the 44 known exotics were found during the current survey.

Families known to contain a conspicuous number of exotics such as Poaceae, Brassicaceae and Boraginaceae occurred at more than half of the sites sampled (Table 2). Only 12 species occurred in more than half of the sites (Table 3), and of these three were exotic, and included the declared noxious weed *Lycium ferocissimum*. Examination of Table 3 and Appendix 1 indicates that *Rhagodia spinescens* and *Enchylaena tomentosa* occurred in more than 45 sites and in all Map Units. These shrubs, from the family Chenopodiaceae, could be regarded as characteristic of the 'Zara' exclosure. A high proportion (48%) of species occurred in less than 10% of the sites.

Table 2. The most common families surveyed within the exclosure.

[1]frequency is out of a total of 77 (the total number of species found in the present study), [2]frequency is out of a total of 144 (the total number of species found in the present study and Mulham's unpublished study).

Family	No. of sites occupied	Frequency[1] of species found during the current survey (% out of 77)	Frequency[2] of species found for 'Zara', overall (% out of 144).
Chenopodiaceae	60	15 (19%)	16 (11%)
Poaceae	60	13 (17%)	24 (17%)
Aizoaceae	38	1 (1%)	1 (1%)
Brassicaceae	38	2 (3%)	4 (3%)
Santalaceae	38	3 (4%)	3 (2%)
Boraginaceae	36	3 (4%)	3 (2%)
Sapindaceae	34	2 (3%)	2 (1%)
Fabaceae	33	5 (7%)	10 (7%)
Solanaceae	32	3 (4%)	3 (2%)
Asteraceae	11	5 (7%)	22 (15%)

Table 3. The most common species found during the survey.

Frequency refers to the number of sites, out of 60, where the particular species was found. *indicates an exotic species.

Species Name	Frequency	Family
Rhagodia spinescens	58	Chenopodiaceae
Stipa spp.	50	Poaceae
Enchylaena tomentosa	45	Chenopodiaceae
Bromus arenarius	45	Poaceae
**Mesembryanthemum crystallinum*	38	Aizoaceae
Enteropogon acicularis	36	Poaceae
Notodanthonia caespitosa	35	Poaceae
Stipa elegantissima	33	Poaceae
**Echium plantagineum*	33	Boraginaceae
Exocarpos aphyllus	32	Santalaceae
Dodonaea viscosa subsp. *angustissima*	31	Sapindaceae
**Lycium ferocissimum*	30	Solanaceae

Vegetation groupings based on site classification

The dendrogram (Fig. 2) indicated that six groups (Map Units) provided the most appropriate level of detail for mapping the vegetation in the exclosure. These six Map Units corresponded to three intergrading vegetation communities found on the Riverine Plain (Cunningham et al. 1981, Semple 1990, Porteners 1993), and closely reflect the vegetation patterns observed on the aerial photograph (Fig. 3).

Species found within each of the six Map Units, and the percentage of sites occupied by each species within a Map Unit are shown in Appendix 1. While Map Units 1 to 5 lay within generally well-defined communities, boundaries between these units are gradational. Map Unit 6 represents a transition from one community to another. As Map Units 1, 2, 3 and 6 have similar complements of species compared to Map Units 4 and 5, these units are discussed together. In discussion of Map Units 1, 2, 3 and 5, superscripts indicate the Map Units in which the species occur, and no superscript indicates occurrence in all four Map Units.

Map Units 1, 2, 3 and 6: *Callitris* Mixed Woodland

Map Units 1, 2, 3 and 6 correspond to the *Callitris* Mixed Woodland described by Porteners (1993). See Figs 3 and 4. *Callitris glaucophylla* was abundant in Map Unit 1 but scattered in Map Units 2 and 3. *Alectryon oleifolius* subsp. *canescens,* which was scattered within Map Units 1 and 2, appears to replace *Callitris glaucophylla* as the latter diminishes. The understorey consisted of *Rhagodia spinescens*, *Dodonaea viscosa* subsp. *angustissima*, *Hakea tephrosperma*[12], *Eremophila longifolia, Atriplex nummularia*[23] and *Enchylaena tomentosa*. *Lycium ferocissimum* and *Exocarpos aphyllus* were also found in Map Units 1, 2, 3 and 6.

Ground flora comprised short-lived annual and perennial grasses and herbs, many of them exotics (Porteners 1993). These included *Mesembryanthemum crystallinum*[123], *Bromus arenarius*, *Stipa* spp., *Echium plantagineum*, *Stipa elegantissima*, *Notodanthonia caespitosa*[236] and *Sisymbrium erysimoides*[12]. Species found at a low number of sites included *Sisymbrium orientale*, *Schismus barbatus, Einadia nutans, Hordeum leporinum* and *Jasminum lineare*. *Vulpia myuros* was abundant in Map Units 1, 3 and 6, while *Atriplex nummularia* and *Trifolium arvense* characterized both Map Units 2 and 3. Map Unit 6 was characterized by the absence *of Mesembryanthemum crystallinum* and a very low cover-abundance of *Dodonaea viscosa* subsp. *angustissima*.

Map Units 1 and 2 accounted for the greatest coverage of the exclosure (Fig. 3), and supported the greatest number of either native or exotic species. The number of exotics and the total number of species, for each Map Unit, were significantly positively correlated ($r = 0.91$, $P < 0.02$). Of the four Map Units included in the *Callitris* Mixed Woodland, only Map Units 1 and 2 had unique species. Of the 71 species within the *Callitris* Mixed Woodland, 29 were absent from both Map Units 4 and 5.

Map Unit 4: White-top Grassland

Map Unit 4 corresponded to Porteners (1993) White-top Grassland with the perennial grass *Notodanthonia caespitosa* abundant at all sites (Fig. 5). Associated grasses of high abundance included the perennials *Stipa* spp., *Enteropogon acicularis, Elymus scaber* var.

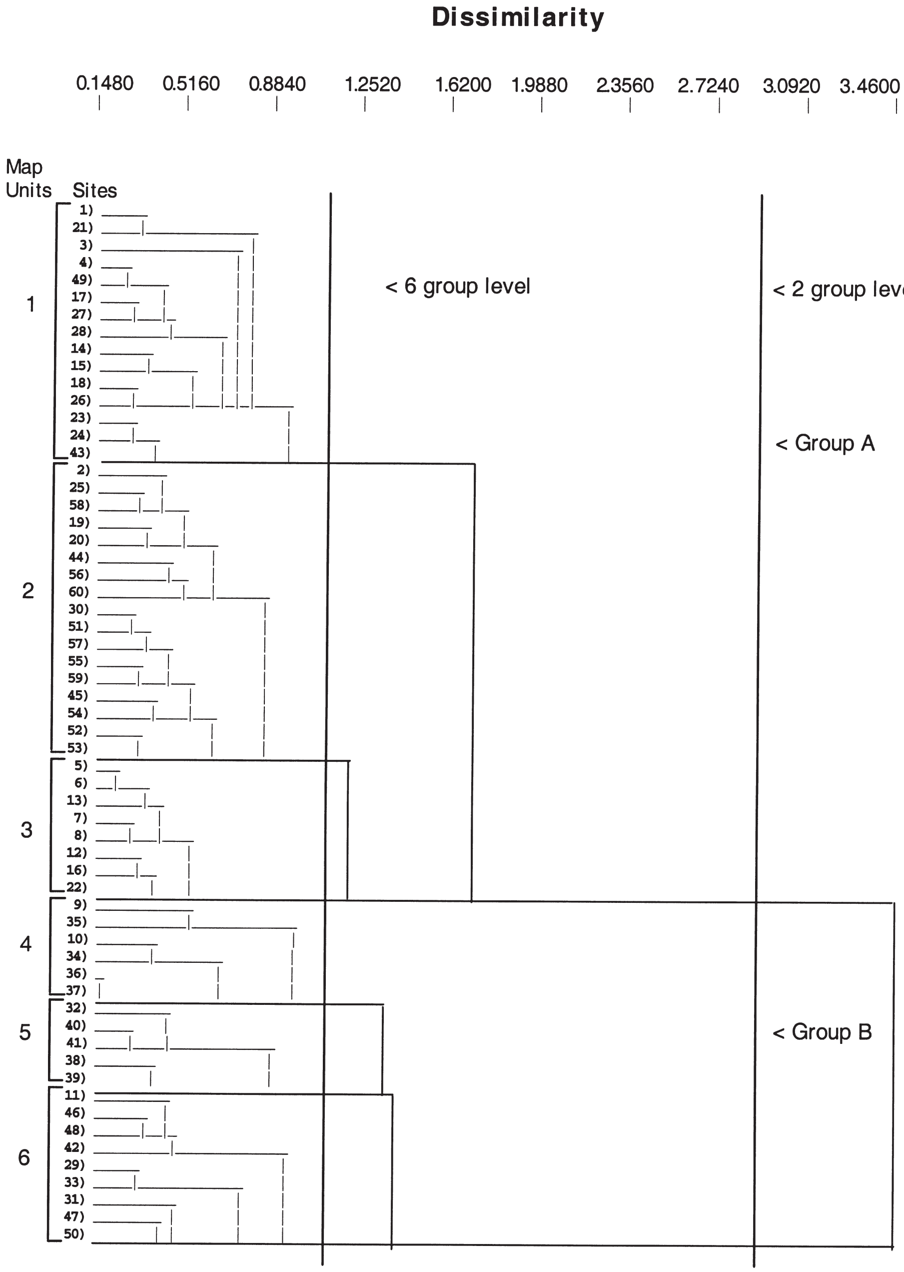

Fig. 2. Dendrogram showing the classification of the 60 sites into the six Map Units based on species abundance and cover.

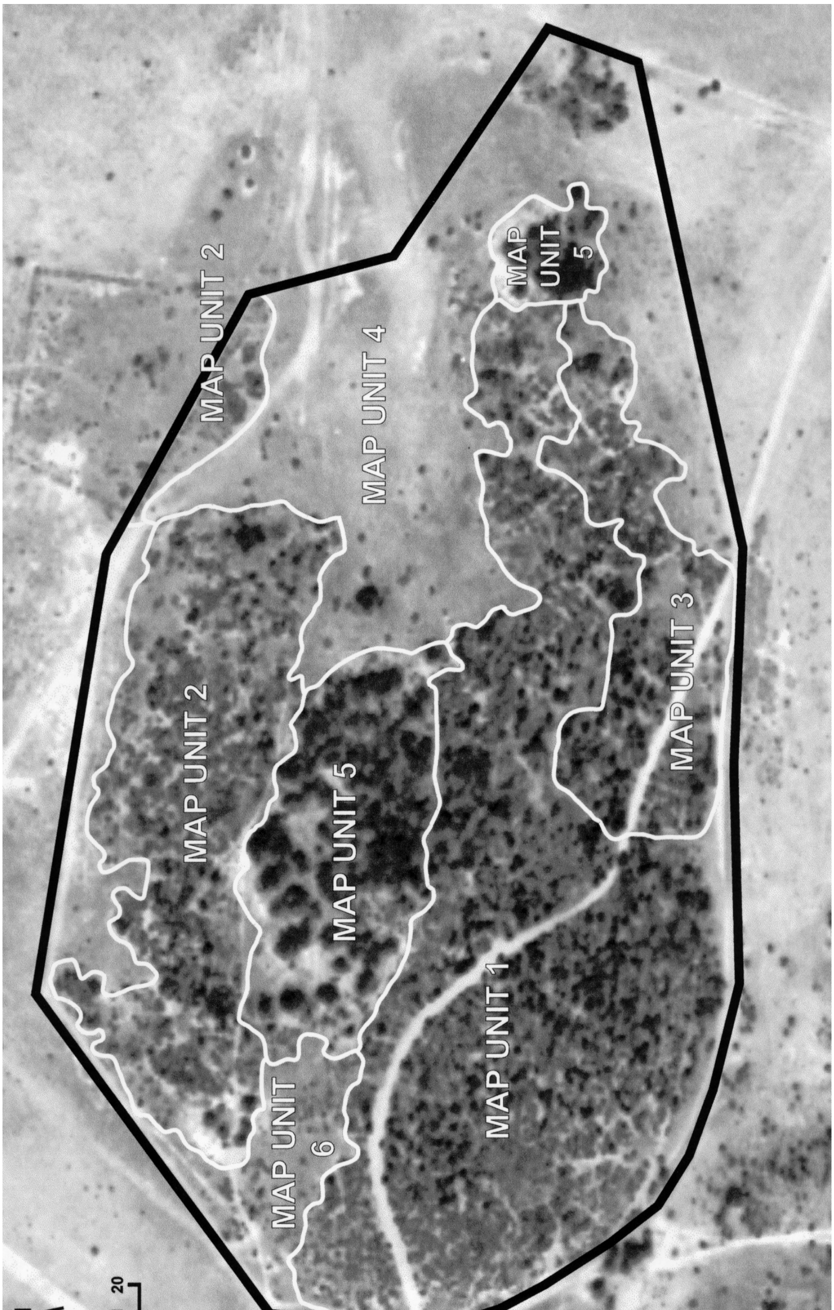

Fig. 3. Distribution of the six Map Units and three vegetation communities defined by cluster analysis.

scaber and the exotic annual *Hordeum leporinum*. Associated forbs included the annual weed *Echium plantagineum*, and the perennial *Maireana pentagona.* Perennial shrubs *Rhagodia spinescens, Atriplex semibaccata* and *Enchylaena tomentosa* were also associated with *Notodanthonia caespitosa* in Map Unit 4.

Apart from the absence of trees and taller shrubs, Map Unit 4 is distinguished from the other units by the absence of *Bromus arenarius, Stipa elegantissima, Sisymbrium orientale* and *Lycium ferocissimum*. This unit also has the lowest mean number of species per site, the lowest total number of species, and the lowest number of exotics.

Statistically, the lower species diversity of the White-top Grassland (Map Unit 4) was significantly different to the higher diversity of the *Callitris* Mixed Woodland (Map Units 1, 2, 3 and 6; $F_{5,54} = 5.01$, $P < 0.05$). Species richness was also greater for Map Units 1, 2 and 3 of the *Callitris* Mixed Woodland which was significantly different to the lower species richness of the White-top Grassland (Map Unit 4; $F_{5,54} = 7.68$, $P < 0.05$). Although these results give an indication of species richness and diversity across the site, the data are probably influenced by season.

Map Unit 5: Black Box Woodland

Map Unit 5 was characterised by a high cover-abundance of *Eucalyptus largiflorens* (Fig. 6). This unit accounted for the smallest coverage of the exclosure (Fig. 3) and included 29 native and 7 exotic species. The number of species per site ranged from 12 to 17. *Eucalyptus largiflorens* was associated with, in order of abundance, the perennial shrubs *Rhagodia spinescens, Enchylaena tomentosa, Exocarpos aphyllus, Einadia nutans* and

Fig. 4. *Callitris* Mixed Woodland with a *Rhagodia spinescens* and *Atriplex nummularia* understorey.

the noxious weed, *Lycium ferocissimum*. Associated ground flora included the perennial grasses *Notodanthonia caespitosa*, *Enteropogon acicularis*, *Stipa elegantissima* and the biennial exotic forb *Sisymbrium orientale*.

Apart from the absence of *Mesembryanthemum crystallinum* and *Dodonaea viscosa* subsp. *angustissima*, Map Unit 5 is distinguished from the other units by the notable absence of *Stipa* spp., *Bromus arenarius* and *Echium plantagineum*. Species endemic to Map Unit 5 were *Eriochlamys behrii*, *Spergularia rubra* and *Atriplex pseudocampanulata*.

Species-environment relations

Axes I and II of the CCA biplot (Fig. 7) accounted for 35.2% and 20.3% respectively of the variation in species distribution. The length of the vectors shown in Fig. 7 indicates the relative importance of the environmental variables in determining the two axes. Significant and important determinants of axis I were soil texture (proportion of sand in the soil), organic carbon, surface firmness, degree of cracking, crust coherence, cryptogam cover and electrical conductivity. Axis I consequently corresponded to a gradient of increasing clay content from left to right in Fig. 7. Plant cover, microtopography and litter cover were important determinants of axis II, with soil cover increasing from the top of Fig. 7 to the bottom. The angle between a vector and an axis provides an inverse measure of the relationship between the various environmental variables. As such, litter cover and plant cover are shown to be inversely related.

Fig. 5. White-top Grassland characterised by *Notodanthonia caespitosa* associated with *Stipa* spp., *Enteropogon acicularis* and some *Rhagodia spinescens* shrubs

The majority of the 30 species, including those omitted from the plot for cartographic reasons, were clustered close to the centroid (origin). These were generally species common at most sites (e.g. *Rhagodia spinescens* (Rgsp) and *Enchylaena tomentosa* (Ehlt)) or species which showed little affinity with any of the measured environmental variables. Some species however showed strong preferences for certain environmental variables. In the upper left-hand sector of the CCA biplot (Fig. 7) are those species which are correlated with sandy (coarse-textured) soils with moderate levels of litter cover. These include *Callitris glaucophylla* (Klta), *Alectryon oleifolius* subsp. *canescens* (Aleo) and *Dodonaea viscosa* subsp. *angustissima* (Ddat). *Hakea tephrosperma* (Hkts) showed an affinity with increasing levels of litter cover and reduced plant cover, whilst *Mesembryanthemum crystallinum* (Msbc) was associated with soils of reduced clay content, low electrical conductivity and sparse cryptogam cover. The above are the key species that define the *Callitris* Mixed Woodland. Their distribution on the biplot indicates their relative contributions in defining the community.

Two species, *Hordeum leporinum* (Hodl) and *Maireana pentagona* (Mapg; lower right sector) were associated with sites of high clay content and abundant plant cover. *Notodanthonia caespitosa* (Dacp), *Enteropogon acicularis* (Enta) and *Echium plantagineum* (Ekmp) are also associated with predominantly clay textured soil, although to a lesser extent. Those that were also correlated with rough soils (high microtopography), high foliage cover of plants, low levels of organic carbon and a lower clay content (lower left-hand sector), included *Citrullus lanatus* (Ctrl) and *Atriplex nummularia* (Atnm).

Fig. 6. Black Box Woodland dominated by *Eucalyptus largiflorens* with an understorey of *Rhagodia spinescens*.

Eucalyptus largiflorens (Uklf) occurred in the right hand sector of Fig. 7 and is strongly associated with sites of abundant litter cover, loamy soils (high organic carbon levels) and with a sparse foliage cover. *Einadia nutans* (Einn) and *Acacia salicina* (Aksa) also showed a similar association.

Soil surface condition

The soil surface in the exclosure was generally intact, moderately stable and uneroded, with low to moderate microtopography on low (< 3%) slopes (Table 4). Approximately half of the surfaces were non-coherent, and the majority of soils had sandy or sandy loam surface textures. Litter cover in the quadrats was moderate, locally derived i.e. not transported from elsewhere, and poorly broken down and incorporated into the soil surface. Predictably, given soil surface textures, cryptogam cover was sparse. While foliage cover of vascular plants was highly variable across the exclosure, basal cover was generally low. The dominant erosion form at the site was sheet erosion of sandy material.

Table 4. Distribution of the soil surface variables across the 60 sites.

Classes are shown in the first row, and the percentage of each class is given in the second row.

A. Slope (%)	**0**	**1–3**	**3–5**	**5–10**	**> 10**	
	11	86	2	1	0	
B. Microtopography (mm)	**≤ 3**	**3–8**	**8–25**	**25–100**	**>100**	
	7	40	42	11	0	
C. Crust coherence	**Sand**	**Easily broken**	**Moderately hard**	**Very hard**	**Non-brittle or self-mulching**	
	11	43	14	22	10	
D. Cracking	**Extensively broken**	**Moderately broken**	**Slightly broken**	**Intact**		
	0	2	8	90		
E. Firmness	**Very loose**	**Loose**	**Moderately firm**	**Firm**		
	0	0	67	33		
F. Cryptogams (%)	**<1**	**1–10**	**10–50**	**> 50**		
	65	19	13	3		
G. Sheet erosion	**Extensive**	**Moderate**	**Slight**	**Insignificant**		
	0	3	23	74		
H. Soil cover (%)	**< 1**	**1–15**	**15–30**	**30–50**	**> 50**	
	11	31	30	21	7	
I. Basal cover (mm)	**< 7**	**7–70**	**70–140**	**> 140**		
	62	29	8	1		
J. Litter cover (%)	**< 10**	**10–25**	**25–50**	**50–75**	**75–100**	**100 (several cm thick)**
	14	26	38	15	5	2
K. Litter source	**Local**	**Transported**				
	100	0				
L. Litter incorporation	**Low**	**Moderate**	**Extensive**			
	71	12	17			
M. Texture	**Light Clay**	**Clay loam**	**Loam**	**Sandy loam**	**Sand**	
	2	8	18	43	29	

The CCA biplot (Fig. 8) indicated that a change in vegetation community from the *Callitris* Mixed Woodland (left hand side), to the White-top Grassland (bottom right) and Black Box Woodland (top right) can be described in terms of two environmental gradients: a gradient in surface soil texture and a gradient in organic carbon and litter cover. Map Units 1, 2, 3 and 6 were generally associated with coarser textured (sandier) soils with a wide range of soil and litter cover levels. Map Unit 5 was associated with increasing organic carbon (loamier soils) and increasing litter cover, whilst Map Unit 4 was associated with both increasing clay content and decreasing litter cover (Table 5, Fig. 8).

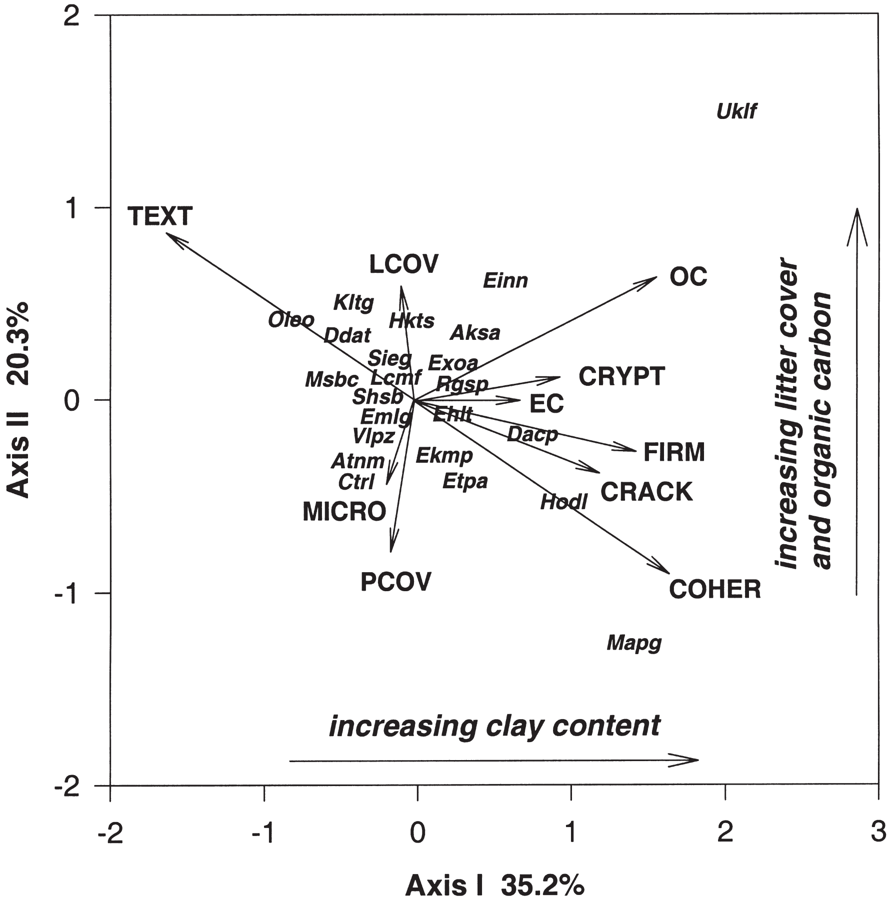

Fig. 7. Species-environment biplot for axes I and II after the Canonical Correspondence Analysis. Species names and codes are given in Appendix 2.

Soil chemical characteristics

Overall, the soils within the exclosure were non-saline ($EC_{1:5}$ < 0.40 dS/m) and slightly acidic, with low percentages of organic carbon (Table 6). Electrical conductivity (EC) on Map Units 1, 2 and 3 were significantly lower than for Units 4 and 6 ($P < 0.05$), whilst Map Unit 5 was not significantly different to the other units.

Discussion

Floristics

Eighty-two percent (49) of the 60 sites in the 'Zara' exclosure corresponded to Porteners' (1993) *Callitris* Mixed Woodland, and the remainder corresponded with the Black Box Woodland and the White-top Grassland units. The *Callitris* Mixed Woodland had significantly greater species richness and diversity (Shannon-Weiner index) compared with the White-top Grassland and Black Box Woodland.

Consistent with other studies of the Riverine Plain and surrounding areas (Semple 1986, 1987, Porteners 1993, Sivertson & Metcalfe 1995), the Poaceae, Asteraceae, Chenopodiaceae and Fabaceae families were most represented (Table 2). Of the 977 species recorded for the Riverine Plain as a whole (Porteners 1993), 144 have been recorded at 'Zara' (Appendix 1)

The small number of species in common with other studies can be explained by two main factors. Firstly, the present study was conducted at only one point in time, during a very dry summer. Consequently, only summer-growing and/or drought tolerant plants were recorded. Further collections made during winter/spring or after rain are likely to increase the number of species recorded, particularly annuals and ephemerals. Secondly, as the exclosure is less than 60 hectares in area, it represents only a small proportion of the landscapes found over the Riverine Plain.

Relationships between soils and vegetation

In our study, the distribution of communities was closely associated with a range of environmental variables including soil texture, cracking, coherence, stability, organic carbon, plant cover and litter cover (Fig. 7). In general, the *Callitris* Mixed Woodland was associated with sandy, coarse-textured soils, the Black Box Woodland with loamier soils, and the White-top Grassland with finer clay-textured soils (Fig. 8). Soil texture, by influencing soil moisture availability, is known to be a critical determinant of species distribution (Noy-Meir 1974, Eldridge 1988).

Within the White-top Grassland, moisture availability is strongly influenced by the high clay content of soils (Williams 1956). Despite surface ponding, the high shrink swell capacity of clays limits the depth of water infiltration to approximately 30 cm (Eldridge 1988). Available water for plants is then limited by the high water holding capacity of the soils. Consequently, the vegetation within Map Unit 4 is dominated by short-lived ephemerals, perennial grasses and perennial shrubs such as *Maireana pentagona* which have shallow, lateral roots confined to the top 30 cm of the soil. The limited water availability for plants, the difficulty for roots to penetrate the hardsetting soils (Williams 1956), the extensive cracking of the soil and the generally high salinity levels means that trees are generally restricted to either sandy rises, prior stream levees, or active watercourses (Semple 1990).

The combination of loamy soils with heavy clay subsoils, abundant litter and the probability of low water availability (due to the dense cover of *Eucalyptus largiflorens*), is probably responsible for the sparse plant cover in the Black Box Woodland sites (Table 5). Despite this sparse plant cover, compared with that in the *Callitris* Mixed Woodland (Fig. 8), the dense litter cover on these soils, a contribution from the upper canopy, is sufficient to protect the surface against raindrop impact, preventing soil slaking and surface sealing, and reducing overland flow of water and sediment movement. Litter also improves the condition of the soil by providing a source of organic matter, encouraging soil biota, leading to greater levels of porosity and therefore infiltration (Eldridge & Koen 1993).

In contrast to the clay soils, the earthy sands of the *Callitris* Mixed Woodland are highly permeable (Eldridge 1989), and characterised by low levels of organic carbon, and consequently low levels of electrical conductivity (Table 6). The deeper, sandier soils of the dune crest supported *Callitris glaucophylla* and shrubs such as *Dodonaea viscosa* which occur on sandplains and dune fields in the north-west of NSW at relatively high densities (Hodgkinson 1992). In sandy soils, a combination of relatively deeper penetration of water, and the availability of much of this moisture for germination, means that, compared with clay soils, sands respond much more rapidly to small falls of rain (Johns et al. 1984). As rainfall in the area is generally winter-dominant, much of the ephemeral growth at the time of the study is likely to be restricted to the sandy soils. This probably accounts for the relatively larger number of ephemeral species found on the sandy soils and perhaps the large numbers of weedy species compared with the clay soils.

Management of the 'Zara' exclosure

The Riverine Plain has been grazed by domestic livestock for more than 150 years, and is a severely modified landscape (Benson 1988). Fragmentation has left the exclosure isolated from other sandhills, and with a large perimeter across which exotic plants can penetrate. Monitoring of vegetation cover, invasion of exotics (both plants and animals) as well as soil health is an essential component of the management of 'Zara'. Strategies such as minimising disturbances in and around the exclosure to prevent the spread of exotics, and fencing of a buffer strip around the exclosure are likely to enhance the conservation value of the exclosure.

The present survey indicated that the vegetation communities at 'Zara' have already been substantially modified by the invasion of exotic weeds such as *Lycium ferocissimum*, and currently support relatively high abundances of common Mediterranean weeds such as *Citrullus lanatus* var. *lanatus*, *Mesembryanthemum crystallinum* and *Echium plantagineum*. Dispersal of these exotics is enhanced by disturbance by livestock and rabbits. Exotic plants influence the vegetation communities directly by their presence, and indirectly through competition with

Table 5. Soil surface variables and their distribution across the six Map Units.

Variables which changed little across the sites have been excluded. The modal (most common) value is in the first row, and the range of values, recorded for each Map Unit, in the second; 100+ for litter cover indicates 100% cover but several cm thick; mod. = moderately.

Map Unit	Texture	Crust coherence	Firmness	Microtopography (mm)	Cryptogam cover (%)	Soil cover (%)	Basal cover (%)	Litter cover (%)
1	**sand**	**easily broken**	**mod. firm**	**3 to 8**	**< 1**	**1 to 15**	**< 7**	**50 to 75**
	(sand to loam)	(sand to very hard)	(mod. firm to firm)	(< 3 to 100)	(< 1 to 50)	(< 1 to > 50)	(< 7 to 140)	(< 10 to 100)
2	**sandy loam**	**easily broken**	**mod. firm**	**8 to 25**	**< 1**	**1 to 15**	**< 7**	**25 to 50**
	(sand to sandy loam)	(sand to very hard)	(mod. firm to firm)	(< 3 to 100)	(< 1 to > 50)	(< 1 to > 50)	(< 7 to > 140)	(< 10 to 75)
3	**sandy loam**	**easily broken**	**mod. firm**	**3 to 8**	**< 1**	**15 to 30**	**7 to 70**	**10 to 25**
	(sand to sandy loam)	(sand to self mulching)	(mod. firm to firm)	(< 3 to 25)	(< 1 to 10)	(1 to > 50)	(< 7 to 140)	(10 to 75)
6	**loam**	**easily broken**	**firm**	**3 to 8**	**< 1**	**15 to 30**	**7 to 70**	**25 to 50**
	(sandy loam to clay loam)	(easily broken to self mulching)	(mod. firm to firm)	(< 3 to 100)	(< 1 to > 50)	(< 1 to > 50)	(< 7 to 140)	(< 10 to 100)
4	**clay loam**	**self-mulching**	**firm**	**8 to 25**	**1 to 10**	**30 to 50**	**< 7**	**25 to 50**
	(loam to clay)	(very hard to self mulching)	(firm)	(3 to 100)	(< 1 to 50)	(1 to 50)	(< 7 to 70)	(10 to 50)
5	**loam**	**easily broken**	**firm**	**8 to 25**	**10 to 50**	**1 to 15**	**< 7**	**25 to 50**
	(sandy loam to loam)	(easily broken to self mulching)	(mod. firm to firm)	(< 3 to 25)	(< 1 to > 50)	(< 1 to 50)	(< 7 to 70)	(< 10 to 100+)

Table 6. Differences in electrical conductivity (EC), organic carbon (OC) and pH between the six Map Units

	Map Units (number of sites)						
Variables	**1 (30)**	**2 (34)**	**3 (16)**	**6 (18)**	**4 (12)**	**5 (10)**	**Total (120)**
EC (dS m^{-1})	0.08 (0.02)^{ab}	0.06 (0.01)^{ab}	0.06 (0.01)^{ab}	0.15 (0.04)^{bc}	0.12 (0.01)^{bc}	0.09 (0.02)^{abc}	0.09 (0.01)
OC (%)	1.04 (0.11)^{a}	1.01 (0.07)^{a}	0.76 (0.04)^{a}	1.31 (0.17)^{a}	1.98 (0.11)^{b}	3.16 (0.70)^{c}	1.31 (0.09)
pH	6.45 (0.09)^{a}	6.36 (0.04)^{a}	6.43 (0.09)^{a}	6.27 (0.10)^{a}	6.21 (0.09)^{a}	6.42 (0.04)^{a}	6.37 (0.03)

Standard error of the mean is in parentheses. Values within a row with a similar superscript are not significantly different at $P = 0.05$. Electrical conductivity data were log_{10} transformed prior to ANOVA.

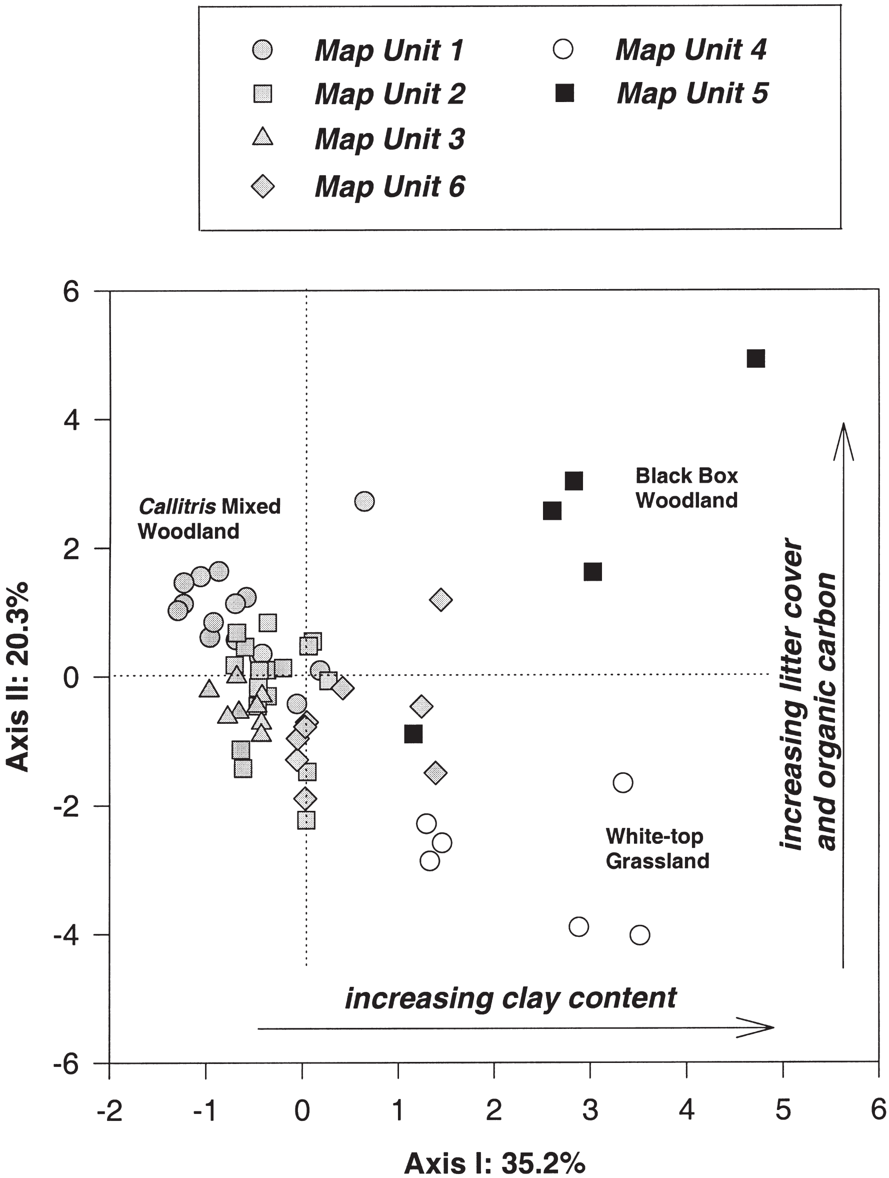

Fig. 8. Projection of the sample sites onto axes I and II of the species-environment biplot.

native species (McIntyre 1990). *Lycium ferocissimum* for example, poses a major threat to the exclosure through its capacity to rapidly invade, colonise and reproduce. *Lycium ferocissimum* provides a harbour for rabbits, and, as the seeds are readily eaten and dispersed by birds, it is present in most areas of the exclosure and dispersal is not restricted by fencing (Appendix 1). Physical removal, combined with the judicious use of herbicides and fire, appears to be an ecologically desirable control option.

Of greater concern in the long-term is the spread of exotic forbs and grasses which are more difficult to control. It is probable that forbs such as *Marrubium vulgare*, *Heliotropum* spp. and *Tribulus terrestris*, as well as the annual grasses *Avena* spp., *Lolium* spp. and *Bromus* spp. will prove a greater challenge for managers. Large areas of the Riverine Plain have already been invaded by exotic forbs and grasses, and their control in the exclosure is likely to be ongoing.

Since the construction of the exclosure in 1997, the Southern Riverina Naturalists have undertaken a rabbit control program using 1080 poison baits in conjunction with the ripping of warrens. As the regeneration of *Alectryon oleifolius* subsp. *canescens* is limited, and the regeneration of *Callitris glaucophylla* is rarely seen in the presence of rabbits or livestock, ongoing rabbit control is essential. Monitoring of rabbit warrens and regular examination of the fencing is recommended.

Control of wildfire has been identified as a contentious issue in the management of the 'Zara' exclosure. It is apparent from the present survey and anecdotal evidence, that the cover and density of shrubs such as *Rhagodia spinescens*, *Atriplex nummularia* and *Enchylaena tomentosa* have increased markedly over the past few decades and will continue to increase given the removal of stock. This may be associated with reductions in ground cover of perennial grasses and a reduced risk of wildfire. In the absence of controlled burning, large areas of the exclosure, particularly in the *Callitris* Mixed Woodland are likely to be converted from a grassland to a chenopod-dominated shrubland. One of the benefits of shrub increase is that the exclosure now provides a regular local seed source of native shrubs. These are collected and used extensively by Greening Australia in revegetation programs.

Conservation significance of the 'Zara' exclosure

The 'Zara' exclosure is an important example of the *Callitris* Mixed Woodlands which were once more common on aeolian landscapes on the Riverine Plain. Today this vegetation community is poorly conserved, threatened or vulnerable, due to inappropriate land use practices (Benson 1988, 1989, 1991, Eardley 1999). The *Callitris* Mixed Woodland at 'Zara' has a healthy understorey, and unlike many sandhills in the area, the community has retained part of its original shrub component (including *Atriplex nummularia* in Map Units 2 and 3).

Although not found in the present study, one ROTAP species *Ptilotus extenuatus* (Appendix 1, Briggs & Leigh 1996) was collected from the exclosure. *Ptilotus extenuatus* is now the only plant species presumed to be extinct on the Hay Plain, and despite numerous attempt to locate other specimens (Briggs & Leigh 1996) the species has not been recorded. *Calotis moorei*, a Schedule 1 species under the

Threatened Species Conservation Act was also collected at 'Zara' in the early 1900s (Short 1991). Additional species may be collected in the future following the exclusion of domestic and feral grazing animals.

The future of the 'Zara' exclosure

The present study provides a basis for future management strategies for sandhill remnants and monitoring programs. Being close to a large population centre (Deniliquin), the exclosure could serve as a focal point for community groups interested in learning more about semi-arid vegetation communities. Permanent sample points, already in place, can provide an invaluable baseline for future soil and ecological studies, and regular updating of the species lists by members of the Riverina Field Naturalists. The reserve can also provide ungrazed, benchmark sites to be incorporated into the Department of Land and Water Conservation's Rangeland Assessment Program. Future studies in the exclosure could include an examination of small mammal populations in relation to vegetation communities, temporal changes in plant communities after exclosure and recruitment of *Callitris glaucophylla* and *Alectryon oleifolius* after removal of sheep, rabbits and noxious shrubs.

The exclosure has the potential to complement other remnants and more formal conservation practices within the Riverina Bioregion (Eardley 1999). However, for it to be successful in the long term, it is important that it be incorporated into any future Land and Water Management Plans and Regional Conservation Plans for the area.

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Appendix 1: Species recorded for the 'Zara' enclosure, and the percentage of sites containing a particular speices within each of the six Map Units.

A = Mulham (unpub.); B = present study; + = species found; - = species not found; * = exotics; ! = ROTAP species; z = recorded by Short (1991).

Botanical Name	A	B	Map Unit (No. of sites)						
			1 (15)	2 (17)	3 (8)	6 (9)	4 (6)	5 (5)	Total (60)
PTERIDOPHYTES									
Adiantaceae									
Cheilanthes austrotenuifolia	+	+	.	6	.	.	.	.	2
Marsileaceae									
Marsilea drummondii	-	+	.	.	.	11	.	20	3
GYMNOPERMS									
Cupressaceae									
Callitris glaucophylla	+	+	80	29	25	.	.	.	32
ANGIOSPERMS-DICOTYLEDONS									
Aizoaceae									
**Mesembryanthemum crystallinum*	+	+	93	100	88	.	.	.	63
Amaranthaceae									
Alternanthera denticulata	+	-							
!Ptilotus extenuatus	+	-							
Apiaceae									
Daucus glochidiatus	+	-							
Asteraceae									
Actinobole uliginosum	+	+	13	12	.	.	.	.	7
**Arctotheca calendula*	+	-							
**Aster subulatus*	+	-							
Brachycome lineariloba	-	+	.	6	.	.	.	.	2
Calotis sp.	-	+	7	.	.	.	.	.	2
Calotis erinacea	+	-							
z*Calotis moorei*	-	-							
Calotis scabiosifolia	+	-							
Calotis scapigera	+	-							
**Carthamus lanatus*	+	-							
**Centaurea melitensis*	+	-							
Centipeda cunninghamii	+	-							
Chrysocephalum apiculatum	+	-							
**Chrysocephalum semipapposum*	+	-							
**Cirsium vulgare*	+	-							
**Cotula bipinnata*	+	-							
Eriochlamys behrii	-	+	.	.	.	.	.	20	2
**Hypochaeris glabra*	+	-							
Pseudognaphalium luteoalbum	+	-							
Senecio quadridentatus	+	+	13	.	.	.	.	20	5
**Sonchus oleraceus*	+	-							
Stuartina muelleri	+	-							
Vittadinia cuneata group	+	+	7	6	.	11	.	.	5
**Xanthium spinosum*	+	-							
Boraginaceae									
**Amsinckia intermedia*	+	+	13	.	13	.	.	.	5
**Echium plantagineum*	+	+	27	71	100	56	67	.	55
**Heliotropium europaeum*	+	+	7	12	.	11	.	.	7

Botanical Name	**A**	**B**	**Map Unit (No. of sites)**						
			1 (15)	**2 (17)**	**3 (8)**	**6 (9)**	**4 (6)**	**5 (5)**	**Total (60)**
Brassicaceae									
**Capsella bursa-pastoris*	+	-							
**Lepidium africanum*	-	+	60	29	63	67	.	60	47
**Sisymbrium erysimoides*	+	+	67	35	.	22	.	20	32
**Sisymbrium orientale*	+	-							
Campanulaceae									
Wahlenbergia sp.	+	+	7	12	.	.	.	.	5
Caryophyllaceae									
**Cerastium glomeratum*	+	-							
**Spergularia rubra*	+	+	.	.	.	.	.	20	2
Chenopodiaceae									
Atriplex leptocarpa	+	+	.	6	.	22	17	.	7
Atriplex nummularia	+	+	13	41	63	11	.	20	27
Atriplex pseudocampanulata	-	+	.	.	.	.	.	20	2
Atriplex semibaccata	+	+	.	.	.	22	50	20	10
Atriplex vesicaria	+	-							
Chenopodium nitrariaceum	+	+	.	6	13	22	.	20	8
Chenopodium pumilio	-	+	7	12	13	22	.	.	10
Einadia nutans	+	+	33	24	13	.	17	60	23
Enchylaena tomentosa	+	+	67	82	75	67	83	80	75
Maireana aphylla	+	+	.	.	.	.	33	.	3
Maireana decalvans	+	+	.	.	.	11	33	20	7
Maireana pentagona	+	+	7	6	.	.	100	40	17
Rhagodia spinescens	+	+	93	100	100	100	83	100	97
Salsola kali	+	+	7	41	.	33	.	20	20
Sclerolaena diacantha	-	+	.	6	.	.	.	.	2
Sclerolaena muricata	-	+	.	6	.	22	33	20	10
Convolvulaceae									
Convolvulus erubescens	+	+	7	6	.	11	.	.	5
Crassulaceae									
Crassula colorata var. *acuminata*	+	+	27	.	.	11	.	.	8
Cucurbitaceae									
**Citrullus lanatus* var. *lanatus*	+	+	20	18	13	11	.	.	13
Euphorbiaceae									
Chamaesyce drummondii	+	-							
Fabaceae-Caesalpinoideae									
Senna artemisioides	-	+	13	.	.	11	.	.	5
Senna artemisioides subsp. *coriacea*	+	-							
Senna artemisioides subsp. *filifolia*	+	-							
Fabaceae-Faboideae									
**Medicago polymorpha*	+	-							
**Medicago truncatula*	+	-							
Swainsona phacoides	+	-							
**Trifolium angustifolium*	+	-							
**Trifolium arvense*	+	+	20	47	100	44	.	20	40
Fabaceae-Mimosoideae									
Acacia oswaldii	+	+	.	.	25	11	.	20	7
Acacia pendula	+	+	.	.	.	.	17		2
Acacia salicina	+	+	20	.	38	22	.	20	15

Botanical Name	A	B	Map Unit (No. of sites) 1 (15)	2 (17)	3 (8)	6 (9)	4 (6)	5 (5)	Total (60)
Geraniaceae									
**Erodium cicutarium*	+	-							
Erodium crinitum	+	-							
Goodeniaceae									
Goodenia fascicularis	+	-							
Goodenia pinnatifida	+	-							
Goodenia pusilliflora	+	-							
Lamiaceae									
**Marrubium vulgare*	+	+	7	.	.	.	.	.	2
Teucrium racemosum	+	+	.	.	.	11	.	20	3
Loranthaceae									
Amyema quandang	+	-							
Lysiana exocarpi subsp. *exocarpi*	+	-							
Malvaceae									
**Malva parviflora*	+	-							
Sida corrugata	+	+	7	.	.	33	33	20	12
Myoporaceae									
Eremophila longifolia	+	+	27	47	88	44	17	20	42
Myoporum montanum	+	-							
Myoporum platycarpum	+	+	7	6	.	.	.	.	3
Myrtaceae									
Eucalyptus largiflorens	+	+	7	6	.	11	.	100	13
Eucalyptus largiflorens x populnea	+	-							
Nyctaginaceae									
Boerhavia coccinea	+	+	7	6	38	.	17	.	10
Oleaceae									
Jasminum lineare	+	+	53	12	63	11	.	20	28
Oxalidaceae									
Oxalis perennans	+	+	.	6	.	11	17	20	7
Pittosporaceae									
Bursaria spinosa subsp. *microphylla*	+	+	20	6	25	11	.	.	12
Pittosporum phylliraeoides	+	-							
Plantaginaceae									
Plantago sp.	+	-							
Polygonaceae									
Muehlenbeckia florulenta	+	-							
**Polygonum aviculare*	+	-							
Portulacaceae									
Calandrinia eremaea	+	-							
Portulaca oleracea	+	-							
Proteaceae									
Hakea leucoptera	+	-							
Hakea tephrosperma	+	+	60	35	13	33	.	.	32
Ranunculaceae									
Clematis microphylla var. *microphylla*	-	+	20	.	50	.	.	.	12
**Myosurus minimus*	+	-							
Ranunculus pentandrus	+	-							
Ranunculus pumilio	+	-							
Rubiaceae									
Asperula conferta	+	-							

Botanical Name	A	B	Map Unit (No. of sites) 1 (15)	2 (17)	3 (8)	6 (9)	4 (6)	5 (5)	Total (60)
Santalaceae									
Exocarpos aphyllus	+	+	73	59	50	33	.	80	53
Santalum acuminatum	+	+	20	.	.	.	.	.	5
Santalum lanceolatum	+	+	20	6	38	.	.	.	12
Sapindaceae									
Alectryon oleifolius subsp. *canescens*	+	+	53	29	13	.	.	.	23
Dodonaea viscosa subsp. *angustissima*	+	+	80	59	75	33	.	.	52
Solanaceae									
**Lycium ferocissimum*	+	+	60	59	38	44	.	80	50
Solanum esuriale	-	+	.	.	.	22	17	.	5
**Solanum nigrum*	-	+	7	.	.	.	.	.	2
Thymelaeceae									
Pimelea microcephala subsp. *microcephala*	+	+	7	6	.	11	.	.	5
Urticaceae									
**Urtica urens*	+	-							
Zygophyllaceae									
Nitraria billardieri	+	-							
**Tribulus terrestris*	-	+	7	6	13	.	.	.	5
ANGIOSPERMS-MONOCOTYLEDONS									
Cyperaceae									
Carex inversa	+	-							
**Cyperus eragrostis*	+	+	.	.	.	11	17	40	7
Eleocharis acuta	+	-							
Phormiaceae									
Dianella longifolia	+	+	.	6	.	.	.	.	2
Poaceae									
Agrostis avenacea var. *avenacea*	+	+	7	.	.	.	.	.	2
**Alopecurus geniculatus*	+	-							
**Avena fatua*	+	+	7	6	25	.	33	.	10
Bromus arenarius	+	+	87	88	100	78	17	20	75
**Bromus diandrus*	+	-							
**Bromus rubens*	+	-							
Chloris truncata	+	-							
Cynodon dactylon	+	-							
Dactyloctenium radulans	+	-							
Notodanthonia caespitosa	+	+	13	65	38	89	100	100	58
Elymus scaber var. *scaber*	-	+	.	.	.	11	50	40	10
Enneapogon nigricans	+	-							
Enteropogon acicularis	+	+	7	94	38	89	83	60	60
Eragrostis australasica	+	-							
**Eragrostis cilianensis*	+	-							
**Hordeum leporinum*	+	+	33	12	.	22	33	.	18
**Hordeum marinum*	+	-							
**Lolium rigidum*	+	+	.	.	.	.	50	.	5
Paspalidium constrictum	+	-							
**Schismus barbatus*	+	+	33	18	38	11	.	20	22
Sporobolus caroli	+	+	.	6	.	.	.	.	2
Stipa elegantissima	+	+	60	65	88	33	.	60	55
Stipa sp.	+	+	87	100	100	78	67	20	83
**Vulpia myuros*	+	+	73	12	88	89	17	.	48
Total no. of species	**129**	**77**	**54**	**51**	**35**	**46**	**26**	**36**	**77**

Appendix 2: Species names and codes (in alphabetical order) used in the cluster analysis and the Canonical Correspondence Analysis. * indicates an exotic species.

Code	Species
Aksa	*Acacia salicina*
Atnm	*Atriplex nummularia*
Atsm	*Atriplex semibaccata*
Avnf	**Avena fatua*
Bhvc	*Boerhavia coccinea*
Bmar	*Bromus arenarius*
Brss	*Bursaria spinosa* subsp. *microphylla*
Cazz	*Calotis* sp.
Chla	*Cheilanthes austrotenuifolia*
Ctrl	**Citrullus lanatus* var. *lanatus*
Dacp	*Notodanthonia caespitosa*
Ddat	*Dodonaea viscosa* subsp. *angustissima*
Ehlt	*Enchylaena tomentosa*
Ekmp	**Echium plantagineum*
Elms	*Elymus scaber* var. *scaber*
Emlg	*Eremophila longifolia*
Etpa	*Enteropogon acicularis*
Exoa	*Exocarpos aphyllus*
Hkts	*Hakea tephrosperma*
Hodl	**Hordeum leporinum*
Jsml	*Jasminum lineare*
Kltg	*Callitris glaucophylla*
Kppm	*Chenopodium pumilio*
Lcmf	**Lycium ferocissimum*
Leaf	**Lepidium africanum*
Mapg	*Maireana pentagona*
Msbc	**Mesembryanthemum crystallinum*
Oleo	*Alectryon oleifolius*
Rgsp	*Rhagodia spinescens*
Sacg	*Sida corrugata*
Sbme	**Sisymbrium erysimoides*
Semz	*Sclerolaena muricata*
Shsb	**Schismus barbatus*
Sieg	*Stipa elegantissima*
Sizz	*Stipa* sp.
Slml	*Santalum lanceolatum*
Slsk	*Salsola kali*
Tmav	**Trifolium arvense*
Uklf	*Eucalyptus largiflorens*
Vlpm	**Vulpia myuros*