EFFECTS OF SHEEP STOCKING ON THE POPULATION STRUCTURE OF ARID SHRUBLANDS IN SOUTH AUSTRALIA

by

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PART I

Text

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SUMMARY

Changes in plant population structure which result from stocking have been given detailed examination on two well-managed sheep stations, one in the north-east and one in the north-west, of arid South Australia.

The work was initiated by an investigation of the physical resources of one of them, to explain the context in which the population studies were carried out. The population studies which followed were based on the premise that there is a decline in stock pressure with increasing distance from a water-point. Using incidence data (analysed by influence analysis) and density data, vegetation pattern close to 8 water-points was compared with vegetation in more distant parts of the paddocks. It was clear that intense stock pressure close to a dam or trough was bringing about a change in vegetation structure. This pattern, which was shown to be easily distinguished from pattern induced by topography or soil in a paddock, was taken to denote degradation.

A number of species which had fairly consistent occurrence near the water-points sampled could be regarded as indicators of this degradation. Some reasons for their behaviour in these situations were examined. It is suggested that changed soil structure stimulates invading populations and that if stocking persists in the future such changes may be progressive.

Commensal relationships between some species, which became apparent during the course of the field work, were also examined.

The implications of the outcome of this study for the future of the arid zone are discussed.

DECLARATION

This thesis contains no material which has been accepted for the award of any other degree or diploma in any University. To the best of my knowledge and belief this thesis contains no material previously published or written by another person, except where due reference is made in the text.

Susan Barker

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CHAPTER I

INTRODUCTION

This thesis relates to the grazing of arid zone vegetation by domestic flocks and is specifically concerned with the deleterious consequences to native pastures which are the basis of this manipulated ecosystem. The particular emphasis here is on the detailed changes in plant population structure. This aspect has been grossly neglected in the past.

The plant communities of the arid zone are particularly sensitive to the effects of grazing because renewal of plant material is only sporadic whereas stocking is generally continuous. Depending on the technique of grazing management, arid vegetation displays gradations of damage from (a) outright destruction of plants, through (b) serious degradation to (c) incipient and subtle shifts in population structure. It is now of paramount importance to maintain the less degraded arid pasture, so it is to category (c) that attention has been directed here. (It is, of course, equally important to promote the recovery of badly degraded country, but this is outside the scope of this thesis.)

The early 1970's have seen a sudden upsurge of concern over the "environmental crisis" throughout Western civilisations. In Australia, for example, there have been Senate Select Committees on Air and Water Pollution (Comm. Aust. Parl. Papers; Anon. 1969a, 1970); in South Australia a Committee on Environment was set up in April 1970 and a new Ministry of Conservation was created in November 1970. In association with the "crisis" there has been an explosion of emotional discussion in popular literature and news media, often with little reference to factual evidence.

Although the work about to be described is concerned with one aspect of environmental deterioration, it is in no way linked with this new issue of the "environmental crisis". The problem of vegetation destruction by man's activities in the arid zone is an old one, and in Australia the attention of graziers, politicians and scientists has been drawn to it for at least 100 years. The present study follows on from a long history of arid zone research which documents, in a general way, the effects of overgrazing; its relevance to the current agitation over the "environmental crisis" is purely coincidental.

Reference to past work on the three general stages of vegetation degradation indicates that most attention has been focussed on the easily recognised effects of overgrazing, where vegetation has been stripped from the landscape; such studies are purely descriptive and include those of S. Dixon (1892), Ratcliffe (1936) and Beadle (1948). Less severe degeneration has been the subject of fewer but more objective studies such as those of Crocker and Skewes (1941) and Moore (1953a and b). The insidious changes brought about by moderate stocking, which are the concern of this thesis, can only be assessed by quantitative means; there is practically no literature on this topic.

However, Osborn, Wood and Paltridge (1932) suggested a line of thought which could be seen in retrospect as a forerunner of the present more fully developed method of approach. They pointed out that as sheep in arid areas need to visit a water-point regularly, the effect of several hundred converging on a single watering place, albeit at different times of day, will bring about a condition of extreme stocking pressure close to the dam or trough. Along any traverse radiating from it, the stocking pressure gradient could be expected to decline with increasing distance from water to a virtually unstocked area beyond four miles from water. (Three miles is the approximate limit to which sheep were then believed to graze under normal conditions.) Zones of stocking pressure as reflected by vegetation pattern were identified. The extent of such zones (A, heavily trampled, overgrazed; B, moderately heavily grazed; C, lightly grazed; D, unstocked) varied from paddock to paddock according to the management regime. This promising line of investigation was not continued.

In the present work, recently developed statistical applications are used to establish precisely the type and extent of vegetation pattern induced by grazing in moderately stocked situations. Osborn, Wood and Paltridge's premise that concentric vegetation "zones" occur round water-points was adopted as a sound starting point for such an investigation. The gradual degradation of arid plant communities is, therefore, assessed by re-examining the vegetation "zoning" round sheep watering places.

Before firm research objectives are described, however, a literature review is presented, which places the study in a broad context. The review refers mainly to south-eastern arid Australia, comparing the present economic status and physical environment of the pastoral industry in this State with that in the geographically related area of western New South Wales. The object of this is two-fold; firstly, to provide an appreciation of the wider issues, which is fundamental for a study having as its possible outcome the means for suggesting modifications to the practice of sheep grazing in arid areas; and secondly, to draw attention to the fact that arid South Australia is fortunate in still possessing considerable areas of what appear to be relatively undamaged native shrub steppe and shrub woodland in its pastoral areas.

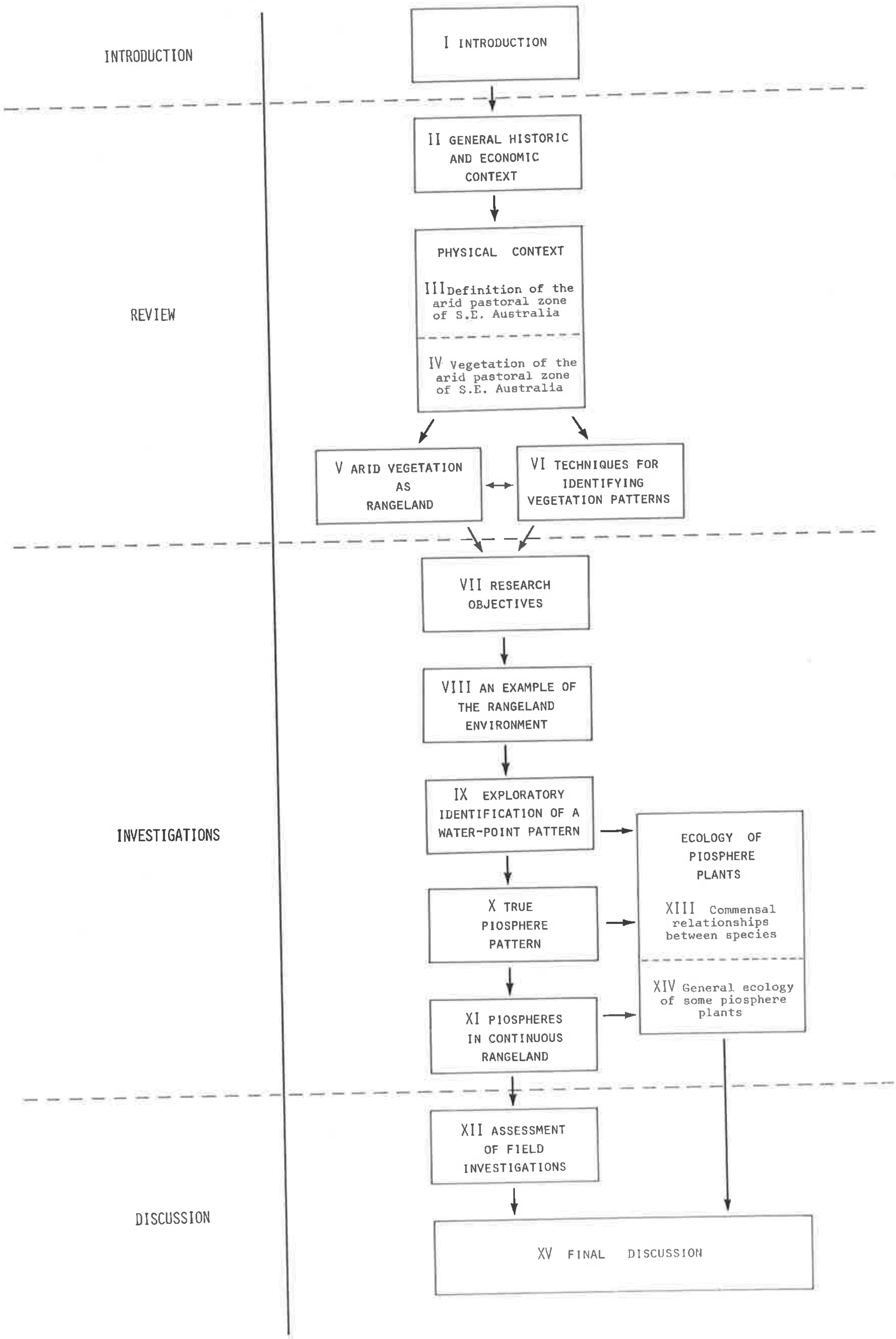
Upon this basis the research proposals are then detailed in Chapter VII. The sequential development of the study stemming from the initial ideas is outlined in Fig. 1.

FIGURE 1

Flow diagram

showing the sequential development of ideas in this thesis

Roman numerals indicate chapter headings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CHAPTER II

GENERAL HISTORIC AND ECONOMIC CONTEXT

HISTORICAL BACKGROUND

The use of arid lands for agriculture in the Middle East and Asia over many centuries is reviewed by Hills (1969) and is also described comprehensively in UNESCO's Arid Zone Research 17, 1961, in which Whyte, for example gives an account of agricultural practices in Ancient Mesopotamia and Butzer debates the effect of climatic change on the Roman colonies in the marginal lands of north Africa. Such papers describe the destruction of natural vegetation both by simple timber-cutting and pastoral activities and by the development of sophisticated irrigation agriculture up to 2000-3000 B.C. With the decline of these civilisations, native vegetation removed centuries earlier was unable to regenerate, thus permitting the landscape to be markedly altered by erosive forces.

The development of a "dustbowl" in the Great Plains region of the United States, resulting from the mis-management of arid and semi-arid land since the 1850's, is described by Bennett, Kenney and Chapline (1938). When these authors were writing 575 million of some 728 million acres of rangeland in the western United States had been depleted such that the grazing capacity had been reduced by 50%. The fouling of reservoirs by siltation arising from soil erosion is described. Sampson and Weyl (1918) cited in Ellison (1960) stress the value of colonisation of denuded areas by herbs in the control of erosion and flooding. Stewart, Cottam and Hutchings (1940) describe the development of "embryonic dunes" in overgrazed shrub communities in low rainfall areas of Utah. Although the beginnings of such degradation have been attributed to exploitative pioneers, Taylor (1948) points out that responsibility also lies with the nineteenth century governments, whose policies encouraged land speculation.

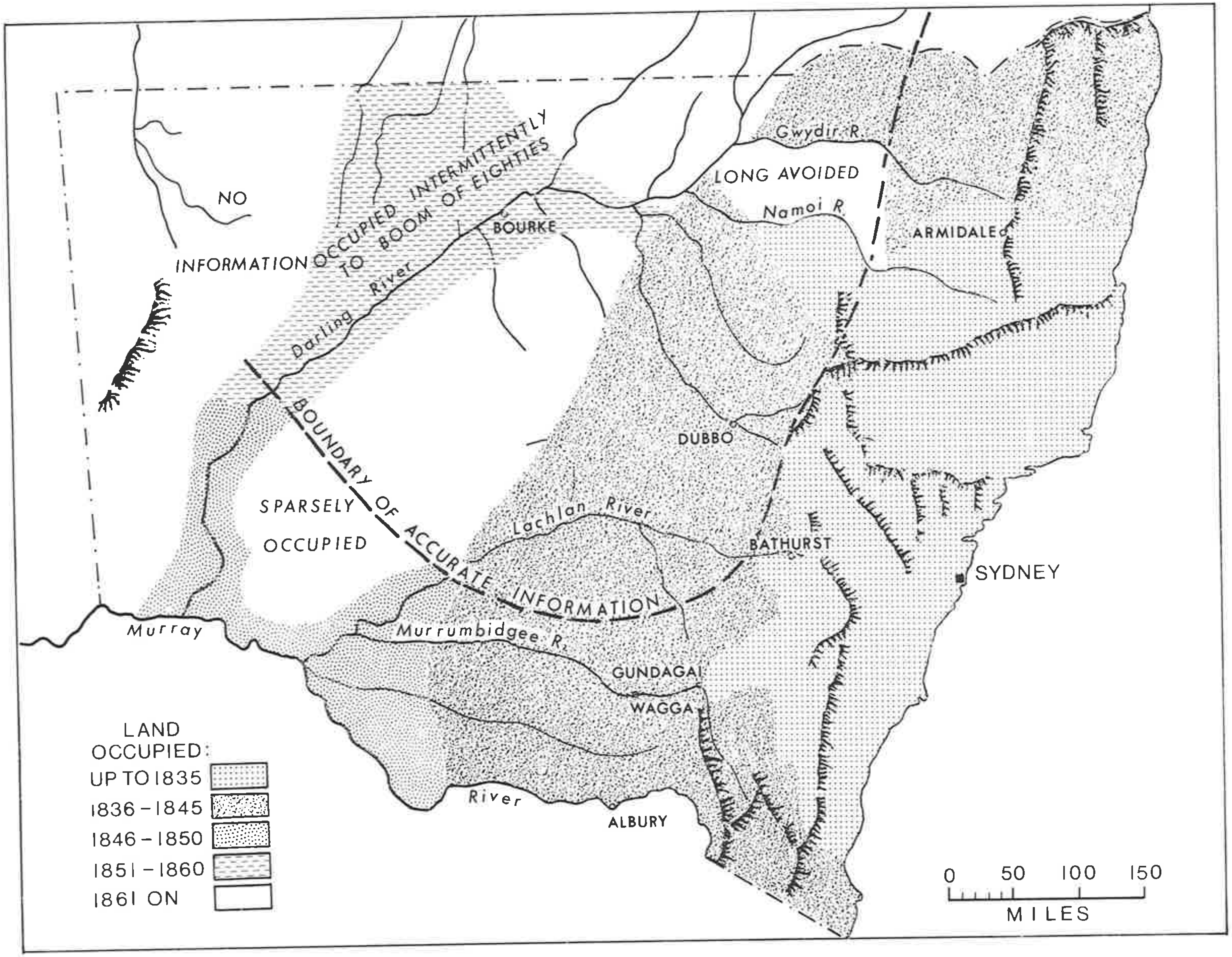
In Australia too, early pastoralism in the arid areas was so injudicious in places that some pastures were completely destroyed within 30 years of their first occupation and became tracts of loose dust subject to severe erosion. Such situations in western New South Wales have been described by Condon and Stannard (1956, 1957a, b and c).

The history of pastoralism in New South Wales has been examined by several authors. Roberts (1935) describes early occupation by squatters up to 1847, by which time land to a front 200-250 miles west of Bathurst was occupied as well as some Darling River frontages (see Fig. 2). Williams (1962) writes about the pastoral industry of the Riverina (defined as all of New South

FIGURE 2

The spread of squatting settlement into the dry areas of New South Wales

after S. H. Roberts (1935, reprinted 1970)



NO
INFORMATION
OCCUPIED INTERMITTENTLY
TO BOOM OF EIGHTIES
Darling River
BOURKE
Gwydir R.
LONG AVOIDED
Namoi R.
ARMIDALE
BOUNDARY OF ACCURATE INFORMATION
SPARSELY
OCCUPIED
DUBBO
Lachlan River
BATHURST
SYDNEY
Murray
Murrumbidgee R.
GUNDAGAI
WAGGA
River
ALBURY
LAND
OCCUPIED:
UP TO 1835
1836 – 1845
1846 – 1850
1851 – 1860
1861 ON
0
50
100
150
MILES

Wales west of Narrandera) between 1860 and 1869; he describes the expansion of sheep production for tallow and then wool at the expense of the cattle industry, the destruction of saltbush (*Atriplex nummularia*) and cottonbush (*Kochia aphylla*) by close-shepherding to fatten sheep, the development of undesirable *Callitris* sp. and *Acacia* sp. scrubs and the invasion of denuded river frontages by wool contaminants such as Bathurst burr and burr medic. Heathcote (1965), in giving a similar account for the Warrego district of northern New South Wales and southern Queensland, points out that improvements in fencing and the provision of water supplies increased the carrying capacity. He quotes estimates of carrying capacities varying from 64 sheep/sq. mile to 160 sheep/sq. mile, but says that even though stock water was plentiful, from the mid-1880's carrying capacities were dwindling, as perennial fodder was destroyed.

Cain (1962) deals solely with the Western Division of Williams' "Riverina". During the 1880's, expansion into the arid areas west of the Darling was supported by massive investments from pastoral finance companies. Squatters and their financial backers were over-optimistic about the country, invested too much capital in improvements, and overstocked, apparently ignoring the destruction which had taken place to the east 20 years earlier. Cain appreciates that the rapid reduction in sheep numbers between 1895 and 1902:

> "…. was the outcome not merely of the paucity of rain; events and practices of earlier days had established conditions in which falling away of rainfall would be disastrous. Overstocking, rabbits and encroachment of noxious scrub had done permanent damage to pastures".

Barnard (1969) however, although aware of these physical changes, maintains that the failure of sheep numbers in the twentieth century to exceed the 1893 maximum is for technological and economic reasons.

By contrast, documentary evidence on the course of early pastoralism in South Australia has been the basis of only limited academic study. Published works referring to the settlement of the arid zone include those of Cockburn (1925-27) who presents short biographies of many early pastoralists, N. A. Richardson (1925) who, as a one time mail contractor, has assembled much hearsay and first-hand information regarding pastoralists north and west of Port Augusta, A. E. V. Richardson (1936) who reviews a century of agricultural and pastoral development in South Australia and Davidson (1938) who discusses the ecology of sheep populations. Histories of Beltana, Mt. Lyndhurst and Kanyaka Stations in the Flinders Ranges have also been published (Anon. 1965, 1968). Meinig (1962) mentions the arid areas only in so far as they were affected by the expanding wheat frontier in the State between 1869 and 1884. Bowes (1968) presents more specific information regarding the settlement of the north of the State. The following brief history of the southern arid zone of South Australia is summarised from these limited sources and from South Australian Parliamentary Papers (SAPP) and Debates (SAPD) up to 1900.

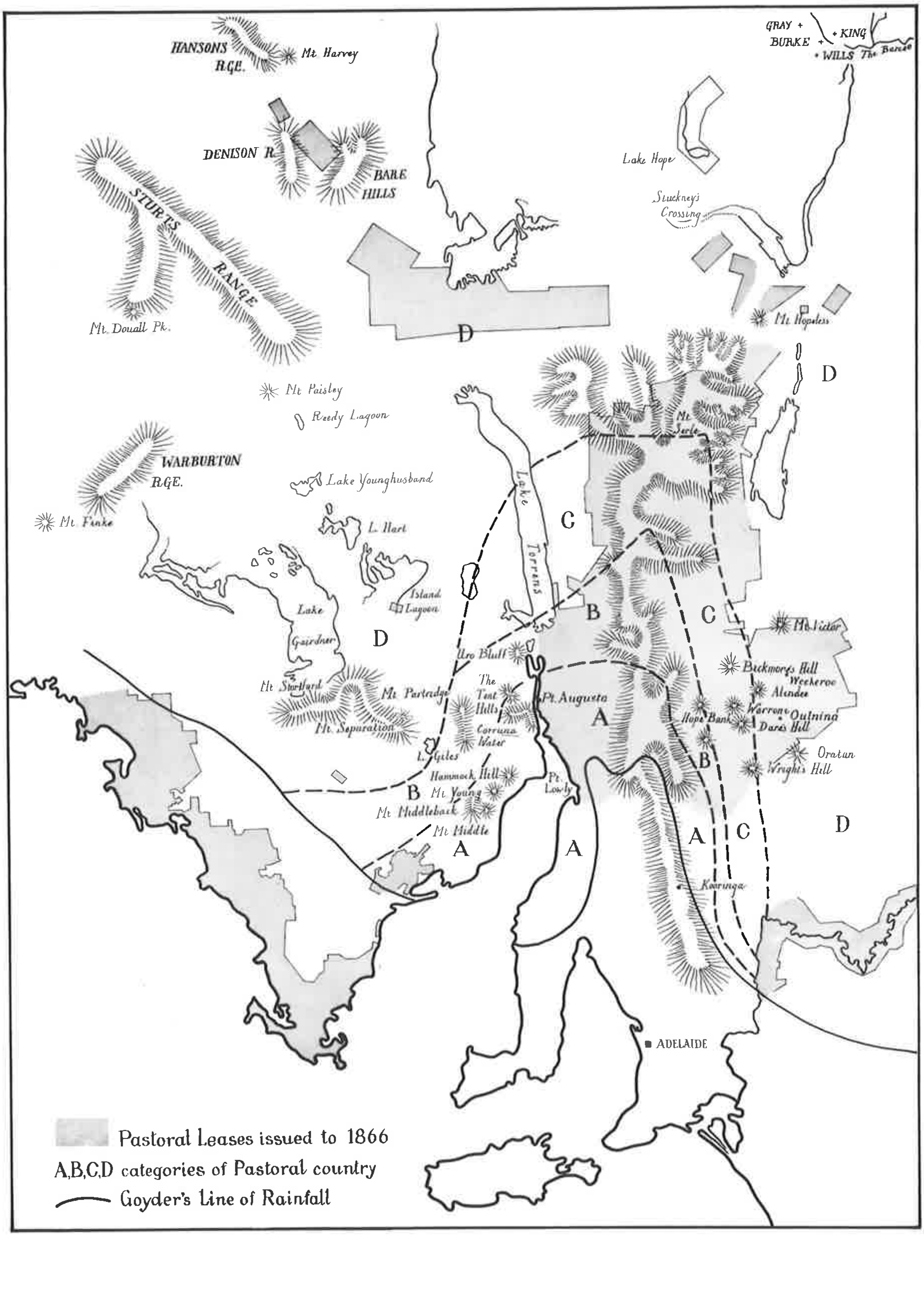
The dry areas of South Australia had no permanent surface water supplies apart from the River Murray and springs in the Flinders Ranges. For this reason pastoral expansion into the dry country, which began in the 1850's was restricted to these localities (Fig. 3). In spite of the experience of their neighbours in New South Wales, South Australian pastoralists understood the variable rainfall regime no better. The drier parts of the State, or "Waste Lands", were regarded as droughted, the implication being that the droughts would end. In 1865 the Surveyor-General, Goyder, was despatched north with instructions to find the ".... line of demarcation between that portion of country where rainfall has extended, and that where the drought prevails" (SAPP 1865-66 No. 62). Goyder's report (SAPP 1865-66 No. 78) not only contained this demarcation, but also the advice that outside the Line of Rainfall (see Fig. 3) the country should be used for pastoral and not for agricultural purposes.

At first the South Australian Government did not give official carrying capacities for the Waste Lands, admitting that it would be impossible to find a man with the necessary knowledge to make the assessment. It was acknowledged, however, that carrying capacities should be lower than those in New South Wales (SAPD 1860). In 1866 (SAPP 1865-66 No. 82) Goyder classified pastoral land into A, B, C

FIGURE 3

Pastoral holdings in the dry areas of South Australia
up to 1866

after G. W. Goyder in SAPP 1866 No. 154



HANSONS RGE.
Mt Harvey
DENISON R.
BARE HILLS
STURTS RANGE
Mt. Douall Pk.
GRAY
BURKE
KING
WILLS
Lake Hope
Stuckney's Crossing
Mt Hopeless
D
Mt Paisley
Reedy Lagoon
WARBURTON RGE.
Lake Younghusband
L. Hart
Mt Finke
Lake Torrens
Mt Serle
C
Island Lagoon
Lake Gairdner
D
B
C
Mt Victor
Uro Bluff
Mt Partridge
Mt. Separation
The Tent Hills
Pt. Augusta
Corruna Water
L. Giles
Hammock Hill
Mt Young
Mt Middleback
Mt Middle
Pt. Lowly
Weekeroo
Alendee
Warrone
Oulnina
Dare's Hill
Hope Bank
Oratun
Wright's Hill
A
B
A
A
A
C
D
Kooringa
ADELAIDE
Pastoral Leases issued to 1866
A,B,C,D categories of Pastoral country
Goyder's Line of Rainfall

and D types, representing "districts less and more remote from the line of demarcation" (see Fig. 3). After a Royal Commission in 1867 (SAPP 1867 No. 14) this classification contained only three grades, A, B and C. It was suggested that the carrying capacities should be 35, 20 and 10 sheep/sq. mile respectively. Goyder considered (SAPP 1867 No. 89) that these limits should be altered to 60, 30 and 10 sheep/sq. mile. Evidence is given of stations in B-type country running 30-40 sheep/sq. mile in the Olary Spur and 45-50 sheep/sq. mile in the hills west of Port Augusta (SAPP 1867 No. 14; SAPP 1891 No. 41).

In spite of Goyder's warning and independent comment by Bonney (SAPP 1867 No. 89) to the effect that in the north good seasons were the exception, dry ones the rule, good rainfalls after 1872 stimulated the expansion of wheat farming into the margins of the pastoral areas; saltbush and bluebush pastures were ploughed up for wheat as far north as Hawker, and in the rainshadowed Murray Basin plains east of Burra and Eudunda. The return of droughts in 1881 proved that Goyder was right and many wheat farms in marginal areas reverted to pastoral use (see Meinig, 1962).

By far the greater part of the Waste Lands beyond Goyder's Line was devoid of permanent surface water in the mid-nineteenth century. This was a major problem facing graziers seeking pastures in the Eastern Plains north of the River Murray and in country west of Port Augusta. Financial losses sometimes amounting to £25,000 for a single station or run (see SAPP 1867 No. 89) were frequently the outcome of abortive attempts to provide stock water from wells and dams (see SAPP 1891 No. 41). Underground water was often too saline for stock, big dams were costly to excavate with bullock teams and small ones did not provide continuous supplies of water. For these reasons many areas north of the River Murray and west of Port Augusta were only intermittently or lightly stocked until after 1900.

It is, therefore, only the older runs in South Australia established in the 1850's and 1860's that were severely degraded in the nineteenth century. These stations along the Murray and in the Flinders and Olary Ranges had sufficient natural surface water or fresh well water to enable them to establish large flocks of sheep before drought periods such as those experienced between 1860-7, 1867-9, 1875-6, 1879-86, 1893-4 and 1896-1903 (see Foley, 1957). In addition some such areas were also ploughed for wheat.

Runs which had to rely on dam water had difficulty in maintaining flocks. For example, on Quondong Station which has been studied in detail by the author, most dams were not built until the late 1870's (Barker, 1970) by which time the pastoral areas were droughted; by 1892 the then lessee claimed to be drought stricken again, relying on a single highly saline well for stock water.

Although there were individual financiers and speculators, South Australian pastoralists do not appear to have been mortgaged by pastoral finance companies as were those in western New South Wales (see Anon. 1939; Cain, 1961), and banks had little confidence in pastoral pursuits (SAPP 1867 No. 98). Until 1922 all improvements (wells, dams shearing facilities) were paid for by the lessee who was later reimbursed by the Government, but no payments were made for unsuccessful wells or dams. This system meant that many lessees suffered serious financial losses before they ever stocked the country and many handed on or abandoned their leases. Droughted stocked properties also appear to have been abandoned (SAPP 1867 No. 89; Richardson, 1925) rather than amalgamated for economy in running costs as was done by mortgage companies (Cain, 1962).

In reviewing the pastoral history of the south-eastern arid areas, it appears that, from an ecologists point of view, South Australia was fortunate in having insufficient supplies of stock water in the early days. If water had been available, the New South Wales pattern of heavy stocking would doubtless have been repeated here, before a better understanding of carrying capacity could be gained. The effects of this situation are evident today, as many sheep stations in South Australia with moderate stocking regimes still possess areas of shrub steppe and shrub woodland in pristine condition.

Their ignorance of the environment led nineteenth century Australians to acquire fallacious ideas regarding the arid inland they were using as pasture, and it is evident from recent literature that some of these misconceptions still persist. One of these relates to the use of the term "carrying capacity".

It was acknowledged in 1900 that the destruction of arid pastures in western New South Wales largely resulted from settlers' opinions that the only factor limiting "carrying capacity" was the availability of water. As water was relatively plentiful, "carrying capacities" were grossly over-estimated with regard to productivity of vegetation; consequent overstocking led to permanent destruction of perennial fodder. This situation was made quite clear by J. H. Boothby, a station inspector (see Heathcote, 1965 p. 158).

Although farmers use the term "carrying capacity" in the sense of year-round ability of a pasture vegetation to carry a number of stock, in pastoral areas the term still relates to the availability of water; increases in the numbers of stock water-points are still said to increase the "carrying capacity" (South Australian Pastoral Act, 1936-50; Heathcote, 1965, 1969; Barnard, 1969).

The urgent need to maintain rangeland vegetation emphasises that the meaning of the term "carrying capacity" as applied to the arid zone should be re-examined. Here, carrying capacity must have some relation to plant productivity, as it does in humid areas, i.e. it must relate to the numbers of stock which can be grazed more or less permanently, such that a perennial shrub or grass cover can be maintained in perpetuity.

A second misconception which had its origins in the minds of north European settlers is that of "drought". Much of inland South Australia and New South Wales was regarded as "drought stricken" for protracted periods. Most references to drought imply that it should be of uncommon occurrence, "normal" seasons being those in which sufficient rain falls to maintain pasture growth. Drought has been defined as "A period of abnormally dry weather, sufficiently prolonged for the lack of water to cause a serious hydrologic imbalance" (Huschke, 1959). Foley (1957) suggests that drought prevails when rainfall deficiency has economic effects; rain deficient periods of as little as five months are regarded as drought by him. As unreliability of rainfall is the outstanding feature of the arid areas of Australia, and as there are barely 100 years of rainfall records, it is still difficult to rationalise estimates of "normal" rainfall or "drought".

SOME ECONOMIC ASPECTS OF THE PASTORAL INDUSTRY

The economics of the pastoral industry have been the subject of several publications in recent years, based on data from the Bureau of Agricultural Economics. As an ecologist the author can make little comment on the statements made in these papers except to indicate the bearing they have on the maintenance of native pastures and on the possible future of pastoralism.

In considering the economic history of pastoralism, Barnard (1969) says that the destruction of pastures in the nineteenth century was the reason for the gradual scaling down of carrying capacity after the 1890's. He then gives two other reasons for the fact that the high stock numbers of this period have only rarely been exceeded since. These are, firstly, that marginal alterations in technology and additional investment have only served to increase yield per animal and provide protection against bad seasons, rather than increase stock numbers, and secondly, that market inducements were lacking to stimulate increased stocking rates. These statements may be correct, (although there have been periods when market prospects were attractive enough to encourage a change from wheat to wool production in humid areas) but the basic reason underlying the lower sheep numbers in the arid zone since the 1890's peak must be the fact that carrying capacities were grossly over-estimated in the first instance, and stocking rates have had to be reduced to maintain pastures in a productive state, irrespective of market prospects.

Waring (1969) discusses efficiency of production and gives three statistics, which he considers are "informative in comparing the technical and economic efficiency of livestock production between farms, regions and zones". They are (1) the rate of return to capital and management, excluding land and livestock (2) net income per livestock unit, and (3) returns/costs ratio. These statistics are exemplified in Table 1. According to Waring, stock may make up as much as 80% of the total capital value of a property; if stock prices rise then capital on books rises, so proportionally, returns are less i.e. returns/capital ratio falls. The effect of this can be seen by comparing columns A and B in Table 1. Waring considers that the figures in column A, which disregard "profits" on increased value of livestock inventories i.e. increased capital, are a better indication of relative efficiency of resource use between states. By comparing the rate of return to capital, South Australia appears to be much less efficient than New South Wales, unless there is a price rise, when the difference between the two diminishes. By excluding land from the capital the disparity increases and is greatest if land and livestock are excluded. This suggests (as do the differences between columns A and B which are based on no-price-rise/price-rise of livestock) that the amount of capital tied up in livestock is greater on New South Wales properties than on South Australian.

This is borne out by reference to Reid (1968) from whom Table 2 is drawn. Although the average size of property in N.S.W. is almost half that in South Australia the numbers of stock per property are almost double. The effect of this is reflected by

TABLE 1

INCOME MEASURES FOR SHEEP PROPERTIES IN THE S.E. ARID ZONE Average per property, 1962-3 to 1964-5				
	Without price gain (A)		With price gain (B)	
	N.S.W.	S.A.	N.S.W.	S.A.
Return to capital and management ($)	11,239	3,146	15,567	8,748
* Returns/costs ratio	1.6	1.3	1.8	1.7
Rate of return to capital and management (%)	6.4	2.8	8.9	7.8
with additional $2 per sheep (%)	6.0	2.6	6.4	7.3
excluding land (%)	12.3	4.8	17.1	13.3
* excluding land and livestock (%)	22.0	6.7	30.4	18.7
* Net farm income per livestock unit ($)	16.4	10.7	21.9	22.9

Source: Waring, 1969

* Efficiency factors

TABLE 2

PROPERTY CHARACTERISTICS IN THE S.E. ARID ZONE Average, 1960-1 to 1962-3		
	N.S.W.	S.A.
Size of flock (nos.)	5,460	3,409
Size of property (ac.)	29,524	58,723

Source: Reid, 1968

fodder and agistment costs in the two states (Table 3); properties in New South Wales on average spend between 2-15 times as much on fodder and agistment (depending on season) than those in South Australia.

These figures must be a reflection of past overstocking in New South Wales, which removed the drought-reserve bush cover, and the present relatively high stocking rates, which militate against a policy of preserving perennial feed for dry seasons.

The interpretation of the papers cited suggests that if increased "technical and economic efficiency" is achieved by greater stocking rates, then the ecologist concerned for the future of the pasture must regard "efficiency criteria" with caution.

Data mapped by Brown and Williams (1970), however, indicate that sheep in the South Australian arid zone cut a heavier greasy and clean fleece than those in western New South Wales. Although they say that one of the factors responsible for heavier fleece

TABLE 3

FODDER AND AGISTMENT COSTS
Average per property, 1960-1967

	1960-1 to 1962-3		1964-5		1965-6		1966-7	
	N.S.W.	S.A.	N.S.W.	S.A.	N.S.W.	S.A.	N.S.W.	S.A.
Fodder ($)	320	162	1,512	164	3,307	145	767	193
Total materials ($)	4,314	3,128	6,488	3,995	7,080	3,289	5,226	3,486
% spent on fodder	7.42	5.17	23.3	4.1	46.7	4.4	14.7	5.5
Droving, agistment ($)	146	16	318	-	912	41	759	25
Total services ($)	5,196	2,338	6,890	3,131	6,380	3,191	6,757	3,572
% spent on droving, agistment	2.80	0.68	5.5	0.0	14.3	1.3	11.2	0.7
TOTAL COSTS: (including labour, rent, depreciation, materials, services)	19,396	13,048	24,292	15,984	23,093	15,674	21,993	16,838
Fodder, agistment	466	178	1,893	164	4,219	186	1,526	218
% total spent on fodder, agistment	2.40	1.36	7.79	1.03	18.26	1.19	6.94	1.29

Source: Australian Sheep Industry Surveys, 1960-61 to 1962-63; 1964-65 to 1966-67
Bureau of Agricultural Economics

weights is the South Australian strong-wool strain of Merino, this type of sheep is run in both districts. A second factor influencing fleece weight is the type of animal; wethers are said to cut the heaviest fleeces, but as the majority of sheep in arid South Australia and western N.S.W. are ewes, Brown and Williams suggest that ewes maintained at a high level of nutrition will cut a heavier fleece than might be anticipated. It can, therefore, be inferred that South Australian arid flocks have a better level of nutrition than those in New South Wales. It is interesting to note that Reid (1968) commenting on the Australian Sheep Industry Survey, uses the assumption that properties with higher grazing pressures are indicated by lower wool cuts per head.

At present, the price of wool is continuing to fall and the Bureau of Agricultural Economics (1970) predicts that this decline will continue during the present decade. Reid (1968) in considering the implications of this warns against increased stocking rates to offset falling incomes, and draws attention to what happened in New South Wales in the 1890's. He points out that there is no indication that properties with higher grazing pressures achieve higher rates of return to total capital; Waring (1969), however, would not consider the criterion Reid uses as particularly informative. Reid is aware of the conservation problems associated with higher sheep numbers and suggests alternative means of production:

> "The reasonably high rates of return to capital excluding the value of land, the wide variation of profitability between properties, and the possibility of increased beef cattle production, make it unlikely that resources will be withdrawn from the pastoral zone in the forseeable future under pressure of low wool prices or rising costs."

In South Australia the arid areas produce only 13-14% of the State's total wool clip (Commonwealth Bureau of Census and Statistics, 1969). If this relatively small quantity is essential for the State's economy it could be argued that the agricultural areas are capable of increasing production by this amount. Also it is likely that quality e.g. fineness, rather than quantity, will determine future wool markets, so the demand for the strong wools from the arid areas is likely to continue to decline.

It could, however, be argued that the South Australian arid zone which cuts the heaviest clean fleece weight per beast of the strong wool type should be slower to change to cattle production than other arid areas where dust and vegetable contaminants decrease the value of the wool clip. (Sheep graziers in western New South Wales acknowledge that soil erosion is their greatest problem (Caskey, 1969).) Waring (1969) comments:

> ".... even if only because of social and institutional rigidities it is likely that there will remain substantial numbers of sheep and cattle in the arid zone throughout the forseeable future."

This remark has particular application to South Australia where 72.6% of sheep stations are owned by family partnership and a further 19% are owned by the operator. On the basis of man-weeks, South Australian sheep stations use more family labour than any other State (Bureau of Agricultural Economics, 1969). This suggests a considerable family interest in the running of sheep stations and if this tradition can be maintained it could promote a degree of stability for the future of many South Australian sheep stations.

CHAPTER III

DEFINITION OF THE ARID PASTORAL ZONE OF SOUTH-EASTERN AUSTRALIA

CAUSES OF ARIDITY

Aridity in this area results from comparatively low rainfall in combination with high evaporation. The arid regions of Australia are part of the system of arid areas lying in the subtropical latitudes north and south of the equator. The low rainfall experienced is brought about mainly by two factors (Hare, 1961). In subtropical latitudes subsidence of air in the moist lower troposphere, and adiabatic warming associated with this movement reduces relative humidity. Further, the high pressure belt associated with this subsidence separates the circumpolar westerlies from the tropical easterlies. As a result the very moist tropical air masses rarely penetrate far enough south to affect these southern areas; the frontal systems of the circumpolar westerlies are lifting mainly the dry subsiding subtropical air and hence little or no rain is produced with the passage of most fronts. The most southerly arid areas receive irregular and usually slight rainfall from the occasional active cold front, but the benefits derived from these diminish towards the centre of the continent.

High evaporation rates result from high values of solar radiation, and because in these subtropical latitudes the air is free of pollutants and cloud, incoming radiation is very intense. Hounam (1963) has calculated that this is equal to 600 cal. cm.$^{-2}$ day^{-1} in January. The resultant annual potential evaporation ranges between 70 and 130 inches from a free water surface.

Maps showing solar radiation, rainfall and evaporation rate are given for south-eastern Australia in Fig. 4, and demonstrate clearly the aridity of the region under consideration.

DELIMITING THE ARID ZONE

The earliest official attempt to distinguish arid areas from more humid ones in Australia, was that of Goyder, a South Australian Surveyor General (see p. 9) who, with little knowledge of rainfall regimes or seasonal averages, drew a "Line of Rainfall" which roughly corresponds with what we now know as the 12 inch isohyet. From comments he made in his report (SAPP 1865-66 No. 78) it is possible that Goyder may have used saltbush *(Atriplex vesicaria)* as an indicator plant to distinguish the areas he considered best suited for pastoralism from those suitable for agriculture.

Considerable research has been carried out since to give a

FIGURE 4

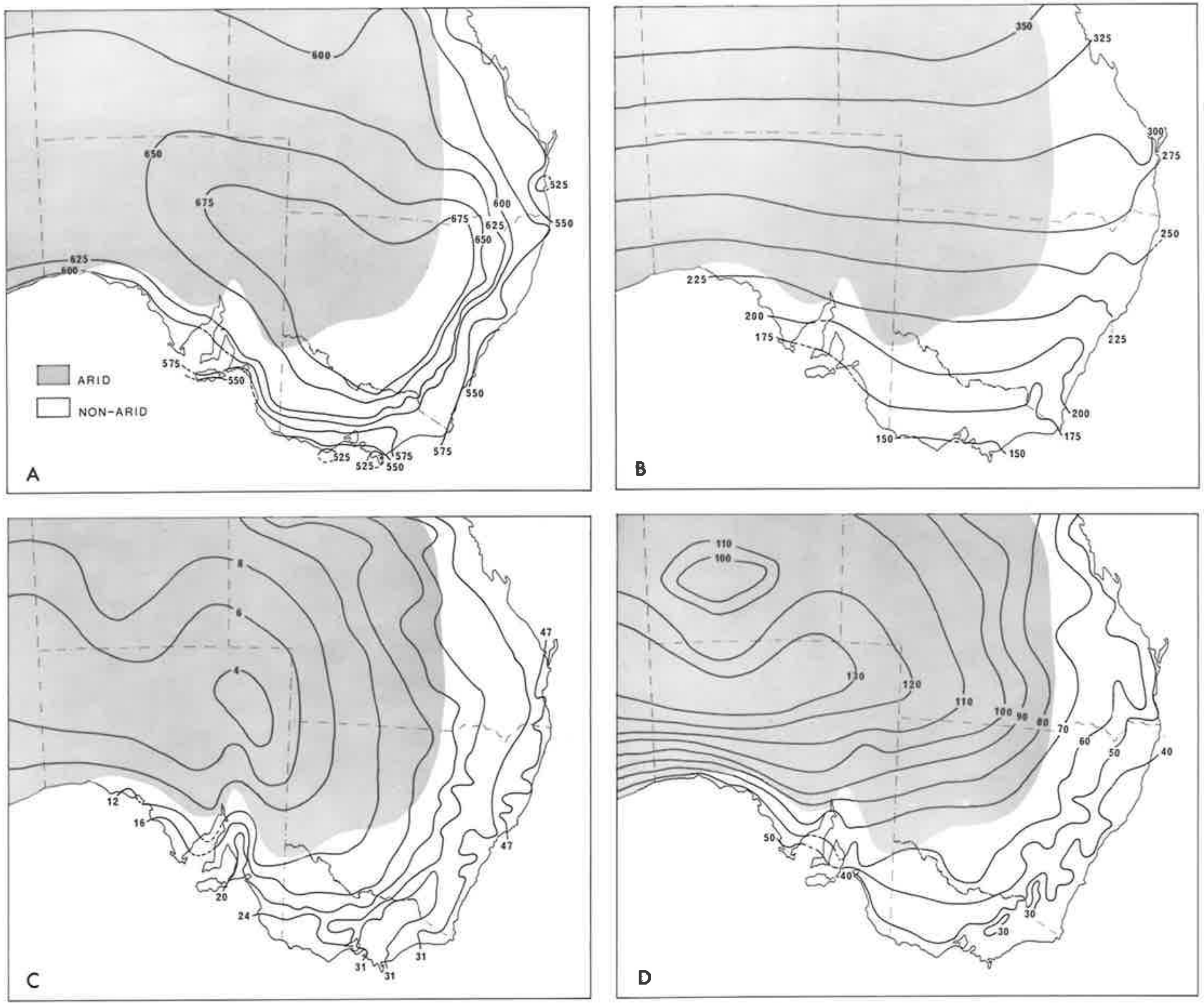
Climatic data relating to the arid areas of south-eastern Australia

A - Average monthly total radiation for January (at the surface in cal./cm^{-2}/day^{-1})

B - Average monthly total radiation for June (at the surface in cal./cm^{-2}/day^{-1})

C - 50 percentile rainfall for the year (in inches)

D - Average evaporation for the year (from Australian Standard Tank, in inches)



ARID
NON-ARID
A
600
650
675
625
550
525
575
B
350
325
300
275
250
225
200
175
150
C
8
6
4
12
16
20
24
31
47
D
110
100
130
120
110
100
90
80
70
60
50
40
30

more precise definition to the arid zone in Australia on the basis of climatological data. Andrews and Maze (1933) review overseas studies to produce a mathematical relationship between precipitation and temperature for an index of aridity. They discuss four such ratios and their modifications, concluding that aridity can only be defined by reference to length of arid period, which, as they say, is critical in determining cultural and natural landscapes. This concept was used by Davidson (1934, 1935, 1936), Trumble (1937, 1939), Prescott (1934, 1936, 1938, 1943, 1949) and Prescott and Thomas (1948-9), who developed precipitation/evaporation (P/E) ratios to indicate the lower limit at which adequate moisture is available for plant growth. Their ratios vary from Davidson's $P/E = \frac{1}{2}$, to Trumble's $P/E = \frac{1}{3}$ for South Australia only, to Prescott and Thomas' $P/E^{0.75} = 0.4$ applicable to Australia as a whole. In all cases (E) is estimated from measurements of saturation deficit.

Prescott and Thomas use their formula to establish break of season and state:

> "Where in no month does the value of the index reach this value, desert conditions may be expected. For periods up to five months pastoral occupation is possible, and when the period is greater than five months agriculture is possible."

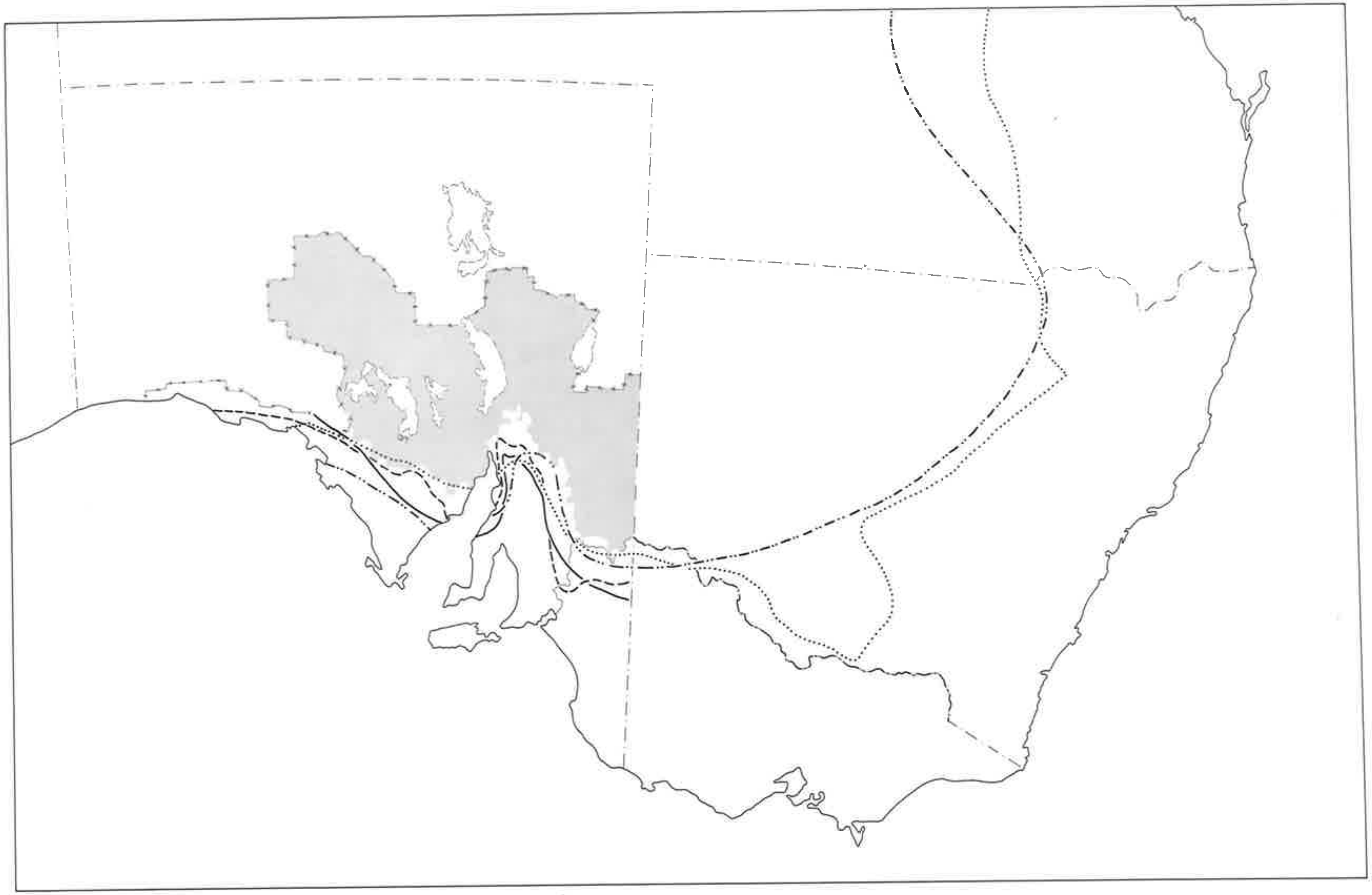
Goyder's subjective judgement may now be justified by means of a mathematical relationship. But however precise a line drawn on a map may or may not be (Fig. 5), it is now implicit in the

FIGURE 5

The arid pastoral zone in South Australia as defined by:-

(1)	Goyder (1866)	————————
(2)	Trumble (1937)	----------
(3)	Prescott and Thomas (1948-9)	.-.-.-.-.-
(4)	Perry (1967, 1970a; after Meigs, 1953)	....

The shaded area is that part of the South Australian arid zone devoted to sheep; its southernmost boundary represents the limit of the area which comes under the jurisdiction of the Pastoral Act 1936-50 and Amendments.



words "arid zone" in Australia, that the area is suitable only for pastoralism. Such areas described as rangelands by Perry (1967) are restricted to places "where rainfall on a given piece of land is inadequate for economic crop production or pasture improvement". In South Australia such land is administered by the Pastoral Board under the Pastoral Act, 1936-50, and Amendments, and the limit of the arid zone in these terms is also shown in Fig. 5. In this area leases are held for up to 42 years. The better watered southern portions are devoted to sheep and are bounded by the Dog Fence. Some pastoral areas occur south of this administrative area, but are held under Perpetual Lease, and are not subject to the provisions of the Pastoral Act.

CHAPTER IV

VEGETATION OF THE ARID PASTORAL ZONE IN SOUTH-EASTERN AUSTRALIA

STATUS OF ARID ZONE VEGETATION

The origins of the Eremaean Flora, as arid vegetation was termed by Tate (1890), are discussed by Burbidge (1960), who points out the similarities between Australian arid chenopods and the halophytic strand and dune chenopods of the Northern Hemisphere.

Following Wood's (1937) studies of the vegetation of South Australia, there is now a general belief that the shrub steppe and shrub woodland, which constitute the principal vegetation formations in the southern arid areas of Australia (Atlas of Australian Resources, 1955) are climax. It is of interest to note that a contrary view was held by Collins (1923) who states that the development of vegetation associations beyond the mulga-saltbush state in the Barrier District of New South Wales may have been arrested by grazing; she suggests it would be necessary to exclude stock to allow succession to continue to the climax situation. Osborn (1925) suggests that the dwarf shrubland and arid scrub communities of Koonamore Station have the character of climax vegetation. There could be little reason for supposing that the climactic status of the vegetation in the two areas, separated by only 120 miles, would be different. Wood (1937) does not say that these formations are climatic climax as such. He says:

> ".... each [is] a climax association in its own micro-climate... The determining factor for each community is the amount of available water in the soil."

Beadle (1948) discusses succession and status of the many plant communities in western New South Wales.

SYNECOLOGY OF ARID ZONE VEGETATION

Climax vegetation

The earliest descriptions of climax vegetation now used as sheep pasture in the south-east of the arid zone are found in the explorers' journals, such as those of Sturt (1833, 1849) and Eyre (1845) (see also Threadgill, 1922), and in newspaper reports and Parliamentary Papers (see, for examples, Williams, 1962; Heathcote, 1965). Early records in scientific literature were by Schomburgk (1876), W. A. Dixon (1880), Woolls (1882), S. Dixon (1883, 1892) and Maiden (1888) all of whom listed native species of *Atriplex*, *Rhagodia* and other "Salsolaceous" plants being grazed at that time.

More detailed accounts are given for New South Wales by Collins (1923, 1924) of the mulga and saltbush associations of the Barrier and Grey Ranges, by Beadle (1948) of the numerous pasture vegetation types of the whole of western New South Wales and by Moore (1953a) of part of the Riverina, where there are relict patches of climax vegetation containing *Acacia pendula* with *Atriplex nummularia* and *A. vesicaria*.

By far the most comprehensive literature describing arid vegetation relates to South Australia. The southern areas with which this thesis is concerned, may be divided into the north-west and north-east regions. For certain biogeographical reasons suggested by Crocker and Wood (1947) the vegetation in the two regions, roughly separated by the Flinders Ranges, varies slightly and will therefore be considered separately.

In the north-east the Koonamore Vegetation Reserve was established in the 1920's. The vegetation in the vicinity of the reserve at that time was described by Osborn (1925). Much later Carrodus, Specht and Jackman (1965) gave an account of the vegetation of the whole of Koonamore Station. Jessup (1948) described some of the vegetation bordering the Murray Basin; Barker (1970) studied Quondong Station, lying east of Jessup's area and only 40 miles from the New South Wales border. A detailed description of Quondong will be given in Chapter VIII of this thesis. Such papers describe the vegetation of the north-east as consisting of *Casuarina cristata* or *Myoporum platycarpum* woodland, with *Acacia aneura* in drainage areas and mallee occupying sand dunes. Bluebushes, *Kochia sedifolia* and *Kochia excavata* var. *trichoptera*, are very common with black oak on calcareous soil. *Atriplex vesicaria* occurs where the porportion of clay in the soil increases.

Early accounts of the north-west district are given by Cannon (1921) and Adamson and Osborn (1922) who present straightforward descriptions of the vegetation around Ooldea, bordering the Nullarbor Plain. Later researchers also include soil surveys, as these are of obvious importance in the understanding of soil erosion. For example, Crocker and Skewes (1941) discuss the interrelationships between soil types and vegetation associations and formations on Yudnapinna Station. The principal associations contain the dominants *Atriplex vesicaria*; *A. vesicaria* and *Kochia planifolia* (now *K. astrotricha*); *Acacia sowdenii* and *Myoporum platycarpum*; *A. aneura*; *A. linophylla* and *Casuarina lepidophloia* (now *C. cristata*). *K. pyramidata* and *A. vesicaria* are consistent species of the water-courses. Crocker (1946) briefly mentions *Acacia sowdenii* tree steppe and *Casuarina lepidophloia* (now *C. cristata*) scrub in northern Eyre Peninsula, in an introductory paper on the soils and vegetation of the Peninsula. Jessup (1951) gives a comprehensive account of the soils, geology and vegetation of a large area of the north-west, including the area of the Lake Torrens Plateau examined by Murray (1931). Jackson (1958) redescribes the vegetation of Yudnapinna Station prior to a discussion of its soils and hydrology. He draws attention to the variety of nomenclature referring to vegetation structure, by pointing out that his own use of "shrub woodland" is equivalent to the "shrub-arid woodland" of Jessup (1951) and the "tree steppe" of Crocker and Skewes (1941).

The descriptions cited above indicate that the north-west does have some vegetational similarities with the north-east. The principal differences lie in the occurrence of *Acacia sowdenii* (western myall) only on the western side of the Flinders Ranges, and in the comparative rarity of *Kochia pyramidata* on the eastern side.

Disclimax vegetation : the effect of grazing

Some of the papers already mentioned discuss, in a general way, the modification of climax communities by grazing. Other papers report the consequences of overgrazing. The early papers of W. A. Dixon (1880), Woolls (1882), Maiden (1888) and S. Dixon (1892) give graphic descriptions and warnings concerning the destruction of native shrubs which was taking place in New South Wales and to a lesser extent in South Australia. These papers clearly had little impact, for Maiden (1903) suggests trees and shrubs, both native and exotic, which could be planted to combat sand drift. McMaster (1903) expresses doubts about these measures as the cost of the suggested plantations would be out of all proportion to the productive capacity of "this extremely low grade country".

Ratcliffe (1936) carried out a survey in arid South Australia to determine the extent and immediate causes of soil erosion and possible means of controlling it. Beadle (1948) was responsible for a similar, but more comprehensive, survey of vegetation types and associated soil erosion in western New South Wales. In the overgrazed situations these authors describe, the destruction of the original shrub vegetation led to the development of disclimax communities such as those described by Moore (1953b) for the semi-arid south-eastern Riverina of New South Wales. An original shrub woodland climax vegetation consisting of *Acacia pendula* and *Atriplex nummularia* has, under progressively heavier grazing given way on light textured soils, first to *Kochia aphylla* with *Stipa falcata*, then to *Danthonia caespitosa* and finally to annuals. According to him the native annuals have little or no pasture value. On heavier soils the climax degenerates to *Stipa aristiglumis*, then *Danthonia* and finally *Chloris truncata*. The retrogressive sequence thus appears to be perennial shrub → perennial grass → annual grass and herbage; Moore quotes Beadle (1948) as regarding this grassland as a climax rather than disclimax. Williams (1955) and Wilson and Leigh (1964) describe disclimax communities with regard to vegetation patterns on Riverina gilgai soils.

The development of disclimax communities in South Australia has been mentioned by Crocker and Skewes (1941) for Yudnapinna Station in the north-west district. In an *Acacia sowdenii-Myoporum platycarpum* climax association, grazing encourages the disappearance of *K. sedifolia* and the appearance of *K. pyramidata*, which is said to be unpalatable. If degeneration is too rapid, forbs such as *Bassia obliquicuspis* and *B. paradoxa* increase, but there is no further degradation until the associated species such as *Cassia* spp. and *Heterodendrum oleaefolium* disappear.

In the *Atriplex vesicaria-K. planifolia* (now *K. astrotricha*) association the saltbush disappears first, with increases in *Bassia divaricata* and *B. decussata*. When *K. planifolia* goes the ephemeral *A. spongiosa* appears. Jessup (1951) also notes the increase of "annuals" and unpalatable species in the grazed country of the north-west district. This degenerative pattern of perennial bush → annual/biennial forbs → ephemerals is similar to that noted above for the Riverina.

Of the north-east district Jessup (1948) says:

> "As a result of the absence of a *K. pyramidata* stage in the *K. sedifolia* dominated pastures of the north-east, the destruction of bluebush presents a much more serious problem than in the north-west of the State",

as the destruction from perennial bush → ephemerals is accomplished more rapidly.

The Koonamore Vegetation Reserve was established in an over-grazed part of Koonamore Station with the object of monitoring the regeneration process by means of fixed quadrats and photography points. Since Osborn's initial paper in 1925, Osborn, Wood and Paltridge (1935), Wood (1936) and Hall, Specht and Eardley (1964) have reported on the sequence of recolonisation recorded at annual intervals. Hall *et al.* (1964) say that relief from sheep stocking has allowed the regeneration of *Atriplex vesicaria* and *A. stipitata*, although the seedling survival of *Cassia nemophila*, *Acacia aneura*, *Myoporum platycarpum* and *Santalum acuminatum* and sucker survival of *Casuarina cristata* is apparently dependent on the exclusion of rabbits also. Collins (1924) makes similar observations regarding the regeneration of *A. aneura* in the Grey Range of N.S.W. She says old residents have reported crops of seedlings which rarely survive. Beadle (1964) suggests that reduction in rhizobial population reduces seedling establishment of the legume *A. aneura*, as root nodules cannot form. Jessup (1948) says that there is ample evidence that *Cassia* sp. was originally far more plentiful in the north-east of South Australia than at the time of his survey.

Some of this non-survival must undoubtedly be due to rabbits, although Ratcliffe (1936) states that the presence of stock is just as fatal to palatable young seedlings as are rabbits. Purdie (pers. comm.) observed the normal regeneration of myall (*Acacia sowdenii*) in a paddock at Middleback Station where sheep, but not rabbits, had been excluded for 40 years.

Regeneration of arid vegetation following bushfires is reported on by Murray (1931) seven years after a fire on the Lake Torrens Plateau. She remarks that *K. pyramidata* is the only survivor of any note, *K. sedifolia* survived less frequently. Herbage appearing after the fire included *Stipa* sp. and *Bassia paradoxa*. Crocker and

Skewes (1941) and Jackson (1958) remark on the ready regeneration of *Cassia eremophila* (now *nemophila*) following a fire on Yudnapinna Station in 1922.

This literature suggests that the problem of regeneration is a complex one. Irrespective of the cause of degradation of vegetation (domestic stock, rabbits, fire or ploughing for agriculture), recovery to an original condition will only occur if the environment is relatively undistrubed. This is rarely the case and edaphic or hydrologic changes promote the development of disclimax vegetation. Field observations by Hall, Specht and Eardley (1964), Crocker and Skewes (1941) and Jessup (1948, 1951) have contributed substantially to knowledge of conditions necessary for germination and regrowth and show that the necessary combination of favourable factors may occur only rarely. Better understanding of such factors will emerge from autecological and ecophysiological studies such as those to be reviewed in the next section.

AUTECOLOGY OF ARID ZONE PLANTS

Hall, Specht and Eardley (1964) stress the need for autecological work in understanding the factors controlling regeneration. Germination experiments and population studies will be reviewed in this section, as such phenological processes will be affected by grazing.

Stipa nitida is one of the plants which has been studied in detail (Osborn and Wood, 1931). Data on germination and phenology are presented together with information regarding plant distribution and variability of the root system in relation to soil type. The effects on *Stipa* of biotic factors, including sheep, are also discussed.

Danthonia caespitosa and species associated with it have been examined by Williams (1961a), who uses his observations on growth and flowering cycles of these plants to account for the development of this disclimax grassland from *Atriplex nummularia* shrubland, under the influence of grazing.

Zimmer (1944), who studied a population of *Callitris robusta* (now *C. columellaris*) growing with *Casuarina cristata, Eucalyptus oleosa* and *E. gracilis* in the Yarrara State Forest, Victoria, states that regeneration was not proceeding because of a hard crust on the soil surface. Once seedlings are established, however, he estimates that the growth of young trees would proceed at a rate such that in 14 years a height of 18 feet and a butt diameter of 6 inches would be achieved. Lange (1965) examined *C. columellaris* at The Pines Station, near Woomera in an attempt to relate growth rings to rainfall periodicity.

Mulga *(Acacia aneura)* has been studied in north-western New South Wales, where Preece (1971a) reports that flowering occurs after rain, principally in spring and late summer. Fruiting occurs most frequently after the summer flowering. Similar observations are made by Davies (1968). Preece (1971b) states further that although regeneration of mulga is not occurring in north-western New South Wales, conditions would be suitable for germination approximately once in nine years. He points to the need for studies on seedling growth. *A. aneura* var. *latifolia*, common in Queensland but more rare in southern arid areas, is described by Everist (1949).

Purdie (pers. comm.) concluded that non-regeneration of *Acacia sowdenii* (western myall) is a result of sheep grazing. Stirling (1962) describes germination and growth of this species; Correll and Lange (1966) suggest it has a possible life span of 250 years.

According to Burbidge (1945) the optimum germination temperature for seed of *Atriplex vesicaria* is 14-18°C, while Beadle (1952) records the optimum as being 20-25°C. This disparity may be due to the fact that seed from different populations was used; Knowles and Condon (1951) describe three ecotypes of *A. vesicaria*. Both Burbidge and Beadle comment on better germination after removal of the bracts, and Beadle attributes this to the inhibitory effect of the accumulation of chloride ions in these organs. He also comments on the permeability of the seeds. Jones (1968) reports that although milling the "fruits" or leaching the salt from them improved the germination of *A. nummularia* in the laboratory, these treatments had no effect under field conditions. Burbidge believes that *A. vesicaria* is unlikely to regenerate after summer rains, as hot days may damage the seedlings. Beadle makes observations on their drought tolerance.

While *Atriplex* seeds may remain viable for several years, those of *Kochia* are viable for shorter periods (Burbidge, 1946; Hall, Specht and Eardley, 1964). Germination occurs in the range 9-30°C. Regeneration of *Kochia* is unlikely to take place on windswept, denuded ground, and Burbidge (1946) points out that litter is important in trapping the wind-blown seeds.

Information on longevity, growth and fruiting characteristics of several species of *Atriplex* and *Kochia* is tabulated by Knowles (1951) and Condon and Knowles (1952).

Hellmuth (1968) reports on the autecology of *Rhagodia baccata*, which is highly valued as a pasture species in some arid areas of Western Australia. This species appears to be a coastal one in South Australia and according to Black (1948) has limited occurrence inland.

The necessity for seed coats to be cracked by high summer temperatures or fire before germination can occur is noted for *Acacia* spp. and *Cassia* sp. by Osborn, Wood and Paltridge (1935), Crocker and Skewes (1941) and Hall, Specht and Eardley (1964).

In addition to the work described much information of an autecological nature is contained in publications concerning vegetation associations by Jessup (1948, 1951) and Crocker and

Skewes (1941) and in the Koonamore papers, where the behaviour of species under certain situations is commented upon.

ECOPHYSIOLOGY OF ARID ZONE PLANTS

The role of ecophysiology in the field of rangeland research is limited to the extent to which it can explain species behaviour and thus account for vegetation pattern. Most of this work has been directed towards species of *Atriplex* and *Kochia* and *Acacia aneura*.

The distribution of *Kochia sedifolia* and *Atriplex vesicaria* relative to each other has been investigated by Carrodus and Specht (1965). Their observations on the shallow root system of *A. vesicaria* and the deep one of *K. sedifolia* tie in with those of Osborn, Wood and Paltridge (1932, 1935); evidence that *A. vesicaria* occurs on soil with impeded drainage agrees with Jackson's (1958). They point out that *K. sedifolia* is found on deeply wetting soils and suggest further that the distribution of the two species thus depends on the depth to which the soil is wetted. Jones and Hodgkinson (1970) compare the rooting pattern and root mass of *A. vesicaria* and *A. nummularia*.

In mulga communities patterned into groves, the ponding of water in the grove areas as opposed to the open areas between is described by Slatyer (1961). The effect is attributed to different soil permeability and togography. Herbage pattern follows that of the trees, being confined to the grove (Perry, 1970b) and may thus be due to improved water relations under the trees, as no difference in nutrients is observed.

Mineral accumulation in plants and nutrient cycling in arid ecosystems has been investigated by numerous workers. *A. vesicaria*, *A. stipitata*, *K. sedifolia* and *K. planifolia* (now *K. astrotricha*) are not halophytes as they often grow on non-saline soil (Osborn and Wood, 1923a and b), although they do accumulate salt (Ashby and Beadle, 1957). Wood (1925) comments on the selective absorption of chloride ions and Brownell (1965) and Wood and Brownell (1957) say that sodium is accumulated as an essential nutrient. Brownell and Jackman (1966) and Lange (1967) relate high sodium accumulation to nitrogen metabolism. The cycling of such metabolites is believed by Rixon (1970) to be strongly affected by vegetation pattern; in soils with an even distribution of nitrate-nitrogen the rate of nitrogen turnover was greatest under the *Atriplex* bushes. Rixon might attribute the pattern noticed by Perry (1970b) to this phenomenon. In soils with an uneven distribution of nitrate-nitrogen, cycling occurs via *Atriplex* bushes. When the area is denuded of *Atriplex*, nitrogen cycling ceases as short rooted species cannot reach the nitrate-rich areas (Charley and McGarity, 1964). Rixon (1970) discusses the input of nutrients from faecal pellets in relation to the distribution of saltbush plants. Jessup

(1969) indicates that soil salinity (chloride) is dependant on saltbush distribution.

The loss of nitrogen and carbon by wind erosion in overgrazed situations is mentioned by Beadle and Tchan (1955). Beadle (1964) suggests that nitrogen-fixing rhizobia are destroyed by wind transport and that this may be a reason for the poor regeneration of mulga. Fixation of atmospheric nitrogen by rhizobia (Beadle and Tchan, 1955) and soil lichen crusts (Rogers and Lange, 1966) contributes to the nitrogen balance of Australian arid soils, though the actual inputs are thought to be very small (Beadle and Tchan, 1955; Rixon, 1970).

Charley and Cowling (1968), commenting on the depleted nutrient capital in eroded soils, maintain that infertility is likely to be as important as hydrological and structural soil changes in restricting regeneration. When surface layers have been removed, very small quantities of phosphorus are available in the subsoil for plants; this limits growth and where legumes are involved nitrogen input is consequently retarded.

Most of the work cited above relates to species or situations found in south-eastern Australia. In addition, Hellmuth (1968, 1969, 1971) has carried out ecophysiological studies on ten Western Australian arid zone plants, of which *Rhagodia baccata* and *Acacia tetragonophylla* also occur in south-eastern arid or semi-arid areas.

CHAPTER V

ARID VEGETATION AS RANGELAND

Rangeland ecology may be defined as the science of interactions between a naturally maintained plant community and extensive controlled grazing by stock. It includes (i) the quantitative effect of stock on vegetation associations, aspects of (ii) dietary selection by stock, and where feasible (iii) the manipulation by man to provide optimum feed.

QUANTITATIVE EFFECT OF STOCK ON VEGETATION ASSOCIATIONS

Much of the prolific American research in this field has little relevance to the Australian situation other than for the development of quantitative techniques which may be applicable. A review is presented by Ellison (1960) covering some forty years of such work.

In Australia, however, rangeland ecology is a relatively young science (see Perry, 1967). The general effects of pastoralism have been referred to in studies of vegetation associations in varying degrees of detail (see Chapter IV). Research dealing solely with the dynamics of interaction between populations of native plants and introduced stock, raised for economic gain, originated with the South Australian work of Osborn, Wood and Paltridge (1932), already cited on p. 3. Their work on zonation round water-points concluded with the observation that moderately heavy stocking, as encountered in the main feeding grounds of the sheep, stimulates the health and vigour of salt-bush; they consequently advocate a policy of heavy stocking followed by spelling to allow recovery of bush. Some ten years later the Yudnapinna experiments were set up (Woodroffe, 1941). The results show (Trumble, 1952; Trumble and Woodroffe, 1954) that on continuously the heavily grazed plots there is an extraordinary increase in weight of bluebush, which suggests a parallel with Osborn, Wood and Paltridge's observation. However, the appearance of the stocked and unstocked bluebush in the photographs accompanying the second paper, belies this statement. Little information is given as to how the data were handled to achieve this result.

The reaction of *Danthonia caespitosa* to grazing in the Riverina is described by Williams (1968b). Although the community is degraded he suggests that it is currently in a "steady state" with the grazing animal, and maintains that the present stocking rate is the same as that which brought about the original degradation. He examines the response of plants in such communities by means of Response and Grazing Pressure Indices (Williams, 1969).

BEHAVIOUR AND DIET OF STOCK

Studies on this subject are, at present, rather exploratory and their usefulness in arid rangeland work has yet to be assessed. Although Tribe (1953) has questioned the value of grazing behaviour research in understanding pasture management, it may yet prove its worth in the prediction of which vegetation types are grazed preferentially by stock; for this reason a brief review of some of this research is included here.

Stock behaviour is affected by the inherent vegetation pattern, which determines where the most valuable fodder is, and in arid areas by the position of the water-point (Osborn, Wood and Paltridge, 1932; Squires, 1970) and fences. Hunter (1964) observed the home range behaviour of hill sheep in Britain, and Rawes and Welch (1969) point out the usefulness of dung in assessing the numbers of sheep grazing in a particular area. Lange (1969) working in an arid environment used sheep pellets to determine the piosphere, which he defines as:

> ".... a region centred on a water point in arid zone vegetation, in which interactions exist between the reliance of stock upon the water-point and their capacity to range radially for food." (Barker and Lange, 1969a).

The usefulness of aircraft in plotting sheep movements has been displayed by Dudzinski, Pahl and Arnold (1969).

The assessment of fodder use by stock can also be approached from dietary studies which may help in predicting grazing pattern. In purely qualitative terms much information can be gained from examination of stomach contents and faeces (Storr, 1961; Martin, 1964; Chippendale, 1968). The development of oesophageal fistula techniques is described in detail in the American literature by Cook, Thorne, Blake and Edlefsen (1958), Weir and Torrell (1959), Edlefsen, Cook and Blake (1960), Van Dyne and Torrell (1964) and Harker, Torrell and Van Dyne (1964).

This has been followed by work in Australia by Arnold and Bush (1963), Arnold, McManus, Bush and Ball (1964) and Grimes, Watkin and May (1965) using the technique in humid zone pastures. Leigh and Mulham (1966a and b, 1967) and Robards, Leigh and Mulham (1967) used the method in the semi-arid Riverina communities described by Moore (1953a and b) and Williams (1955, 1961a). Leigh and Mulham showed that the minor herbaceous constituents of these pastures made up the majority of the diet, until they had been grazed out, when the perennial bush (*Atriplex vesicaria, A. semibaccata, Kochia aphylla* and *K. pentogona*) were eaten. There can be little doubt as to the conclusions reached in these studies, although the usefulness of oesophageal fistulae in assessing absolute quantities of matter eaten must be regarded with caution. The author (unpublished results) achieved 70% recovery of total matter taken in. The remainder may by-pass the fistula or may be lost in the sample washing process. J. Marshall (pers. comm.) considers that recovery from an oesophageal fistula can be satisfactory; she found that the hand separation method of estimating components of the forage sample was not reliable, accuracy depending on the species composition of the forage. The technique does, nevertheless, give some indication of dietary preferences.

IMPROVEMENT OF PRODUCTIVITY

The most favourable environment for such work is in the semi-arid areas. Saltbush is believed to be highly nutritious on account of its relatively high protein content (see Wood, 1933). This does not mean, however, that it is the best feed under all conditions. Wilson (1966a) maintains that although species of *Kochia* and *Atriplex* have some value as feed, *A. vesicaria* has a lower protein content in summer than at other times of the year. Wilson, Leigh and Mulham (1969) point out that as *A. vesicaria* disappears in the Riverina, *Danthonia caespitosa*, which takes its place, provides good feed in the spring, giving maximum wool growth then. If such a pasture can be maintained in semi-arid areas without saltbush, stock would not need to drink so much water to overcome the high salt concentrations in saltbush (Wilson, 1966b). (It should be noted that in the more arid areas the grass dominants of these disclimax communities behave as ephemerals.)

The possibilities of improving dryland pastures by sowing native or exotic species has been discussed by Williams (1960), Jones and Muirhead (1966), Muirhead and Jones (1966), Leigh and Davidson (1968) and Whalley (1970). It seems likely that species introduced into arid or semi-arid areas of south-eastern Australia would only have limited benefits.

Williams (1961b) comments on the thinning of trees to allow rainfall to further encourage the growth of grasses and shrubs (see Plates 1a and 1b). In semi-arid areas this may be acceptable and even necessary (Anon. 1969b), but the practice must be of questionable value in arid areas, where trees are important as drought reserve fodder and as a means of combating erosion.

The long term re-establishment of perennial shrubs in degraded pasture has been examined in fenced vegetation reserves, principally those at Koonamore (Osborn, 1925; Osborn, Wood and Paltridge, 1935; Wood, 1936; Hall, Specht and Eardley, 1964) where a long period of stock exclusion has been documented, and at Broken Hill, where the results of the first two years of exclosure were recorded (Pidgeon and Ashby, 1940). Such experiments demonstrate the slow recovery of natural vegetation to something approaching the original climax, in situations where seed reserves remain. It is unlikely that the dominant climax shrub *Atriplex nummularia* would ever regenerate naturally in the Riverina, where most seed sources were destroyed in the 1860's.

Severely degraded and eroded pastures in western New South Wales have been assessed for grazing capacity (see Condon, Newman and Cunningham, 1969); stocking rates have been suggested and the importance of water-point location in different soil and vegetation types has been stressed. Jones (1966a and b, 1967) has reported on the re-vegetation of scalds by natural means and by ploughing and water-ponding in the Riverina of New South Wales, whilst in South Australia disc-pitting has been tried as an aid to regeneration (Young, 1969).

No other manipulative research has been reported in South Australia. Deliberate sowing of species is likely to be less successful in the arid areas of this State, than it is in the semi-arid Riverina.

* * * * * *

Although the Review chapters may be criticised for covering topics which appear to be rather peripheral to the present one, the different factors shaping land use in arid areas and determining the scope (in economic and technical terms) for future research must be appreciated by rangeland ecologists.

The arid environment is one which man has always had difficulty in manipulating (see p. 5). Improvement of plant productivity by fertilisers, irrigation or plant introduction is difficult, possibly dangerous and probably uneconomic. Productivity in arid Australia thus tends to be based on native species. Their inherent advantages have long been recognised.

> "It seems reasonable to suppose that in our peculiar climate, subject to periods of continued drought, and having in many cases soils peculiarly saline, that the plants which have withstood these influences for ages past would be more reliable than others developed under different conditions of soils and climate." (Dixon, 1880).

The consequences of exploiting native shrub and grass pastures in Australia were also noted in the nineteenth century.

> ".... it has been too much the interest of everyone to let the sheep and cattle of today eat the best there is even if they destroy it off the face of the earth, *without regard for what those of tomorrow will do*." (Dixon, 1880; my italics).

The adoption of conservative stocking policies is essential, but there is little information in the reviewed papers which is helpful to station managers who have the responsibility of maintaining plant productivity. This is not to criticise the published work, but rather to point out that in the broad spectrum of arid zone research there has been relatively little directed towards the practical problem of maintaining a balance between native vegetation and introduced stock.

Thus from the author's point of view also, there appear to be few "hard facts" in comparison with the volume of publications. Anyone seeking definite guidelines on a specific topic is unlikely to find them in the literature, but is made aware of numerous generalised statements. It is felt that the Review provides a valuable background; as such it demonstrates clearly that, because of the wide variation in physical conditions and cultural history within the arid zone, generalisations must be avoided, as techniques and observations applicable to one area cannot apply to all.

CHAPTER VI

REVIEW OF TECHNIQUES FOR IDENTIFYING VEGETATION PATTERN

To introduce this chapter, it must be pointed out that there is an enormous quantity of literature relating to the identification of pattern in vegetation. The review given here is, therefore, only a selective one, made with the object of choosing a suitable technique for handling the data derived in the present investigation.

The recognition of pattern in vegetation is fundamental to ecological studies and is based on the following consideration. Ecology involves the study of interrelationships and when dealing with vegetation, this implies spatial pattern. As pattern, i.e. departure from randomness, in turn implies (significant statistical) differences between groups of samples, then such (statistical) differences, if found, point to the existence of pattern and thus to relationships.

In the last 20 years there has been a change in approach to ecology, not in the basic line of thinking about relationships, but in the way inferences are made, i.e. whether subjectively or objectively. For instance, Watt's (1947) demonstration of the relationship between pattern and plant processes is an example of the subjective approach. Since then objective statistical methods for detecting relationships have been given emphasis; the majority of such methods have been discussed by Greig-Smith (1964).

The general causes of pattern are ascribed by Kershaw (1959b) to plant morphology, plant sociology and physiography (slope, soil, etc.). He makes the point that in a climax community in a uniform environment (with no physiographic effects - an idealised situation), the pattern present is solely morphological; sociological pattern is only present in the seral stages.

One form of analysis for identifying pattern has been developed by Kershaw (1958, 1959a and b). He and Greig-Smith (1961) plot in graph form the variance of parameters of population as a function of block size, the position of peaks on the graph indicating the scale of pattern. These authors use density, and then frequency and cover for finding morphological patterns in stoloniferous and tussock grass communities. The technique has since been used to determine scales of other types of pattern in vegetation. Anderson (1967) and Anderson, Jacobs and Malik (1969) found large scale pattern in *Atriplex vesicaria* communities in Australia, which they believe to be related to environmental (physiographic) features. Greig-Smith and Chadwick (1965) examining *Acacia-Capparis* semi-desert scrub in the Sudan, discovered little evidence of patterning using this technique. They comment that the physiographic pattern engendered by a watercourse "... caused considerable heterogeneity; pattern analysis of this type is not entirely appropriate to heterogeneity of this degree". It is difficult to see how this technique can lead to any practical application.

Kershaw's approach to the identification of pattern in the grid analysis described above, depends on block size (i.e. quadrat or sample size) being varied. Other techniques which have been developed for detecting pattern depend instead on the information contained in fixed-size quadrats.

These methods classify vegetation by separating similar quadrats from dissimilar ones according to the information about interrelationships of the species that the quadrats contain. This can be done in either of two ways. The view can be taken that there are 1, 2, 3 ..... *n* discrete groups to which quadrats may be assigned; the main techniques of such divisive classifications do not attempt to relate these groups to each other. The alternative view is that a search for such discrete groups is not profitable, since the more natural concept is of a linear continuum along which each quadrat (sample) has a place. The process by which stands of vegetation have been arranged into a continuum in phytogeographic studies is called ordination. For example, Curtis and McIntosh (1951) develop an analysis from which a continuum is established using "importance value", the definition of which is supposed to reflect the relative contribution of components to the total vegetation. A similar gradient analysis has been carried out by

Bray and Curtis (1957), whereas Whittaker (1960) applies an obverse line of argument. Where Curtis and co-workers set up their ordination strictly on vegetation data and then relate it to the environment, Whittaker sets up an environmental ordination against which he examines vegetation. Goodall (1954) uses factor analysis for the purpose of ordination. Results of these techniques are plotted along axes in two or more dimensions.

Yarranton (1967) comments that correlation of the results of ordination methods with environmental variables does not demonstrate the relationships between a single species and the environment, as species are handled collectively. Of ordination he says, "Correlation of the results with environmental variables either is subjective or involves parameters derived from data concerning all species".

Before leaving this discussion of classification by ordination (continuum analysis) it should be pointed out that Lange (1968) showed that some features of ordination can be used simultaneously with divisive classification, features of which are to be described in the following paragraphs.

The divisive classification pioneered by Goodall (1953) for studying plant communities has three distinguishing features. (1) Incidence data only are used. (2) The data are analysed by contingency tables for identifying association between species. (3) Such information gained about interspecific association is used to sort the vegetation samples into a single set of discrete groups. This is done in the following way. In each of 1 to n quadrats distributed through a plant community by restricted randomisation, the presence or absence of 1 to m species is recorded. Contingency tables are drawn up and the corresponding χ^2 values for all possible pair-wise associations of species are noted. These values amount to the objective basis for the decision about existence of relationships. Of the paired associates, that pair having the highest significant value is found and the most frequent species of that pair (say, R) is selected.

The original n quadrats are then divided into those with R and those without R. For the group containing R, the above procedure is repeated and subdivision may be according to the presence or absence of species J. Again the process is repeated on the group containing R and J until a group of quadrats is isolated in which there are no interspecific associations (above a certain preselected significance level). This group is said to be homogeneous as the species within it do not depart from random with respect to mutual occurrence in its quadrats. The group may be called, say, A.

The accumulated quadrats not containing R, J .... are then pooled and the whole process repeated on them such that a number of mutually exclusive groups A, B .... are eventually achieved. The groups A, B .... are finally combined in all possible pairs to see if significant interspecific interactions are restored; if not, then the groups concerned are amalgamated. Thus single classification of all species into discrete groups is obtained, and when mapped the field disposition of such groups may indicate correlated environmental features.

Williams and Lambert (1959) following on from Goodall's work similarly separate quadrats into groups A, B .... which are also regarded as homogeneous. They do not, however, use Goodall's most frequent species for subdividing the quadrats. Instead the species which has the highest sum of χ^2 values produced by its associations with each other species in turn is used for subdivision. That species (S) is used to separate the n quadrats into one group with S and one group without S. The procedure is then repeated on both these groups (not just the positive group as in Goodall's strategy) and may result in subdivision. The sub-groups are similarly handled until end-groups are isolated, within each of which no species sum of χ^2 values is above a preselected significance level. The mapped disposition of these groups resulting from this association analysis may, as with Goodall's strategy, indicate causative environmental features.

Lange (1966, 1968) and Wellbourn and Lange (1967) criticise some features of these methods and suggest alternative points. In a complex vegetation, there is a web of interspecific associations. No single classification, however derived, adequately describes all the information which can be obtained separately from different parts of the web. As some of the information from parts of the web may be independent, Lange (1968) argues that these should be analysed separately, - by a multiple classification, in order to portray all the information which could be derived. He then argues that the information in these separate elements may be expressed as a linear continuum, claiming that quadrats so classified by virtue of sequential relationships between them, display the underlying influence (cause) better than a series of discrete groups not so related; this strategy is called influence analysis. The relative merits of, for example, Williams and Lambert's and Lange's system of back plotting of classified quadrats may be judged from Figs. 2 and 4 in Lange (1968).

The success of these methods is obviously dependent on sampling techniques i.e. on size and shape of quadrat and on their intensity and layout in the study area. Some of these questions have been discussed in connection with the concept of minimal area. This refers to the fact that the number of species usefully sampled first increases with increased sample size up to some value, after which further increase in number of species is less for equivalent sample size increase. This value, called the minimal area, is said to represent the most efficient quadrat to use. Similar relationships suggest a minimal number of quadrats to use. Although an appreciation of these ideas is necessary to give an indication of the sampling unit required for a certain vegetation type, the chosen one does not always represent the minimal area, as a requirement for information at whatever cost, rather than efficiency, is the criterion upon which such choices are made. Goodall (1961) was unable to find a minimal area in the Victorian mallee of Australia; Greig-Smith (1964) indicates that his attempts are, in fact, a determination of the scale of pattern. As scale and intensity of pattern of different species affect the minimal area, Greig-Smith concludes that the concept has little practical value; once minimal area has been determined (by empirical methods) it does not necessarily indicate a suitable sample size for all parameters.

Shape of quadrats has also been discussed in the literature (see Greig-Smith, 1964). Davies (1931) shows that a long narrow quadrat tends to minimise variance associated with the mean when yields are estimated. Clapham (1932) makes a similar observation and suggests that in non-random situations such rectangular quadrats should be placed at right-angles to any possible boundaries.

Regarding layout of quadrats, a simple grid is obviously the most easy to establish, whereas randomisation is time-consuming. A random layout is essential where one is attempting to establish a population mean and variance, but for contingency tests it is not strictly necessary.

This review forms the basis for the decisions regarding sampling techniques and methods of analysis employed in the present investigation of changes in vegetation pattern brought about by sheep grazing. These decisions are outlined in the next chapter. Before concluding, it is interesting to note in some work by Goodall (1967) a possible future trend in the analysis of pattern. He attempts to construct a computer model for predicting changes under grazing. In view of the variability and unpredictability of the grazing situation, it is difficult to see how such models can be of much practical use to the station manager in the real world, at this stage of their development.

CHAPTER VII

RESEARCH OBJECTIVES

Chapters II, IV and V have indicated that in New South Wales, where many areas have been denuded of their original bush and perennial grass cover, much effort has been devoted to exploring means by which damage wrought in the nineteenth century can be repaired. In South Australia similar damage was not as severe, so that present concern is with preserving shrub vegetation, which, in providing a perennial bush cover, contributes substantially to the stability of manipulated arid ecosystems.

Although there will always be a role, if a diminishing one, for descriptive ecology, it is essential that future research in South Australia is aimed at making quantitative estimates of grazed vegetation which still, as far as is known, resembles the ungrazed state. From such analytical studies it will not only be possible to determine the spatial extent of degradation, but also to identify the plant indicators of degeneration. With such information it may be possible to predict the consequences to arid zone vegetation (other than complete destruction) if pastoralism continues, and to suggest means of alleviating such effects. In addition, such estimates repeated over periods of years or decades would undoubtedly be an incontrovertible means of monitoring gradual changes in vegetation resulting from continued grazing.

Long term studies are outside the scope of this thesis. However, at any one time gradations in population structure resulting from variations in past stock intensities can be studied very simply; it is best approached in terms of Osborn, Wood and Paltridge's (1932) idea of stock pressure gradient and concomitant vegetation zoning round water-points. Lange (1969) called the area in which such stock/water-point/vegetation interactions occurred, the piosphere. From a theoretical point of view this situation leads to considerations such as those shown by Fig. 6; if such an ideal situation exists, then under the conditions specified, the first few hundred yards from water could display distinct vegetational changes. It is the object of this thesis to find the actual extent and nature of such changes in various piospheres.

Several points were taken into consideration in deciding upon a suitable analytical method for tackling this problem. First, only shrubs and annual/biennial forbs were to be sampled. Grasses were excluded as these will always grow if there is sufficient moisture and will be preferentially grazed; shrubs are the plants which provide essential reserves for dry periods and are, therefore, of paramount importance to the pastoralist in maintaining continual productivity. Second, the majority of field sampling had to be accomplished single-handed and as the

FIGURE 6

Variation in use of a paddock by stock, with increasing distance from water

The object of these graphs is to show the order of difference between stock-use of areas close to a waterpoint and stock-use of areas in more distant parts of a paddock.

The graphs are based on a number of purely hypothetical assumptions; firstly, that

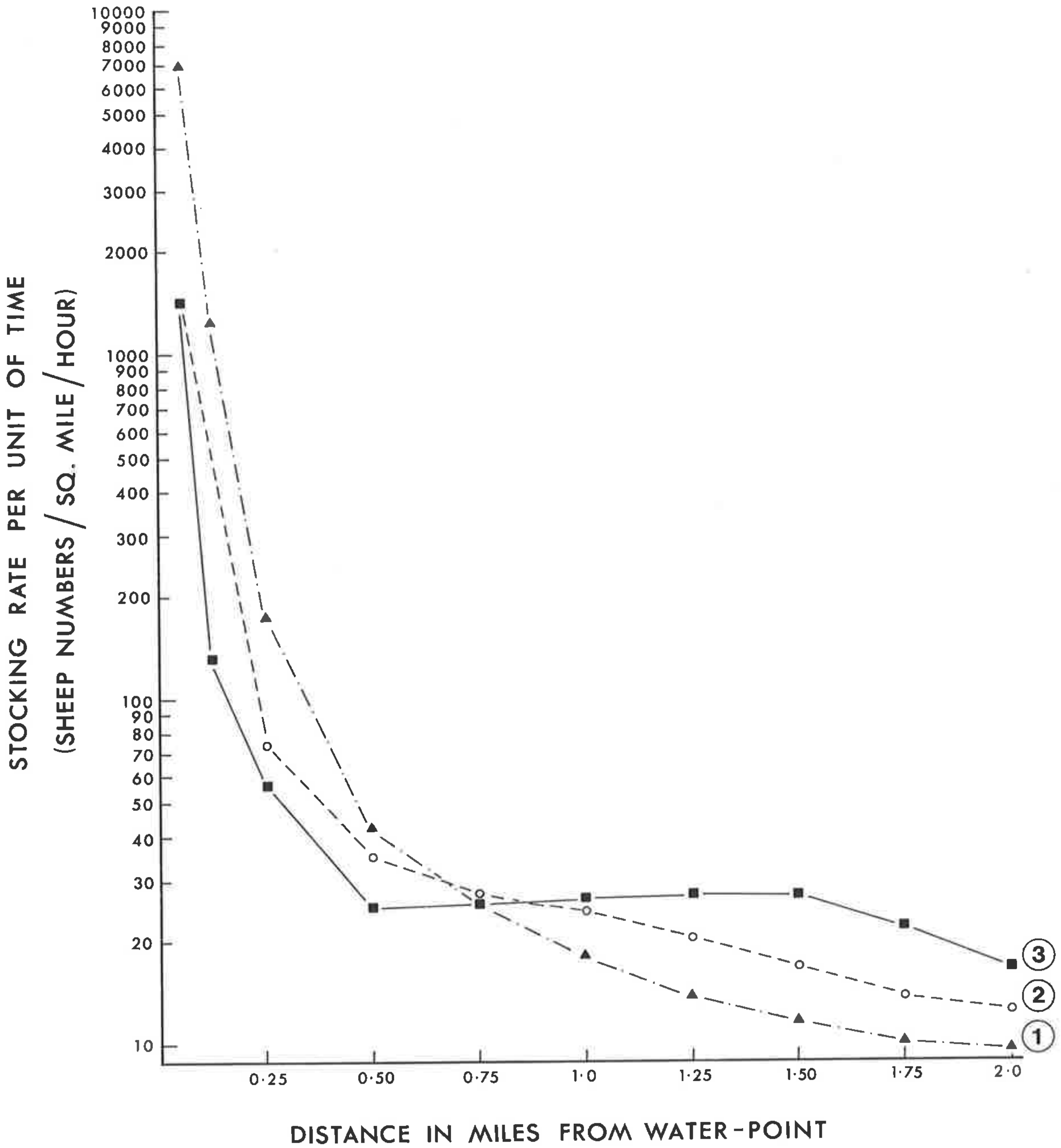
(a) the paddock has an area of 16 square miles (4 × 4 miles) and has a central water-point,
(b) the paddock contains 250 sheep,
(c) they drink only once per day,
(d) with the water-point as the focus, the paddock consists of 10 concentric zones,
(e) having had a drink the sheep disperse radially through these concentric zones up to a distance of 2 miles from water,

and secondly, that in any 24 hour period, three alternatives be considered;

(1) the sheep spend an equal amount of time in each of the zones (d, above), as in column (1) below,
(2) the sheep spend most time in the further zones of the paddock, as in column (2),
(3) the sheep spend most time at some intermediate distance, as in column (3).

Distance in miles from water	Time spent in each zone in hours		
	(1)	(2)	(3)
0.00 - 0.06	2.4	0.5	0.5
0.06 - 0.12	2.4	0.5	0.25
0.12 - 0.25	2.4	1.0	0.75
0.25 - 0.50	2.4	2.0	1.25
0.50 - 0.75	2.4	2.5	2.5
0.75 - 1.00	2.4	3.5	3.5
1.00 - 1.25	2.4	3.5	4.75
1.25 - 1.50	2.4	3.5	5.5
1.50 - 1.75	2.4	3.5	3.0
1.75 - 2.00	2.4	3.5	2.0

The three situations (1), (2), (3) specified in the table above correspond with the graphs (1), (2), (3) opposite.


STOCKING RATE PER UNIT OF TIME
(SHEEP NUMBERS / SQ. MILE / HOUR)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
0·25
0·50
0·75
1·0
1·25
1·50
1·75
2·0
DISTANCE IN MILES FROM WATER-POINT
3
2
1

nature of the study involved fairly extensive areas, a simple sampling method had to be adopted. Third, as it was essential to be able to distinguish the areal extent of an imposed pattern from that of a natural one, data which could be mapped easily were also desirable.

These points were resolved in the following way. Cover, estimated either by linear measurement (Greig-Smith and Chadwick, 1965) or by point frame methods (Goodall, 1952), biomass or productivity (Pechanec and Pickford, 1937), and canopy volume (Culver and Till, 1967) are all parameters requiring a considerable amount of time for data collection and were, therefore, excluded from further consideration. Some techniques, such as point frame estimates for cover, were inappropriate for the vegetation type being considered.

Density and incidence data are, however, collected relatively rapidly. Density data may be mapped directly to give a visual picture of population variation. Incidence data may be subjected to simple statistical tests the results of which may be mapped. Such techniques have been described by Goodall (1953) and Williams and Lambert (1959) and modified by Lange (1968). Density and incidence were, therefore, the parameters used to identify vegetation pattern in this study, using Lange's (1968) influence analysis for handling the incidence data.

The data were collected on a radial sampling grid centred on the water-point. Although this may seem to provide biassed data, the situation is biassed in itself. The increasing numbers of samples per unit area close to water, means simply that several quadrats sample an area which, on a criss-cross grid, might only be sampled by a few; it does not alter the outcome of the classification of quadrats on influence rating. Under the conditions used to plot the graphs (Fig. 6) it is clear that in the first 400-800 yards (metres) the gradient of change is likely to be very steep. It was later found that the sample bias was not great enough to register this rapid change; it became necessary as the work proceeded to strengthen the bias even further by increasing the number of quadrats in this area.

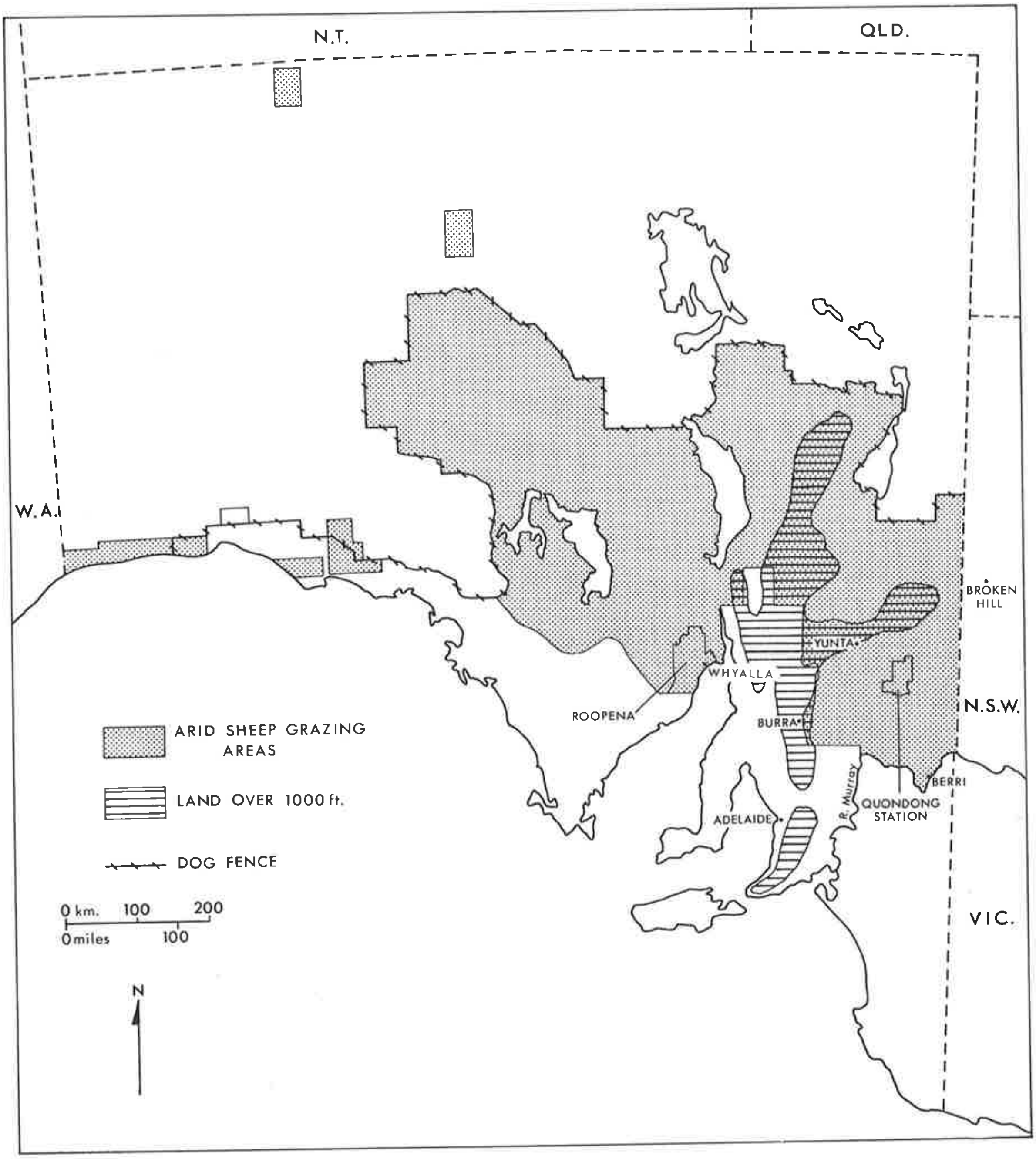
The work was carried out in the easily accessible southern arid areas of the State, about 200 miles (approx. 300 km) north of Adelaide. By comparison with more northern sheep grazing regions they have a slightly higher rainfall and are composed of more or less continuous bluebush or saltbush-*Acacia* or *Casuarina* woodland associations, with very little herbage, compared with the grassy mulga sandhills and gibber plains of the north.

In the first instance it was necessary for the author to become acquainted with the type of vegetation encountered in the Australian arid zone. This was accomplished on Quondong Station, north-east of Burra (Fig. 7); initial sampling of water-points was also carried out here. In general the area consists of black oak-

FIGURE 7

Locality diagram

indicating the sheep stations where field investigations
were carried out


N.T.
QLD.
W.A.
BROKEN HILL
YUNTA
WHYALLA
ROOPENA
BURRA
N.S.W.
BERRI
R. Murray
QUONDONG STATION
ADELAIDE
VIC.
ARID SHEEP GRAZING AREAS
LAND OVER 1000 ft.
DOG FENCE
0 km. 100 200
0 miles 100
N

bluebush woodland with occasional mallee dunes. The majority of the work was carried out on Middleback and Tregalana Stations (shown together as Roopena in Fig. 7) south-west of Port Augusta, where the vegetation is a myall-saltbush or myall-bluebush woodland with patches of black oak. The two areas have similar environmental features and are separated by only 180 miles. They are similar enough for the same research procedures to be applied, but comparisons between the two areas, which may be made in future chapters, demonstrates the caution with which generalisations about the arid zone must be regarded.

The following chapters comprise the original work of this thesis, which was initiated by a detailed survey of Quondong Station.

CHAPTER VIII

QUONDONG STATION : AN EXAMPLE OF THE RANGELAND ENVIRONMENT

INTRODUCTION

In South Australia, a sheep station comprises an area of arid zone country, which being Crown Land, is leased from the State Government, for the production of wool from Merino sheep. It may cover an area within the approximate range 100-3,500 square miles (64,000-2,000,000 acres; 250-9,000 sq. km), and is subdivided into large paddocks up to 50 square miles in area. It is the equivalent of a large American ranch. The station is generally managed by a resident manager and possibly one or more overseers. The differences between one station and its neighbours in a particular area are most probably accounted for by past and present management regimes, which may affect the landscape considerably. For this reason the rangeland ecologist tends to regard the station as a discrete unit, rather than as part of a landscape continuum.

This chapter, some of which has already been published (Barker, 1970), describes the type of environment in which pastoralist and ecologist have to work, the one, guided by experience and intuition, determining the landscape changes the other has to assess objectively. Of the subject matter presented here, some is basic data concerning the climate, soils, geology and hydrology, which has been reported by other authors or is readily available from Government departments. Most is original observation on topography, soils and vegetation. The method by which such information was obtained is also reported.

CLIMATE

As may be deduced from Chapter III the dominant climatic feature of Quondong is the low rainfall. The average annual rainfall recorded on the Station for the period 1955-70 is 723 points (Table 4); no data is available prior to this date. The occurrence of rain is most erratic, more so, for instance, than in coastal arid areas of the State, which are considered to be more reliable pastoral areas (Commonwealth Bureau of Meteorology, 1961). Although the figures are variable it appears that on average most rain is received in May and least in October. The figures given are those for the homestead; other parts of the station may receive different rainfalls, but records of these rainfalls are not kept.

Data concerning temperature to which evaporation rate is directly related are shown in Table 5 for Yunta, which is the

TABLE 4

RAINFALL IN POINTS
(by courtesy of the Pastoral Board)

QUONDONG 1955-70

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1955	0	343	175	31	250	150	4	83	111	27	66	4	1,244
1956	0	0	244	77	130	63	147	17	78	38	53	0	847
1957	0	252	20	0	17	270	4	68	18	64	15	96	824
1958	-	-	-	-	-	-	-	-	-	-	-	-	-
1959	5	51	93	0	47	0	56	31	17	111	0	33	444
1960	17	28	23	53	75	13	152	56	113	0	139	0	669
1961	0	47	5	109	22	0	26	49	67	5	255	115	700
1962	233	0	88	0	128	26	9	62	0	31	0	279	856
1963	156	0	3	88	178	164	86	66	0	50	10	46	847
1964	42	0	0	48	29	21	0	60	321	3	7	71	602
1965	0	-	-	0	15	52	61	54	66	0	28	107	383
1966	32	78	32	0	63	46	28	0	47	36	60	174	596
1967	32	143	19	0	16	11	11	66	24	0	0	0	322
1968	240	39	33	107	107	105	121	60	0	21	0	25	858
1969	46	286	133	6	76	22	108	7	55	158	27	0	924
1970	33	0	12	163	15	16	10	92	181	36	155	25	738
Mean	56	84	59	45	78	64	55	51	73	39	54	65	723

nearest recording station to Quondong. The hottest months, January and February, have maxima of 90°F (32°C) and the coolest months, June and July, 61°F (16°C) and 58°F (14°C) respectively. Extreme maxima and minima indicate the range of temperature which can be

TABLE 5

TEMPERATURE IN °F (by courtesy of the Bureau of Meteorology)												
YUNTA 1951-65												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Av. max.	89.8	89.7	82.5	74.1	66.9	61.2	57.5	61.5	66.3	72.9	82.6	84.0
Av. min.	57.5	58.1	53.5	47.3	42.3	38.3	36.8	39.5	41.2	46.6	52.3	54.2
Av. mean	73.7	73.9	68.0	60.7	54.6	49.7	47.1	50.5	53.7	59.7	67.5	69.1
Extreme max.	115.0	110.0	105.0	93.3	82.0	75.0	73.0	83.0	98.0	104.0	108.0	111.0
Date	2/60	28/65	18/65	2/54	1/58	19/60	27/60	11/59	29/65	20/65	30/62	19/65
Extreme min.	44.0	40.0	34.4	30.0	25.0	20.0	20.0	23.0	26.4	33.7	34.0	35.4
Date	1/56	29/58	22/56	15/63	24/57	17/59	9+10/59	8/62	27/53	4/53	3/65	11/52

experienced in the region. The annual potential evaporation from a free water surface is approximately 75 inches (2000 mm) (see Fig. 4).

Wind direction, which is said to affect sheep behaviour, has also been recorded at Yunta (Table 6). During the warmer

TABLE 6

% FREQUENCY OF WIND DIRECTION AT 0900 HR
(by courtesy of the Bureau of Meteorology)

YUNTA 1962-63

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
N	3	9	3	2	1	7	2	3	7	3	10	12
NE	14	7	2	5	10	8	3	3	3	10	17	7
E	2	1	0	2	0	0	2	0	1	0	2	0
SE	45	54	54	30	20	2	8	11	27	34	24	51
S	0	0	3	3	5	0	2	3	2	3	7	6
SW	13	18	17	25	20	17	18	18	27	24	26	12
W	2	0	0	0	5	5	3	8	5	3	0	0
NW	16	9	13	14	24	32	38	36	25	18	12	7
CALMS	5	2	8	19	15	29	24	18	3	5	2	5

months the prevailing winds are from the southerly quarter, whereas in winter, winds are more frequent from the north-west.

GEOLOGY

Quondong Station lies in the northern section of the Murray Basin and although this comprises more than one third of the Basin within South Australia, its geology is not well known. Most of the details given here are from O'Driscoll (1960) and Ludbrook (1961), whose information is based on only 25 bore logs from the area.

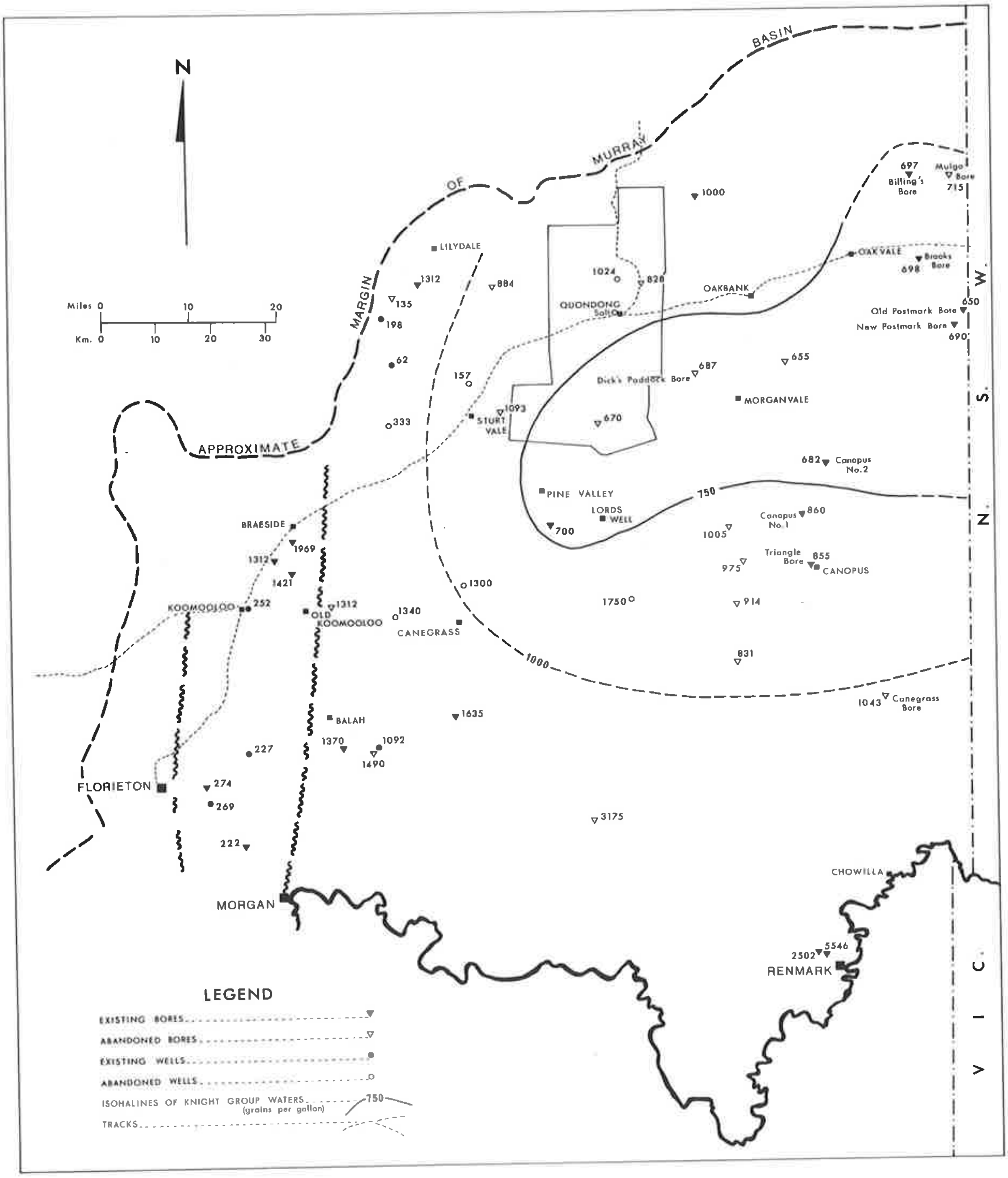
This part of the Murray Basin is bounded to the north and west by the arc of the Mount Lofty and Olary Ranges, where Palaeozoic and Proterozoic rocks outcrop, the nearest to Quondong Homestead being about 25-30 miles (40-50 km) north-west. These strata dip away under later deposits and are not recorded in bore logs north of the river, although it is thought that bedrock is not far below the bottom of the Canopus No. 2 Bore, which is 1004 feet (302 metres) deep (see Fig. 8).

The Basin is infilled with Tertiary and post-Tertiary sediments, the lowest of which (north of the river) is the Knight Group, consisting of littoral deposits of silty sands, gravels, clays and carbonaceous marls of mid- to upper Eocene age. Marine inundation during the Oligocene extended at least as far north as Canopus Station and was responsible for the deposition of the next layer of sediments, the Glenelg Group, which are principally marls.

FIGURE 8

Salinity plan of the northern Murray Basin

after E. P. D. O'Driscoll (1960)


N
Miles 0 10 20
Km. 0 10 20 30
APPROXIMATE MARGIN OF MURRAY BASIN
LILYDALE
QUONDONG
Salt
OAKBANK
OAK VALE
Brooks Bore
Billing's Bore
Mulga Bore
Old Postmark Bore
New Postmark Bore
Dick's Paddock Bore
MORGANVALE
STURT VALE
PINE VALLEY
LORDS WELL
Canopus No. 2
Canopus No. 1
Triangle Bore
CANOPUS
BRAESIDE
KOOMOOLOO
OLD KOOMOOLOO
CANEGRASS
Canegrass Bore
BALAH
FLORIETON
MORGAN
CHOWILLA
RENMARK
750
1000
N. S. W.
V I C.
LEGEND
EXISTING BORES
ABANDONED BORES
EXISTING WELLS
ABANDONED WELLS
ISOHALINES OF KNIGHT GROUP WATERS (grains per gallon)
TRACKS

The most extensive inundation of the Murray Basin took place in the early Miocene; then, and during the estuarine Pliocene the Murray Group of limestone sediments were laid down. A Pleistocene fresh-water lake in the northern Murray Basin is referred to by Firman (1965) as Lake Bungunnia. According to Firman's map the lake would have extended over the southern half of Quondong Station. The Blanchetown clay and Bungunnia limestone deposits recognised by Firman are overlain by Recent aeolian dunes, containing calcrete layers.

SOILS

General description

The soils of Quondong have been mapped and described in the Atlas of Australian Soils (1960). A wide region of the northern Murray Basin is covered by what are described by Northcote (1960) as; "Plains with more or less isolated tracts of dunes; broad plains of brown calcareous earths ... with areas of exposed caliche and crusty loamy soils ... with claypans, saline soils, swamps and intermittent lakes in the lower lying portions, dunes of brown sand and brown calcareous earths".

Some of the Recent aeolian dunes possess highly calcareous solonised soils classified by Northcote (1965) as Gcl.12. A high proportion of calcium carbonate occurs both in the A horizon and in lower layers, where nodular or massive calcrete may be found. In the far south-east of the Station are deep sandy dunes, recognisable from the vegetation map (Map 7) by the presence of mallee. These have soils classified as Uc5.11.

Patterned ground

Although it was not intended to carry out any investigations of the soils of Quondong, the occurrence of an unusual phenomenon is described briefly here. It was in the solonised soil type (Gcl.12) that massive patterned ground was observed. Literature concerning types of patterned ground both in Australia and overseas has been reviewed by the present author in a paper reporting the discovery of the Quondong pattern (Barker and Lange, 1969b).

The phenomenon was first observed during a ground survey of the vegetation of Quondong, when straight-sided channels 1-1½ feet (0.5 metres) wide by 3-12 inches (8-32 cm) deep and up to 60 feet (20 metres) long were noticed. Examination of aerial photographs revealed whole systems of these channels or gutters forming a roughly polygonal pattern (see Plate 2). Each polygon was approximately 150-300 feet (50-100 metres) across, dimensions which are far in excess of other patterned ground mentioned in the literature. The characteristic puff appearance of gilgai was absent, though the vertical sides of the channels gave the impression that rifting might have occurred; there was no evidence of sorting of stones from fines, even though nodular calcrete occurs a few inches below the ground surface. The ground in the area does not undulate but slopes gently to the south-east where there is a small swamp about three quarters of a mile away.

A limited investigation was carried out, the results of which are outlined here. Two soil pits were dug to a depth of approximately 3 feet (1 metre) across two of the channels, one a well formed channel 1 foot (0.3 metre) deep (see Plate 3) and one a shallow gutter (see Plate 4) 4 inches (10 cm) deep. Below both the channel and the gutter was a narrow vertical trench apparently infilled with material which may be from the top of the profile. This vertical trench was remarkable for its straight sides and flat bottom.

The gutter was given further examination and samples from the centre of the gutter through the infilled section (Profile 1) and from the undistrubed section to one side (Profile 2) were subjected to chemical and physical analyses (see Table 7). Although the profiles are similar, the analyses show differences that are of interest. In the infilled trench there is a higher percentage of organic carbon throughout the profile, and lower percentages of calcium carbonate and clay in the 11-19 inches (28-43 cm) horizon,

TABLE 7

SOIL ANALYSIS DATA FOR GUTTER PROFILE

Location Quondong Station, N.E. of South Australia. Chowilla 1:250,000 map (S1 54-6) grid ref. 327291 140°17'E and 33°00'20"S.

Profile 1 Samples taken from infilled trench below gutter.
Principal profile form Gc1.12

Depth	Description	% Clay	% Total Soluble Salts	% Organic Carbon	% $CaCO_3$
0-2 in. (0-5 cm)	Dark reddish brown, powdery sandy loam	14	.030	.59	3.1
2-7 in. (5-13 cm)	Dark reddish brown, powdery sandy loam	16	.029	.49	4.4
7-11 in. (13-28 cm)	Dark reddish brown, powdery sandy loam	17	.029	.44	6.4
11-19 in. (28-48 cm)	Dark reddish brown, powdery sandy clay loam	16	.029		9.1
19-27 in. (48-69 cm)	Yellowish red, powdery sandy clay loam	15	.031		11.0
27-31 in. (69-79 cm)	Yellowish red, massive hard sandy clay loam	17	.097		46.0

Profile 2 Samples taken from undisturbed soil to one side of gutter.
Principal profile form Gc1.12

Depth	Description	% Clay	% Total Soluble Salts	% Organic Carbon	% $CaCO_3$
0-2 in. (0-5 cm)	Dark reddish brown, powdery sandy loam	15	.028	.38	3.1
2-7 in. (5-13 cm)	Dark reddish brown, powdery sandy clay loam	17	.029	.35	9.0
7-11 in. (13-28 cm)	Dark reddish brown, weakly cemented massive sandy clay loam	18	.032	.24	13.0
11-17 in. (28-43 cm)	Yellowish red, hard weakly cemented massive loamy clay	20	.032		18.0
17-31 in. (43-79 cm)	Yellowish red, hard weakly cemented massive loamy clay	17	.086		43.0

(Analyses by C.S.I.R.O. Division of Soils, Adelaide) than in the undisturbed soil. The trench also shows a marked increase in calcium carbonate from 11%-46%, whereas the soil to the side of the trench has a more gradual increase in calcium carbonate.

These extremely large polygonal segments and the clearly defined channels cannot be very old. In places, roots of the black oak *(Casuarina cristata)* bridge the channels, which must, therefore, have developed after the roots had grown (Plate 5). However, the cause of the microrelief is not known. A rather similar patterned ground on a playa surface in New Mexico (Lang, 1943) was attributed to drying cracks. The polygons in this case were 80 to 90 feet across, and delimited by broad faint depressions about 3 feet wide and 1 inch deep in the middle, which were picked out on aerial photographs by the concentrations of shrubs in the grooves. Neal, Langer and Kerr (1968) also report desiccation polygons on playa surfaces, and these are of the scale of the Quondong polygons, but are delimited by wedge-shaped fissures. The channels found at Quondong were not in a swamp or depression where water collects; the vegetation is a black oak-bluebush *(Kochia sedifolia)* association, which is characteristic of well drained calcareous soils. As the channels are flat bottomed it seems likely that they do not have vertical drainage. It is possible that drainage may occur at the corners of the hexagons. A purely speculative explanation based on the general resemblance to drying cracks, is that it may result from cracking at depth in the soil, but deep excavations would be necessary to establish this point.

UNDERGROUND HYDROLOGY

General description

Underground water sources are often valuable supplies of stock water. Those of the Quondong area of the Murray Basin have been described by O'Driscoll (1960) from whom the following information including Fig. 8 is drawn.

The Murray, Glenelg and Knight Group sediments, mentioned earlier, are all aquifers yielding water of varying salinity. In the central region the Murray and Glenelg waters are far too saline for stock having salinities of up to 7.3% (5000 gr./gal.). Near the Basin margin however, the Murray group sands occasionally yield water of lower salinity, some of which is suitable for stock. This aquifer is probably recharged with rainwater run-off from the higher ground of the Mt. Lofty and Olary Ranges.

The best waters are from the Knight sands below the Murray and Glenelg sediments; they are extensive and contain water of poor quality. In the southern areas the salinity is likely to be over 1.4% (1000 gr./gal.); in the south and west the water becomes quite unsuitable for stock (see Fig. 8). Further north, salinity varies from 1.3% (900 gr./gal.) around Pine Valley and Morganvale, to about 1.0% towards the north-east margin of the Basin in South Australia. Billing's Bore and Mulga Bore on Oakvale Station have salinities of 1.0% (697 gr./gal.) and 1.1% (715 gr./gal.) respectively.

Not only does the salinity of the water vary, but chemical composition does also. Canopus No. 1 and 2 Bores have high ratios of carbonate to chloride, whereas further north the proportion of chloride rises, even though the overall salinity is lowered.

Use as stock water

Of two wells on Quondong Station yielding saline water, one near the homestead has been filled in. Salinity analyses for the other in Well Paddock and for a bore in North West Boundary Paddock are given in Table 8. The well was a watering point for sheep and cattle in the 1890's even though the Government Analyst regarded the water as too saline at that time; it is not currently used. The bore sunk in North West Boundary has never been developed, although the figures in Table 8 show it to be less saline than the well. However, the use of such water for stock depends not only on the salinity of the water, but also on that of the vegetation, which for saltbush and bluebush may range between 8% and 20% dry weight (Wilson, 1966b).

Pierce (1957) showed that as the salinity of water rose, so sheep increased their water intake; when the water contained more than 1.5% solium chloride the appetite of sheep fed on hay

TABLE 8

CHEMICAL ANALYSES OF QUONDONG UNDERGROUND WATER					
		Well in Well Pdk.		Bore in N-West boundary Pdk.	
		gr./gal.	%	gr./gal.	%
	Cl^-	461.30	0.66	393.40	0.55
	$SO_4^=$	192.47	0.28	142.63	0.20
	$CO_3^=$	14.85	0.02	3.00	0.005
	Na^+ & K^+	270.22	0.37	221.50	0.34
	Ca^{++}	39.16	0.05	31.30	0.04
	Mg^+	45.42	0.06	36.10	0.045
	TOTAL	1,023.92	1.44	827.93	1.18
Assumed comp. of salts	$CaCO_3$	23.75	0.03	5.00	0.005
	$CaSO_4$	102.78	0.14	99.52	0.13
	Mg_2SO_4	150.32	0.21	90.73	0.125
	MgCl	58.93	0.08	69.62	0.10
	NaCl & KCl	688.14	0.98	563.06	0.80
Hardness, °English	Total	286.30	0.41	226.80	0.32
	Temp.	23.75	0.03	5.00	0.005
	Perm.	262.55	0.37	221.80	0.34
	Due to Ca^{++}	99.40	0.13	78.25	0.11
	Due to Mg^+	186.90	0.12	148.55	0.21

declined. High carbonate contents did not have such marked effects. Wilson (1966b) who gave sheep *Atriplex nummularia* (old man saltbush) and water containing 0.9% to 1.2% sodium chloride found that they ate half as much as sheep on saltbush and fresh water, and lost condition rapidly. He suggested, therefore, that water containing more than 0.5% sodium chloride be considered unsuitable for sheep grazing saltbush. Wilson (1966c) discusses the feasibility of improving the usefulness of saline bores with rain water.

The Quondong bore water has a combined sodium and potassium chloride content of 563 gr./gal., about 0.77%, and would be unsuitable for stock unless diluted.

TOPOGRAPHY AND DRAINAGE : SURFACE HYDROLOGY

Introduction

There is little detail in the geology and soils literature relating to the relief of Quondong, but as this has obvious relevance in the supply of fresh water for stock a simple study of the topography and drainage was carried out.

Method

In view of the size of the area, ground survey was limited. Using stereo-pairs of aerial photographs, the position of ridges and drainage lines was ascertained. It was impossible to gauge the exact heights of all the ridges, as some of them were very low and only discernible when exaggerated by stereo-pairs, in terms of relative height above drainage lines. It was estimated that the principal ridges and drainage lines had heights relative to each other of between 3 feet and 25 feet (1 metre and 7 metres).

Spot heights were obtained from the Military Survey and from the Electricity Trust of South Australia. This information was assembled as a map shown in Fig. 9 and the following observations resulted from the study.

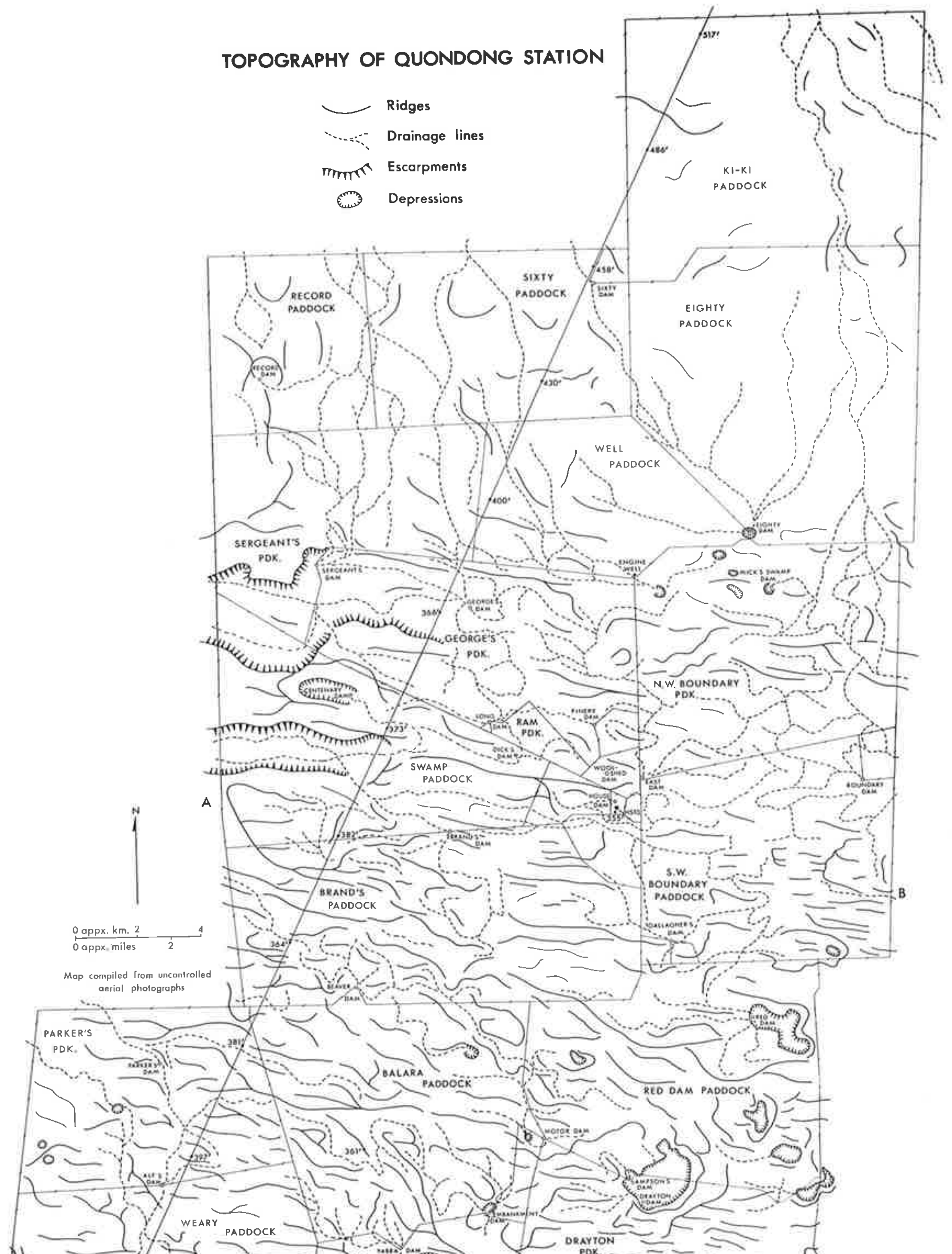
Results

The general elevation falls 233 feet (78 metres) in a south-easterly direction from the north of Ki Ki Paddock to the south-east corner of Drayton Paddock. On the basis of topographic characteristics the Station may be divided into two regions north and south of a line joining the points A and B shown in Fig. 9.

To the north, the country is a gently undulating outwash plain of the Olary Ranges, traversed by broad ill-defined watercourses or washes, the intervening areas being occupied by low calcareous ridges. There are two main drainage systems in this region; one flows from north to south in Record, Sixty, Sergeant's, Well,

FIGURE 9

Topography of Quondong Station


TOPOGRAPHY OF QUONDONG STATION
Ridges
Drainage lines
Escarpments
Depressions
KI-KI PADDOCK
SIXTY PADDOCK
RECORD PADDOCK
EIGHTY PADDOCK
WELL PADDOCK
SERGEANT'S PDK.
GEORGE'S PDK.
N.W. BOUNDARY PDK.
RAM PDK.
SWAMP PADDOCK
S.W. BOUNDARY PADDOCK
BRAND'S PADDOCK
PARKER'S PDK.
BALARA PADDOCK
RED DAM PADDOCK
WEARY PADDOCK
DRAYTON PDK.
YABBA PDK.
A
B
N
0 appx. km. 2 4
0 appx. miles 2
Map compiled from uncontrolled aerial photographs
517'
486'
458'
430'
400'
366'
373'
382'
364'
381'
361'
284'

Ki Ki and Eighty Paddocks and the other flows from west to east through Sergeant's and Swamp Paddocks. The two systems mingle and lose their identity in George's and the Boundary Paddocks. Only in the watercourse running through Ki Ki and Eighty Paddocks has gully erosion proceeded to the extent that parts of it could be regarded as a creek, with banks and a flat sandy bed (Plate 6). It is probable that this has occurred subsequent to sheep being depastured in the area, as a result of increased run-off due to compaction. This phenomenon has been observed elsewhere (Jackson, 1958).

South of the line A-B the ridges and dunes are more numerous and the broad alluvial expanses of water courses are absent. The drainage lines are relatively small and are radial, draining into claypans and other low-lying areas. Some of the claypans have lunettes along their eastern margins. These may be an indication of a higher rainfall regime in the Recent past, as lunettes may be formed either by wave action on lake shores during wet winter months or by deflation from dry lake beds during the summer (Campbell, 1968). The current rainfall would be insufficient for water to lie in the Quondong claypans for any length of time.

The far south-east of the Station is occupied by a continuous area (some 10-12 sq. ml. or 25-30 sq. km) of deep sandy dunes of Recent aeolian origin, oriented in an east-west direction.

Discussion : availability of stock water

It is evident from the Underground Hydrology section that bore water of high enough quality for stock is unlikely to be found anywhere in the Quondong area. All stock water must, therefore, be derived from surface run-off stored in earth dams. The distribution of these on Quondong is shown in Fig. 9.

From the aerial photographs it is apparent that most of the dams are well supplied with drainage lines, and this is doubtless because managers site dams where water runs or collects naturally, and also because sheep pads to the dam become highly compacted thus promoting run-off and converting poor natural gradients into distinct drains. In addition, managers may construct drainage channels; these have not been shown on the map.

Of the 25 dams shown, all but 7 were established before 1890 (see Appendix 1). On the basis of these water-points fence lines were positioned such that sheep in each paddock had access to at least one water-point. Once established, these improvements generally remain as permanent features of the landscape, the behaviour of stock relative to them considerably modifying the immediate vicinity. Record Dam is not used as it has not been known to fill to the present manager's knowledge, and Ki Ki Paddock has never had a permanent water source. Consequently, recently installed piping, tanks and troughs provides the south-east corner of Record and the south-west corner of Ki Ki Paddocks with water from Sixty Dam, while the south-east corner of Ki Ki is supplied by water from a dam in Oakbank Station, which is under the same management. Such water-points are not necessarily permanent fixtures.

* * * * * *

Although the preceding description is simply a general commentary on the non-living physical resources of a station, such information is not always readily available. Its value to rangeland ecologists lies in the fact that climate, soil type, hydrology and topography affect the actual and potential availability of stock water, upon which depends the subdivision of the station into fenced paddocks. This in turn has a direct bearing on grazing history and present pasture use. It is essential that anyone trying to interpret vegetation patterns in grazed situations, fully appreciates the constraints imposed by the environment on the degree to which managers can manipulate the grazing system.

FLORISTICS

Introduction

At the time of the survey no information on the vegetation in the northern Murray Basin was available; the surveys nearest to Quondong were those of Jessup (1948) in Counties Eyre, Burra and Kimberley, Beadle (1948) in western New South Wales and Carrodus, Specht and Jackman (1965) on Koonamore Station. In order to acquaint the author with the types of plants to be found as pasture species on Quondong, a survey of floristics was carried out.

Method

Over a period of one year, March 1967-April 1968, plant collections were made on the Station. Fortunately, during this period sufficient rain fell to allow the growth of herbaceous plants, which were included in the collection, although they were not a major component of the vegetation. The collections, consisting of some 150 species, are now housed in the State Herbarium of South Australia.

In view of the necessity for accurate identification in the projected piosphere samplings, a portable herbarium was constructed for the ready recognition of plants in the field. Specimens collected were mounted on stiff paper and protected by transparent film before being bound in hard-cover book form. This voucher collection was easily handled in the field.

Results and discussion

The complete list of species found on Quondong is given in Appendix 2. Forty families are represented on the Station; the most numerous in terms of variety of species being the Chenopodiaceae (37 species), followed by the Compositae (18 species) and Graminae (17 species). The Leguminosae were collectively the next most numerous, although this family is now considered as three separate ones (Eichler, 1965), the Mimosaceae (6 species) the Caesalpiniaceae 1 species, 4 varieties and Fabaceae (2 species). The Myoporaceae was represented by 8 species and the Malvaceae by 7 species.

Of the species and varieties listed, 75 may be classed as herbs, 62 as shrubs and 15 as trees, although it must be appreciated that certain plants could be included in either of two categories.

These observations regarding the floristics parallel those of other authors commenting on the Eremaean Zone (Crocker and Wood, 1947; Gardner, 1959; Burbidge, 1960) in terms of the prominent families. The reasons for the regular occurrence in arid areas of the taxa noted have been discussed by Wood (1959) and Burbidge (1960).

PASTURE VEGETATION

Introduction

As might be expected, the distribution of the above-mentioned floristic elements is irregular over the several hundred square miles of the Station. Their organisation into a number of natural communities, all of which may be utilised by sheep, was next examined.

Method

The method adopted for determining the different vegetation types was essentially that employed by the C.S.I.R.O. in their Land Research Surveys (Christian and Stewart, 1952); that is, as much field traversing as possible was accomplished within the time available to provide control for interpretation from air photographs.

Before going into the field, the localities of distinctive vegetation components were noted from aerial photographs. 56 ground traverses covering a distance of some 220 miles (see Map 1) were then carried out to confirm the estimated localities of different communities. The position of the observer was continually verified by reference to the air photographs and paddock plans, which showed all tracks, fences and water-points.

Along each traverse, data were recorded as a continuous log, distances between reference points being checked by odometer readings to the nearest 0.1 mile. Reconnaissance had shown that data collection was best achieved by a system which noted "character plants", i.e. those judged subjectively to be of "significant presence". To this end the following information was collected.

Groves of trees covering extensive areas, *Casuarina cristata, Eucalyptus* spp. and *Callitris columellaris*, were delimited, with other species, *Acacia aneura, A. Burkittii, A. victoriae, Myoporum platycarpum* and *Heterodendrum oleaefolium* noted where they occurred. Shrubby species, including *Triodia irritans, Kochia sedifolia, Atriplex vesicaria* and *Cassia nemophila* were also recorded; grasses and other herbaceous components were grouped as ephemerals.

These details were then mapped (Maps 2-6). The locations of species not distinguishable as discrete groves from the air photographs are shown by point symbols; because of problems of scale the position of these can only be approximate. Presence of a symbol on the traverse map indicates that a certain species is present in that locality; absence of a symbol implies absence of the species on the ground, although this must not be taken as factual evidence, as it is possible that some individuals were overlooked during the sampling.

The development of these traverses into a vegetation map of the Station was achieved in the following way. Enlarged aerial photographs at a scale of approximately 2½ inches to the mile were used to construct a map base. Using the field traverses, it was possible to interpolate from the air photographs, the disposition of certain of the more widespread character plants between the traverse lines. Those included on the final map were *C. cristata*, *Eucalyptus* spp., *C. columellaris*, *A. aneura*, *A. vesicaria*, *T. irritans* and ephemerals. Point symbols rather than block shading were used for depicting vegetation types. This technique has several advantages; the whole Station could be classed as a black oak-bluebush woodland, but at the scale employed it is possible to note small scale variations, which can be mapped easily with a point symbol; the technique also avoids the necessity of drawing boundaries as between two mutually exclusive classes and permits mapping of gradients of change (see Map 7).

Results

Maps 2-7 show the main results. Compared with some stations, the broad vegetation pattern on Quondong is simple, on account of the comparative geologic and topographic uniformity. There are four principal vegetation types, which are described in the following paragraphs. These are (I) *Casuarina cristata* (black oak) woodland, (II) Mallee, (III) *Callitris columellaris* (Murray pine) woodland,

(IV) *Acacia aneura* (mulga) woodland (Plates 7-10). In addition, paragraph (V) covers a miscellany of local but distinctive vegetation types characteristic of water-collecting areas other than the major watercourses or washes.

(I) *Casuarina cristata* (black oak) woodland (see Plate 7), found on the old calcareous dune ridges north and south of the line A-B, occupies by far the greatest area of the station and is extremely dense in parts, particularly in the south. Although many groves of this tree are dead, especially in George's Paddock, it is regenerating freely by means of suckers all over the station, even in apparently dead stands. This is of interest as workers in other parts of the State (Hall, Specht and Eardley, 1964; R. M. Purdie, pers. comm.) imply that under heavy stocking or in times of drought *Casuarina* suckers are grazed down before they can reach maturity.

Other tree species found commonly throughout this woodland are *Myoporum platycarpum*, freely regenerating from seed, contrary to observations by Hall, Specht and Eardley at Koonamore, and *Heterodendrum oleaefolium*, the regenerating suckers of which are grazed down as in other parts of the State (Hall, Specht and Eardley, 1964; R. M. Purdie, pers. comm.).

Eremophila longifolia (emu bush), *Acacia oswaldii*, *Pittosporum phylliraeoides* (native willow, apricot), and *Santalum acuminatum* (quondong) are rather less common.

The shrub layer consists principally of *Kochia sedifolia* (bluebush) with *K. excavata* var. *trichoptera* and *Bassia diacantha*. On the tops of the calcareous ridges there is often very little else, but other shrubs fairly common locally are *Ptilotus obovatus*, *Olearia muelleri*, *Scaevola spinescens*, *Cratystylis conocephala*, *Cassia nemophila* var. *nemophila*, *C. nemophila* var. *coriacea*, *Acacia colletioides* and *Templetonia egena* (desert broombush), with *Kochia brevifolia*, *K. georgei*, *K. astrotricha*, *Lycium australe* (boxthorn), *Nitraria schoberi* (nitrebush), *Eremophila glabra* (tar bush), *E. scoparia* and *Zygophyllum aurantiacum* less common.

C. nemophila var. *zygophylla*, *C. nemophila* var. *platypoda*, *Acacia hakeoides* and *Ptilotus atriplicifolius* are rare.

Atriplex vesicaria (bladder saltbush) occurs only in small quantities; an apparently isolated area in Ki Ki Paddock is the southernmost extension of saltbush from the floodplains of the Olary Spur on the adjacent Lilydale Station. Elsewhere on Quondong, *A. vesicaria* is associated with low lying areas in the south.

Kochia pyramidata, recognised as a symptom of degraded arid pastures in the north-west of the State (Jessup, 1948; Correll, 1967), does not occur extensively on Quondong Station.

Rhagodia spinescens var. *deltophylla*, *Rh. nutans* and *Enchylaena tomentosa* are found throughout the *Casuarina* woodland, but mainly under trees and in drainage lines.

(II) The mallees, *Eucalyptus oleosa* and *E. gracilis* (see Plate 8) on the dunes in Drayton Paddock, a northern extension of the Murray Mallee, have a sparse shrub understorey. *Triodia irritans* (porcupine grass) provides most of the ground cover; further north there is less porcupine grass and shrubs are present, including *Chenopodium desertorum, Grevillea huegelii, Hakea leucoptera, Olearia pimelioides, Kochia triptera* var. *erioclada* and the herb *Boerhavia diffusa*. In places the mallee intergrades with dunes carrying *Casuarina cristata* and *Hakea leucoptera*, with *Kochia tomentosa* and *K. triptera* var. *erioclada*.

(III) In two small areas of the station sand dunes are occupied by *Callitris columellaris*, with *Hakea leucoptera, Kochia brevifolia, K. triptera* var. *erioclada* and the grass *Eragrostis laniflora* in the understorey (see Plate 9).

(IV) *Acacia aneura* (mulga) (see Plate 10) stands are found in the drainage lines and watercourses which dissect the *Casuarina* woodland in the northern half of the station. Timber is much less dense in these areas and in the well defined watercourse of Ki Ki and Eighty Paddocks includes *Acacia victoriae* as well as other tree species mentioned in the description of the black oak woodland. Shrubs and forbs found in these areas are

Eremophila maculata (native fuschia)
E. oppositifolia
Bassia paradoxa
Atriplex limbata
A. spongiosa
A. angulata
A. lindleyi
A. acutibracta
Swainsona viridis
Ixiolaena leptolepis
Erodiophyllum elderi (Koonamore daisy, hardheads)
Senecio magnificus
Pterocaulon sphacelatum
Hibiscus krichauffianus
H. farragei

Solanum esuriale
Acacia burkittii
Cassia nemophila var. *nemophila*
C. nemophila var. *coriacea*
Sida intricata
S. corrugata
S. corrugata var. *angustifolia*

Herbaceous plants found in watercourses and wash areas are

Stipa nitida
Cymbopogon exaltatus
Eragrostis dielsii
E. setifolia
Chloris acicularis
Enneapogon avenaceous
E. cylindricus
Panicum effusum
Danthonia sp.
Vittidinia triloba
Brachyscome ciliaris
Helipterum floribundum
Calotis hispidula
Nicotiana goodspeedii
Convolvulus erubescens
Goodenia subintegra
Chenopodium pumilio
Arabidella trisecta
Malvastrum spicatum
Morgania glabra

(V) Although many of the above watercourse species occur along tracks, in sink-holes, drains and in the vicinity of dams, others are quite specific to sink-holes and similar small depressions -

Gilesia biniflora
Alyssum linifolium
Teucrium racemosum
Euphorbia eremophila
Oxalis corniculata
Marsilea drummondii (nardoo)
Eriochlamys behrii
Centipeda thespidioides
Abutilon malvifolium

while some are specific to areas around dams and the drains leading into them, for example,

Centaurium spicatum
Glinus lotoides
Gnaphalium luteo-album
Tetragonia tetragonoides (native spinach)
Portulaca oleracea
Verbena officinalis
Minuria leptophylla
Atriplex eardleyi
A. spongiosa
Babbagia acroptera
Bassia brachyptera
Tribulus terrestris
Plantago varia

In addition, alien weeds are to be found only in watercourses and other water-collecting areas:

Xanthium spinosum (Bathurst burr)	*Cucumis myriocarpus* (paddy melon)
Salvia lanigera	*Asphodelus fistulosus* (wild onion)
Inula graveolens (stinkwort)	*Sida leprosa* var. *hederacea*
Nicotiana glauca (tobacco bush)	*Diplotaxis tenuifolia*
Centaurea melitensis	*Heliotropium supinum*
Citrullus lanatus (bitter melon)	*H. europaeum*
	Polygonum aviculare
	Chenopodium murale

These are obviously very dependant on water for survival and are unlikely to spread to drier sites.

Swamps found round Centenary Dam and Mick's Swamp Dam are characterised by *Muehlenbeckia cunninghamii* (lignum), *Chenopodium nitrariaceum* and *Eragrostis australasica* (canegrass), while parts of the southern clay pans have *Disphyma australe* (pigface) and *Pachycornia* sp. growing on them.

Discussion

The vegetation pattern here described is similar to that in the immediately surrounding areas of the Murray Basin plains. It is clear, however, that events at places more distant from Quondong are not necessarily similar to those described. This raises an important point. Results or observations gained from one location in the arid zone must not be extrapolated injudiciously. For example, comments made by Hall, Specht and Eardley (1964) on the regeneration of *Casuarina cristata* and *Myoporum platycarpum* at Koonamore, and by Jessup (1948) on the spread of *Kochia pyramidata* in overstocked situations in the north west, are at variance with observations made at Quondong. Generalisations made on the basis of particular results have introduced a great number of misleading statements into the literature.

GRAZING HISTORY

As far as the rangeland ecologist is concerned, grazing history is important in accounting for current pasture status - that is, the extent to which pasture is degraded. Unfortunately such information is not easily obtained. Stations which have been in the same family for several generations often have records dating back to the last century. The Quondong lease, however, has been held by several lessees and records have been lost or mislaid. The following account is derived from official documents held by the Lands Department and State Archives (see for examples, Appendix 3).

Early pastoralists in South Australia relied upon supplies of surface water for stock, with the result that grazing in arid country began in the Flinders and Olary Ranges. The northern part of the Murray Basin was without surface water (SAPP 1865-66 No. 57), so this region was not opened up until the 1870's.

The present Quondong Station was originally three administrative units; a run known as Quondong Vale (including Brand's Paddock, S.W. Boundary Paddock and all paddocks to the north of these), part of the Drayton Run (now Red Dam and Drayton Paddocks) and part of the Pine Valley Run (Balara, Yabba, Weary, and Parker's Paddocks).

Although the lease of Quondong Vale was first acquired in 1873, it is unlikely that any grazing was carried out during the first few years as there would be no permanent water until 1867 when a Woolshed Dam in the south of George's Paddock was dug. A further seven dams had been dug by 1880 and eight more and the Engine Well were complete by 1890; if sufficient rain had fallen during this period to fill the dams, then considerable areas would have become available for grazing (see Appendix 1).

The watercourse or wash country close to the homestead in George's, Swamp, Brand's and the Boundary Paddocks, which were fenced prior to 1884, was probably the only area in constant use for shepherding sheep up to 1896. The surveyor described this area as fair pasture; open country covered with various bushes and bluebush plains with a little grass; greater part heavily timbered with black oak etc. There is evidence that in the country north of this (now Sixty, Record, Eighty and Ki Ki Paddocks) the lessee had difficulty in establishing dams; also as the vegetation was described as heavily timbered with only a few open bluebush plains, it was probably only lightly grazed, if at all.

It is apparent from correspondence with the Surveyor General's

Office that the lessee had other problems. By 1890 the north of the Murray Basin was over-run by rabbits and dingoes (see also SAPP 1891 No. 33) and by 1892 was drought stricken. No rain had been received for twelve months and leases to the south had been abandoned. Although the lessee said he would not restock the country as his lease was about to expire in 1894, he continued to run sheep until 1896, when he finally abandoned the country. He had 340 shepherded sheep watering on the Engine Well at that time in an attempt to convince the Government Analyst that the water was not too saline for stock. It may be this event which accounts for the effect seen in Plate 11 where close to the Engine Well, George's Paddock is denuded of bluebush.

Less is known about the Drayton and Pine Valley runs; as these two leases were taken out together in 1874 by the same person they were presumably run as a single unit. This area corresponds to the southern topographic region. The surveyor described it as "Poor pasture; undulating; light red sandy loam with occasional clay flats, limestone rubble on the surface ... dense black oak, mallee, sandalwood, and various bushes, undergrowth and saltbush". Six dams and a well were dug by 1890. Embankment Dam was the first and shepherding was certainly carried on there in the nineteenth century. Weary Dam, dug in 1881, was used to water bullock teams crossing from New South Wales to Burra. As the pasture was assessed as being poorer than that further north, sheep on the

Drayton-Pine Valley Run would have been more susceptible to the drought prevailing by 1890, leading to the abandonment of parts of it only 17 years after the lease was first taken up.

It seems reasonable to assume that the northern part of Quondong Station (Quondong Vale) was more heavily grazed during the nineteenth century than the southern part (Drayton-Pine Valley). Whatever the actual stock numbers may have been in these two areas, it seems certain from Goyder's remarks (SAPP 1867 No. 82) that the practice of shepherding was far more destructive than the present one of allowing sheep to range freely within paddocks.

Between 1901 and 1909 one lessee acquired the leases described above now comprising Quondong Station; since then six more dams have been dug and more paddocks fenced, thus allowing more extensive use of pasture. The regular use of the country for sheep grazing probably dates from about 1910. Information in the Department of Lands indicates that the heavier use of the watercourse country to the north of the homestead continued for at least some of the past 60 years, the Drayton-Pine Valley section being referred to on one occasion as showing no sign of erosion or overstocking, as water supplies were too small to permit that, whereas there are implications that some of the watercourse paddocks had been overstocked.

Historical records for other stations are certainly more complete, particularly where the lease has been held by one family for several generations. It would clearly be of immense value in long term assessment of arid pasture condition if station records were held in pastoral archives.

GENERAL DISCUSSION

The preceding account emphasises that a sheep station is not homogeneous in terms of environment. This makes uniform utilisation of pasture very difficult. Although the information given in this chapter may, in hindsight, be useful to explain phenomena to a station manager, it is doubtful whether it would stimulate him to change a management system he has evolved through experience.

To the rangeland ecologist, the heterogeneity of a sheep station creates problems in the design of experiments, for which purpose a sound understanding of the total environment is most important. The main points that must be continually borne in mind, when considering experimental work on the relationships between sheep and vegetation in station country, are that any interactions:

(1) take place within a paddock having one or more water-points, which determine diurnal sheep movements,

and that they are influenced by:

(2) variable topography and soils, which cause variable vegetation pattern,
(3) low and extremely variable rainfall regimes, which have rigid control over pasture renewal,

(4) seasonally varying wind direction, which affects sheep movements,
(5) high summer temperatures, which control the amount of water sheep need.

A lack of understanding of the implications behind these statements is, perhaps, the reason for the comparative lack of success in some "agronomic" approaches to work in the arid zone (*sensu strictu*); for example, the Yudnapinna experiment (Trumble and Woodroffe, 1954). In grazing experiments of this type the probability of replicates established in arid vegetation being initially similar, is remote.

Some of the effects of using arid vegetation as sheep pasture are beginning to be understood. The break up of the soil surface and destruction of a lichen crust, immediately lays the soil open to erosion by wind and water even where vegetation remains. Nutrients are, therefore, removed with the top layers of soil. (It has been suggested by Correll (1967) that the loss of nitrogen in this way has encouraged the change from *Kochia sedifolia* to *K. pyramidata* shrubland north-west of Port Augusta.) While the surface layers may be pulverised, lower soil layers round water points and along sheep pads become highly compacted, promoting run-off, and allowing subsequent storage of water in dams, which would otherwise enter the soil (Jackson, 1958).

Such physical changes as these are clear within a short period of time and are now, therefore, predictable for all sheep grazing areas. However, the longevity of arid zone plants (Correll and Lange, 1966; R. M. Purdie, pers. comm.) means that changes in vegetation (apart from its complete removal in overstocked situations) will be much slower to appear, and consequently with our present state of knowledge, much less predictable. Not only does arid vegetation vary all over the State according to environmental differences, but even on one station the vegetation pattern will differ from paddock to paddock and within individual paddocks. The position of water points in paddocks will obviously affect the utilisation of these different pasture types, for it is well known that sheep degrade vegetation close to water before that in other parts of paddocks (Osborn, Wood and Paltridge, 1932; Barker and Lange, 1969a). Sheep grazing habits are not yet fully understood, but general observations have been made that sheep preferentially graze watercourse vegetation and tend to graze into the wind along the southern edges of paddocks.

The even use of pasture is made particularly difficult in areas where paddock size and shape is strictly controlled (as at Quondong) by the limited number of suitable catchments for dams which have substrates of the necessary water-holding capacity. In other arid areas of South Australia plentiful bore water and piped river water allow more strategic positioning of troughs in small paddocks, thus encouraging stock to utilise pasture they might otherwise ignore.

The descriptions given here exemplify the multivariate situation which arid rangeland eoclogists have to understand before changes in vegetation can be attributed to stocking. It must also be understood that, even when changes due to stocking are identified, the plants which may indicate degeneration in one part of the State do not necessarily indicate degeneration in other areas.

It was within such heterogeneous environments that the studies of vegetation pattern in relation to sheep water-points, described in subsequent chapters, were carried out.

CHAPTER IX

EXPLORATORY IDENTIFICATION OF A WATER-POINT PATTERN

INTRODUCTION AND DESCRIPTION OF STUDY AREA

It is predictable from the ideas of Osborn, Wood and Paltridge (1932) and Lange (1969) that a radially attenuating stock level away from a water-point might give rise to a vegetation pattern having some degree of concentricity. The initial work on vegetation pattern associated with water-points was primarily carried out to establish the existence of such pattern. Some of the following description has already been published (Barker and Lange, 1969a).

The first site selected for sampling was at Weary Dam on Quondong Station (see Figs. 7 and 9). It was chosen for four reasons; the author was well acquainted with the species present, having just completed the vegetation survey described in Chapter VIII; the pasture appeared to have been well managed with no obvious signs of deterioration despite having had a potential for grazing since 1881 when the dam was established; the paddock of about 25 square miles (62 sq. km) was served by only the one permanent water-point, which thus minimised complications in pattern arising from having two water-points; the vegetation association appeared to be a fairly even one (see Plate 12).

The woodland found here consisted of the character tree *Casuarina cristata* (black oak) with a low shrub understorey of *Kochia sedifolia* (bluebush) and *K. excavata* var. *trichoptera* (henceforward referred to simply as *K. excavata*) containing some tall shrubs, *Cassia nemophila* (punty bush, bean bush) and *Eremophila scoparia* (broom).

METHOD

As most of the drainage into the dam was from the north and west, a base peg was established on the north-east side of the dam and eleven 2,000-yard (approx. 1,850 metres) long radial traverses were surveyed at $11\frac{1}{4}^{\circ}$ intervals from the peg. For the well-spaced bush vegetation under consideration a 65 feet by 5 feet (325 square feet, approx. 90 sq. metres) strip quadrat was used for sampling at 400-yard intervals. Quadrats were oriented along the traverse line so that they were at right-angles to the boundaries of the anticipated concentric water-point pattern. Their position was staggered on alternate traverses in order to give better sample distribution (see Maps 8 and 9).

To simplify counting, each quadrat was divided into 13 units each 5 feet square in which all wholly or partly rooted plants were noted for incidence and total numbers. The identity of all species was continually checked by means of the portable herbarium described on pp. 84 and 85.

In the laboratory, the data were first used to describe the vegetation in general terms, and were then analysed for pattern. Incidence data were, for reasons given in Chapter VII, handled using influence analysis and the outcome was mapped accordingly using a shaded isopleth technique. The determined influence rating of each quadrat was plotted, even though a single quadrat falling, for example, in a swamp might give an anomalous distortion of isopleths (isotels in this case). Blumenstock (1953) discusses a statistical method which determines the ".... relationship between reliability of plotted data and the degree of precision that should reasonably be exercised in the drawing of isarithms to fit the data". Although such generalisation may be desirable for future work of the present type, such a technique was not employed for this series of studies.

Density data were subjected to weighted regression using grouped data. Actual densities per quadrat of a number of species were also mapped to indicate relative population sizes; this was done by using the proportional circle technique of allowing the square root of the population values to be relative to the circle radius. Flannery (see Robinson and Sale, 1969, p. 125) has recently shown that the visual impact of circles thus derived is such that observers underestimate the size of the larger circles relative to the smaller ones. The suggested alternative method was rejected for present purposes, as it would have entailed an excessive amount of extra calculation, in addition to recalculation for maps already drawn.

RESULTS AND DISCUSSION

Description of plant population : density, frequency and dispersion

The 38 species found in the Weary Paddock sample area are listed in Table 9, with their average densities per square chain (=0.1 acre =0.04 hectare) and % frequency.

In terms of % frequency the character species (or dominants) appear to be in the order *K. excavata* and *Bassia diacantha* (both non-perennials) followed by the woody species *K. sedifolia* and *C. cristata.* These observations agree in a general way with the remarks made in the introduction regarding the nature of the vegetation.

One third of the species have average densities of less than 1 per square chain. These are *Babbagia acroptera, Bassia obliquicuspis, B. divaricata, Salsola kali, Ptilotus obovatus, Eremophila glabra, Myoporum platycarpum, Acacia oswaldii, Templetonia egena, Cassia nemophila* var. *zygophylla, Zygophyllum iodocarpum, Exocarpos aphyllus* and *Grevillea huegelii.* This indicates the difficulty of selecting a single practicable sample size which yields statistically useful information about all species.

The remaining two thirds of species contribute substantially to the total number of individuals per acre. The dispersion (i.e. density/frequency ratio) of these 25 species is displayed in Fig. 10, which indicates the degree of clumping or scattering of each species.

TABLE 9

THE PLANT SPECIES SAMPLED IN WEARY PADDOCK
with their average density per square chain* and the
percentage of total samples in which they occur+

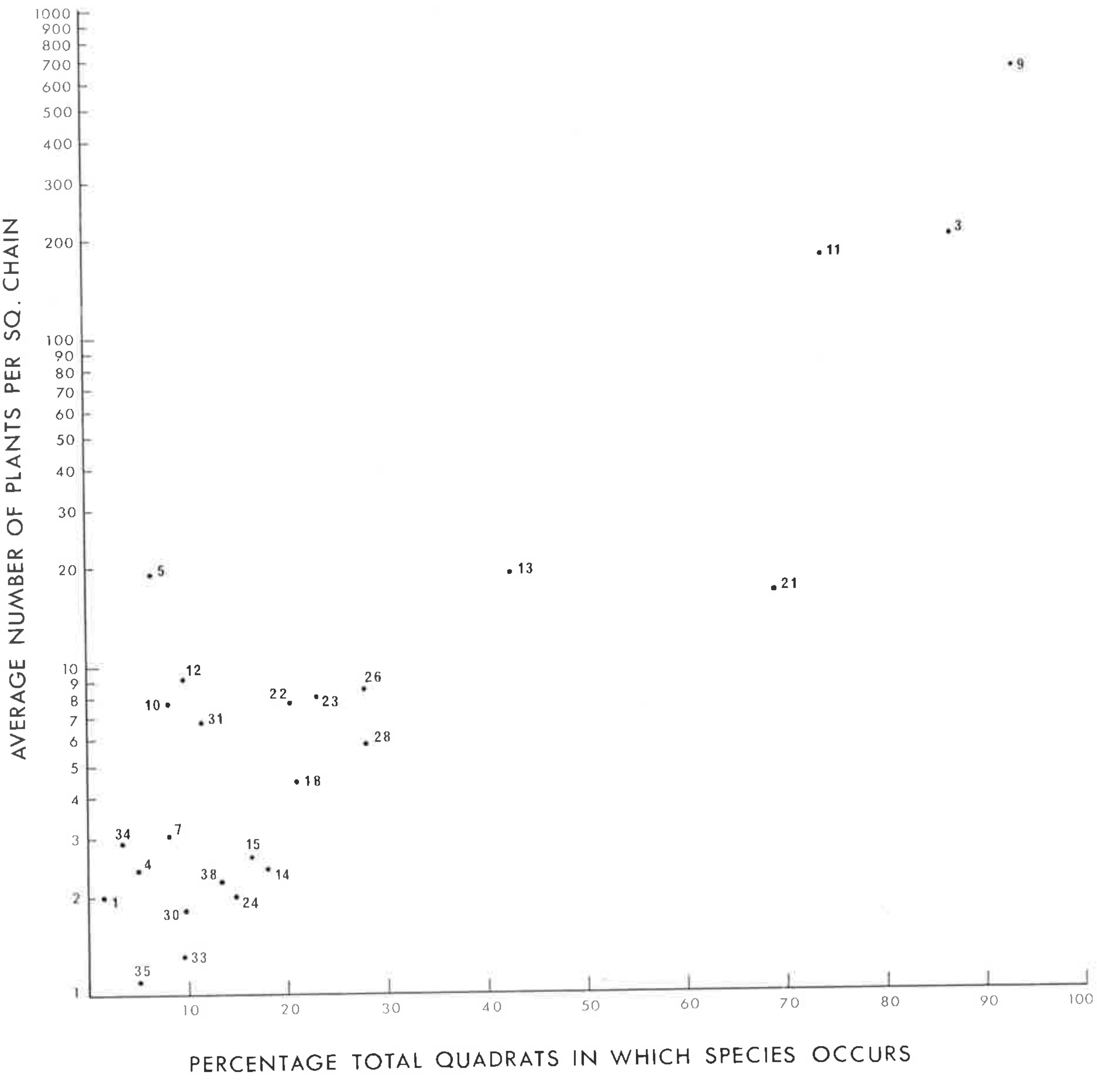
Species	Density*	Frequency+
1. *Atriplex stipitata*	2.0	1.6
2. *Babbagia acroptera*	0.44	1.6
3. *Bassia diacantha*	120.0	87.0
4. *B. brachyptera*	2.42	5.0
5. *B. paradoxa*	19.1	6.6
6. *B. obliquicuspis*	0.87	6.6
7. *B. sclerolaenoides*	3.1	8.2
8. *B. divaricata*	0.4	1.6
9. *Kochia excavata*	643.0	93.4
10. *K. georgei*	7.7	8.2
11. *K. sedifolia*	175.8	74.0
12. *K. triptera*	9.23	9.8
13. *Enchylaena tomentosa*	18.9	42.6
14. *Rhagodia spinescens*	2.4	18.0
15. *R. spinescens* var. *deltophylla*	2.6	16.4
16. *Salsola kali*	0.2	1.6
17. *Ptilotus obovatus*	0.66	5.0
18. *Eremophila scoparia*	4.4	21.3
19. *E. glabra*	0.2	1.6
20. *Myoporum platycarpum*	0.88	6.6
21. *Casuarina cristata*	16.5	69.0
22. *Cratystylis conocephala*	7.7	21.3
23. *Olearia muelleri*	8.1	23.0
24. *Acacia colletioides*	2.0	14.8
25. *A. oswaldii*	0.2	1.6
26. *Cassia nemophila* var. *nemophila*	8.5	27.9
27. *C. nemophila* var. *zygophylla*	0.4	3.3
28. *C. nemophila* var. *coriacea*	5.7	28.0
29. *Templetonia egena*	0.88	5.0
30. *Heterodendrum oleaefolium*	1.8	9.8
31. *Zygophyllum aurantiacum*	6.8	11.5
32. *Z. iodocarpum*	0.66	3.3
33. *Scaevola spinescens*	1.3	9.8
34. *Lycium australe*	2.9	3.3
35. *Nitraria schoberi*	1.1	5.0
36. *Exocarpos aphyllus*	0.4	3.3
37. *Grevillea huegelii*	0.66	3.3
38. *Stipa nitida*	2.2	13.1

FIGURE 10

Dispersion of species in Weary Paddock

(excluding species having densities of less than one per square chain)

1. *Atriplex stipitata*
3. *Bassia diacantha*
4. *Bassia brachyptera*
5. *Bassia paradoxa*
7. *Bassia sclerolaenoides*
9. *Kochia excavata* var. *trichoptera*
10. *Kochia georgei*
11. *Kochia sedifolia*
12. *Kochia triptera*
13. *Enchylaena tomentosa*
14. *Rhagodia spinescens*
15. *Rhagodia spinescens* var. *deltophylla*
18. *Eremophila scoparia*
21. *Casuarina cristata*
22. *Cratystylis conocephala*
23. *Olearia muelleri*
24. *Acacia colletioides*
26. *Cassia nemophila* var. *nemophila*
28. *Cassia nemophila* var. *coriacea*
30. *Heterodendrum oleaefolium*
31. *Zygophyllum aurantiacum*
33. *Scaevola spinescens*
34. *Lycium australe*
35. *Nitraria schoberi*
38. *Stipa nitida*



AVERAGE NUMBER OF PLANTS PER SQ. CHAIN
PERCENTAGE TOTAL QUADRATS IN WHICH SPECIES OCCURS
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
10
20
30
40
50
60
70
80
90
100
9
3
11
5
13
21
12
26
22
23
10
31
28
18
34
7
4
15
38
14
1
24
30
33
35

For example, *K. excavata* (9) which lies on the diagonal in Fig. 10 is evenly dispersed, as are *K. sedifolia* (11), *Enchylaena tomentosa* (13), *Eremophila scoparia* (18) and *Cassia nemophila* var. *coriacea* (28).

Bassia diacantha (3) and *Casuarina cristata* (21), which are displaced to the right of the diagonal i.e. with a low density/frequency ratio, have a well scattered distribution (hyper-dispersed or regular, see Greig-Smith, 1964). Conversely, species displaced to the left of the diagonal, *B. paradoxa* (5), *Kochia triptera* (12), *K. georgei* (10) and *Zygophyllum aurantiacum* (34), appear to have clumped distributions (contagious, see Greig-Smith, 1964), i.e. high density/frequency ratio.

Vegetation pattern :
the effect of stocking on plant populations

Incidence data

From the 61 quadrats, data on the incidence of the 24 species judged to be neither too rare nor too common to lack statistical power, were used to compute a species × species table from the species × samples table. Cell entries are χ-values bearing their sign, positive or negative; interactions with $p > 0.01$ were set aside. Within the remainder, two nodes of associated species occurred, one involving 6 species, the other only 2. Two patterns did, therefore, appear to be present in the vegetation with regard to species incidence.

Table 10 summarises Node 1 interactions.

TABLE 10

SIGNIFICANCE LEVELS OF INTERSPECIFIC ASSOCIATIONS BETWEEN SPECIES LINKED INTO NODE 1 IN WEARY PADDOCK

Rhagodia spinescens	*Ptilotus obovatus*	*Bassia paradoxa*	*Kochia georgei*	*Bassia diacantha*	*Kochia sedifolia*	
%f = 18.0	5.0	6.6	8.2	87.0	74.0	
	NS	NS	NS	$*\bar{*}*$	$*\bar{*}*$	*Rhagodia spinescens*
		NS	NS	$*\bar{*}$	$*\bar{*}$	*Ptilotus obovatus*
			NS	NS	$*\bar{*}$	*Bassia paradoxa*
				$*\bar{*}$	NS	*Kochia georgei*
					NS	*Bassia diacantha*
						Kochia sedifolia

NS = $p > 0.01$
** = $0.001 < p < 0.01$
*** = $p < 0.01$
\- = negative association

All possible combinations of the Node 1 species were listed in dictionary order, together with the frequencies with which each combination was represented in the 61 quadrats. Table 11 summarises the salient points of this list.

TABLE 11

POSSIBLE INCIDENCE COMBINATIONS OF TABLE 10 SPECIES, with observed frequencies (f), recoded lists of these combinations regarding *→ as a pole combination, and influence ratings (IR)

	R. spinescens	*P. obovatus*	*B. paradoxa*	*K. georgei*	*B. diacantha*	*K. sedifolia*	f	Recoding						IR	Condensed Recoding without *Kochia georgei*					IR
	+	+	-	+	-	-	3	+	+	-	+	+	+	5	+	+	-	+	+	4
	+	-	+	-	+	-	2	+	-	+	-	-	+	3	+	-	+	-	+	3
	+	-	-	-	+	+	1	+	-	-	-	-	-	1	+	-	-	-	-	1
	+	-	-	-	+	-	2	+	-	-	-	-	+	2	+	-	-	-	+	2
	+	-	-	-	-	+	2	+	-	-	-	+	-	2	+	-	-	+	-	2
	+	-	-	-	-	-	1	+	-	-	-	+	+	3	+	-	-	+	+	3
	-	+	-	-	+	+	1	-	+	-	-	-	-	1	-	+	-	-	-	1
	-	+	-	-	+	-	1	-	+	-	-	-	+	2	-	+	-	-	+	2
	-	-	+	-	+	-	1	-	-	+	-	-	+	2	-	-	+	-	+	2
	-	-	+	-	-	-	1	-	-	+	-	+	+	3	-	-	+	+	+	3
*→	-	-	-	-	+	+	38	-	-	-	-	-	-	0	-	-	-	-	-	0
	-	-	-	-	+	-	6	-	-	-	-	-	+	1	-	-	-	-	+	1
	-	-	-	-	-	+	2	-	-	-	-	+	-	1	-	-	-	+	-	1
							Σ = 61													

The presence of *Bassia diacantha* and *Kochia sedifolia* and the absence of the other species constitutes one pole of the influence. The absence of *B. diacantha* and *K. sedifolia* and the presence of other species would constitute the opposite pole of the influence.

For convenience, the major pole combination (Table 11, *→) was recoded to fully negative; all other combinations were recoded to be consistent with this, and influence ratings (IR) attributed in proportion to departures from the pole. The influence ratings 0-5 classify the 61 quadrats with respect to the Node 1 influence, but as IR 4 was not realised in any quadrats, it would have been necessary to interpolate this when plotting on a map. This was considered undesirable, so reference to *K. georgei* was deleted. This move reduced the range to 0-4, all the IRs 0, 1, 2, 3 and 4 were realised (Condensed Recoding, Table 11), and the resultant isotel map (Map 8) yielded relative classification of quadrats identical to that which would have been achieved had the 0-5 ratings been used.

The map shows, from the layout of the isotels, that the pattern engendered by Node 1 species is related to the dam, as was predicted from the premise of an attenuating stocking gradient with increasing distance from water. The irregularities, however, are considerable, particularly in the arm extending to 1,300 yards along bearing S 85^{o}E. The IR 5 isotel here corresponds with peculiarities which were noticed in the field, such as incidence of several uncommon species, unusually large black oaks and the presence of kangaroo wallows. From aerial photographs it appears that this particular area is situated in a slight depression, but other depressions are not picked out in the isotel map.

Node 2 displays negative association between *Cassia nemophila* var. *nemophila* and *Enchylaena tomentosa*. Map 8 shows incidence of these two species, and shows that there is a tendency for the incidence of *Cassia* to increase with increasing distance from the water-point.

Density data

These were analysed to see if there were significant relationships between species density and radial distance from the dam, to test the hypothesis that stocking pressure gradients also produce density gradients in plant populations.

Density gradients were shown for eight species, after recourse to grouped data and the weighted regression discussed by Lange (1968). Table 12 summarises the statistical features of these analyses. These results support the hypothesis.

Some of these gradients, shown diagrammatically in Map 9, might have been predicted. For instance, the very palatable *Cratystylis conocephala*, and *Kochia sedifolia*, which is grazed readily when more palatable plants are not available (Leigh and Mulham, 1965), show a marked reduction in density towards the dam. It is suggested that these data indicate reductions from high initial values; similarly the supposedly less palatable *Kochia triptera, B. paradoxa* and *Atriplex stipitata* show a rise in density near the dam, probably on account of stocking, which has either allowed the establishment of

TABLE 12

SIGNIFICANT RELATIONSHIPS BETWEEN SPECIES DENSITIES AND RADIAL DISTANCE FROM WEARY DAM: tests of significance and related statistics				
Species	Weighted Mean	Regression Coefficient b	z-value	P
Atriplex stipitata	3.2107	-0.0099	-2.4053	$0.01 < p < 0.02$
Bassia paradoxa	3.2107	-0.0114	-2.7568	$0.001 < p < 0.01$
Enchylaena tomentosa	3.2107	-0.0224	-1.2082	$0.01 < p < 0.02$
Kochia georgei	3.2107	-0.0149	-2.9548	$0.001 < p < 0.01$
Kochia sedifolia	3.2107	0.0373	2.9072	$0.001 < p < 0.01$
Kochia triptera	3.2107	-0.0120	-2.3790	$0.01 < p < 0.02$
Rhagodia spinescens	3.2107	-0.0265	-3.9242	$p < 0.001$
Cratystylis conocephala	3.2107	0.0178	2.4237	$0.01 < p < 0.02$

a new population or has stimulated a previously insignificant one.

E. tomentosa, K. georgei and *Rhagodia spinescens* are all said to be palatable and might have been expected to show a rise in density away from the dam, but do not. A number of alternative explanations might be sought. Factors other than palatability may be involved. Trampling and soil pulverisation, for example, may outweight grazing *per se* in stimulating and suppressing plants, as may commensal relationships between plant species.

A pattern not identified by the statistical test was that of *Kochia excavata*. Linear regression cannot identify non-linear trends, but when a search for these was made an apparent non-linear trend for *K. excavata* was observed. Here, as shown in Map 9 and Fig. 11, populations are low close to the dam, increasing markedly up to 600-800 yards from the dam, and declining slightly with increasing distance.

GENERAL CONCLUSIONS

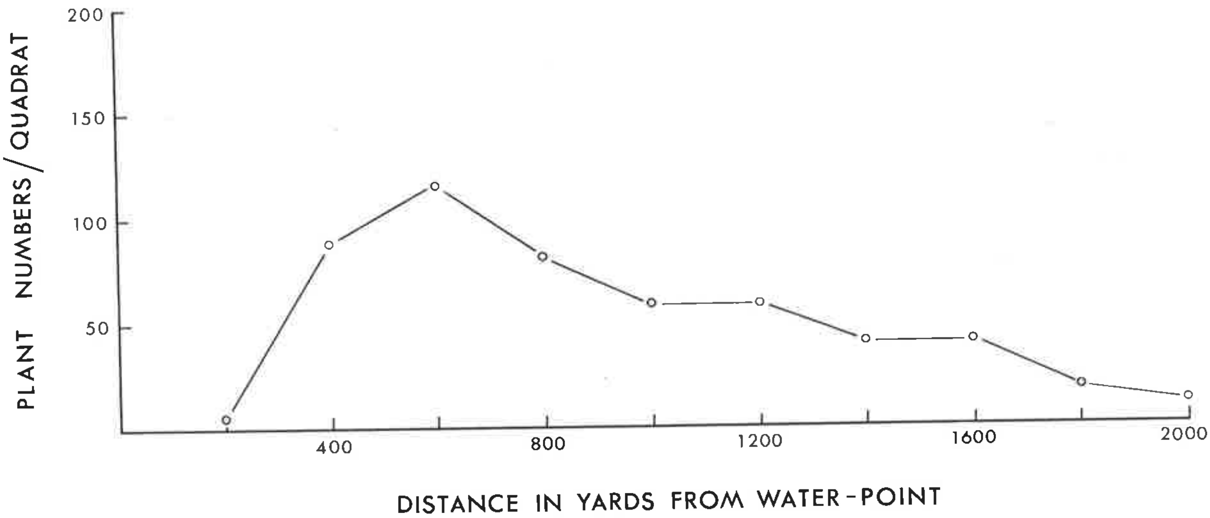
The vegetation of an area within a 2,000 yard radius of a water-point has been described. This embraces only the innermost of the zones recognised by Osborn, Wood and Paltridge (1932). The majority of the species in the study area were not affected significantly by stocking in terms of the variables measured.

FIGURE 11

Change in population size of *Kochia excavata* at Weary Dam, with increasing distance from water

Each point represents the average population size of the quadrats sampled at the radial distances shown

The individual population sizes for each quadrat are shown in Map 9


PLANT NUMBERS/QUADRAT
200
150
100
50
400
800
1200
1600
2000
DISTANCE IN YARDS FROM WATER-POINT

Nevertheless, a pattern which focusses on Weary Dam has been domonstrated by both incidence and density data. If such a pattern is the result of stocking as suggested by Osborn, Wood and Paltridge, then it is evident that even in well managed pastures, changes in vegetation are occurring.

Incidence data alone are enough to reveal the pattern, and the form of the statistical analysis used displays clearly the idea of a gradient. It must be appreciated, however, that the isotels are not fixed boundaries, their location depending on quadrat position; different positioning of quadrats would produce a slightly different isotel layout.

Density data also display the water-point pattern, providing corroborative evidence for the general isotel layout. With one exception the density gradients were clearly identified by the weighted regression correlating density with distance from water, and these are clearly visible in Map 9. It was considered that for future work only visual assessments based on maps would be used; one of the most interesting patterns, that of *K. excavata* was revealed by this technique and not by the statistical tests. There are, after all, some features for which the ecologist can adduce evidence of significance, which defy significance tests.

Together, density and incidence show that *Bassia diacantha, B. paradoxa, Kochia sedifolia, K. georgei, K. triptera, K. excavata, Rhagodia spinescens, Enchylaena tomentosa, Cratystylis conocephala,* *Atriplex stipitata* and *Cassia nemophila* var. *nemophila* are involved in generating this pattern.

If such patterns result from grazing, then palatability must play some part in determining it. According to some authorities (Leigh and Mulham, 1965; Jessup, 1951) and from personal experience of the author, certain of the above species appear to be palatable (*R. spinescens, C. conocephala, K. georgei,* and *K. excavata*), others moderately so, *K. sedifolia, E. tomentosa, B. diacantha* and *B. paradoxa* when young) and others unpalatable (*A. stipitata, K. triptera,* and *C. nemophila* var. *nemophila*).

One would expect that under grazing the palatable species would gradually disappear and unpalatable ones take their place. This appears to be what has happened in some cases, where *K. sedifolia* and *C. conocephala* are absent towards the dam and *K. triptera* *A. stipitata* are present close to the dam. There are some anomalies, however, as the supposedly fairly palatable species, *K. georgei, R. spinescens* and *E. tomentosa*, appear relatively close to the water-point.

This anomalous behaviour suggests two points. The first is that factors other than palatability must be taken into account. For instance, it may be that conditions close to the dam favour regeneration of some species, both palatable and unpalatable, but this does not explain why the "palatable" species close to the dam have not succumbed to the intense stocking pressure. It seems unlikely that the palatable species regenerate under the protection of unpalatable ones, as only two of these, *Nitraria schoberi* and *Lycium australe*, would be big enough to give cover to other plants, and they do not occur frequently enough (Table 9) to be significant. The *K. triptera* and *A. stipitata* plants were all small (less than 12 inches; 30 cm). It is possible that the effects of grazing on a species at different water-points will be dependent on its ecological associates in each case.

The second point which can be raised at this stage, is that references to plant palatability as explanations for plant population behaviour under grazing, must be treated with caution. Insufficient is known about the dietary preferences of sheep and opinions concerning palatability are often conflicting. Indeed, the palatability of a species may vary from one area to another.

The unique pattern displayed by *K. excavata* conforms neither to the expected pattern for palatable species, nor to the converse situation described for *K. georgei et al.* It may be quite characteristic to Weary Dam (as, indeed, may be some of the other species patterns). For this reason, no explanation will be attempted at this stage.

The remaining point for discussion is the cause of the pattern. The area sampled is, in the terms of the definition (p. 44), part of a piosphere. It is reasonable to assume that the pattern found here is a result of grazing, and could therefore be referred to as a "piosphere effect". However, dams have to be sited in areas where water runs or collects naturally. As aboriginal chips have been found around Weary Dam, it is possible that it was a natural, if temporary, waterhole before white man came into the area. The vegetation in the region of the dam may, therefore, always have been somewhat different.

It now became clear that it would be necessary to distinguish unequivocally between topographic effects on vegetation round water-points and the true "piosphere effect". The following chapter describes two situations where topographic effects were absent or negligible.

CHAPTER X

TRUE PIOSPHERE PATTERN

KI KI PIOSPHERE

DESCRIPTION OF STUDY AREA

A water-point independent of natural pattern (i.e. one unrelated to a water catchment or any other landscape feature likely to cause non-randomness in vegetation) was selected 21 miles (about 30 km) north-east of Weary Dam, in Ki Ki Paddock about half a mile east of Sixty Dam. As mentioned on p. 83, this dam supplies a trough in the south-west corner of the paddock, which was the focal point (see Maps 7, 10 and 11). No minor topographic variations within a mile of the trough in Ki Ki Paddock could be observed from stereoscopic examination of aerial photographs.

The vegetation association in Ki Ki is essentially the same as that in Weary Paddock, except that the black oak woodland is slightly more open. The understorey consists of a few tall shrubs (*Dodonaea attenuata* (hopbush), *Cassia nemophila*, *Eremophila sturtii* (turpentine bush) and *Acacia colletioides* (wait-a-while) with low shrubs (*Kochia sedifolia* and *K. excavata*) giving the area its characteristic appearance.

Past grazing history is virtually unknown, but according to the present manager, stocking was likely to have been light and discontinuous owing to a lack of water, until 3 to 4 years ago when troughs were established and fences appropriately modified. Since then stocking has been moderately heavy, but intermittent, so there would have been little opportunity for the establishment of perennial species, although existing populations could have been modified.

METHOD

The layout of traverses and quadrats is indicated in Maps 10 and 11. It differed slightly from the Weary Paddock layout. The angle between the traverses was reduced from $11\frac{1}{4}^{\circ}$ to 10° to increase the intensity of sampling at the circumference of the study area. Sampling began at 25 yards from the base peg, as opposed to 200 yards at Weary, as it was felt that much interesting information could be gained from the 0-200 yard area. Sample interval was also reduced close to the base peg as gradients of change are likely to be most rapid here. The first interval was 25 yards, the distance being gradually increased to a maximum of 400 yards, which was achieved at 400 yards distant from the base peg.

Sampling techniques and methods of handling the data were identical to those described on p. 104 except that the density data were not subjected to a weighted regression analysis.

RESULTS AND DISCUSSION

Description of plant populations : density, frequency and dispersion

Twenty nine species were found in the Ki Ki study area and these are listed in Table 13, with their average densities per square chain and % frequency.

The character species or dominants as indicated by frequencies of 50% or over appear to be, in order, *Kochia excavata, Bassia diacantha, Kochia sedifolia, Bassia obliquicuspis, Bassia sclerolaenoides* and *Atriplex acutibracta*. Apart from *K. sedifolia* these are all non-perennial plants. There are two differences in comparison with the vegetation in the Weary area; one is the relative openness of the *Casuarina cristata* woodland, indicated by the low frequency (17%), and the other is the consistent occurrence of *A. acutibracta* in Ki Ki.

Again, one third of the species found have densities of less than one per square chain; they are *Olearia muelleri, Kochia pyramidata, Heterodendrum oleaefolium, Atriplex stipitata, Dodonaea attenuata, Sida corrugata, Chenopodium desertorum, Cassia nemophila* var. *platypoda, C. nemophila* var. *zygophylla* and *Eremophila glabra*. Apart from the last two, these low density species are all different from those in Weary Paddock. *K. pyramidata, S. corrugata, D. attenuata* and *C. desertorum* were not noted in Weary Paddock, while the remainder had densities of more than one per square chain in Weary.

TABLE 13

THE PLANT SPECIES SAMPLED IN KI KI PADDOCK
with their average density per square chain* and the percentage of total samples in which they occur+

Species	Density*	Frequency+
1. *Atriplex acutibracta*	36.8	64.9
2. *Atriplex vesicaria*	14.9	20.8
3. *Bassia obliquicuspis*	195.9	92.2
4. *Bassia sclerolaenoides*	157.0	83.1
5. *Bassia diacantha*	600.2	98.7
6. *Bassia patenticuspis*	26.5	39.0
7. *Kochia sedifolia*	86.8	94.8
8. *Kochia excavata* var. *trichoptera*	1692.5	100.0
9. *Kochia georgei*	8.5	26.0
10. *Enchylaena tomentosa*	19.0	45.5
11. *Rhagodia spinescens* var. *deltophylla*	17.6	40.3
12. *Cassia nemophila* var. *coriacea*	4.9	27.3
13. *Chenopodium ulicinum*	2.1	14.3
14. *Olearia muelleri*	0.5	3.9
15. *Acacia colletioides*	3.0	12.9
16. *Scaevola spinescens*	1.2	9.1
17. *Eremophila sturtii*	1.2	7.8
18. *Rhagodia spinescens* var. *spinescens*	1.4	10.4
19. *Cassia nemophila* var. *nemophila*	2.4	10.4
20. *Cassia nemophila* var. *zygophylla*	0.7	2.6
21. *Cassia nemophila* var. *platypoda*	0.7	3.9
22. *Kochia pyramidata*	0.3	2.6
23. *Heterodendrum oleaefolium*	0.2	1.3
24. *Eremophila glabra*	0.2	1.3
25. *Atriplex stipitata*	0.3	2.6
26. *Dodonaea attenuata*	0.3	3.0
27. *Sida corrugata*	0.3	3.0
28. *Chenopodium desertorum*	0.2	1.3
29. *Casuarina cristata*	2.4	16.9

The dispersion of the remaining species is shown in Fig. 12. The populations seem to be less variable in Ki Ki than in Weary Paddock. The most clumped (or contagious) species is *Atriplex vesicaria* (2), the most regular species is *K. sedifolia* (7), but neither of these demonstrate extreme situations. This comparative lack of variability in these species suggests uniformity of environment.

Vegetation pattern : the effect of stocking on plant populations

Incidence data

Out of the total of 29 species sampled in the 77 quadrats, 17 were considered neither too common nor too rare to lack statistical power, and these were utilised for further analysis. Tree species were excluded and data for the two varieties of *Rhagodia spinescens* were pooled as were those of the four varieties of *Cassia nemophila*.

A species X species table was produced as described previously for the Weary data (p. 107). The only associations which appear have very low χ values. At $\chi \geq 3.0$ there are only two nodes. One reveals positive association between *Enchylaena tomentosa* (10) and *R. spinescens* (11) and between *E. tomentosa* (10) and *C. nemophila* (12). *R. spinescens* associates with *C. nemophila* at $\chi \geq 2.0$ as do *Atriplex vesicaria* (2) and *Bassia sclerolaenoides* (4) (Fig. 13).

FIGURE 12

Dispersion of species in Ki Ki Paddock

(excluding species having densities of less than one per square chain)

1. *Atriplex acutibracta*
2. *Atriplex vesicaria*
3. *Bassia obliquicuspis*
4. *Bassia sclerolaenoides*
5. *Bassia diacantha*
6. *Bassia patenticuspis*
7. *Kochia sedifolia*
8. *Kochia excavata* var. *trichoptera*
9. *Kochia georgei*
10. *Enchylaena tomentosa*
11. *Rhagodia spinescens* var. *deltophylla*
12. *Cassia nemophila* var. *coriacea*
13. *Chenopodium ulicinum*
15. *Acacia colletioides*
16. *Scaevola spinescens*
17. *Eremophila sturtii*
18. *Rhagodia spinescens* var. *spinescens*
19. *Cassia nemophila* var. *nemophila*
29. *Casuarina cristata*

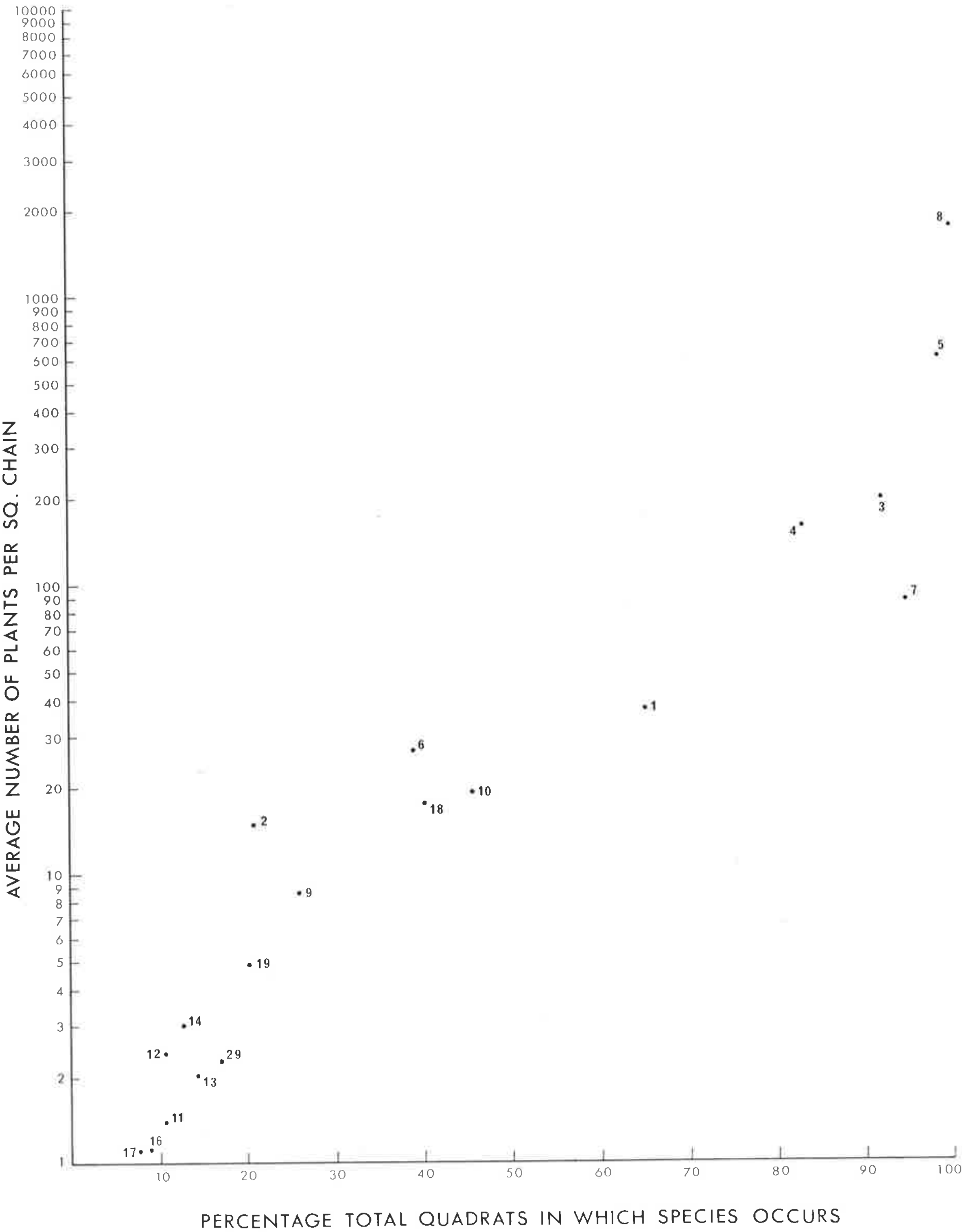

AVERAGE NUMBER OF PLANTS PER SQ. CHAIN
PERCENTAGE TOTAL QUADRATS IN WHICH SPECIES OCCURS
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
10
20
30
40
50
60
70
80
90
100
8
5
3
4
7
1
6
10
18
2
9
19
14
12
29
13
11
16
17

FIGURE 13

Nodes of associated species at $\chi \geqslant 3.0$ and $\chi \geqslant 2.0$ in Ki Ki piosphere

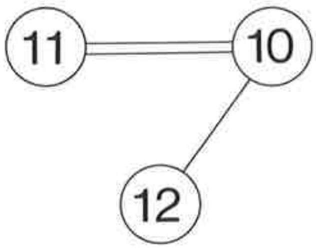
——— indicates association, positive association
---- indicates dissociation, negative association

(2) *Atriplex vesicaria*
(3) *Bassia obliquicuspis*
(4) *Bassia sclerolaenoides*
(5) *Bassia diacantha*
(6) *Bassia patenticuspis*
(7) *Kochia sedifolia*
(10) *Enchylaena tomentosa*
(11) *Rhagodia spinescens* (including var. *deltophylla*)
(12) *Cassia nemophila* (including vars. *coriacea*, *zygophylla* and *platypoda*)
(13) *Chenopodium ulicinum*

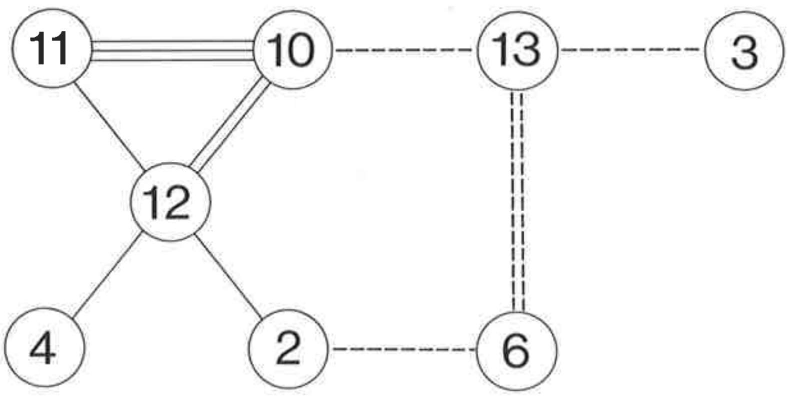
(i) Nodes at $\chi \geqslant 3.0$
(ii) Nodes at $\chi \geqslant 2.0$

NODE 1. NODE 2.

(i)



(ii)



NODE 3.

In Node 2, *Chenopodium ulicinum* (13) and *Bassia patenticuspis* (6) disocciate at $\chi \geqslant 3.0$ and they are linked to Node 1 at $\chi \geqslant 2.0$ by disocciation between *E. tomentosa* and *C. ulicinum* and between *B. patenticuspis* and *A. vesicaria* (Fig. 13).

A possible Node 3 of association between *K. sedifolia* (7) and *Bassia diacantha* (5) is also apparent at $\chi \geqslant 2.0$ (Fig. 13).

These interactions are all very weak; the sign and strength of Node 1 and 2 interactions are shown in Table 14. The only associations that could be considered as really valid were those at $\chi \geqslant 3.0$. The Node 2 negative association between *C. ulicinum* and *B. patenticuspis* was not thought to be worth mapping because of the relatively low frequency (14%) of *C. ulicinum*.

The influence ratings for combinations of Node 1 species (the three positive associates, *C. nemophila, R. spinescens* and *E. tomentosa*) were determined simply by the presence of any combination of 0, 1, 2 or 3 of these species (Table 15). The resultant isotel map (Map 10) suggests that the pattern bears no relationship to the water-point and that the vegetation is being influenced by something else.

Field observations in this and other areas indicate that the influence is a commensal one, as *Enchylaena* and *Rhagodia* are frequently found together in the shelter of trees and large shrubs, such as *C. nemophila*, thus giving rise to the observed set of positive associations. It is interesting to note that the Weary

TABLE 14

SIGNIFICANCE LEVELS OF INTERSPECIFIC ASSOCIATIONS BETWEEN SPECIES LINKED INTO NODES 1 AND 2 IN KI KI PADDOCK
Cell entries are χ values (positive or negative) on one degree of freedom

	Rhagodia spinescens	*Enchylaena tomentosa*	*Cassia nemophila*	*Atriplex vesicaria*	*Bassia obliquicuspis*	*Bassia sclerolaenoides*	*Chenopodium ulicinum*	*Bassia patenticuspis*
%f =	50.7	45.5	44.2	20.8	92.2	83.1	14.3	39.0
Rhagodia spinescens		+ 4.3	+ 2.8	+ 0.9	+ 0.9	+ 0	+ 0.7	- 1.0
Enchylaena tomentosa			+ 3.4	+ 0.1	+ 1.0	+ 0.2	- 1.6	- 0
Cassia nemophila				+ 2.0	+ 0.6	+ 2.1	+ 0.9	- 0.8
Atriplex vesicaria					- 0.2	+ 0.1	+ 1.7	- 1.5
Bassia obliquicuspis						- 0.5	- 1.9	+ 1.6
Bassia sclerolaenoides							+ 1.1	+ 0.3
Chenopodium ulicinum								- 2.5
Bassia patenticuspis								

data showed negative association between *C. nemophila* var. *nemophila* and *Enchylaena tomentosa* in Node 2. Re-examination of both sets of

TABLE 15

POSSIBLE INCIDENCE COMBINATIONS OF NODE 1 SPECIES IN KI KI PADDOCK with observed frequencies (f) and influence ratings (IR)				
C. nemophila	*R. spinescens*	*E. tomentosa*	f	IR
-	-	-	29	0
-	-	+	5	1
+	-	-	5	1
-	+	-	5	1
+	-	+	6	2
+	+	-	2	2
-	+	+	8	2
+	+	+	17	3
			Σ = 77	

data suggest two factors which probably account for this apparent disparity. In Weary Paddock, trees are more frequent and as they also provide cover for *Enchylaena* and *Rhagodia* they would obscure any commensal relationship between *Cassia* and these two species. The pooling of the Ki Ki data for *Rhagodia* and *Cassia* and the omission of trees from the analysed data must also have had some effect on the outcome of the analysis. These relationships will be commented upon more fully in Chapter XIII.

It is evident, from the results just described, that the period of grazing has been insufficient for incidence of species to have been affected, although cover and density of some species undoubtedly have.

Density data

On the basis of the inference made from the Weary Dam results that *K. sedifolia* had disappeared close to the dam as a result of sheep activity, population densities of this species in the Ki Ki study area were plotted (Map 11). They show no trends due, probably, to the short period of grazing.

Populations of *K. excavata* were also plotted (Map 11) and they display the same rise and then fall in population size with increasing distance from the water-point as did the populations at Weary Dam (Fig. 14 cf. Fig. 11).

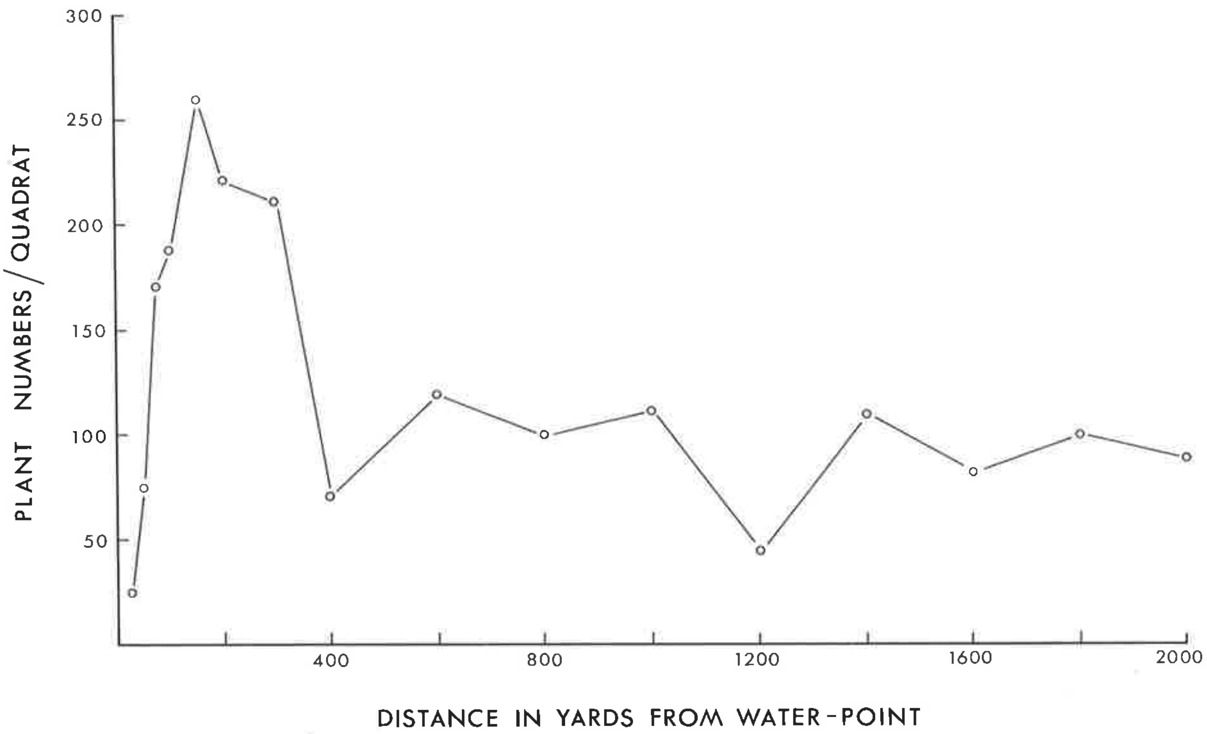
The size of populations of this plant close to water suggests that it is capable of regenerating under severe stock pressure. This is borne out by field observations of the high proportion of juveniles in the area. Regeneration must be stimulated close to the water-point by sheep activity, which spreads seed and creates a friable and fertile seed bed. Small or extinct populations very close to water doubtless result from sheer pressure of sheep numbers; where populations of *K. excavata* reach their maximum, sheep activity must be more of a stimulant than a depressant on population size. This point is reached 150 yards from Ki Ki trough and 600 yards from Weary Dam.

FIGURE 14

Change in population size of *Kochia excavata* at Ki Ki Trough, with increasing distance from water

Each point represents the average population size of the quadrats sampled at the radial distances shown

The individual population sizes for each quadrat are shown in Map 11


300
250
200
150
100
50
PLANT NUMBERS / QUADRAT
400
800
1200
1600
2000
DISTANCE IN YARDS FROM WATER-POINT

It is only possible to speculate about the causes of this difference in distance. Sheep apparently eat *K. excavata* readily. If one can assume that having had a drink, they spend some time close to the water-point grazing *K. excavata*, then it could be suggested that the plant has receded from Weary Dam because of intensive or prolonged grazing. On the other hand *K. excavata* could be naturally further from Weary Dam, for physiographic or edaphic reasons, so that any stimulating effect of sheep does not appear until some distance out. Similar stimulation of *Atriplex vesicaria* populations was noted by Osborn, Wood and Paltridge (1932).

Whatever the causes, the phenomenon exists in this species. As it is a non-perennial it could be expected to register change due to sheep activity more rapidly than a perennial. However, other non-perennials such as *Bassia diacantha* and *B. obliquicuspis* do not show any pattern. They would not be eaten much by sheep on account of their spiny fruit, but this is no reason why the development of juvenile populations should not be encouraged by friable, fertile soil.

CONCLUSIONS

Floristically, the Ki Ki sample area is not as diverse as the Weary Paddock one, and this is due mainly to the number of species only found close to Weary Dam. At present, no species appears to be invading or disappearing from the immediate vicinity of Ki Ki trough, consequently no piosphere pattern is displayed by influence analysis. Instead a commensal relationship has been identified.

The only pattern considered to be a true piosphere one is that of *K. excavata*, as shown by its population densities. It is similar to that found at Weary Dam and was quite unpredicted; the precise reasons for a plant population to react in this way are unknown. Although the densest populations do form a peak some distance from water, as shown by Figs. 11 and 14, this is not to suggest that cover is also greater here than elsewhere in the paddock.

K. excavata, a plant 6 inches to 9 inches high, certainly seems to regenerate freely when subjected to stocking under the conditions found at Quondong. It displays high frequencies and densities compared with other plants of similar habit. As sheep graze the plant, it is probably one of the main pasture species in this locality, and as such replaces *A. vesicaria*, the main pasture species in other parts of the State.

It could be inferred from these results that *K. excavata* is tolerant of high stock numbers, but it must be emphasised that as far as is known, stocking pressures have been light or discontinuous in the areas studied. Under different regimes the plant may prove to be very sensitive.

As the anticipated sharp gradient of change in other species close to the water-point did not exist, it was clear that Ki Ki

Paddock had not been grazed long enough (or severely enough) for incidence and density to have been affected. Attention was thus directed to older water-points, which were also independent of physiographic features.

BARRETT'S PIOSPHERE

DESCRIPTION OF STUDY AREA

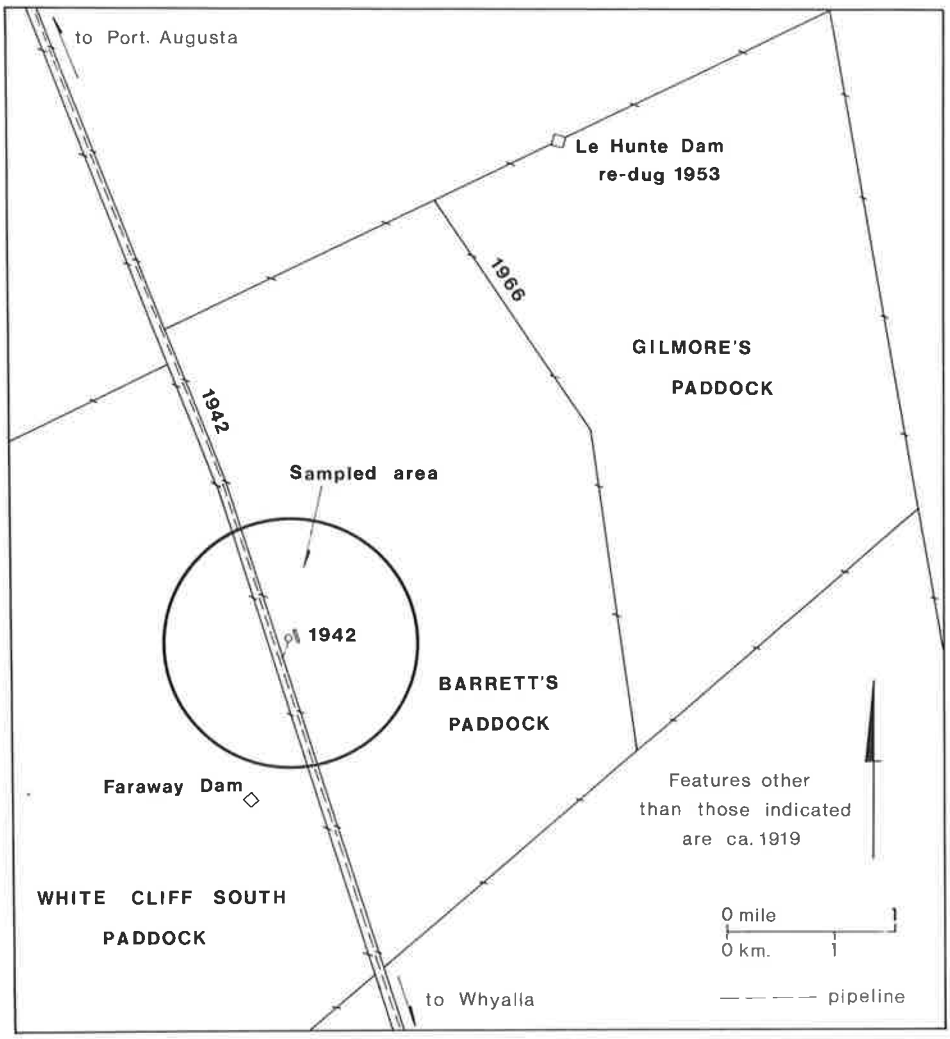
The third site, located on Tregalana Station (Roopena), near Whyalla, was selected because, like Ki Ki, the watering point appeared to be independent of topographic pattern in its immediate vicinity. The focal point of the piosphere area was a trough known as Barrett's or No. 5, supplied by a spur from the Morgan-Whyalla pipeline (Fig. 15 and Plates 13 and 14). The area had an added advantage in that the grazing history was well known.

The region is geologically uniform consisting of Quaternary deposits of ".... older alluvium and low angle slope deposits partly derived from talus and partly from re-working of desert sands" according to the Geological Survey of South Australia. The topography, however, is not as uniform as in Ki Ki Paddock, and a form line map indicating

FIGURE 15

Location diagram

showing the Barrett's Paddock study area



to Port. Augusta
Le Hunte Dam
re-dug 1953
1966
GILMORE'S
PADDOCK
1942
Sampled area
1942
BARRETT'S
PADDOCK
Faraway Dam
Features other
than those indicated
are ca. 1919
WHITE CLIFF SOUTH
PADDOCK
0 mile
1
0 km.
1
to Whyalla
pipeline

the general position of rises and depressions was derived from stereoscopic examination of aerial photographs. This is shown in Map 12.

Barrett's trough is situated on an east facing slope, which grades down to a saltbush plain bordering Myall Creek. The sample grid just reaches this plain. To the north of the trough the ground rises and then falls very gradually to a west-east watercourse, which drains into Myall Creek; similar topography is found to the south although a slight natural drain cuts through the piosphere about a quarter of a mile from the trough. The western part of the study area lies in White Cliff South Paddock (see Fig. 15), on the far side of the Port Augusta-Whyalla road. Here the ground rises to the crest of a ridge and then slopes away to a watercourse containing Faraway Dam.

The character trees of the arid woodland found here are *Acacia sowdenii* (myall) and *Casuarina cristata*, with *Myoporum platycarpum* (false sandalwood) and *Heterodendrum oleaefolium* (bullock bush) also common. The shrub understorey consists principally of *Kochia sedifolia* and *Atriplex vesicaria* (saltbush) with *K. pyramidata* (black bluebush) and *K. georgei* occurring less commonly. Forbs and some herbaceous ephemerals appear after rain and although regarded as useful fodder, are a minor constituent of the total vegetation association.

Prior to 1942, Gilmore's Paddock (see Fig. 15) originally included what is now Barrett's Paddock and stock then had to water at Le Hunte Dam. As this dam was unreliable, stocking was not continuous and the present study area, being 2-3 miles from the dam, would not have been subject to intense sheep activity. After the pipeline was constructed in 1942, Barrett's tank and trough were installed; sheep subsequently watered there for long periods when the dam failed. Stocking pressure would have been heavy round the trough at these times. Le Hunte Dam became a permanent water-point after it was re-dug in 1953 and numbers of stock using the trough were reduced. Since 1966, when Gilmore's Paddock was subdivided, Barrett's has carried approximately 250-300 sheep. It is clear from this grazing history that in the vicinity of Barrett's trough any effects of stocking, identified from the data collected in 1969, will have occurred since the tank and trough were first installed, - a period of 27 years.

METHOD

The sample grid, centred on the trough paddock, was limited to a radius of 1300 yards (2000 km), as beyond this limit topography was clearly affecting vegetation pattern. Quadrat positions are indicated in Map 12 and in all other Maps relating to this section. As in Ki Ki Paddock, the sample interval was reduced close to the base peg.

Incidence and density were recorded exactly as in the previous analyses, except that populations of young plants and seedlings of the shrub dominants, brought on by rain, were also included. The categories noted are summarised in Table 16. The data collected were handled as before.

TABLE 16

CHARACTERISTICS OF THE JUVENILE AND MATURE PLANTS OF THREE MAJOR SHRUB POPULATIONS SAMPLED IN BARRETT'S PADDOCK

	Seedlings	Young plants	Mature plants
Atriplex vesicaria	Up to 4" high Unbranched Up to 6 leaves Non-woody	Up to 8" high Branched Many leaves Woody	Over 8" high Well branched
Kochia pyramidata	Up to 3" high Unbranched Up to 20 leaves Non-woody	Up to 6" high Slightly branched Main axis well thickened	Over 6" high Well branched
Kochia sedifolia	Up to 2" high Unbranched Up to 15 leaves Non-woody	Up to 6" high Branched Stems woody, grey in colour	Over 6" high Well branched Old stems black in colour

RESULTS AND DISCUSSION

Description of plant populations : density, frequency and dispersion

This information is presented in Table 17 and Fig. 16. The character plants (or dominants) of the Barrett's Paddock association (see Plate 13), which have frequencies of 50% or over, are *Kochia sedifolia, Atriplex vesicaria, K. georgei, Bassia obliquicuspis, Enchylaena tomentosa,* and *K. pyramidata*. The character trees, judged

TABLE 17

THE PLANT SPECIES SAMPLED IN BARRETT'S PADDOCK
with their average density per square chain* and the percentage of total samples in which they occur+

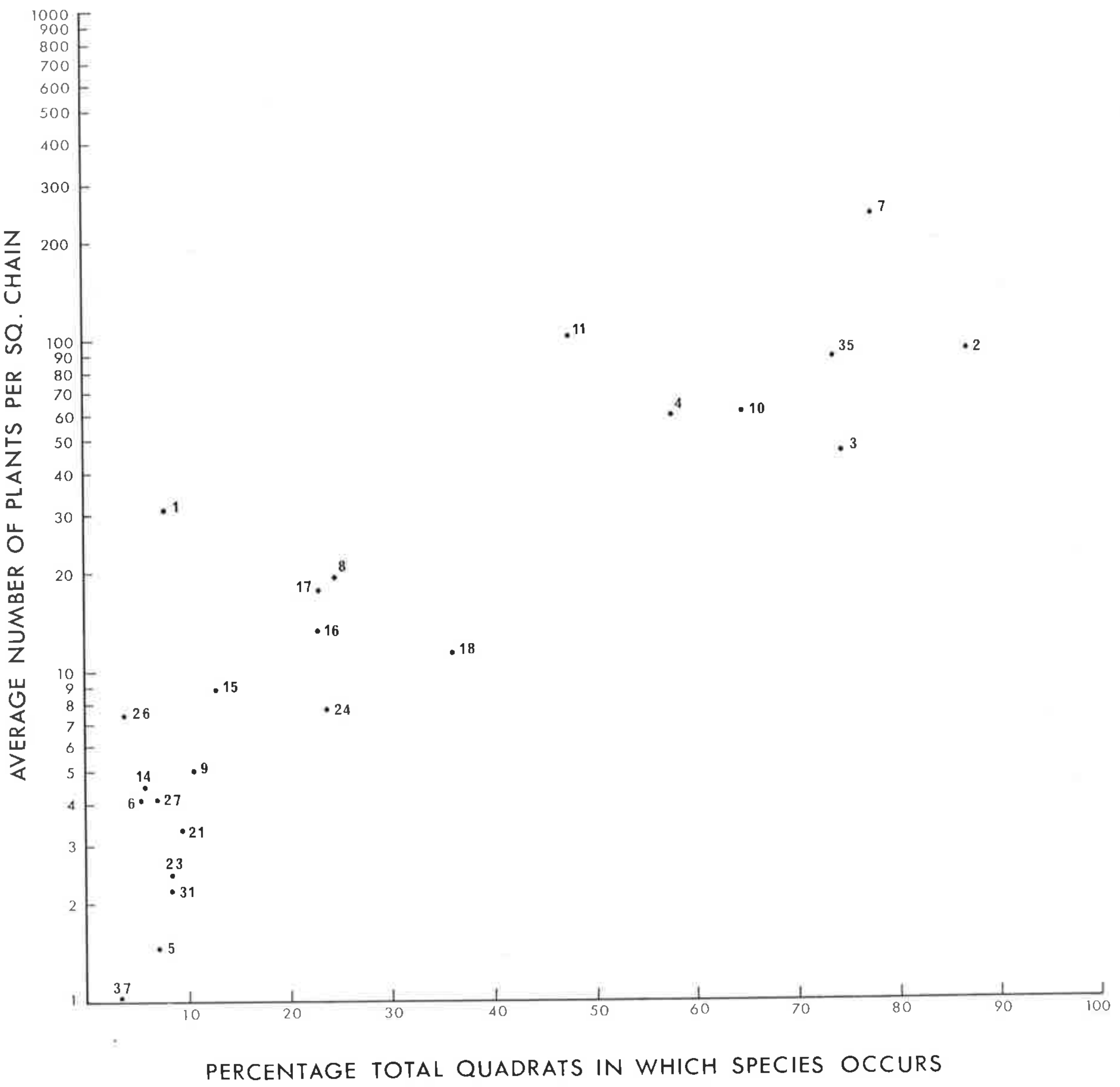
Species	Density*	Frequency+
1. *Kochia brevifolia*	31.1	7.8
2. *Kochia sedifolia*	92.9	87.1
3. *Kochia georgei*	46.0	74.6
4. *Kochia pyramidata*	59.6	57.8
5. *Kochia excavata* var. *trichoptera*	1.5	7.0
6. *Kochia astrotricha*	4.1	5.1
7. *Atriplex vesicaria*	238.9	77.8
8. *Atriplex spongiosa*	19.4	24.6
9. *Atriplex eardleyae*	5.0	10.5
10. *Enchylaena tomentosa*	64.8	61.3
11. *Bassia sclerolaenoides*	100.8	47.7
12. *Bassia brachyptera*	0.4	4.7
13. *Bassia lanicuspis*	0.2	0.8
14. *Bassia diacantha*	4.6	5.9
15. *Bassia biflora*	9.1	12.8
16. *Bassia paradoxa*	13.8	22.7
17. *Bassia patenticuspis*	17.8	23.0
18. *Chenopodium desertorum*	11.6	36.2
19. *Malacocera tricornis*	0.7	3.1
20. *Sida intricata*	0.6	2.0
21. *Lycium australe*	3.3	9.4
22. *Nitraria schoberi*	0.05	0.4
23. *Chenopodium ulicinum*	2.4	7.4
24. *Rhagodia spinescens* var. *deltophylla*	7.7	23.8
25. *Cassia nemophila* var. *coriacea*	0.3	2.0
26. *Babbagia acroptera*	7.4	3.9
27. *Frankenia pauciflora*	4.1	7.0
28. *Marrubium vulgare*	0.1	0.8
29. *Exocarpos aphyllus*	0.2	1.2
30. *Santalum acuminatum*	0.05	0.4
31. *Casuarina cristata*	2.2	8.2
32. *Heterodendrum oleaefolium*	0.7	4.3
33. *Myoporum platycarpum*	0.05	0.4
34. *Acacia sowdenii*	0.2	1.2
35. *Bassia obliquicuspis*	89.4	73.8
36. ? *Zygophyllum compressum*	0.8	5.1
37. *Zygophyllum iodocarpum*	1.0	3.1
38. *Stipa nitida*	0.2	0.4
39. *Salsola kali*	0.7	2.7
40. *Kochia tomentosa*	0.05	0.4

FIGURE 16

Dispersion of species in Barrett's Paddock

(excluding species having densities of less than one per square chain)

1. *Kochia brevifolia*
2. *Kochia sedifolia*
3. *Kochia georgei*
4. *Kochia pyramidata*
5. *Kochia excavata* var. *trichoptera*
6. *Kochia astrotricha*
7. *Atriplex vesicaria*
8. *Atriplex spongiosa*
9. *Atriplex eardleyae*
10. *Enchylaena tomentosa*
11. *Bassia sclerolaenoides*
14. *Bassia diacantha*
15. *Bassia biflora*
16. *Bassia paradoxa*
17. *Bassia patenticuspis*
18. *Chenopodium desertorum*
21. *Lycium australe*
23. *Chenopodium ulicinum*
24. *Rhagodia spinescens* var. *deltophylla*
26. *Babbagia acroptera*
27. *Frankenia pauciflora*
31. *Casuarina cristata*
35. *Bassia obliquicuspis*
37. *Zygophyllum iodocarpum*



AVERAGE NUMBER OF PLANTS PER SQ. CHAIN
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
7
11
35
2
4
10
3
1
8
17
16
18
15
26
24
9
14
6
27
21
23
31
5
37
10
20
30
40
50
60
70
80
90
100
PERCENTAGE TOTAL QUADRATS IN WHICH SPECIES OCCURS

on a subjective basis to be *Acacia sowdenii* followed by *Casuarina cristata*, rate very low in terms of % frequency (1.2% and 8.2% respectively). This demonstrates the unsuitability of the sample size for tree vegetation, although the small trees of the black oak have a better chance of appearing in a quadrat than do the large myalls.

The vegetation association in Barrett's Paddock is floristically more diverse than that in Ki Ki, although 40% of species have densities of less than one per square chain. They are (from Table 17) *Sida intricata, Nitraria schoberi, C. nemophila* var. *coriacea, Exocarpos aphyllus, Santalum acuminatum, H. oleaefolium, M. platycarpum, Salsola kali, Stipa nitida, K. tomentosa, Bassia brachyptera, B. lanicuspis, Malacocera tricornis, Marrubium vulgare, Zygophyllum compressum* and *A. sowdenii*. Five of these are trees and the last five were never found in the total Quondong flora (see Chapter VIII).

As far as this study is concerned, the most important difference between this area and the Quondong study areas is the low frequency of *Kochia excavata* and *Bassia diacantha* and the high frequency of *A. vesicaria* and *K. pyramidata* in Barrett's Paddock. This is undoubtedly caused by environmental factors, the precise nature of which are unknown. The amount of calcareous material or its depth below the soil surface (Jessup, 1948) may explain the difference, but the matter was not investigated.

Fig. 16 shows that *Kochia brevifolia* (1), *Bassia sclerolaenoides*

(11), and *Babbagia acroptera* (26) have clumped (or contagious) distributions, whereas *K. sedifolia* (2), *K. georgei* (3) and *B. obliquicuspis* (35) are hyper-dispersed (or regular). *A. vesicaria* (7), and *K. pyramidata* (4) and *Chenopodium desertorum* (18) lie on the diagonal. The association is thus a variable one.

Vegetation pattern : the effect of stocking on plant populations

Incidence data

Species considered neither too frequent nor too rare to be statistically valid were subjected to influence analysis. (The remainder were set aside for the related reasons that (a) ubiquitous or near-ubiquitous species cannot yield statistically significant contingency interactions, and (b) the expected value of contingency table cell entries with very infrequent species are too low for valid application of the χ^2 test.) Diagrams of the interactions at $\chi \geqslant 4.0$ are given in Fig. 17, which reveals two independent nodes, Nodes 1 and 2. Attention is first given to Node 1.

It is immediately apparent that no single set of influence ratings and consequent map could adequately express these interactions. It is necessary to bring out the information by means of several sets of influence ratings, each centred on one of the major parts of the node. Three sets of influence ratings are here used for this

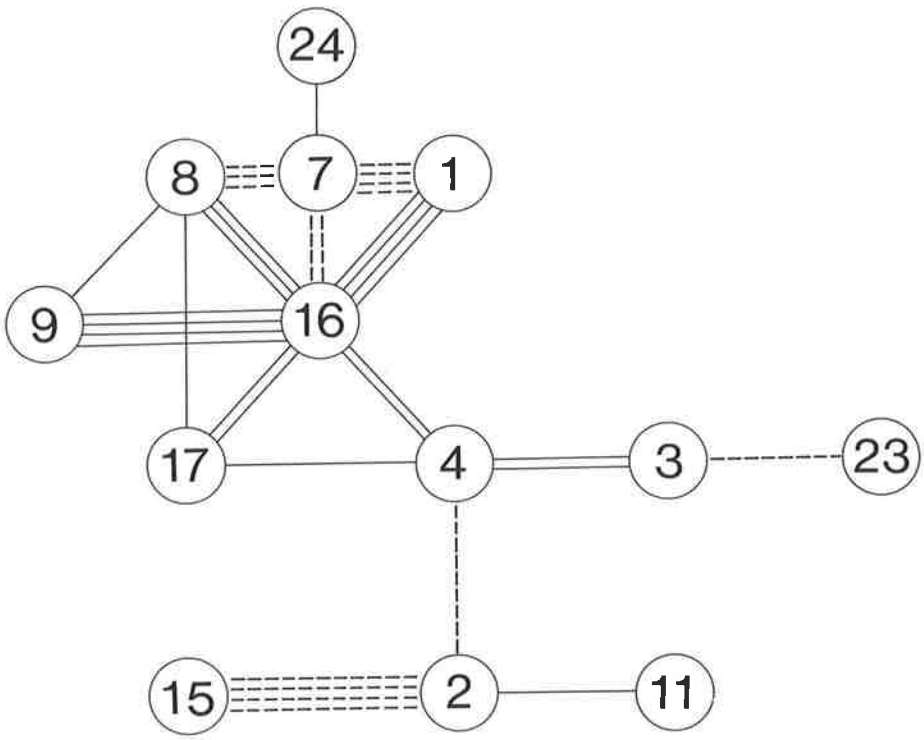
FIGURE 17

Nodes of associated species at $\chi \geq 4.0$ in Barrett's piosphere

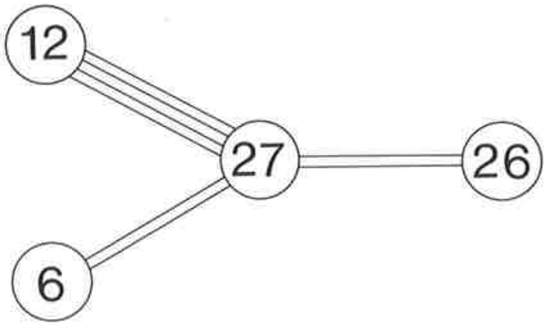
——— indicates association, positive association
---- indicates dissociation, negative association

(1) *Kochia brevifolia*
(2) *Kochia sedifolia*
(3) *Kochia georgei*
(4) *Kochia pyramidata*
(6) *Kochia astrotricha*
(7) *Atriplex vesicaria*
(8) *Atriplex spongiosa*
(9) *Atriplex eardleyae*
(11) *Bassia sclerolaenoides*
(12) *Bassia brachyptera*
(15) *Bassia biflora*
(16) *Bassia paradoxa*
(17) *Basseis patenticuspis*
(23) *Chenopodium ulicinum*
(24) *Rhagodia spinescens* var. *deltophylla*
(26) *Babbagia acroptera*
(27) *Frankenia pauciflora*

NODE 1.



NODE 2.



purpose, based on three groupings of the species involved (Nodes 1a, 1b and 1c).

In the lower half of the Node 1 diagram, *Bassia paradoxa* (16) has powerful positive interactions with *Kochia brevifolia* (1), *Atriplex eardleyae* (9) and *A. spongiosa* (8). *Atriplex vesicaria* (7) displays strong negative association with *K. brevifolia* and *A. spongiosa* and a weaker one with *B. paradoxa*. It also demonstrates a weak positive association with *Rhagodia spinescens* var. *deltophylla* (24), but as this species was believed to display special behaviour (see p. 123), it was omitted from further consideration at this stage. The interactions of the other species, Node 1a, are summarised in Table 18. The incidence of these species is shown in Maps 13 and 15.

The coding procedure was similar to that described for the Weary analysis (p. 108). The major pole combination (Table 19 *→) is constituted by the presence of *A. vesicaria* and the absence of all the other species; the opposite pole of the influence is shown by the absence of *A. vesicaria* and the presence of all the other species. The major pole recombination was recoded to fully negative; all the other combinations were recoded to be consistent with this and influence ratings (IR) 0-5 attributed to them in proportion to departures from the pole. No condensed recoding, as performed for the Weary analysis, was necessary. Quadrats in which none of the species occurred were not coded and are shown by an

TABLE 18

SIGNIFICANCE LEVELS OF INTERSPECIFIC ASSOCIATIONS BETWEEN SPECIES LINKED INTO NODE 1a IN BARRETT'S PADDOCK
Cell entries are χ values (positive or negative) on one degree of freedom

Kochia brevifolia	*Bassia paradoxa*	*Atriplex spongiosa*	*Atriplex eardleyae*	*Atriplex vesicaria*	
%f = 7.8	22.7	24.6	10.5	77.8	
	+ 8.8	+ 7.2	+ 5.0	− 7.8	*Kochia brevifolia*
		+ 6.7	+ 7.4	− 4.6	*Bassia paradoxa*
			+ 4.9	− 5.3	*Atriplex spongiosa*
				− 2.4	*Atriplex eardleyae*
					Atriplex vesicaria

asterisk on the map.

The result of back-plotting quadrats, so classified, on to a map according to the coding in Table 19 is shown in Map 14, Node 1a. It shows that the most powerful influence patterning the vegetation is the water-point on which the isotels are focussed. This situation is brought about by the occurrence of the four positive associates, *B. paradoxa*, *A. spongiosa*, *A. eardleyae* and

TABLE 19

POSSIBLE INCIDENCE COMBINATIONS OF NODE 1a SPECIES
IN BARRETT'S PADDOCK
with observed frequencies (f) and influence ratings (IR)

	K. brevifolia	*B. paradoxa*	*A. vesicaria*	*A. eardleyae*	*A. vesicaria*	f	Recoding					IR
	-	-	-	-	-	11						*
*→	-	-	-	-	+	150	-	-	-	-	-	0
	-	-	-	+	+	1	-	-	-	+	-	1
	-	-	+	-	-	6	-	-	+	-	+	2
	-	-	+	-	+	14	-	-	+	-	-	1
	-	-	+	+	+	2	-	-	+	+	-	2
	-	+	-	-	-	2	-	+	-	-	+	2
	-	+	-	-	+	9	-	+	-	-	-	1
	-	+	-	+	-	2	-	+	-	+	+	3
	-	+	-	+	+	3	-	+	-	+	-	2
	-	+	+	-	-	2	-	+	+	-	+	3
	-	+	+	-	+	3	-	+	+	-	-	2
	-	+	+	+	+	3	-	+	+	+	-	3
	+	-	-	-	-	4	+	-	-	-	+	2
	+	-	-	-	+	2	+	-	-	-	-	1
	+	-	-	+	+	1	+	-	-	+	-	2
	+	-	+	-	-	3	+	-	+	-	+	3
	+	+	-	-	-	1	+	+	-	-	+	3
	+	+	-	-	+	2	+	+	-	-	-	2
	+	+	-	+	-	2	+	+	-	+	+	4
	+	+	-	+	+	1	+	+	-	+	-	3
	+	+	+	-	-	6	+	+	+	-	+	4
	+	+	+	-	+	5	+	+	+	-	-	3
	+	+	+	+	-	3	+	+	+	+	+	5
	+	+	+	+	+	2	+	+	+	+	-	4
						Σ = 240						

K. brevifolia, close to the trough paddock and the virtual absence of *A. vesicaria* there (see Maps 13 and 15). This concludes the section concerning Node 1a.

* *

Turning to the interactions displayed in the upper part of the Node 1 diagram (Fig. 17), it seems reasonable to use two further sub-groups to bring out information from the interactions. The details of the interactions involved in these two groups are displayed in Table 20. One sub-group (Node 1b) displays positive interaction between all its members, *Bassia paradoxa* (16), *B. patenticuspis* (17), *A. spongiosa* (8) and *Kochia pyramidata* (4) (see Maps 13 and 17). These species tend to repeat the pattern of the Node 1a reaction, but are an alternative group not so closely involved in dissociation with *A. vesicaria*. Plotting the number of these positive associates occurring in each quadrat (as in the Ki Ki situation, p. 123) gives the influence ratings shown in Table 21 and should generate a map rather similar to that for Node 1a, as the group contains two of the species strongly associated in Node 1a (*B. paradoxa* and *A. spongiosa*). Map 14, Node 1b, shows that this is the case, pattern again being focussed on the water-point.

* *

TABLE 20

SIGNIFICANCE LEVELS OF INTERSPECIFIC ASSOCIATIONS BETWEEN SPECIES LINKED INTO NODES 1b AND 1c IN BARRETT'S PADDOCK
Cell entries are χ values (positive or negative) on one degree of freedom

	Bassia paradoxa	*Atriplex spongiosa*	*Bassia patenticuspis*	*Kochia pyramidata*	*Kochia georgei*	*Kochia sedifolia*	*Bassia sclerolaenoides*	*Bassia biflora*	
%f =	22.7	24.6	23.0	57.8	74.6	87.1	47.7	12.8	
		+ 6.7	+ 5.4	+ 5.0	+ 0.9	+ 0.2	− 0.1	− 0.3	*Bassia paradoxa*
			+ 4.7	+ 2.4	− 0.5	+ 1.9	− 0.2	− 2.4	*Atriplex spongiosa*
				+ 4.3	+ 2.0	+ 0.2	+ 2.8	− 0.3	*Bassia patenticuspis*
					+ 5.4	− 3.6	− 2.0	+ 3.7	*Kochia pyramidata*
						− 2.7	+ 2.2	+ 2.3	*Kochia georgei*
							+ 4.1	− 6.1	*Kochia sedifolia*
								− 3.5	*Bassia sclerolaenoides*
									Bassia biflora

The second sub-group of species from Table 20 (Node 1c) also contains *K. pyramidata* (4), positively associated with *K. georgei*

TABLE 21

POSSIBLE INCIDENCE COMBINATIONS OF NODE 1b SPECIES IN BARRETT'S PADDOCK with observed frequencies (f) and influence ratings (IR)

K. pyramidata	*A. spongiosa*	*B. paradoxa*	*B. patenticuspis*	f	IR
+	-	-	-	70	1
-	-	+	-	1	1
+	-	+	-	12	2
+	+	+	-	7	3
+	-	+	+	7	3
+	-	-	+	16	2
+	+	-	+	6	3
+	+	+	+	10	4
-	-	-	-	81	0
-	-	-	+	7	1
-	+	-	-	7	1
+	+	-	-	11	2
-	+	+	-	1	2
-	-	+	+	2	2
-	+	-	+	2	2
				Σ = 240	

(3) and *Bassia biflora* (15) and dissociated from *K. sedifolia* (2) and *B. sclerolaenoides* (11). *K. georgei* apparently reinforces the

K. pyramidata-B. biflora interaction, but also reacts positively with *B. sclerolaenoides*. On account of this behaviour it was considered that *K. georgei* would complicate mapping, and it was therefore omitted.

Thus one pole of the influence consists of the presence of *K. pyramidata* and *B. biflora* and the absence of *K. sedifolia* and *B. sclerolaenoides*. The opposite pole, possessing *K. sedifolia* and *B. sclerolaenoides*, is the major combination shown in Table 22, and was recoded to fully negative, the other combinations being altered accordingly. The map produced using the IRs 0-4 is shown in Map 14, Node 1c.

Field observations, suggesting that *B. biflora* (Map 13) is confined to low-lying areas, are confirmed by these results, as comparison with the topography map (Map 12) shows that the strongest patterning influences are the watercourses, which contain the quadrats at the *B. biflora-K. pyramidata* pole of the influence. The inner piosphere area does not display any concentric pattern. However, many quadrats with an IR of 2 are found in the vicinity of the trough, without any apparent relation to a watercourse (which is where most of the other IR 2 quadrats are). Inspection of Maps 13, 16 and 17 suggest that this is brought about by *K. pyramidata* occurring with one of its dissociates, *K. sedifolia* or *B. sclerolaenoides*.

It is evident from the preceding descriptions of Nodes 1b and 1c that *K. pyramidata* contributes to both the piosphere pattern

TABLE 22

POSSIBLE INCIDENCE COMBINATIONS OF NODE 1c SPECIES IN BARRETT'S PADDOCK with observed frequencies (f) and influence ratings (IR)										
	K. sedifolia	*B. sclerolaenoides*	*K. pyramidata*	*B. biflora*	f	Recoding				IR
	-	-	-	-	1					*
	-	-	+	-	9	+	+	-	+	3
	-	-	+	+	17	+	+	+	+	4
	-	+	-	-	1	+	-	-	-	1
	-	+	+	-	3	+	-	+	-	2
	+	-	-	-	44	-	+	-	-	1
	+	-	-	+	2	-	+	-	+	2
	+	-	+	-	51	-	+	+	-	2
	+	-	+	+	10	-	+	+	+	3
*→	+	+	-	-	50	-	-	-	-	0
	+	+	-	+	1	-	-	-	+	1
	+	+	+	-	48	-	-	+	-	1
	+	+	+	+	3	-	-	+	+	2
					Σ = 240					

(Node 1b) and to the watercourse pattern (Node 1c), and seemingly forms a link between the two. Because some of its associates in Node 1b are, from their distributions in Map 13, obvious invaders of the inner piosphere area, it could be inferred that *K. pyramidata* was behaving similarly in spreading into the region of the trough paddock from the watercourses. This possibility will be discussed later.

The account of the behaviour of *B. biflora* contained in some of the above paragraphs demonstrates how one species, which may appear to be interesting in the field, can be singled out with its immediate associates to display its actual behaviour. In this particular case the group of interactions also highlighted the behaviour of another important species, *K. pyramidata*. Similar treatment was given to *A. vesicaria*, *A. spongiosa* and *A. eardleyae*. The details are described elsewhere (Barker and Lange, 1970), and in concluding this section of the discussion it need only be said that the interactions of these plants taken separately with their associates in Barrett's Paddock was unquestionably related to sheep activity round the trough, which parallels the observations made on their behaviour as a group in Node 1a.

* *

Node 2 (Fig. 17) consists of only four positive associates occurring with relatively low frequency in the paddock (Table 23). They are *Babbagia acroptera* (26), *Frankenia pauciflora* (27), *Bassia brachyptera* (12) and *Kochia astrotricha* (6). The numbers of these

TABLE 23

SIGNIFICANCE LEVELS OF INTERSPECIFIC ASSOCIATIONS BETWEEN SPECIES LINKED INTO NODE 2 IN BARRETT'S PADDOCK
Cell entries are χ values (positive or negative) on one degree of freedom

Kochia astrotricha	*Babbagia acroptera*	*Bassia brachyptera*	*Frankenia pauciflora*	
%f = 5.1	3.9	4.7	7.0	
	+ 1.7	+ 5.5	+ 5.8	*Kochia astrotricha*
		+ 3.3	+ 5.5	*Babbagia acroptera*
			+ 7.0	*Bassia brachyptera*
				Frankenia pauciflora

species occurring in each quadrat was plotted according to the combination shown in Table 24.

Map 14, Node 2, indicates the pattern engendered by these associates. Field observations suggested that they grew in local depressions and where the substrate contained more clay and quartzitic rubble than elsewhere. This accounts for their occurrence on the sloping areas south of the trough and in the Faraway Dam watercourse and their absence in areas lacking clay and quartzite. They are of

TABLE 24

POSSIBLE INCIDENCE COMBINATIONS OF NODE 2 SPECIES IN BARRETT'S PADDOCK
with observed frequencies (f) and influence ratings (IR)

K. astrotricha	*B. acroptera*	*B. brachyptera*	*F. pauciflora*	f	IR
-	-	-	-	217	0
-	-	-	+	1	1
-	-	+	-	2	1
-	-	+	+	2	2
-	+	-	-	2	1
-	+	-	+	2	2
-	+	+	-	1	2
-	+	+	+	1	3
+	-	-	-	5	1
+	-	-	+	1	2
+	-	+	-	1	2
+	-	+	+	3	3
+	+	-	+	1	3
+	+	+	+	1	4
				$\Sigma = 240$	

little importance in the present context, except to point out that *Babbagia acroptera* and *Bassia brachyptera* were two of the species of minor importance occurring close to Weary Dam; their appearance in local water catches in Barrett's tends to confirm the belief that at least some of the vegetation pattern at Weary Dam was the result of topography rather than grazing activity.

Density data

The population densities of three of the shrub dominants are illustrated in Maps 15, 16 and 17. The densities of *B. paradoxa, A. eardleyae, K. brevifolia* and *A. spongiosa*, plotted on a previous occasion (Barker and Lange, 1970), showed that the maximum populations were within 25 yards of the trough paddock. More distant populations did not depict any particular density gradient, so densities of these populations are not shown here.

Densities of mature *A. vesicaria* (Map 15) are low within 250 yards of the trough and tend to increase with increasing distance from water, except where traverses cross the road and populations suddenly increase in White Cliff South Paddock. Numbers of seedlings and young plants are also low within this radius, but do not display a marked increase on the other side of the road. Further examination reveals that some juvenile populations equal or exceed mature populations and most of these, indicated by ⇽, are within the 250 yard radius of the trough, as are juvenile populations present in quadrats without mature plants (⬅). This might mean that *A. vesicaria* is beginning to re-establish itself near the trough since the relief from intense stocking 16 years ago.

A rather different situation exists with regard to *K. sedifolia* (Map 16), where population sizes are no smaller or larger close to the water-point than they are some distance away, but then become smaller in the watercourses. Populations of juveniles (young plants and seedlings) are very small, those of seedlings exceeding those of young plants in both frequency and size. In only one quadrat does the population of juveniles exceed that of mature plants.

Conversely, the high populations of *K. pyramidata* (Map 17) are found in the watercourses and to the south-east of the trough (X, Plate 14). Populations of juveniles are much greater than those of *K. sedifolia*. The populations of young plants of *K. pyramidata* are more frequent and larger than those of seedlings. This observation is at variance with that noted above for *K. sedifolia*, and it seems as though the inputs into the young plant populations from the seedling populations of *K. pyramidata* are greater than the inputs into those of *K. sedifolia*. If this is so, then it could be argued that the survival rate of seedlings of *K. pyramidata* is greater than that of *K. sedifolia*. Environmental or seasonal factors could account for this, but it has been noted that *K. pyramidata* plants produce a thick axis while still very young, unlike those of *K. sedifolia*, whose axes seem to remain fragile for some time, thus being vulnerable to trampling.

The population sizes of juveniles of *K. pyramidata* equal or exceed those of mature plants in a number of quadrats indicated by ←on Map 17. Many of these occur within the 250 yard radius of the trough as in *A. vesicaria*. Some of these juvenile populations occur in quadrats lacking mature plants, indicated thus ←, whereas in other parts of the paddock juveniles are always accompanied by mature populations. These observations suggest that the species is spreading rather than merely replacing itself, in the inner piosphere area. The inference can then be made that it is the effect of sheep activity close to the trough which has brought this about. Jessup (1948) comments that *K. pyramidata* is often confined to watercourses, not because of the waterholding capacity of the soil, but because of the lack of lime near the surface in these situations. The stimulation of young populations of *K. pyramidata* near a water-point could, therefore, be associated with a changing mineral status of the soil because of the increased quantities of dung and urine here (Lange, 1969). For example, one might expect that nitrogen inputs would increase, but whether this could be suggested as a stimulant for *K. pyramidata* is questionable, as Correll (1967) believes that the *loss* of nitrogen from the top soil layers has encouraged the replacement of *K. sedifolia* by *K. pyramidata* on Yudnapinna Station.

CONCLUSIONS

It is reasonable to assume that before the tank and trough were installed, the vegetation in the region of the present water-point in

Barrett's Paddock would have been essentially similar to that existing at the time of sampling over the fence in White Cliff South Paddock, having more or less even populations of the shrub dominants mentioned on p. 132, with *K. pyramidata* being virtually confined to the watercourses.

Incidence data used for influence analysis have identified five species, which appear to be invaders, having strong positive correlations with the water-point and occurring only rarely elsewhere. These are *B. paradoxa, B. patenticuspis, A. eardleyae, A. spongiosa* and *K. brevifolia*. The first four of these are non-perennials and may, at present, be relatively unimportant, but they nevertheless represent the initial stages of degradation. The environment in the water-point area has become modified in a way these species are able to exploit. Their populations become established rapidly because they complete a life cycle in a relatively short period of time. They are all consumed by sheep, the *Bassia* spp. being avoided only when they are fruiting, and their survival in the heavily stocked water-point area is probably due to the fact that when they are present, other more acceptable grass forage is also available.

Kochia brevifolia, on the other hand, is a perennial with a suckering rootstock. It is also grazed by sheep and is also able to survive severe stock pressure near the water-point. Its status in the piosphere situation is difficult to interpret. Murray (1931) remarked that it is the first coloniser of claypans on the Lake

Torrens Plateau. It occurs elsewhere in the State as far south as Glenelg in coastal situations and as a roadside weed.

Mention should also be made here of another invader species, *Marrubium vulgare*. It has a frequency of only 0.8% in the study area and therefore has no statistical significance. It is, however, of practical significance, as the plant is a notoriously aggressive alien weed with little fodder value. It is likely to compete with and replace the existing fodder species near the water-point.

Factors contributing to the development of these invading populations are not fully understood. Undoubtedly seed is brought into the area on the hooves or fleeces of stock and by vehicles. The chopping up of the ground surface by hooves and the addition of nutrients as stimulating factors were discussed in relation to the Ki Ki study area (p. 126).

Both incidence and density data make it clear that some of the existing populations in Barrett's Paddock have also been modified by stocking. *K. sedifolia* and *K. georgei* appear to be relatively unaltered as yet. *A. vesicaria* has practically disappeared from the water-point area, though the appearance of young plants and seedlings within 250 yards of the trough suggest that the species may be re-colonising the eaten-out area. Nevertheless, as *A. vesicaria* is regarded as valuable feed, any changes in its population must be regarded with concern.

K. pyramidata appears to be invading the inner piosphere area from populations in a small water-course about quarter of a mile south-east of the trough. This change must also be regarded as retrograde. Jessup (1948) remarks that it is a free seeding species. From the high numbers of juveniles, noted in the present study, and their apparently hardy nature (compared with *K. sedifolia*, which has a superficially similar habit) this plant could be regarded as aggressive.

In the simple piosphere just described where the water-point is not dependent on radial drainage lines to supply it and where moderate grazing has been continuous for 20-30 years, the vegetation pattern which focusses on the trough can definitely be attributed to stock pressure, that is, it is a true piosphere effect. It was shown to be easily distinguished from the natural pattern caused by topography.

However, the species involved in this piosphere effect are quite different from those generating the pattern at Weary Dam (possibly a natural pattern) and in the Ki Ki piosphere, where only *K. excavata* showed any shifts since stocking. In Barrett's *K. excavata* has a frequency of only 7%.

The results presented in this chapter are of considerable importance for two reasons. Firstly, they show that the interactions between stock, water-point and vegetation (the piosphere effect) are definitely demonstrable in terms of plant populations. Within a paddock where vegetation may be patterned by topography, another pattern is found, which is unquestionably imposed by stock pressure near a water-point. Secondly, although these patterns are revealed by species interactions, which can be very complex, it is nevertheless possible to distinguish between natural pattern and the imposed piosphere effect.

This is probably the first time that the effect of stock round a water-point has been described in such quantitative terms. It would, however, be naive to suppose that the species identified here as contributing to the piosphere effect are common to all piosphere situations. The actual plants involved will vary according to the regional vegetation association, as exemplified by the differences between Quondong and Roopena.

The next chapter describes five other piospheres, which are contiguous with each other in a more complex topographic situation. The same techniques are used and the possible effects of bias caused by radial sampling, on the outcome of influence analysis, is also tested.

CHAPTER XI

PIOSPHERES IN CONTINUOUS RANGELAND

DESCRIPTION OF STUDY AREA

Investigations were transferred to a region about 16 miles (25 km) south-west of Barrett's Paddock and south of Middleback Station (Roopena) homestead. The study area covered about 5 square miles and extended from Two-Mile Dam in a southerly direction as far as the Winter Paddock Flat (Fig. 18 and Plate 15).

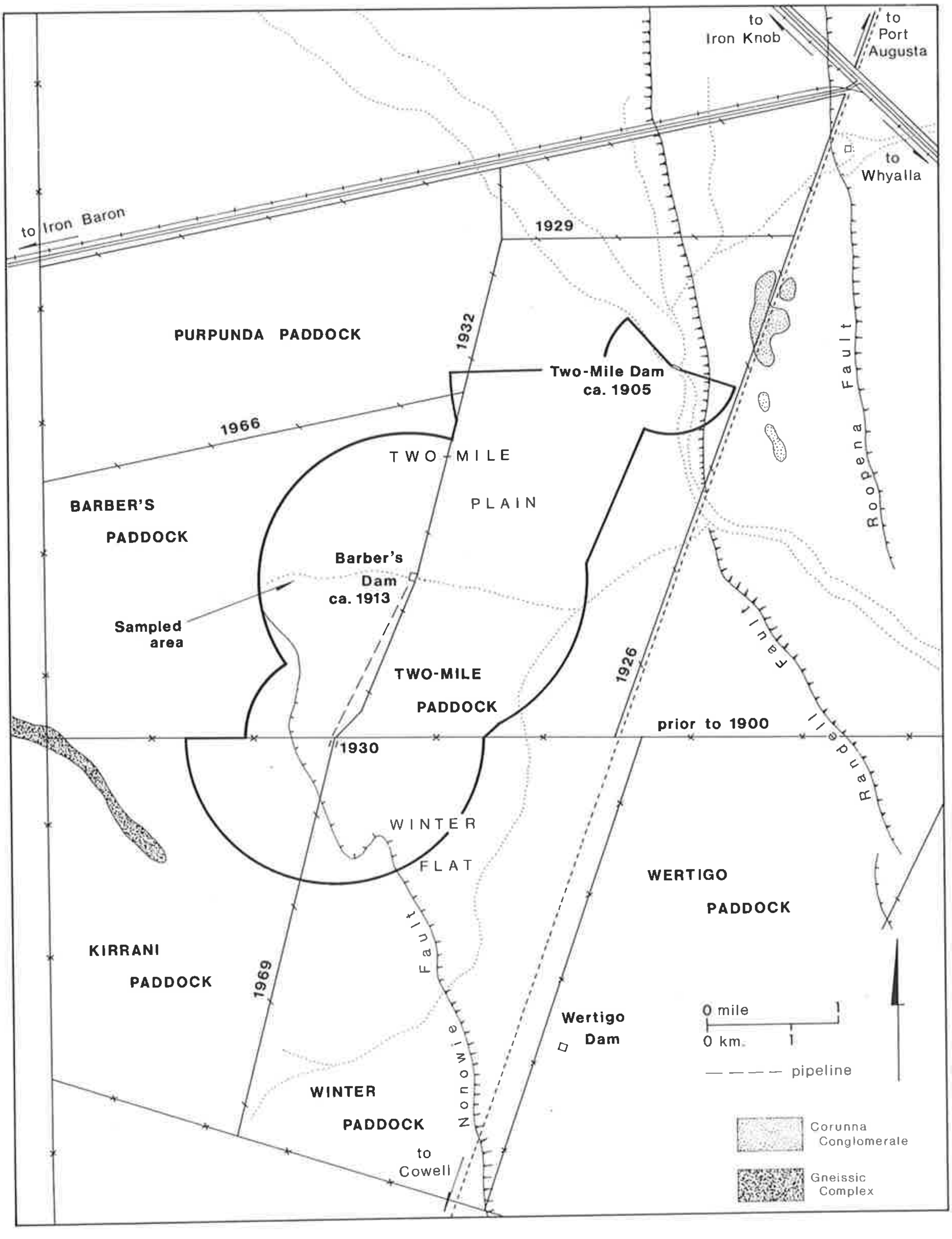
Because of its larger size the area is topographically more diverse than that of Barrett's Paddock and is certainly more so than the Quondong areas. A form line map is given in Map 18.

Geologically the area is moderately uniform. Half a mile north-east of Two-Mile Dam is a Palaeozoic outcrop of Corunna Conglomerate, consisting of sandstones and interbedded shales, while to the extreme south-west of the area, in Kirrani Paddock, is a Gneissic outcrop containing sedimentary schists and quartzite. Elsewhere, as in Barrett's Paddock, the substrate is composed of Quaternary alluvial and dune deposits, according to the Geological Survey of South Australia. Two faults cross the region. The Randell Fault has a throw of 15 to 20 feet, while that of the Nonowie Fault is negligible (2 to 5 feet), having little effect on the topography.

FIGURE 18

Location diagram

showing the Two-Mile Dam - Winter Flat study area



to Iron Knob
to Port Augusta
to Whyalla
to Iron Baron
1929
PURPUNDA PADDOCK
1932
Two-Mile Dam ca. 1905
1966
TWO-MILE
PLAIN
BARBER'S PADDOCK
Barber's Dam ca. 1913
Sampled area
Roopena Fault
TWO-MILE PADDOCK
1926
Randell Fault
prior to 1900
1930
WINTER FLAT
WERTIGO PADDOCK
KIRRANI PADDOCK
1969
Nonowie Fault
Wertigo Dam
0 mile 1
0 km 1
pipeline
WINTER PADDOCK
to Cowell
Corunna Conglomerate
Gneissic Complex

The terrain is generally undulating with some marked watercourses.

At the foot of the Randell scarp two drainage lines lead into Two-Mile Dam. It is possible that this was the site of a natural water soak, as aboriginal chips have been found in the red sand associated with the Randell Fault and nardoo (*Marsilea drummondii*), a valuable dietary constituent of the aborigine, is present in the watercourse.

South-west of the Two-Mile watercourse is an open area referred to as the Two-Mile Plain, which extends into Barber's and Purpunda Paddocks. It is, in fact, a shallow basin and now appears to be the main catchment for Two-Mile Dam. To the south, the basin has a rim, which borders Barber's Dam watercourse.

The Nonowie Fault, crossing the study area in Barber's, Kirrani and Winter Paddocks seems to mark the start of a gentle rise in elevation, the rising ground being drained by a watercourse containing Barber's Dam and some shallow washes which unite with the Barber's Dam watercourse after draining through Kirrani and Winter Paddocks. Winter Paddock has little relief and could be regarded as an outwash plain of the higher land in Kirrani Paddock. The elevation of the whole area falls gradually from 300 feet above M.S.L. in Kirrani Paddock to 150 feet at Two-Mile Dam.

The general vegetation association is essentially similar to that in Barrett's Paddock, but the rocky outcrops carry *Eremophila alternifolia, Acacia burkittii, A. kempeana* and *Ptilotus obovatus* in addition to saltbush, bluebush and occasional myall. The sample grid (Map 18) stops short of both the outcrops.

The Randell Fault at Two-Mile Dam is characterised by red sand supporting *Kochia pyramidata* and *K. tomentosa*, with occasional saltbush and bluebush. *Acacia sowdenii* (myall) and *Myoporum platycarpum* (false sandalwood) are the character trees. This vegetation association extends south of the dam, before giving way to *K. sedifolia* (bluebush) on the Plain (see Plate 16).

Myall woodland is sparse on the Two-Mile Plain and on the upland south of Barber's Dam watercourse, but myalls delineate the broad expanses of the watercourses. The line of the Nonowie Fault is picked out by *Casuarina cristata* (black oak) woodland, which occurs along its length, interspersed with myall. The shrub constituents of the vegetation are *K. sedifolia*, *K. pyramidata* and *Atriplex vesicaria*. Ephemeral populations, as at Barrett's, are a minor constituent, except on Winter Flat and Two-Mile Plain, where *Stipa nitida* grows profusely after rain. Apart from the occasional *Eremophila scoparia*, the whole area is notable for a lack of tall shrubs such as those at Quondong, viz, *Acacia colletioides*, *Dodonaea attenuata*, *Cassia nemophila* and *Eremophila sturtii*.

The leases of the area which now comprises Middleback Station were probably first taken out in the 1860's, but lack of permanent stock waters would have prevented its continuous use as pasture, although the vermin-proof fences were erected in the late 1800's.

Two-Mile Dam, constructed by the government to supply traffic on the road between Cowell and Port Augusta, was not gazetted until 1908, although there could have been some other dam or water source there before, as there are remains of brush shepherds' yards near both Two-Mile and Barber's Dams. The present Barber's Dam was built between 1910 and 1919. Sheep in the Winter Paddock originally watered at Wertigo Dam, but in 1930 a pipeline was constructed from Barber's Dam to supply a trough on the vermin-proof fence in Winter Paddock.

Two-Mile, Barber's and Winter Paddocks have all been subdivided by the present lessees over the period from 1925 to the present, as indicated in Fig. 18. Before these subdivisions, which have reduced paddock size to between 4 and 6 square miles, sheep would have had the opportunity to graze more widely than at present, depending on seasonal conditions.

The numbers of stock carried in these paddocks since 1953 is shown in Appendix 4. In Two-Mile and Barber's the average numbers of stock carried over this period were approximately 250-270 per paddock, while in Winter Paddock, before its recent division, about 570 sheep were carried on average. It is understood that before 1953 stocking might have been somewhat heavier, and it is believed that Two-Mile Paddock has always been heavily used, periodically, as a holding paddock for large numbers of sheep at shearing time.

METHOD

The sampling and analytical techniques were similar to those described earlier. The grid layout is shown in Map 18 and in all other maps relating to this section. In this series of analyses some species of sufficiently low frequency and density to have warranted their exclusion in previous analyses, were included because it was felt that some such species had very localised, but important distribution, while others could assume greater statistical significance in the neighbouring piospheres. This meant that each interaction had to be examined with care to see that low incidence did not render the association spurious.

Sampling was focussed on:-

(1) Two-Mile Dam (238 quadrats)
(2) Barber's Dam in Two-Mile Paddock (223 quadrats)
(3) Barber's Dam in Barber's Paddock (233 quadrats)
(4) Winter Trough (127 quadrats)
(5) Kirrani Trough (95 quadrats)
It will be seen from Map 18 that the last two water-points are by chance situated in a minor watercourse along the vermin-proof fence. They are not, therefore, independent of topographic effects.
(6) the corners of Two-Mile and Barber's Paddocks at Winter Trough
No water is available for stock at these points and radial sampling was carried out here to demonstrate that although bias may be imposed by the radial traverses close to the point of origin, if the vegetation is lacking pattern such bias has no effect on the outcome of influence analysis.

For influence analysis of incidence data each of these units was first treated separately, and then the data were pooled and analysed as one unit:-

(7) analysis of the total data from the area between Two-Mile Dam and Winter Flat.

The remainder of this chapter will be devoted to seven sub-sections titled as above, in which the results, discussion and conclusions relating to each piosphere influence analysis will be described. To avoid unnecessary repetition, density data will only be described in the section dealing with the analysis of the total data.

TWO-MILE DAM

RESULTS AND DISCUSSION

Description of plant populations : density, frequency and dispersion

These data are presented in Table 25 and Fig. 19. In terms of % frequency the dominant species are in the order, *Kochia pyramidata* (black bluebush), *Bassia patenticuspis*, *B. obliquicuspis*, *K. georgei* and *K. sedifolia* (bluebush). This is quite different from Barrett's where *Atriplex vesicaria* was an important constituent of the

TABLE 25

THE PLANT SPECIES SAMPLED IN TWO-MILE PADDOCK AT TWO-MILE DAM with their average density per square chain* and the percentage of total samples in which they occur+

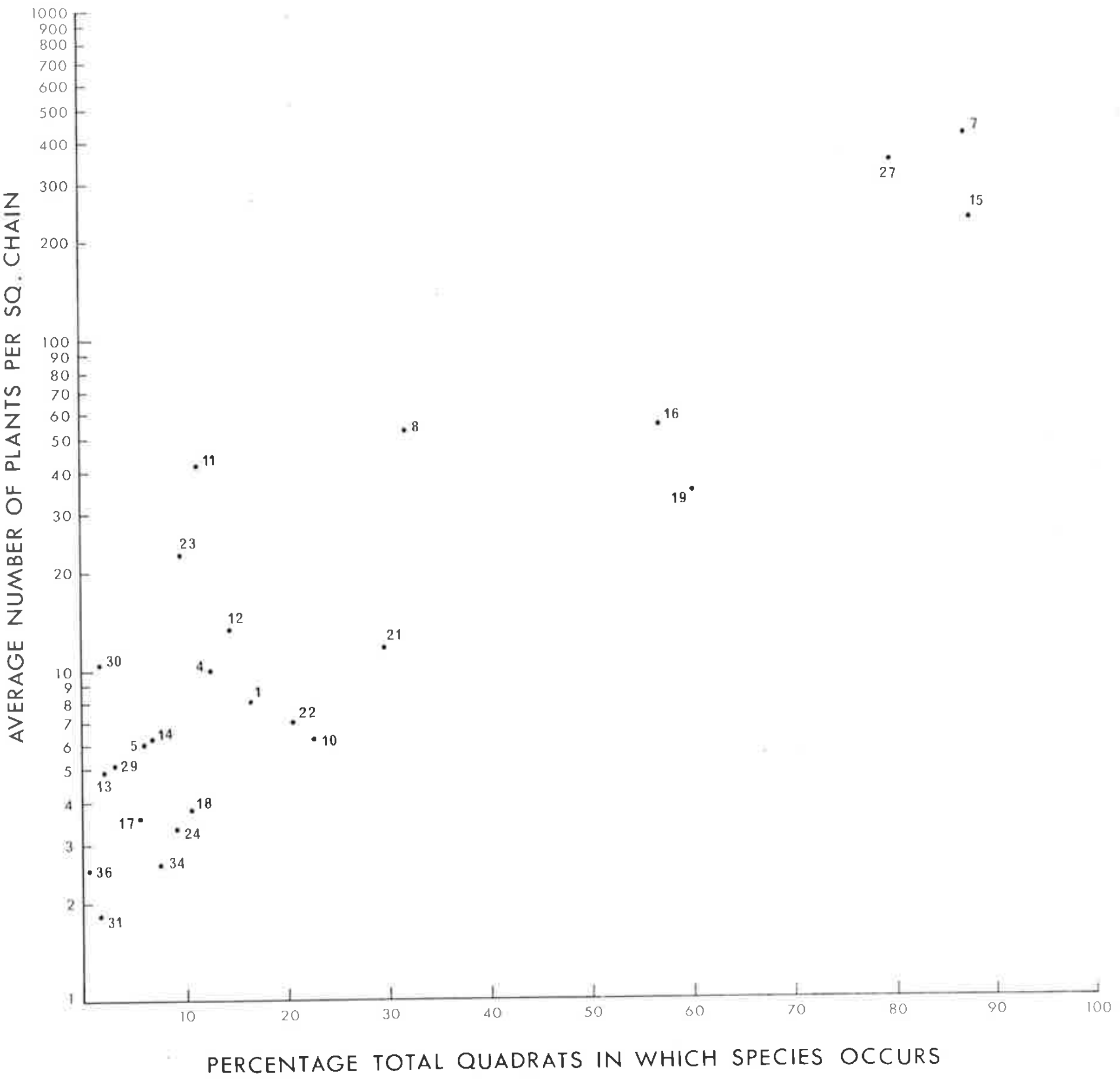
Species	Density*	Frequency+
1. *Atriplex vesicaria*	8.1	16.4
2. *Atriplex stipitata*	0.7	2.9
3. *Atriplex acutibracta*	0.4	2.1
4. *Atriplex spongiosa*	10.0	12.6
5. *Atriplex eardleyae*	6.0	5.9
6. *Bassia paradoxa*	0.1	0.4
7. *Bassia patenticuspis*	453.3	80.7
8. *Bassia sclerolaenoides*	52.9	31.9
9. *Bassia biflora*	0.4	1.3
10. *Chenopodium desertorum*	6.2	22.7
11. *Chenopodium ulicinum*	4.2	11.3
12. *Marrubium vulgare*	14.5	13.9
13. *Inula graveolens*	4.9	2.1
14. *Carthamus lanatus*	6.2	6.7
15. *Kochia pyramidata*	231.3	87.8
16. *Kochia sedifolia*	54.3	56.7
17. *Kochia brevifolia*	3.6	5.5
18. *Kochia excavata* var. *trichoptera*	3.8	10.5
19. *Kochia georgei*	34.5	60.1
21. *Kochia tomentosa*	12.0	29.4
22. *Enchylaena tomentosa*	6.9	20.6
23. *Rhagodia spinescens* var. *deltophylla*	2.2	9.7
24. *Lycium australe*	3.3	9.2
25. *Sida intricata*	0.9	4.6
27. *Bassia obliquicuspis*	344.0	79.8
28. *Bassia diacantha*	0.1	0.4
29. *Centipeda thespidioides*	5.1	2.9
30. *Marsilea drummondii*	10.9	1.7
31. *Verbena officinalis*	1.8	1.7
32. *Ptilotus obovatus*	0.05	0.4
33. *Myoporum platycarpum*	0.05	0.4
34. *Vittadinia triloba*	2.6	7.6
35. *Heterodendrum oleaefolium*	0.05	0.4
36. *Solanum* sp.	2.5	0.4
37. *Kochia astrotricha*	0.05	0.4
38. *Acacia sowdenii*	0.05	0.4

FIGURE 19

Dispersion of species in Two-Mile Paddock at Two-Mile Dam

(excluding species having densities of less than one per square chain)

1. *Atriplex vesicaria*
4. *Atriplex spongiosa*
5. *Atriplex eardleyae*
7. *Bassia patenticuspis*
8. *Bassia sclerolaenoides*
10. *Chenopodium desertorum*
11. *Chenopodium ulicinum*
12. *Marrubium vulgare*
13. *Inula graveolens*
14. *Carthamus lanatus*
15. *Kochia pyramidata*
16. *Kochia sedifolia*
17. *Kochia brevifolia*
18. *Kochia excavata* var. *trichoptera*
19. *Kochia georgei*
21. *Kochia tomentosa*
22. *Enchylaena tomentosa*
23. *Rhagodia spinescens* var. *deltophylla*
24. *Lycium australe*
27. *Bassia obliquicuspis*
29. *Centipeda thespidioides*
30. *Marsilea drummondii*
31. *Verbena officinalis*
34. *Vittadinia triloba*
36. *Solanum* sp.



AVERAGE NUMBER OF PLANTS PER SQ. CHAIN
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
10
20
30
40
50
60
70
80
90
100
PERCENTAGE TOTAL QUADRATS IN WHICH SPECIES OCCURS
7
27
15
16
8
11
19
23
12
21
30
4
1
22
10
5
14
29
13
18
17
24
34
36
31

vegetation and *K. sedifolia* ranked highest. The character tree, *Acacia sowdenii* (myall), rates under 1% at Two-Mile.

Of the 36 species listed, 11 (that is, 30%) have densities of less than 1 per square chain. *Bassia paradoxa, B. biflora, Sida intricata* and *K. astrotricha*, whose incidences in Barrett's were statistically important, are some of these. Some of the others were trees, as in Barrett's, and the rest were *Atriplex stipitata, A. acutibracta* and *Ptilotus obovatus*, which were present in the Quondong study areas, but not in Barrett's. *Kochia excavata* rates a little higher here than in Barrett's.

The majority of the species with densities greater than 1 per square chain are shown by Fig. 19 to have high density/frequency ratios and are thus contagious in their distribution. *Bassia patenticuspis* (7) and *Kochia sedifolia* (16) are neither clumped nor hyper-dispersed, and only *K. georgei* (19) and *K. pyramidata* (15) tend to be scattered.

Vegetation pattern : the effect of stocking on plant populations

Incidence data

The nodes derives at $\chi \geqslant 4.0$ using influence analysis are shown in Fig. 20. The main one is very complex, although it could be made to appear simpler if shown at higher levels of χ. However, the

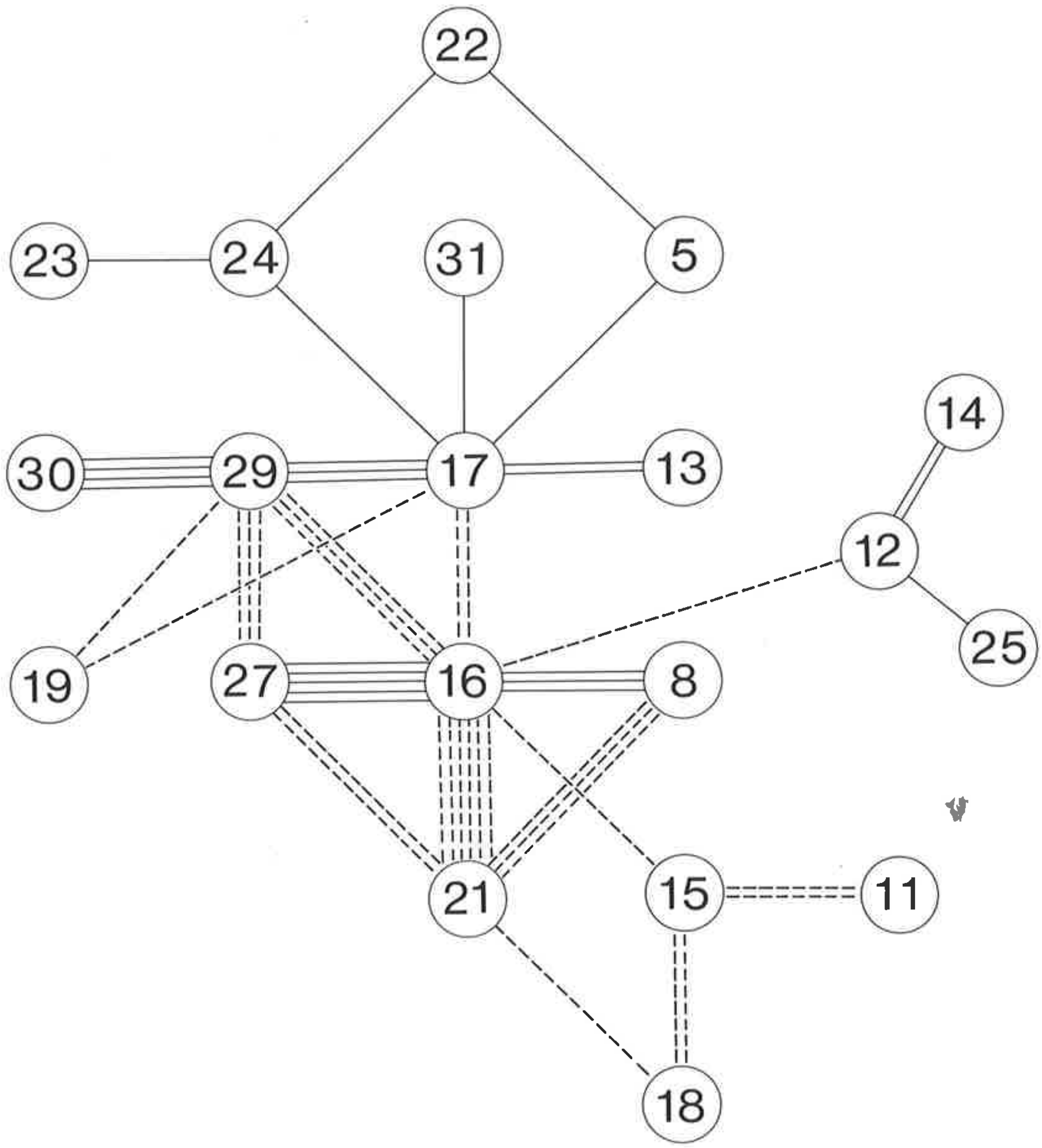
FIGURE 20

Nodes of associated species at $\chi \geq 4.0$
in Two-Mile piosphere

——— indicates association, positive association
---- indicates dissociation, negative association

(1) *Atriplex vesicaria*
(2) *Atriplex stipitata*
(5) *Atriplex eardleyae*
(11) *Chenopodium ulicinum*
(12) *Marrubium vulgare*
(13) *Inula graveolens*
(14) *Carthamus lanatus*
(15) *Kochia pyramidata*
(16) *Kochia sedifolia*
(17) *Kochia brevifolia*
(18) *Kochia excavata*
(19) *Kochia georgei*
(21) *Kochia tomentosa*
(22) *Enchylaena tomentosa*
(23) *Rhagodia spinescens* var. *deltophylla*
(24) *Lycium australe*
(25) *Sida intricata*
(29) *Centipeda thespidioides*
(30) *Marsilea drummondii*
(31) *Verbena officinalis*

NODE 1.



NODE 2.

maximum amount of information is gained at a relatively low value of 4.0 which is nevertheless still statistically valid.

The most powerful interaction is that of dissociation between *Kochia tomentosa* (21) and *K. sedifolia* (16), which first becomes apparent at $\chi \geqslant 9.0$ (see Map 19 and compare with relevant portion of Map 35). Lesser degrees of dissociation are also present between *K. tomentosa* and *Bassia obliquicuspis* (27) and *B. sclerolaenoides* (8). These three dissociates of *K. tomentosa* are themselves strongly associated, that between *K. sedifolia* and *B. obliquicuspis* occurring first at $\chi \geqslant 8.0$. From their fairly high frequencies, these are important components of the general vegetation association.

The dominant, *K. pyramidata* (15), dissociates at $\chi \geqslant 5.0$ from *K. excavata* (18) and *Chenopodium ulicinum* (11) and this trio is linked with the strong interactions described above only by *K. pyramidata* dissociating with *K. sedifolia* and *K. excavata* dissociating with *K. tomentosa*, both at $\chi \geqslant 4.0$. Lower levels of χ show positive association between *K. tomentosa* and *K. pyramidata* and between *K. excavata* and *K. sedifolia* and *B. sclerolaenoides* and between *Chenopodium ulicinum* and *B. sclerolaenoides*.

This group of interactions (Node 1a) is displayed in Table 26 and shows that *K. excavata* and *C. ulicinum* reinforce the major positive associates (*B. obliquicuspis*, *K. sedifolia* and *B. sclerolaenoides*), while *K. pyramidata* supports the negative interaction of *K. tomentosa* with them.

TABLE 26

SIGNIFICANCE LEVELS OF INTERSPECIFIC ASSOCIATIONS BETWEEN SPECIES LINKED INTO NODE 1a AT TWO-MILE DAM
Cell entries are χ values (positive and negative) on one degree of freedom

Bassia obliquicuspis	*Kochia sedifolia*	*Bassia sclerolaenoides*	*Kochia excavata*	*Chenopodium ulicinum*	*Kochia pyramidata*	*Kochia tomentosa*	
%f = 79.8	56.7	31.9	10.6	11.3	87.8	20.6	
	+ 8.2	+ 5.0	+ 2.3	+ 0.3	− 0.0	− 4.8	*Bassia obliquicuspis*
		+ 6.5	+ 3.9	+ 3.2	− 3.2	− 8.2	*Kochia sedifolia*
			+ 3.5	+ 1.1	− 1.5	− 5.8	*Bassia sclerolaenoides*
				+ 1.6	− 3.8	− 3.2	*Kochia excavata*
					− 4.3	− 2.4	*Chenopodium ulicinum*
						+ 3.1	*Kochia pyramidata*
							Kochia tomentosa

The major components only were mapped, according to the influence ratings in Table 27. The isotels shown in Map 20, Node 1a, are focussed along the side of the dam and watercourse. There are a

TABLE 27

POSSIBLE INCIDENCE COMBINATIONS OF NODE 1a SPECIES AT TWO-MILE DAM
with observed frequencies (f) and influence ratings (IR)

	B. obliquicuspis	*K. sedifolia*	*B. sclerolaenoides*	*K. tomentosa*	f	Recoding				IR
	-	-	-	-	17					*
	-	-	-	-	28	+	+	+	+	4
	-	-	+	-	2	+	+	-	-	2
	-	+	+	+	1	+	-	-	+	2
	+	-	-	-	16	-	+	+	-	2
	+	-	-	+	31	-	+	+	+	3
	+	-	+	-	57	-	+	-	-	1
	+	-	+	+	8	-	+	-	+	2
	+	+	-	-	6	-	-	+	-	1
	+	+	-	+	1	-	-	+	+	2
*→	+	+	+	-	71	-	-	-	-	0
					Σ = 238					

number of quadrats, marked with an asterisk, actually on the floor of the watercourse, in which none of the species occur. The Two-Mile Plain is picked out by an IR of 1, which results from the presence of *B. obliquicuspis* and *K. sedifolia* in the absence of *B. sclerolaenoides*.

The red sandy soils devoid of lichen crust (see Rogers, 1970) at the foot of the Randell scarp near Two-Mile Dam are believed to be the reason for the occurrence of *K. tomentosa* here. This species is not regarded as one characteristic of watercourses, as it occurs on the scarp face and never on the floor of the watercourse. The plant appears to be very palatable, often surviving only in the shelter of *K. pyramidata*, but it does, nevertheless, survive even under the intense stock pressure near the dam. No juveniles of this perennial species were found, however.

It is tentatively suggested that the absence of *B. sclerolaenoides* on parts of the Two-Mile Plain also results from some edaphic cause, in this case a low soil lime content, which might be anticipated in a basin catchment where a fair porportion of clay would be present.

This concludes the discussion of the species in the lower half of Node 1.

* *

Re-examination of Fig. 20 shows that the three major positive associates of Node la *(B. obliquicuspis, K. sedifolia* and *B. sclerolaenoides)* also dissociate with another large group of positive associates. *B. obliquicuspis* (27) dissociates with *Centipeda thespidioides* (29); *K. sedifolia* (16) dissociates with *K. brevifolia* (17) and *C. thespidioides*. There are strong positive links between

K. brevifolia, Inula graveolens (13), *C. thespidioides* and *Marsilea drummondii* (30). These are linked through *K. brevifolia* to some weaker associates, *Atriplex eardleyae* (5), *Verbena officinalis* (31), *Enchylaena tomentosa* (22), *Lycium australe* (24) and *Rhagodia spinescens* var. *deltophylla* (23). (*Kochia georgei* (19) also dissociates with *K. brevifolia* and *C. thespidioides* at $\chi \geqslant 4.0$ and associates with *B. obliquicuspis*, but only at $\chi = 3.7$. It nevertheless reinforces the role of the three major associates.)

Although the nine minor associates detailed above dissociate with the major positive associates, *B. obliquicuspis, K. sedifolia* and *K. pyramidata*, none of them have any statistical links with any of these *Kochia* species. The pattern displayed by this large group of associates ranked against the major ones would thus be different to that of Node 1a. The interactions of the minor associates is shown in Table 28, which also shows that all but three of these species *(L. australe, E. tomentosa* and *R. spinescens)* occur in fewer than 6% of quadrats, but Map 19 indicates that they are all very close to the dam and in the watercourse. This is, then, a case where low incidence species included in an analysis show valid interactions in a situation where they have a very local distribution.

The map to show the group behaviour of the nine minor associates did not include *B. scleroleanoides, B. obliquicuspis* and *K. sedifolia* whose behaviour in this case can be inferred from Node 1a (Map 20). Any combination of the nine associates occurring in the quadrats is

TABLE 28

SIGNIFICANCE LEVELS OF INTERSPECIFIC ASSOCIATIONS BETWEEN SPECIES LINKED INTO NODE 1b AT TWO-MILE DAM
Cell entries are χ values (positive or negative) on one degree of freedom

Marsilea drummondii	*Centipeda thespidioides*	*Kochia brevifolia*	*Inula graveolens*	*Atriplex eardleyae*	*Verbena officinalis*	*Lycium australe*	*Enchylaena tomentosa*	*Rhagodia spinescens*	
%f = 1.7	2.9	5.5	2.1	5.9	1.7	9.2	20.6	9.7	
	+ 7.7	+ 0.7	+ 1.5	+ 0.7	+ 2.0	+ 0.4	− 0.1	+ 0.4	*Marsilea drummondii*
		+ 6.1	+ 0.6	+ 0.0	+ 1.0	− 0.3	− 0.1	− 0.3	*Centipeda thespidioides*
			+ 5.5	+ 4.3	+ 4.8	+ 4.7	+ 3.0	+ 1.0	*Kochia brevifolia*
				+ 0.2	+ 1.2	+ 2.6	+ 1.2	+ 1.2	*Inula graveolens*
					+ 2.7	+ 2.9	+ 4.4	+ 2.9	*Atriplex eardleyae*
						+ 1.9	+ 2.0	+ 0.1	*Verbena officinalis*
							+ 4.6	+ 4.6	*Lycium australe*
								+ 1.9	*Enchylaena tomentosa*
									Rhagodia spinescens

displayed, according to the coding in Table 29. The result is shown

TABLE 29

POSSIBLE INCIDENCE COMBINATIONS OF NODE 1b SPECIES
IN TWO-MILE PADDOCK AT TWO-MILE DAM
with observed frequencies (f) and influence ratings (IR)

M. drummondii	*C. thespidioides*	*K. brevifolia*	*I. graveolens*	*A. eardleyae*	*V. officinalis*	*L. australe*	*E. tomentosa*	*R. spinescens*	f	IR
–	–	+	–	+	+	+	+	–	1	5
–	–	+	–	+	–	+	+	–	1	4
–	–	–	–	+	–	+	+	+	1	4
–	–	–	–	+	–	+	+	–	1	3
–	–	–	–	–	–	+	–	–	7	1
–	–	–	–	–	–	–	+	–	20	1
–	–	+	–	+	–	–	+	–	1	3
–	–	–	–	–	–	–	–	+	9	1
–	–	–	–	–	–	+	+	+	3	3
–	–	–	–	–	–	+	–	+	2	2
–	–	–	+	–	–	–	–	–	2	1
–	–	–	–	–	–	+	+	–	1	2
–	–	–	–	+	–	–	–	–	2	1
–	–	–	–	+	–	+	+	+	1	4
–	–	–	–	+	–	–	+	–	3	2
–	–	+	–	–	–	+	+	–	1	3
–	–	–	–	–	–	–	+	+	1	2
–	–	–	–	+	–	–	–	+	1	2
–	–	+	+	–	–	+	+	–	1	4
–	+	+	–	–	–	–	–	–	2	2
–	–	+	+	–	–	+	–	+	1	4
–	+	–	–	–	+	–	+	–	1	3
–	+	+	–	–	–	+	+	+	1	4
+	+	+	–	–	–	–	–	–	2	3
–	–	+	+	–	+	+	+	–	1	5
–	–	+	–	+	+	–	–	–	1	3
–	–	+	–	+	–	–	+	+	1	4
+	+	–	–	–	–	–	–	–	2	2
–	–	–	–	–	–	–	–	–	167	0
									Σ = 238	

in Map 20, Node 1b.

The strongest influence on the vegetation is obviously the dam and watercourse, although Map 20 shows that there is considerable pattern in the paddock away from the watercourse. Examination of Map 19 provides evidence that this is mainly the result of the incidence of *Lycium*, *Enchylaena* and *Rhagodia*, which although having their highest incidence along the watercourse and in particular on the western fence of the dam, are also distributed throughout the rest of the sampled area. *Lycium* occurs in 23 quadrats and *Enchylaena* in 50; the positive association between the two is based on their mutual occurrence in 11 watercourse quadrats and in only 4 in more distant parts of the paddock. *Rhagodia* occurs in 23 quadrats as does *Lycium*; their positive association depends on their mutual presence in 6 watercourse quadrats and only 3 more distant ones.

The sampling grid has clearly biassed the situation along the western fence of the dam. If the base peg had been located at the eastern end of the dam, 1 or 2 quadrats might have sampled this area thereby reducing the probability of combined incidence of *Lycium* with *Enchylaena* or *Rhagodia*.

The possibility that the incidence of these plants is stimulated by a piosphere effect near Two-Mile Dam must not be overlooked, but the fact that *Enchylaena* and *Rhagodia* seem consistently to grow in the shelter of trees or large bushes (e.g. *Lycium* and *Cassia*) (see Chapter XIII) suggests that their populations near the dam are directly attributable to the ameliorating effect of the watercourse on the environment. Similar arguments could be applied to explain the incidence of *Kochia brevifolia* and *A. eardleyae* near the dam, but they do not have the same widespread distribution away from the water-point, and from experience in Barrett's Paddock it is likely that these are true piosphere plants.

As a result of these arguments, it was decided that mapping should be repeated omitting *Enchylaena, Rhagodia* and *Lycium*. The results are shown in Map 20, Node 1c. The reduction in numbers of species simplified the arrangement of isotels. The dam and water-course are still shwon to be the most important influence on the vegetation, and pattern elsewhere is negligible.

Nodes 1b and 1c clearly delineate the dam and the watercourse in which it lies. As mentioned earlier this site, like Weary Dam, could always have been a water catch with some degree of natural pattern. In the watercourse, plants would benefit from water accumulating after rain, and from a higher water-table than elsewhere in the paddock. Some populations would be stimulated by this, for instance those of *Marsilea*, a "water" fern, *Centipida thespidioides* found in sink holes at Quondong, *Lycium, Rhagodia* and *Enchylaena*, which have already been discussed, *Kochia brevifolia*, commonly found in local water catches (see Jessup, 1948; Barker, 1970), *Verbena officinalis*, also occurring in the south-east of the State and *Inula graveolens*, a Mediterranean weed which behaves as an ephemeral in the arid zone. Before concluding this discussion of Node 1b and 1c species, it must be pointed out that further ecological details concerning some of the above species will be given in Chapter XIV.

* *

In reconsidering Fig. 20, it is apparent that *K. sedifolia*, as well as being part of the above interactions, is also negatively associated with *Marrubium vulgare* (12), a Mediterranean perennial weed. *Marrubium* is positively associated with the native *Sida intricata* (25) and *Carthamus lanatus* (14), another Mediterranean weed, which behaves as an ephemeral. These species, Node 1d, do not have any interactions with any of the members of Node 1b at $\chi \geqslant 4.0$. Their interactions with *K. sedifolia* are given in Table 30, and their incidences are shown in Map 19.

A map showing the pattern engendered by these species was constructed by plotting the number of the three species occurring in each quadrat, according to the combinations in Table 31. The components of the general vegetation association, in this case *K. sedifolia*, were disregarded. The result in Map 20, Node 1d, indicates that *Marrubium, Carthamus* and *Sida* (see Map 19) are responsible for a distinct sinuous pattern at right-angles to the watercourse. Field observations and examination of aerial photographs (see Plate 15 and Map 12) indicate that this pattern coincides with a

TABLE 30

SIGNIFICANCE LEVELS OF INTERSPECIFIC ASSOCIATIONS BETWEEN SPECIES LINKED INTO NODE 1d AT TWO-MILE DAM
Cell entries are χ values (positive or negative) on one degree of freedom

Marrubium vulgare	*Carthamus lanatus*	*Sida intricata*	*Kochia sedifolia*	
%f = 13.9	6.7	4.6	56.7	
	+ 5.4	+ 4.6	− 3.3	*Marrubium vulgare*
		+ 2.0	− 2.2	*Carthamus lanatus*
			− 1.8	*Sida intricata*
				Kochia sedifolia

natural drainage line from the Two-Mile Plain. This has been exploited by the cutting of artificial drains during the past 10-15 years to provide additional rain-water run-off for the dam. The occurrence of pattern remote from the main focus results from the presence of *Marrubium* in quadrats located on or near other drains in the paddock. This pattern must be one which has developed since grazing began in the area. Increased run-off resulting from compaction has promoted the deposition of sand in the drains and gullies approaching Two-Mile Dam, and *Marrubium* and *Carthamus*

TABLE 31

POSSIBLE INCIDENCE COMBINATIONS OF NODE 1d SPECIES IN TWO-MILE PADDOCK AT TWO-MILE DAM with observed frequencies (f) and influence ratings (IR)

M. vulgare	*C. lanatus*	*S. intricata*	f	IR
+	+	+	1	3
+	+	-	7	2
+	-	+	4	2
-	+	+	1	2
-	+	-	4	1
-	-	+	3	1
+	-	-	16	1
-	-	-	202	0
			Σ = 238	

thrive in these situations. The absence of these species from the old watercourse is due to the lack of sand there.

* *

Node 2 in Fig. 20 shows simple association between *Atriplex vesicaria* (1) and *A. stipitata* (2). This is based on the occurrence of *A. vesicaria* in 28 quadrats, in only five of which does *A. stipitata* also occur in a widely scattered distribution. This relationship is regarded as spurious and draws attention to the danger attached to including low incidence species in the analysis, where they do not have a localised distribution. It is interesting to note that like *Marrubium*, *A. stipitata* occurs in drains where there is an accumulation of sand.

* *

In ending this discussion of the incidence data results at Two-Mile Dam, attention is drawn to *Atriplex spongiosa*, one of the major piosphere species at Barrett's. This plant is present at Two-Mile also as shown in Map 19, but it does not have any statistically significant relationships with any other species.

CONCLUSIONS

This series of analyses has identified a diverse flora associated with Two-Mile Dam. Some of these plants were doubtless present before pastoral activities began. For example, *K. tomentosa* found near the dam and extending up on to the Randell scarp is confined to the red sand in this area and is not a watercourse or piosphere species. *Marsilea drummondii*, *Centipeda thespidioides* and *Verbena officinalis* have probably always been in the watercourse. *Sida intricata*, a constituent of Node 2 at Barrett's, where it was found in local water catches, must also be considered as a plant of drains and other low lying areas, as is *Atriplex eardleyae* (see Barker, 1970), which was an important Node 1a piosphere plant at Barrett's.

The true invaders at Two-Mile can thus only be *Carthamus lanatus*, *Marrubium vulgare* and *Kochia brevifolia*. Of these, probably the only important one is *Marrubium*, which for reasons mentioned on p. 151 is an undesirable weed. It appears to be extending further into the paddock from the dam area along artificial drains.

There is no clear evidence from the incidence data that any species have disappeared from the vicinity of Two-Mile Dam. The absence of *K. sedifolia* near to the dam is almost certainly due to the watercourse. It is tempting, however, to account for the low incidence of *K. excavata* (10.6%) in terms of its gradual disappearance. This plant was ubiquitous in the Ki Ki study area. In view of the remarks made concerning its apparent palatability on p. 127, it is possible to suggest (though there is no substantial evidence to support the idea) that it was once in far greater quantities in Two-Mile than it is now, previous heavy stocking having reduced the population.

BARBER'S DAM IN TWO-MILE PADDOCK

RESULTS AND DISCUSSION

Description of plant populations : density, frequency and dispersion

These data are summarised in Table 32 and Fig. 21. The most frequent species, i.e. over 50%, are *Bassia obliquicuspis*, *Kochia sedifolia* (bluebush), *Atriplex vesicaria* (saltbush), *K. georgei* and *B. patenticuspis*. The dominant at Two-Mile *(K. pyramidata)* is present in only 49% of quadrats at Barber's. *Atriplex eardleyae* is absent at Barber's, whereas *Bassia paradoxa* has a greater incidence there than at Two-Mile. *Atriplex acutibracta*, *Kochia excavata* and *Chenopodium ulicinum*, important constituents of the Ki Ki study area, are more frequent in the sampled area at Barber's Dam than that at Two-Mile. *Atriplex vesicaria*, and to a lesser extent, *A. stipitata* are more frequent in the Barber's piosphere than in Two-Mile.

Of the 31 species found near Barber's Dam, 13 (i.e. about 40%) have densities of less than one per square chain. Some of these, *Atriplex eardleyae*, *Inula graveolens*, *Carthamus lanatus* and *Kochia tomentosa* were important at Two-Mile Dam, while *Kochia triptera* was important at Weary Dam.

TABLE 32

THE PLANT SPECIES SAMPLED IN TWO-MILE PADDOCK AT BARBER'S DAM with their average density per square chain* and the percentage of total samples in which they occur+

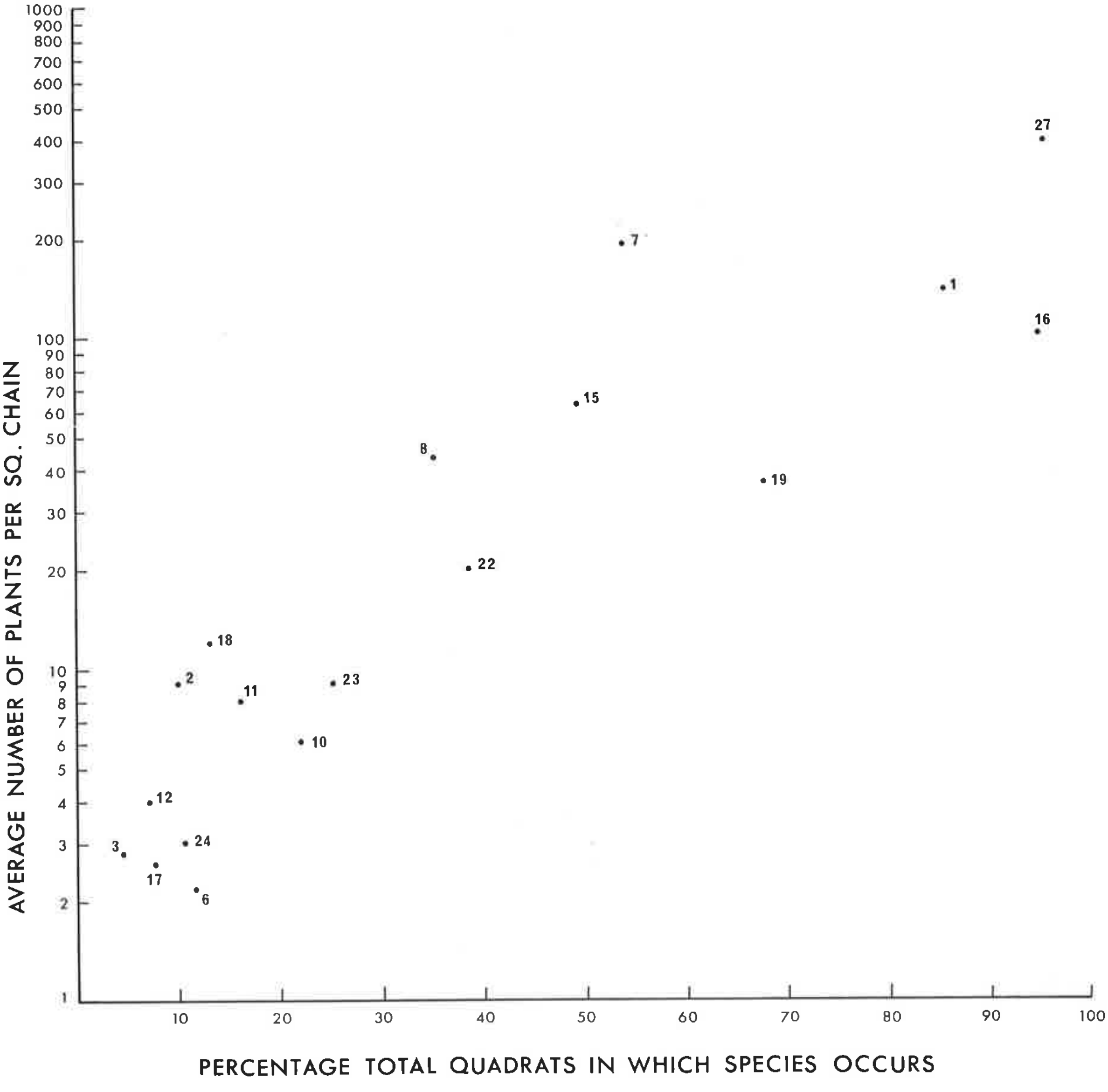
Species	Density*	Frequency+
1. *Atriplex vesicaria*	145.6	85.7
2. *Atriplex stipitata*	9.1	9.9
3. *Atriplex acutibracta*	2.8	4.5
4. *Atriplex spongiosa*	0.06	0.4
6. *Bassia paradoxa*	2.2	11.7
7. *Bassia patenticuspis*	195.2	53.8
8. *Bassia sclerolaenoides*	43.5	35.0
9. *Bassia biflora*	0.5	3.1
10. *Chenopodium desertorum*	14.7	39.9
11. *Chenopodium ulicinum*	8.1	16.1
12. *Marrubium vulgare*	4.0	7.2
13. *Inula graveolens*	0.3	0.9
14. *Carthamus lanatus*	0.1	0.4
15. *Kochia pyramidata*	64.4	49.3
16. *Kochia sedifolia*	104.5	95.1
17. *Kochia brevifolia*	2.6	7.6
18. *Kochia excavata* var. *trichoptera*	12.3	13.0
19. *Kochia georgei*	37.2	67.7
20. *Kochia triptera*	0.4	2.7
21. *Kochia tomentosa*	0.3	1.3
22. *Enchylaena tomentosa*	23.2	38.6
23. *Rhagodia spinescens* var. *deltophylla*	9.1	25.1
24. *Lycium australe*	3.1	10.3
27. *Bassia obliquicuspis*	406.2	95.5
34. *Vittadinia triloba*	0.6	0.9
35. *Heterodendrum oleaefolium*	0.2	1.8
38. *Acacia sowdenii*	0.5	3.6
39. *Cassia nemophila* var. *coriacea*	0.2	1.8
40. *Salsola kali*	0.2	0.4
41. *Exocarpos aphyllus*	0.06	0.4
42. *Chenopodium murale*	0.2	0.4

FIGURE 21

Dispersion of species in Two-Mile Paddock at Barber's Dam

(excluding species having densities of less than one per square chain)

1. *Atriplex vesicaria*
2. *Atriplex stipitata*
3. *Atriplex acutibracta*
6. *Bassia paradoxa*
7. *Bassia patenticuspis*
8. *Bassia sclerolaenoides*
10. *Chenopodium desertorum*
11. *Chenopodium ulicinum*
12. *Marrubium vulgare*
15. *Kochia pyramidata*
16. *Kochia sedifolia*
17. *Kochia brevifolia*
18. *Kochia excavata* var. *trichoptera*
19. *Kochia georgei*
22. *Enchylaena tomentosa*
23. *Rhagodia spinescens* var. *deltophylla*
24. *Lycium australe*
27. *Bassia obliquicuspis*



AVERAGE NUMBER OF PLANTS PER SQ. CHAIN
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
10
20
30
40
50
60
70
80
90
100
27
7
1
16
15
8
19
22
18
2
11
23
10
12
3
24
17
6
PERCENTAGE TOTAL QUADRATS IN WHICH SPECIES OCCURS

Most species again display clumped distributions (Fig. 21), which is an indication of heterogeneity. *K. sedifolia* (16) is the most scattered, with *Atriplex acutibracta* (3), *Marrubium vulgare* (12), *A. stipitata* (2) and *K. excavata* (18) exhibiting the most contagious distributions.

Plate 17 shows the general appearance of the vegetation near the trough paddock.

Vegetation pattern : the effect of stocking on plant populations

Incidence data

There is only one node at $\chi \geqslant 4.0$ and it is shown in Fig. 22. It has certain similarities with the principal node at Two-Mile Dam. For example, it shows that a positive association existing between *Lycium australe* (24), *Enchylaena tomentosa* (22) and *Rhagodia spinescens* var. *deltophylla* (23), is much stronger than it was at Two-Mile. In the Two-Mile Dam node *Lycium* is directly associated with *Kochia brevifolia* (17), whereas at Barber's *Enchylaena* is the direct associate with *K. brevifolia*. It is nevertheless evident that this group of interactions is common to both areas. The strength of these associations is undoubtedly for the reasons discussed in the section on Two-Mile Dam, that is, that *E. tomentosa* and *R. spinescens* grow almost exclusively under trees or under large

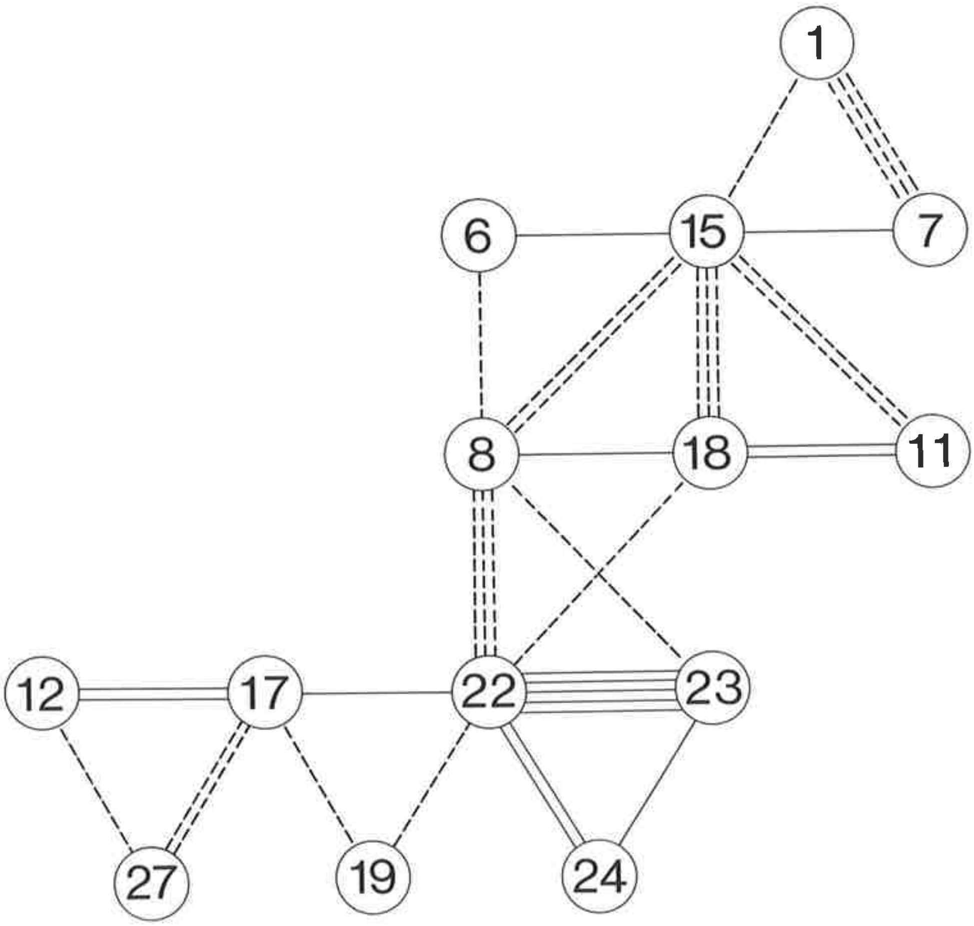
FIGURE 22

Nodes of associated species at $\chi \geqslant 4.0$ in Barber's piosphere in Two-Mile Paddock

——— indicates association, positive association
---- indicates dissociation, negative association

(1) *Atriplex vesicaria*
(6) *Bassia paradoxa*
(7) *Bassia patenticuspis*
(8) *Bassia sclerolaenoides*
(11) *Chenopodium ulicinum*
(12) *Marrubium vulgare*
(15) *Kochia pyramidata*
(17) *Kochia brevifolia*
(18) *Kochia excavata* var. *trichoptera*
(19) *Kochia georgei*
(22) *Enchylaena tomentosa*
(23) *Rhagodia spinescens* var. *deltophylla*
(24) *Lycium australe*
(27) *Bassia obliquicuspis*

NODE 1.



bushes such as *Lycium*, or in watercourses. The pattern they generate is likely to form a mosaic away from the watercourses. *E. tomentosa* associates with *K. brevifolia* on account of their occurrence in the watercourse close to the dam.

The dissociation between *E. tomentosa* and *Bassia sclerolaenoides* (8) is of passing interest; whereas *E. tomentosa* tends to grow in places where it is sheltered or receives extra water, *B. sclerolaenoides* is found in open well drained situations.

Because of their special behaviour *Lycium, Enchylaena* and *Rhagodia* were omitted from further consideration at this stage.

* *

With these three species reomved from the node, two groups of species remain. In one of them, *Marrubium vulgare* (12) and *K. brevifolia* (17) are strongly associated (they were not at Two-Mile Dam) and they dissociate from *B. obliquicuspis* (27), one of the general vegetation association dominants. *K. brevifolia* dissociates with *K. georgei* (19) another of the association dominants. From Table 33 it appears that *K. georgei* should back up the picture furnished by *B. obliquicuspis*, but the positive association is weak, so the mapping of this group of interactions was simplified by omitting *K. georgei*. The result, based on the coding in Table 34 is displayed in Map 22, Node 1a.

TABLE 33

SIGNIFICANCE LEVELS OF INTERSPECIFIC ASSOCIATIONS BETWEEN SPECIES LINKED INTO NODE 1a AT BARBER'S DAM (TWO-MILE PADDOCK)
Cell entries are χ values (positive or negative) on one degree of freedom

Marrubium vulgare	*Kochia brevifolia*	*Kochia georgei*	*Bassia obliquicuspis*	
%f = 7.2	7.6	67.7	95.5	
	+ 5.1	− 1.7	− 3.4	*Marrubium vulgare*
		− 3.6	− 4.5	*Kochia brevifolia*
			+ 0.8	*Kochia georgei*
				Bassia obliquicuspis

The focal point of the isotels is the trough paddock by the dam. The most powerful IRs are within 50-75 yards of the trough. Weaker IRs at some distance from the dam result from the presence of *Marrubium*. *K. brevifolia* does not occur more than 100 yards from the trough (Map 21).

* *

TABLE 34

POSSIBLE INCIDENCE COMBINATIONS OF NODE 1a SPECIES AT BARBER'S DAM (TWO-MILE PADDOCK) with observed frequencies (f) and influence ratings (IR)

	B. obliquicuspis	*M. vulgare*	*K. brevifolia*	f	Recoding			IR
	-	-	-	5				*
	-	-	+	2	+	-	+	2
	-	+	-	1	+	+	-	2
	-	+	+	3	+	+	+	3
*→	+	-	-	190	-	-	-	0
	+	-	+	8	-	-	+	1
	+	+	-	10	-	+	-	1
	+	+	+	4	-	+	+	2
				Σ = 223				

In the second group of species (Fig. 22) there are seven species. Positive association exists between *B. sclerolaenoides* (8) and *K. excavata* (18) and *Chenopodium ulicinum* (11), with dissociation between *B. sclerolaenoides* and *K. pyramidata* (15). It can be noted here that of these species, it was *K. excavata* and *C. ulicinum*, which dissociated with *K. pyramidata* at Two-Mile Dam. *Bassia paradoxa* (6), *K. pyramidata* and *B. patenticuspis* (7) are positively associated, the last two displaying negative association with *A. vesicaria* (1). All these interactions are summarised in Table 35.

TABLE 35

SIGNIFICANCE LEVELS OF INTERSPECIFIC ASSOCIATIONS BETWEEN SPECIES LINKED INTO NODE 1b AT BARBER'S DAM (TWO-MILE PADDOCK)
Cell entries are χ values (positive or negative) on one degree of freedom

	Bassia paradoxa	*Kochia pyramidata*	*Bassia patenticuspis*	*Atriplex vesicaria*	*Bassia sclerolaenoides*	*Kochia excavata*	*Chenopodium ulicinum*
	%f = 11.7	49.3	53.8	85.7	35.0	13.0	16.1
Bassia paradoxa		+ 4.9	+ 3.0	− 2.1	− 3.3	− 1.8	− 1.5
Kochia pyramidata			+ 4.8	− 3.2	− 4.4	− 5.6	− 4.1
Bassia patenticuspis				− 5.2	− 2.0	− 2.4	− 2.3
Atriplex vesicaria					+ 2.2	+ 2.1	+ 2.4
Bassia sclerolaenoides						+ 4.5	+ 2.3
Kochia excavata							+ 5.1
Chenopodium ulicinum							

From the experience gained in Barrett's Paddock it seems likely that *B. patenticuspis, K. pyramidata* and *B. paradoxa* will have some bearing on a grazing pattern in the piosphere area under discussion. In spite of its low incidence, therefore, *B. paradoxa* was included in the influence coding. *B. sclerolaenoides, K. excavata* and *C. ulicinum*, which also have relatively low incidence, merely reinforce the behaviour of *A. vesicaria*, one of the dominants.

The species selected from the above table for mapping were, therefore, *B. paradoxa, B. patenticuspis, K. pyramidata* and *Atriplex vesicaria*, and the outcome based on the coding in Table 36 is shown in Map 22, Node 1b.

The main focal point is again the water-point, but watercourses and the Two-Mile Plain are also depicted, due to the occurrence of *K. pyramidata* in combination with *A. vesicaria*. *K. sedifolia*, whose dissociation from *K. pyramidata* and *B. biflora* picked out the watercourses at Barrett's, only dissociates from *K. pyramidata* at $\chi \geqslant 3.0$ at Barber's.

Because of its association with *K. pyramidata* in the basin of the Two-Mile Plain *B. patenticuspis* (cf. Maps 31 and 36) may be a species of situations where as a non-perennial, it can capitalise on any moisture accumulation. The watercourses, however, contain very little *B. patenticuspis*. Its association with *A. spongiosa, B. paradoxa* and *K. pyramidata* at Barrett's picked out the piosphere effect there, as its incidence near Barber's Dam suggests it does here also.

TABLE 36

POSSIBLE INCIDENCE COMBINATIONS OF NODE 1b SPECIES AT BARBER'S DAM (TWO-MILE PADDOCK) with observed frequencies (f) and influence ratings (IR)

	B. paradoxa	*K. pyramidata*	*B. patenticuspis*	*A. vesicaria*	f	Recoding				IR
*→	−	−	−	+	67	−	−	−	−	0
	−	−	+	−	6	−	−	+	+	2
	−	−	+	+	34	−	−	+	−	1
	−	+	−	−	5	−	+	−	+	2
	−	+	−	+	27	−	+	−	−	1
	−	+	+	−	26	−	+	+	+	3
	−	+	+	+	33	−	+	+	−	2
	+	−	+	+	1	+	−	+	−	2
	+	+	−	+	3	+	+	−	−	2
	+	+	+	−	9	+	+	+	+	4
	+	+	+	+	12	+	+	+	−	3
					Σ = 223					

CONCLUSIONS

The true piosphere effect at Barber's Dam in Two-Mile Paddock is thus very restricted. Species which are confined to the immediate vicinity of the trough are *K. brevifolia* and *B. paradoxa* (Map 21) with *Marrubium* concentrated here but also found elsewhere. *B. patenticuspis* also appears to be a piosphere plant both at Barrett's and at Barber's, but its frequency in the area sampled at Two-Mile and its occurrence on the Two-Mile Plain must also be borne in mind. Its distribution there may be due to some edaphic factor.

With the possible exception of *A. vesicaria* and *B. obliquicuspis* the incidence data do not pick out any species which have disappeared from near the water-point.

BARBER'S DAM IN BARBER'S PADDOCK

RESULTS AND DISCUSSION

Description of plant populations : density, frequency and dispersion

These data are presented in Table 37 and Fig. 23. The most frequent species are *Kochia sedifolia* (16) (in 91% of quadrats) and *Bassia obliquicuspis* (27) (in 84%). They are followed at some distance by *K. georgei* (19) (56%) and *Atriplex vesicaria* (1) (54%). Saltbush is thus very much less frequent here than on the other side

TABLE 37

THE PLANT SPECIES SAMPLED IN BARBER'S PADDOCK AT BARBER'S DAM with their average density per square chain* and the percentage of total samples in which they occur+

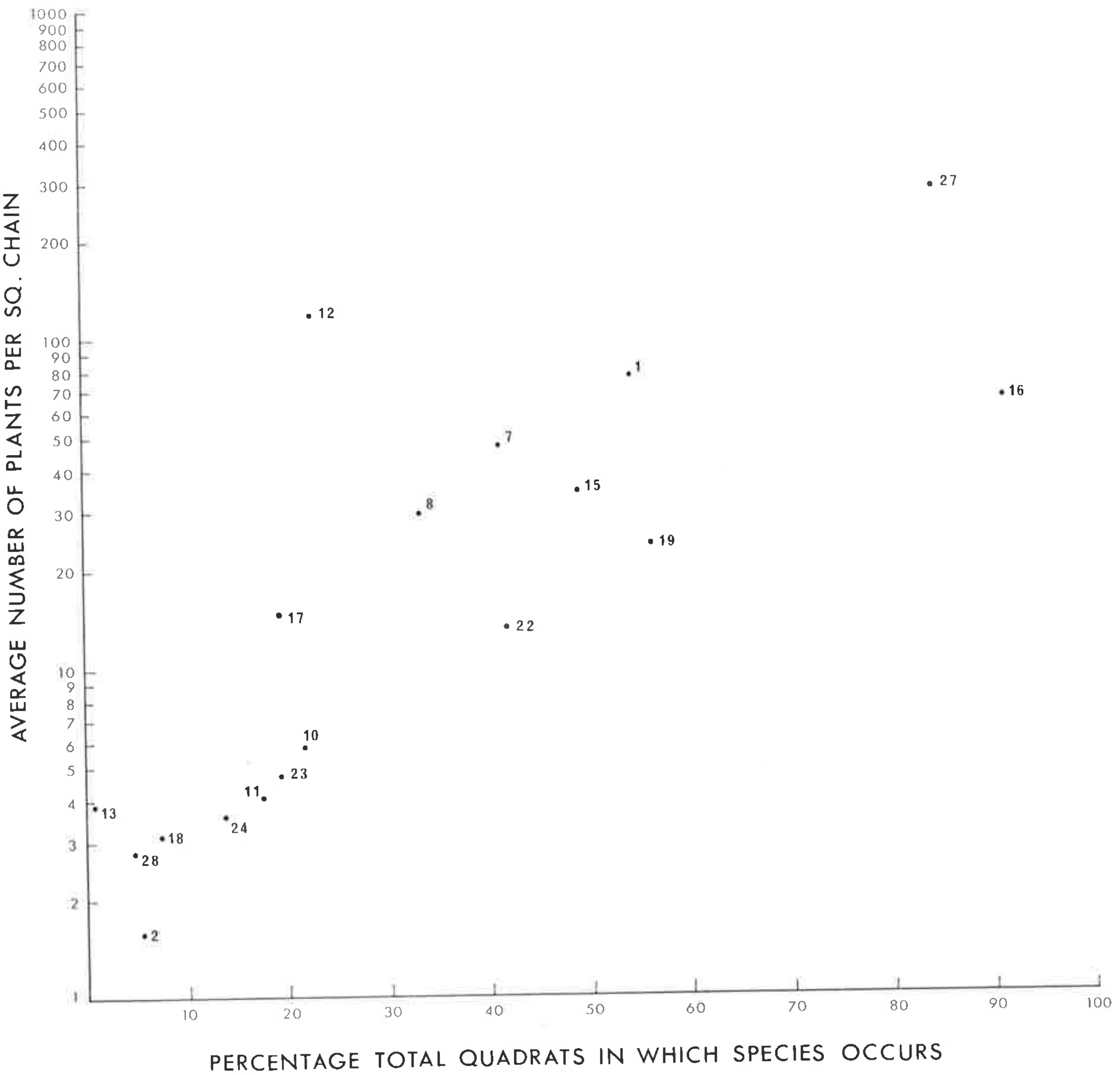
Species	Density*	Frequency+
1. *Atriplex vesicaria*	76.8	54.1
2. *Atriplex stipitata*	1.6	5.4
7. *Bassia patenticuspis*	47.1	41.2
8. *Bassia sclerolaenoides*	29.6	33.0
9. *Bassia biflora*	0.7	2.1
10. *Chenopodium desertorum*	5.8	21.9
11. *Chenopodium ulicinum*	4.1	17.6
12. *Marrubium vulgare*	142.2	22.7
13. *Inula graveolens*	3.9	0.8
14. *Carthamus lanatus*	0.05	0.4
15. *Kochia pyramidata*	33.8	48.9
16. *Kochia sedifolia*	66.2	91.4
17. *Kochia brevifolia*	15.1	19.3
18. *Kochia excavata* var. *trichoptera*	3.1	7.3
19. *Kochia georgei*	23.9	55.8
21. *Kochia tomentosa*	0.05	0.4
22. *Enchylaena tomentosa*	13.5	41.6
23. *Rhagodia spinescens* var. *deltophylla*	4.7	19.3
24. *Lycium australe*	3.6	13.7
26. *Frankenia pauciflora*	0.7	1.3
27. *Bassia obliquicuspis*	285.9	84.2
28. *Bassia diacantha*	2.8	4.7
32. *Ptilotus obovatus*	0.05	0.4
33. *Myoporum platycarpum*	0.05	0.4
35. *Heterodendrum oleaefolium*	0.2	0.8
38. *Acacia sowdenii*	0.2	0.8
39. *Cassia nemophila* var. *coriacea*	0.1	0.8
43. *Casuarina cristata*	0.4	2.1
44. *Santalum acuminatum*	0.05	0.4
45. *Acacia oswaldii*	0.05	0.4

FIGURE 23

Dispersion of species in Barber's Paddock at Barber's Dam

(excluding species having densities of less than one per square chain)

1. *Atriplex vesicaria*
2. *Atriplex stipitata*
7. *Bassia patenticuspis*
8. *Bassia sclerolaenoides*
10. *Chenopodium desertorum*
11. *Chenopodium ulicinum*
12. *Marrubium vulgare*
13. *Inula graveolens*
15. *Kochia pyramidata*
16. *Kochia sedifolia*
17. *Kochia brevifolia*
18. *Kochia excavata* var. *trichoptera*
19. *Kochia georgei*
22. *Enchylaena tomentosa*
23. *Rhagodia spinescens* var. *deltophylla*
24. *Lycium australe*
27. *Bassia obliquicuspis*
28. *Bassia diacantha*



AVERAGE NUMBER OF PLANTS PER SQ. CHAIN
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
27
12
1
16
7
15
8
19
17
22
10
23
11
13
24
18
28
2
10
20
30
40
50
60
70
80
90
100
PERCENTAGE TOTAL QUADRATS IN WHICH SPECIES OCCURS

of the dam, where frequency was 86%. The species also has a more contagious distribution in Barber's Paddock (Fig. 23). There is less *B. patenticuspis* (7) and populations of *Marrubium* (12) are denser and more frequent in Barber's Paddock than on the other side of the dam.

Apart from these differences, the general vegetation associations are similar on either side of the fence, which one might expect as the two paddocks were one until 1932.

Plate 18 shows the vegetation in the vicinity of the trough in Barber's Paddock.

Vegetation pattern : the effect of stocking on plant populations

Incidence data

The single node of interactions developed at $\chi \geqslant 4.0$ is shown in Fig. 24.

Enchylaena tomentosa (22) may be dismissed with the comment that its positive association with *K. pyramidata* (15) reflects its occurrence almost exclusively in the watercourse, and its dissociation with *B. sclerolaenoides* merely indicates that this last species is rarely found in watercourses. A similar situation was found over the fence in Two-Mile Paddock.

* *

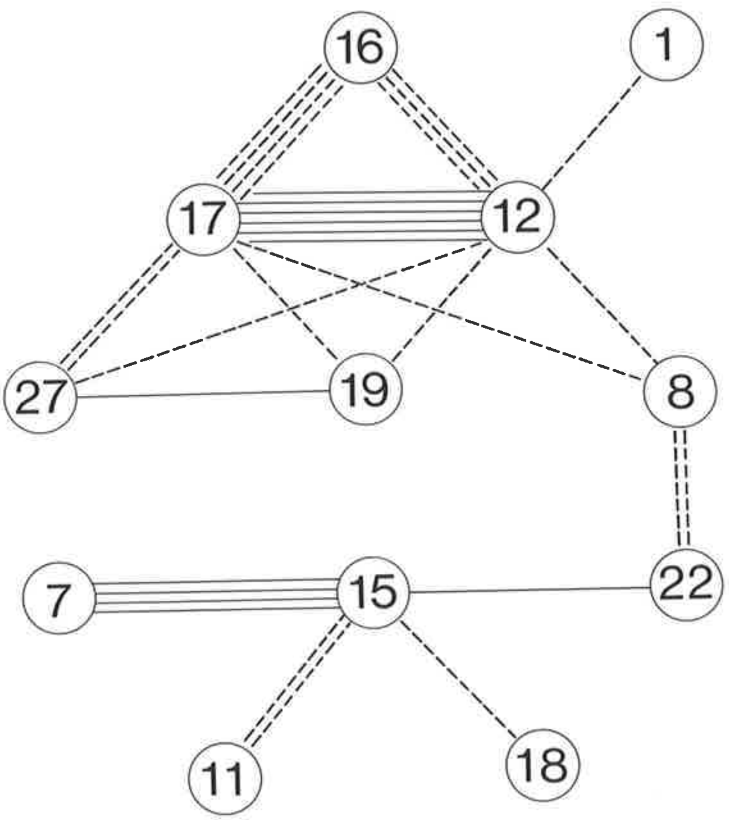
FIGURE 24

Nodes of associated species at $\chi \geq 4.0$
in Barber's piosphere in Barber's Paddock

——— indicates association, positive association
---- indicates dissociation, negative association

(1) *Atriplex vesicaria*
(7) *Bassia patenticuspis*
(8) *Bassia sclerolaenoides*
(11) *Chenopodium ulicinum*
(12) *Marrubium vulgare*
(15) *Kochia pyramidata*
(16) *Kochia sedifolia*
(17) *Kochia brevifolia*
(18) *Kochia excavata* var. *trichoptera*
(19) *Kochia georgei*
(22) *Enchylaena tomentosa*
(27) *Bassia obliquicuspis*

NODE 1.



Without *E. tomentosa* two groups of species can be distinguished. One centres on the strong attraction between *K. brevifolia* (17) and *Marrubium* (12) (Map 23) and repulsion between these two and *K. sedifolia* (16) (see relevant portion of Map 35). Other species dissociating with either of the two strong associates are *A. vesicaria* (1), *K. georgei* (19), *B. sclerolaenoides* (8) and *B. obliquicuspis*. These interactions are summarised in Table 38. For coding and mapping, *B. sclerolaenoides* was disregarded as it had a relatively low frequency in addition to weak interactions. Of the four other associates, *K. sedifolia, B. obliquicuspis* and *K. georgei* were first selected for coding to display mapped interactions with the piosphere plants *K. brevifolia* and *Marrubium*.

These five species, Node 1a, were coded as in Table 39 and the resultant map is Map 24, Node 1a. This clearly shows that the dam has the strongest influence on the vegetation, due to the incidence of *K. brevifolia* and *Marrubium* near it (Map 23). However, considerable areas of the more distant parts of the sampled area display IRs of 1 rather than 0, as might be expected. This is largely due to the presence of *K. georgei* in the watercourse and on Two-Mile Plain, and its absence elsewhere.

For comparison, a plot was made using *A. vesicaria* in place of *K. georgei*, in combination with the other species of Node 1a. This new node, referred to as Node 1b, is coded as in Table 40 and mapped accordingly (Map 24, Node 1b). (It will be recalled that in the

TABLE 38

SIGNIFICANCE LEVELS OF INTERSPECIFIC ASSOCIATIONS BETWEEN LINKED INTO NODE 1a AND 1b AT BARBER'S DAM (BARBER'S PADDOCK)
Cell entries are χ values (positive or negative) on one degree of freedom

	Kochia brevifolia	*Marrubium vulgare*	*Atriplex vesicaria*	*Kochia georgei*	*Bassia sclerolaenoides*	*Bassia obliquicuspis*	*Kochia sedifolia*
	%f = 19.3	22.7	54.1	55.8	33.0	84.2	91.4
Kochia brevifolia		+ 9.3	– 2.7	– 3.4	– 3.5	– 4.4	– 6.3
Marrubium vulgare			– 3.1	– 3.8	– 3.9	– 3.7	– 5.5
Atriplex vesicaria				+ 1.4	– 0.7	+ 1.4	+ 0.6
Kochia georgei					+ 3.0	+ 4.6	+ 2.7
Bassia sclerolaenoides						+ 1.4	+ 2.8
Bassia obliquicuspis							+ 3.9
Kochia sedifolia							

piosphere on the other side of the dam neither *K. sedifolia* nor *A. vesicaria* displayed any interaction with *Marrubium* or *K. brevifolia*,

TABLE 39

POSSIBLE INCIDENCE COMBINATIONS OF NODE 1a SPECIES AT BARBER'S DAM (BARBER'S PADDOCK) with observed frequencies (f) and influence ratings (IR)

	K. sedifolia	*B. obliquicuspis*	*K. georgei*	*M. vulgare*	*K. brevifolia*	f	Recoding					IR
	+	+	+	+	+	6	-	-	-	+	+	2
	+	+	+	+	-	10	-	-	-	+	-	1
	+	+	+	-	+	5	-	-	-	-	+	1
*→	+	+	+	-	-	95	-	-	-	-	-	0
	+	+	-	+	+	4	-	-	+	+	+	3
	+	+	-	+	-	5	-	-	+	+	-	2
	+	+	-	-	+	1	-	-	+	-	+	2
	+	+	-	-	-	63	-	-	+	-	-	1
	+	-	+	-	+	1	-	+	-	-	+	2
	+	-	+	-	-	4	-	+	-	-	-	1
	+	-	-	+	+	9	-	+	+	+	+	4
	+	-	-	+	-	3	-	+	+	+	-	3
	+	-	-	-	+	1	-	+	+	-	+	3
	+	-	-	-	-	6	-	+	+	-	-	2
	-	+	+	-	-	3	+	-	-	-	-	1
	-	+	+	+	+	1	+	-	-	+	+	3
	-	+	-	+	+	3	+	-	+	+	+	4
	-	-	-	+	+	10	+	+	+	+	+	5
	-	-	-	+	-	1	+	+	+	+	-	4
	-	-	-	-	+	1	+	+	+	-	+	4
	-	-	-	-	-	1						*
						Σ = 233						

TABLE 40

POSSIBLE INCIDENCE COMBINATIONS OF NODE 1b SPECIES
AT BARBER'S DAM (BARBER'S PADDOCK)
with observed frequencies (f) and influence ratings (IR)

	K. sedifolia	*B. obliquicuspis*	*A. vesicaria*	*M. vulgare*	*K. brevifolia*	f	Recoding					IR
	-	-	-	-	-	1						*
	-	-	-	-	+	1	+	+	+	-	+	4
	-	-	-	+	+	8	+	+	+	+	+	5
	-	-	+	+	-	1	+	+	-	+	-	3
	-	-	+	+	+	2	+	+	-	+	+	4
	-	+	-	+	+	1	+	-	+	+	+	4
	-	+	+	-	-	3	+	-	-	-	-	1
	-	+	+	+	+	3	+	-	-	+	+	3
	+	-	-	-	-	5	-	+	+	-	-	2
	+	-	-	-	+	2	-	+	+	-	+	3
	+	-	-	+	-	2	-	+	+	+	-	3
	+	-	-	+	+	6	-	+	+	+	+	4
	+	-	+	-	-	6	-	+	-	-	-	1
	+	-	+	+	-	1	-	+	-	+	-	2
	+	-	+	+	+	4	-	+	-	+	+	3
	+	+	-	-	-	62	-	-	+	-	-	1
	+	+	-	-	+	4	-	-	+	-	+	2
	+	+	-	+	-	10	-	-	+	+	-	2
	+	+	-	+	+	7	-	-	+	+	+	3
*→	+	+	+	-	-	94	-	-	-	-	-	0
	+	+	+	-	+	3	-	-	-	-	+	1
	+	+	+	+	-	4	-	-	-	+	-	1
	+	+	+	+	+	3	-	-	-	+	+	2
	Σ = 233											

as these dominants occurred more or less continuously throughout the area that the other two species occupied.)

Map 24, Nodes 1a and 1b, demonstrates that *A. vesicaria* does not behave like *K. georgei* in depicting the Two-Mile Plain and watercourse, using incidence data. Apart from isolated IRs of 1, which form no particular pattern and are caused by the presence of either *K. sedifolia* or *B. obliquicuspis* or *A. vesicaria*, the full range of influence ratings is achieved within 400-600 yards of the base point.

* *

Returning to Fig. 24, it is seen that the remainder of the node contains *K. pyramidata* (15) strongly associated with *B. patenticuspis* (7) and dissociating with *Chenopodium ulicinum* (11) and *Kochia excavata* (18), thus displaying behaviour similar to that on the other side of Barber's Dam and at Two-Mile Dam. *B. sclerolaenoides*, an associate of these last two species in the areas just mentioned, associates with *K. excavata* at only χ = 3.7 in Barber's Paddock; it was therefore excluded from this group of associates, Node 1c. Their interactions are summarised in Table 41. *K. excavata* is negatively associated with *B. patenticuspis* and *K. pyramidata*, as is *C. ulicinum*. It barely displays a positive association with *C. ulicinum*, and as it occurs in only 17 quadrats it was rejected for

TABLE 41

SIGNIFICANCE LEVELS OF INTERSPECIFIC ASSOCIATIONS BETWEEN SPECIES LINKED INTO NODE 1c AT BARBER'S DAM (BARBER'S PADDOCK)
Cell entries are χ values (positive or negative) on one degree of freedom

Bassia patenticuspis	*Kochia pyramidata*	*Kochia excavata*	*Chenopodium ulicinum*	
%f = 41.2	48.9	7.3	17.6	
	+ 7.0	− 0.8	− 2.0	*Bassia patenticuspis*
		− 3.9	− 4.3	*Kochia pyramidata*
			+ 0.3	*Kochia excavata*
				Chenopodium ulicinum

coding in Table 42; its position on the isotel map was plotted by means of a symbol (Map 24, Node 1c).

This node clearly does not focus on the water-point, but instead picks out the watercourse and Two-Mile Plain, the incidence of *K. pyramidata* and *B. patenticuspis* (cf. Maps 31 and 36) being continuous throughout these areas. *C. ulicinum* and *K. excavata* distinguish the more elevated areas between.

TABLE 42

POSSIBLE INCIDENCE COMBINATIONS OF NODE 1c SPECIES
AT BARBER'S DAM (BARBER'S PADDOCK)
with observed frequencies (f) and influence ratings (IR)

	K. pyramidata	*B. patenticuspis*	*C. ulicinum*	f	Recoding			IR
	-	-	-	67				*
	-	-	+	28	-	-	-	0
	-	+	-	17	-	+	+	2
	-	+	+	6	-	+	-	1
	+	-	-	39	+	-	+	2
	+	-	+	2	+	-	-	1
*→	+	+	-	70	+	+	+	3
	+	+	+	4	+	+	-	2
				$\Sigma = 233$				

There is a similarity between Node 1a and Node 1c as both nodes pick out the watercourse and Two-Mile Plain, the one by the presence of *K. georgei* and the other by *K. pyramidata* and *B. patenticuspis*. *K. georgei* does not have positive interactions with *K. pyramidata* and *B. patenticuspis* strong enough ($\chi = 2.7$ and 3.0 respectively) for inclusion in the same node at $\chi \geqslant 4.0$. However, the high incidence value of all three species suggests that the association is a valid one.

In connection with this group of associates, it is worth noting that *K. excavata, C. ulicinum* and *B. sclerolaenoides* all formed part of Node 1b on the other side of the dam, but were not mapped because of their relatively low incidence compared with their major associate, *A. vesicaria*. If these species had been included, then they might have shown up the higher ground, on either side of the watercourse and adjacent to Two-Mile Plain, in Two-Mile Paddock also.

CONCLUSIONS

The piosphere species here are obviously *Marrubium vulgare* and *Kochia brevifolia*, with *Bassia patenticuspis* also being a possibility. Background pattern is caused by the dissociation of *K. georgei* with *K. sedifolia* and *B. obliquicuspis*, and the dissociation of *K. pyramidata* and *B. patenticuspis* with *K. excavata* and *Chenopodium ulicinum*.

The discussions relating to Nodes 1a and 1b illustrate well how the ecologist can simplify the expression of the interactions of a group of species, by careful selection of those that are used for plotting the final outcome. This results in more straightforward interpretation. For example, when *K. georgei* (in Node 1a) was replaced by *A. vesicaria* (in Node 1b) two different pictures of vegetation influences were identified, as *K. georgei* clearly delineated the watercourses, whereas *A. vesicaria* did not.

The outcome of Node 1c suggests that a piece of useful information regarding background pattern in Two-Mile Paddock may have been overlooked by ignoring *K. excavata, C. ulicinum* and *B. sclerolaenoides* in Node 1b at Barber's Dam. Node 1b at Barber's Dam in Two-Mile Paddock could be replotted to reveal this, but, as will be seen later a similar outcome is achieved in the analysis of the total data contained in the final section of this chapter.

WINTER TROUGH

RESULTS AND DISCUSSION

Description of plant populations : density, frequency and dispersion

These data are summarised in Table 43 and Fig. 25. It is obvious that this area is floristically much poorer than any of the other piospheres discussed, as there are only 23 species found compared with 30 and above in the other sampled areas. Ten of the species (i.e. 43%) in Winter Paddock have densities of 1 or less per square chain. These include *Kochia excavata* and *Lycium australe*,

TABLE 43

THE PLANT SPECIES SAMPLED IN WINTER PADDOCK
with their average density per square chain* and the percentage of total samples in which they occur+

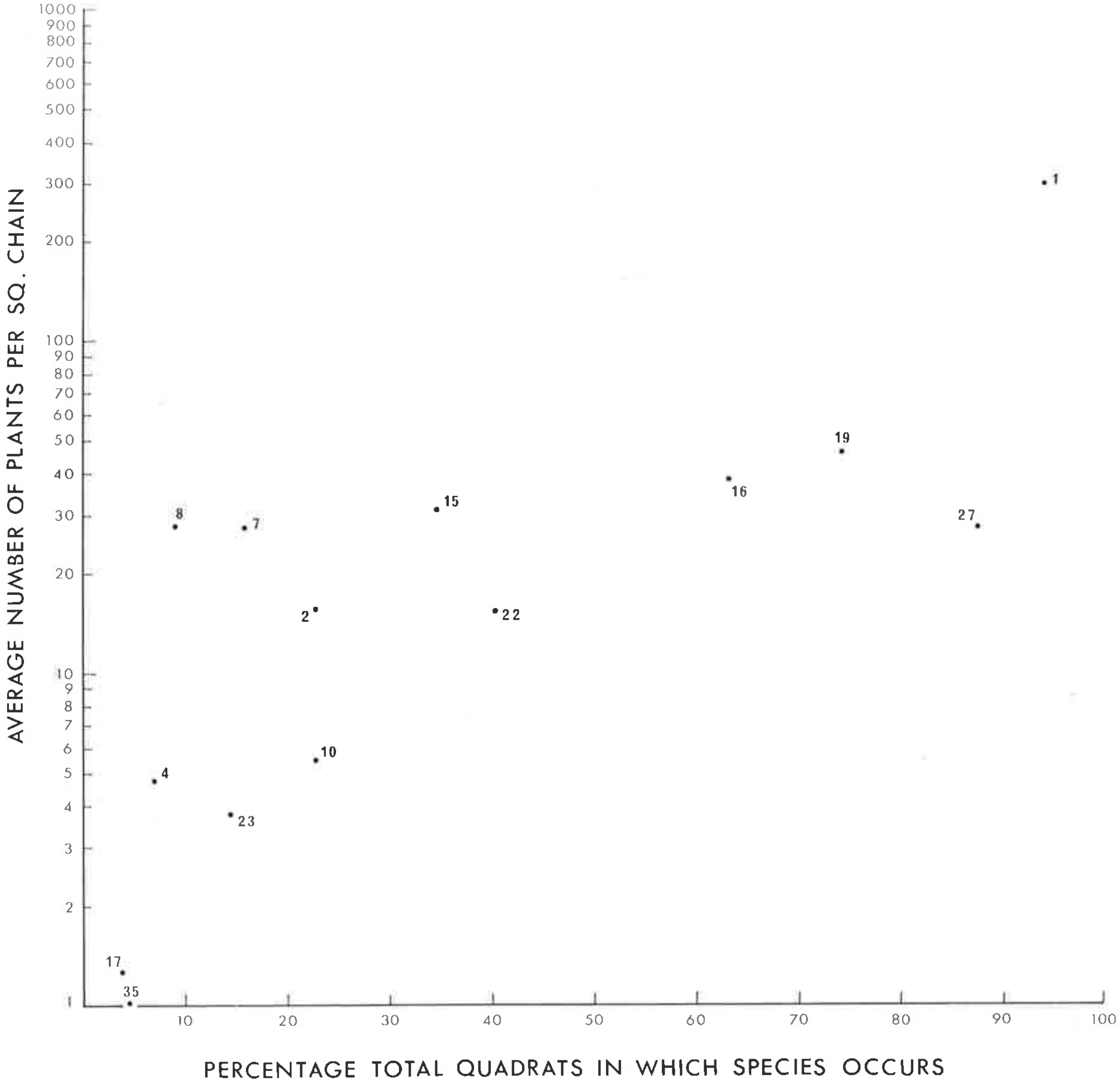
Species	Density*	Frequency+
1. *Atriplex vesicaria*	305.1	93.7
2. *Atriplex stipitata*	16.1	22.8
3. *Atriplex acutibracta*	0.2	0.8
4. *Atriplex spongiosa*	4.8	7.1
7. *Bassia patenticuspis*	27.7	15.7
8. *Bassia sclerolaenoides*	28.0	8.7
10. *Chenopodium desertorum*	5.5	22.8
15. *Kochia pyramidata*	31.1	34.6
16. *Kochia sedifolia*	38.9	63.0
17. *Kochia brevifolia*	1.3	3.9
18. *Kochia excavata* var. *trichoptera*	0.9	5.5
19. *Kochia georgei*	46.5	74.0
22. *Enchylaena tomentosa*	15.7	40.2
23. *Rhagodia spinescens* var. *deltophylla*	3.8	14.2
24. *Lycium australe*	0.1	0.8
27. *Bassia obliquicuspis*	273.8	87.4
28. *Bassia diacantha*	0.1	7.1
33. *Myoporum platycarpum*	0.1	0.8
35. *Heterodendrum oleaefolium*	1.0	4.7
38. *Acacia sowdenii*	0.1	0.8
43. *Casuarina cristata*	0.3	0.8
47. *Eremophila oppositifolia*	0.1	0.8
48. *Blennodia trisecta*	0.1	0.8

FIGURE 25

Dispersion of species in Winter Paddock

(excluding species having densities of less than one per square chain)

1. *Atriplex vesicaria*
2. *Atriplex stipitata*
4. *Atriplex spongiosa*
7. *Bassia patenticuspis*
8. *Bassia sclerolaenoides*
10. *Chenopodium desertorum*
15. *Kochia pyramidata*
16. *Kochia sedifolia*
17. *Kochia brevifolia*
19. *Kochia georgei*
22. *Enchylaena tomentosa*
23. *Rhagodia spinescens* var. *deltophylla*
27. *Bassia obliquicuspis*
35. *Heterodendrum oleaefolium*


AVERAGE NUMBER OF PLANTS PER SQ. CHAIN
PERCENTAGE TOTAL QUADRATS IN WHICH SPECIES OCCURS
1000
900
800
700
600
500
400
300
200
100
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50
60
70
80
90
100
1
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16
27
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7
2
22
10
4
23
17
35

which were of statistical importance in neighbouring piospheres.

The dominants, with frequencies of over 50% are in the order, *Atriplex vesicaria*, *Bassia obliquicuspis*, *Kochia georgei* and *K. sedifolia*, which, although ordered differently, are the same as the dominants at Barber's Dam. It is notable that *Atriplex stipitata* is more frequent here than in any of the other sample sites.

The dispersion of the populations demonstrates heterogeneity, most populations being clumped, especially *Bassia sclerolaenoides* (8) and *B. patenticuspis* (7), while *B. obliquicuspis* (27) is the most scattered.

Plate 19 shows the inner piosphere area at Winter Trough.

Vegetation pattern :
the effect of stocking on plant populations

Incidence data

The two nodes of interactions at $\chi \geqslant 4.0$ derived using influence analysis are shown in Fig. 26. They are both simple ones.

In Node 1 *Bassia obliquicuspis* (27) is positively associated with *Atriplex vesicaria* (1) and *Kochia georgei* (19). *B. obliquicuspis* dissociates with *Atriplex spongiosa* (4). *B. obliquicuspis* and *A. vesicaria* are very nearly ubiquitous, but the quadrats in which they are absent, although only 6 in number, are close to the water-point; *A. spongiosa* occurs in only 9 quadrats,

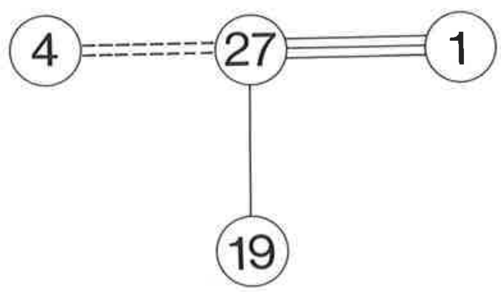
FIGURE 26

Nodes of associated species at $\chi \geqslant 4.0$
in Winter piosphere

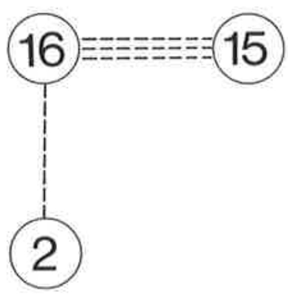
——— indicates association, positive association
---- indicates dissociation, negative association

(1) *Atriplex vesicaria*
(2) *Atriplex stipitata*
(4) *Atriplex spongiosa*
(15) *Kochia pyramidata*
(16) *Kochia sedifolia*
(19) *Kochia georgei*
(27) *Bassia obliquicuspis*

NODE 1.



NODE 2.



but again these are close to the trough paddock. The interactions of Node 1 are not, therefore, considered to be spurious.

Their strengths are summarised in Table 44, where it can be seen that *K. georgei* merely supports the dissociation of *B. obliquicuspis* and *A. vesicaria* with *A. spongiosa*. *K. georgei* was, therefore, rejected for the coding shown in Table 45, where the major pole consists of *A. vesicaria* with *B. obliquicuspis*; the opposite one, constituted by *A. spongiosa* on its own, occurs in only

TABLE 44

SIGNIFICANCE LEVELS OF INTERSPECIFIC ASSOCIATIONS BETWEEN SPECIES LINKED INTO NODE 1 AT WINTER TROUGH
Cell entries are χ values (positive or negative) on one degree of freedom

Bassia obliquicuspis	*Atriplex vesicaria*	*Kochia georgei*	*Atriplex apongiosa*	
%f = 87.4	93.7	74.0	7.1	
	+ 6.2	+ 4.2	− 4.7	*Bassia obliquicuspis*
		+ 3.8	− 0.1	*Atriplex vesicaria*
			− 0.9	*Kochia georgei*
				Atriplex spongiosa

TABLE 45

POSSIBLE INCIDENCE COMBINATIONS OF NODE 1 SPECIES
AT WINTER TROUGH
with observed frequencies (f) and influence ratings (IR)

	B. obliquicuspis	*A. vesicaria*	*A. spongiosa*	f	Recoding			IR
	–	–	–	5				*
	–	–	+	1	+	+	+	3
	–	+	–	5	+	–	–	1
	–	+	+	4	+	–	+	2
*→	+	+	–	110	–	–	–	0
	+	+	+	2	–	–	+	1
				Σ = 127				

one quadrat. The incidence of *A. spongiosa* is shown in Map 25; that of *A. vesicaria* can be seen from Map 34.

The plotted outcome of the coding is shown in Map 26, Node 1, which clearly shows that the main influence affecting this node of species is the location of the drinking trough. Isolated IRs of 1 away from the trough paddock result from the presence of *A. vesicaria* without *B. obliquicuspis*.

* *

Returning to Fig. 26, Node 2 displays dissociation of *K. sedifolia* with both *Kochia pyramidata* (15) and *Atriplex stipitata* (2). Details of the interactions (Table 46) show

TABLE 46

SIGNIFICANCE LEVELS OF INTERSPECIFIC ASSOCIATIONS BETWEEN SPECIES LINKED INTO NODE 2 AT WINTER TROUGH
Cell entries are χ values (positive or negative) on one degree of freedom

Kochia sedifolia	*Kochia pyramidata*	*Atriplex stipitata*	
%f = 63.0	34.6	22.8	
	− 5.1	− 3.8	*Kochia sedifolia*
		+ 2.0	*Kochia pyramidata*
			Atriplex stipitata

that *A. stipitata* and *K. pyramidata* associate only at $\chi = 2.0$. The coding in Table 47 shows that the major pole consists of *K. sedifolia* in the absence of *K. pyramidata* and *A. stipitata*.

Map 26, Node 2, shows that these interactions display certain similarities with Node 1, isotels appearing to focus on the trough paddock. However, the isotel layout also picks out the

TABLE 47

POSSIBLE INCIDENCE COMBINATIONS OF NODE 2 SPECIES AT WINTER TROUGH with observed frequencies (f) and influence ratings (IR)								
	K. sedifolia	*K. pyramidata*	*A. stipitata*	f	Recoding			IR
	−	+	+	9	+	+	+	3
	−	+	−	22	+	+	−	2
	−	−	−	6				*
	+	−	+	8	−	−	+	1
*→	+	−	−	58	−	−	−	0
	+	+	−	12	−	+	−	1
	+	+	+	1	−	+	+	2
	−	−	+	11	+	−	+	2
				Σ = 127				

Winter Flat, and extends from the trough paddock along the vermin-proof fence, where there is a slight natural drain running into Two-Mile Paddock (see Map 18).

The Winter Flat is easily discernible on aerial photographs (see Plate 15) and has less bush cover than the rest of the paddock (see Plates 21 and 22). There is herbage growth with small populations of *A. stipitata*, *K. pyramidata* and *A. vesicaria*. It is considered that Winter Flat is the floor of a broad shallow wash which eventually joins the Barber's Dam watercourse.

Apart from the Winter Flat, *A. stipitata* only occurs again within 300 yards of the trough (see Map 25). If this plant was strictly a watercourse plant, then one would expect it to occur in Kirrani Paddock and on the other side of the vermin-proof fence, particularly in Two-Mile Paddock into which the drain runs. This is not so however, and it is only possible, at this stage, to suggest that fruit of *A. stipitata* have been carried from Winter Flat to the area near the trough in the hooves of stock. The plant is unpalatable to sheep and if more *A. vesicaria* disappears from the inner piosphere area, then *A. stipitata* may take its place.

* *

One of the regular species in neighbouring piospheres, *K. brevifolia*, was present in only 5 quadrats in Winter Paddock close to the trough. The only interactions it has, which could possibly be regarded as significant are positive ones with *A. spongiosa* (χ = 2.0) and *K. pyramidata* (χ = 2.6) and negative ones with *A. vesicaria* (χ = -2.7), *K. sedifolia* (χ = -2.5) and *B. obliquicuspis* (χ = -2.6). All these species have already been handled in Nodes 1 and 2 and if their weak interactions with

K. brevifolia were plotted, the map would be similar to that of Node 1.

CONCLUSIONS

The ground in the immediate vicinity of Winter Trough is highly pulverised and provides a friable seed bed. This is an environment which has been exploited by *Atriplex spongiosa*, an invader of the inner piosphere area as indicated by Node 1. The species which dissociate from it and have therefore disappeared from this area are *A. vesicaria* and *B. obliquicuspis*. The extent of these interactions is restricted to within 100 yards of the base point. It will be recalled that *A. spongiosa* was one of the major piosphere species in Barrett's Paddock, where again it reacted negatively with *A. vesicaria*.

It is uncertain whether *A. stipitata* can be regarded as a piosphere plant; if it can, then its presence close to the Winter Trough could be regarded as retrogressive. If *A. vesicaria* continues to disappear close to the trough, then it is possible that *A. stipitata* will spread. As it is not eaten by sheep, it will provide some vegetative cover, although much of the damage round water-points is a result of trampling and in this respect *A. stipitata* could be as vulnerable as

A. vesicaria.

KIRRANI TROUGH

RESULTS AND DISCUSSION

Description of plant populations : density, frequency and dispersion

This area is even poorer floristically than the Winter pisophere area, having only 17 species (Table 48 and Fig. 27). Although the sample areas in Winter and Kirrani Paddocks are smaller than the neighbouring ones, together they would only contain 26 species. Six of the species of Kirrani Paddock have densities of less than one per square chain. *Bassia patenticuspis, Lycium australe, Kochia excavata* and *A. stipitata*, which were important species in other piospheres, are absent here.

The dominants, in order, are *Atriplex vesicaria, Kochia georgei, K. sedifolia* and *Bassia obliquicuspis*, which is similar to the situation in Winter Paddock.

The population here seems to be a fairly homogeneous one as

TABLE 48

THE PLANT SPECIES SAMPLED IN KIRRANI PADDOCK with their average density per square chain* and the percentage of total samples in which they occur+

Species	Density*	Frequency+
1. *Atriplex vesicaria*	380.1	91.6
7. *Bassia patenticuspis*	0.1	1.1
8. *Bassia sclerolaenoides*	1.1	7.4
9. *Bassia biflora*	0.5	3.2
10. *Chenopodium desertorum*	5.6	24.2
15. *Kochia pyramidata*	41.6	33.7
16. *Kochia sedifolia*	42.9	65.3
17. *Kochia brevifolia*	3.2	8.4
19. *Kochia georgei*	35.3	67.4
22. *Enchylaena tomentosa*	13.6	38.9
23. *Rhagodia spinescens* var. *deltophylla*	3.3	16.8
26. *Frankenia pauciflora*	0.9	2.1
27. *Bassia obliquicuspis*	80.8	60.0
35. *Heterodendrum oleaefolium*	0.7	5.3
38. *Acacia sowdenii*	0.4	2.1
43. *Casuarina cristata*	1.4	6.3
46. *Eremophila scoparia*	0.3	2.1

shown by Fig. 27, *K. georgei* (19) being the most scattered species and *K. pyramidata* (15) the most clumped.

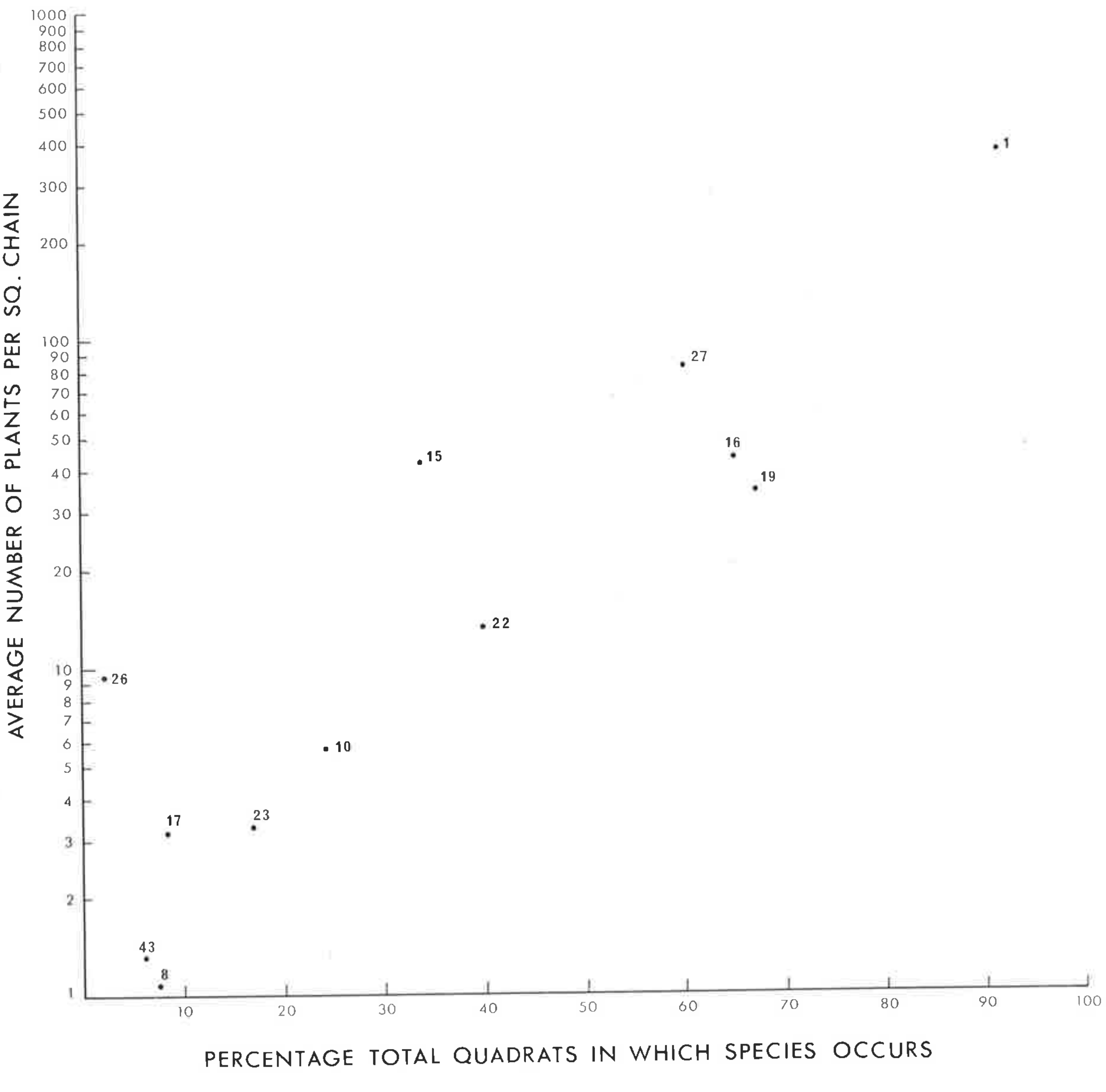
Plate 20 shows the area by the Kirrani Trough.

FIGURE 27

Dispersion of species in Kirrani Paddock

(excluding species having densities of less than one per square chain)

1. *Atriplex vesicaria*
8. *Bassia sclerolaenoides*
10. *Chenopodium desertorum*
15. *Kochia pyramidata*
16. *Kochia sedifolia*
17. *Kochia brevifolia*
19. *Kochia georgei*
22. *Enchylaena tomentosa*
23. *Rhagodia spinescens* var. *deltophylla*
27. *Bassia obliquicuspis*
43. *Casuarina cristata*


AVERAGE NUMBER OF PLANTS PER SQ. CHAIN
1000
900
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5
4
3
2
1
1
27
16
19
15
22
26
10
17
23
43
8
10
20
30
40
50
60
70
80
90
100
PERCENTAGE TOTAL QUADRATS IN WHICH SPECIES OCCURS

Vegetation pattern :
the effect of stocking on plant populations

Incidence data

The single node derived by influence analysis is shown in Fig. 28. Relationships at $\chi \geqslant 4.0$ become more meaningful at $\chi \geqslant 3.0$. *Rhagodia spinescens* var. *deltophylla* (23), dissociating with *K. georgei* (19) was rejected. *B. obliquicuspis* (27) associates with *K. sedifolia* (16) and also with *A. vesicaria* (1) and these species mutually dissociate with the associated *K. brevifolia* (17) and *K. pyramidata* (15). *K. georgei* also dissociates with *K. brevifolia*, but as Table 49 shows that it is only weakly associated with *B. obliquicuspis*, *K. sedifolia* and *A. vesicaria*, it was rejected for mapping. The results based on the coding of Table 50 are shown in Map 27.

The focus of the influence is the trough paddock, but lower IRs extend along the vermin-proof fence, a pattern which results from the absence of *B. obliquicuspis* on a sandy rise. The outermost circumference of the area is fringed by a wash in which *K. sedifolia* is absent (cf. Maps 18, 27 and 35).

CONCLUSIONS

The only invading piosphere plant here is *Kochia brevifolia*,

FIGURE 28

Nodes of associated species at $\chi \geq 4.0$ and $\chi \geq 3.0$ in Kirrani piosphere

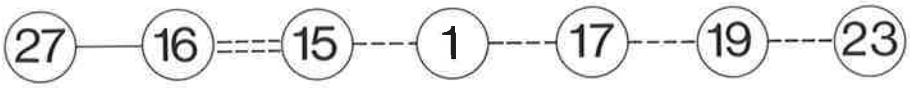
—— indicates association, positive association
---- indicates dissociation, negative association

(1) *Atriplex vesicaria*
(15) *Kochia pyramidata*
(16) *Kochia sedifolia*
(17) *Kochia brevifolia*
(19) *Kochia georgei*
(23) *Rhagodia spinescens* var. *deltophylla*
(27) *Bassia obliquicuspis*

(i) Node at $\chi \geq 4.0$
(ii) Node at $\chi \geq 3.0$

NODE 1.

(i)



(ii)

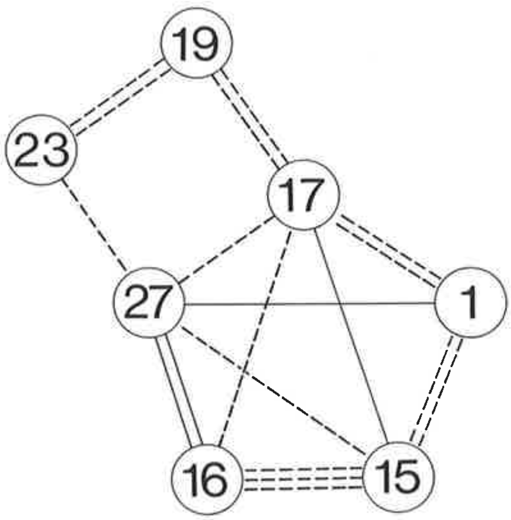


TABLE 49

SIGNIFICANCE LEVELS OF INTERSPECIFIC ASSOCIATIONS BETWEEN SPECIES LINKED INTO NODE 1 AT KIRRANI TROUGH
Cell entries are χ values (positive or negative) on one degree of freedom

	Bassia obliquicuspis	*Kochia sedifolia*	*Atriplex vesicaria*	*Kochia georgei*	*Kochia brevifolia*	*Kochia pyramidata*	
	%f = 80.8	42.9	91.6	67.4	8.4	33.7	
Bassia obliquicuspis		+ 4.9	+ 3.5	+ 2.5	− 2.1	− 2.9	*Bassia obliquicuspis*
Kochia sedifolia			+ 2.4	+ 1.9	− 2.5	− 4.2	*Kochia sedifolia*
Atriplex vesicaria				+ 2.5	− 3.8	− 3.3	*Atriplex vesicaria*
Kochia georgei					− 3.4	− 0.7	*Kochia georgei*
Kochia brevifolia						+ 3.4	*Kochia brevifolia*
Kochia pyramidata							*Kochia pyramidata*

whose occurrence in 7 localised quadrats gives rise to one pole of the interaction. *Kochia pyramidata* occurs close to the water-point but also in the watercourse at the circumference of the study area. *B. obliquicuspis* and *K.*

TABLE 50

POSSIBLE INCIDENCE COMBINATIONS OF NODE 1 SPECIES AT KIRRANI TROUGH with observed frequencies (f) and influence ratings (IR)

	B. obliquicuspis	*K. sedifolia*	*A. vesicaria*	*K. brevifolia*	*K. pyramidata*	f	Recoding					IR
	−	−	−	+	+	3	+	+	+	+	+	5
	−	−	+	−	−	9	+	+	−	−	−	2
	−	−	+	−	+	10	+	+	−	−	+	3
	−	−	+	+	+	3	+	+	−	+	+	4
	−	+	+	−	−	9	+	−	−	−	−	1
	−	+	+	−	+	4	+	−	−	−	+	2
	+	−	+	−	−	3	−	+	−	−	−	1
	+	−	+	−	+	4	−	+	−	−	+	2
*→	+	+	+	−	−	42	−	−	−	−	−	0
	+	+	+	−	+	7	−	−	−	−	+	1
	+	+	+	+	+	1	−	−	−	+	+	2
						Σ = 95						

sedifolia constituting the opposite pole of the influence tended to be absent from these areas. The absence of *K. sedifolia* is almost certainly due to the natural drain here, rather than to any stock effect.

CORNERS OF TWO-MILE AND BARBER'S PADDOCKS AT WINTER TROUGH

RESULTS AND DISCUSSION

Description of plant populations : density, frequency and dispersion

These data are presented in Tables 51 and 52 and in Figs. 29 and 30. The total number of species is low in both cases and about 30% of them have densities of less than 1 per square chain. The dominants in both areas are *Atriplex vesicaria, Kochia sedifolia, Bassia obliquicuspis* and *K. georgei.*

The populations of these areas are neither clumped nor hyper-dispersed as shown in Figs. 29 and 30, and indicates that the general vegetation association is more homogeneous than the other sampled areas.

Vegetation pattern

Incidence data

No statistically significant interactions were displayed by influence analysis. Even though one might expect the data to be

TABLE 51

THE SPECIES SAMPLED IN THE WINTER TROUGH CORNER OF TWO-MILE PADDOCK with their average density per square chain* and the percentage of total samples in which they occur+		
Species	Density*	Frequency+
1. *Atriplex vesicaria*	484.3	100.0
7. *Bassia patenticuspis*	0.4	3.3
8. *Bassia sclerolaenoides*	1.7	13.3
9. *Bassia biflora*	10.0	20.0
10. *Chenopodium desertorum*	31.7	73.3
11. *Chenopodium ulicinum*	0.4	3.3
15. *Kochia pyramidata*	3.9	16.6
16. *Kochia sedifolia*	104.8	96.7
19. *Kochia georgei*	23.5	76.7
21. *Kochia tomentosa*	0.4	3.3
22. *Enchylaena tomentosa*	8.3	36.7
23. *Rhagodia spinescens* var. *deltophylla*	0.4	3.3
27. *Bassia obliquicuspis*	74.8	83.3
35. *Heterodendrum oleaefolium*	0.9	3.3

biassed close to the base point, on account of the radial sampling grid, no pattern was demonstrable. Clearly such bias is not instrumental in inducing pattern to be displayed, where pattern does not exist.

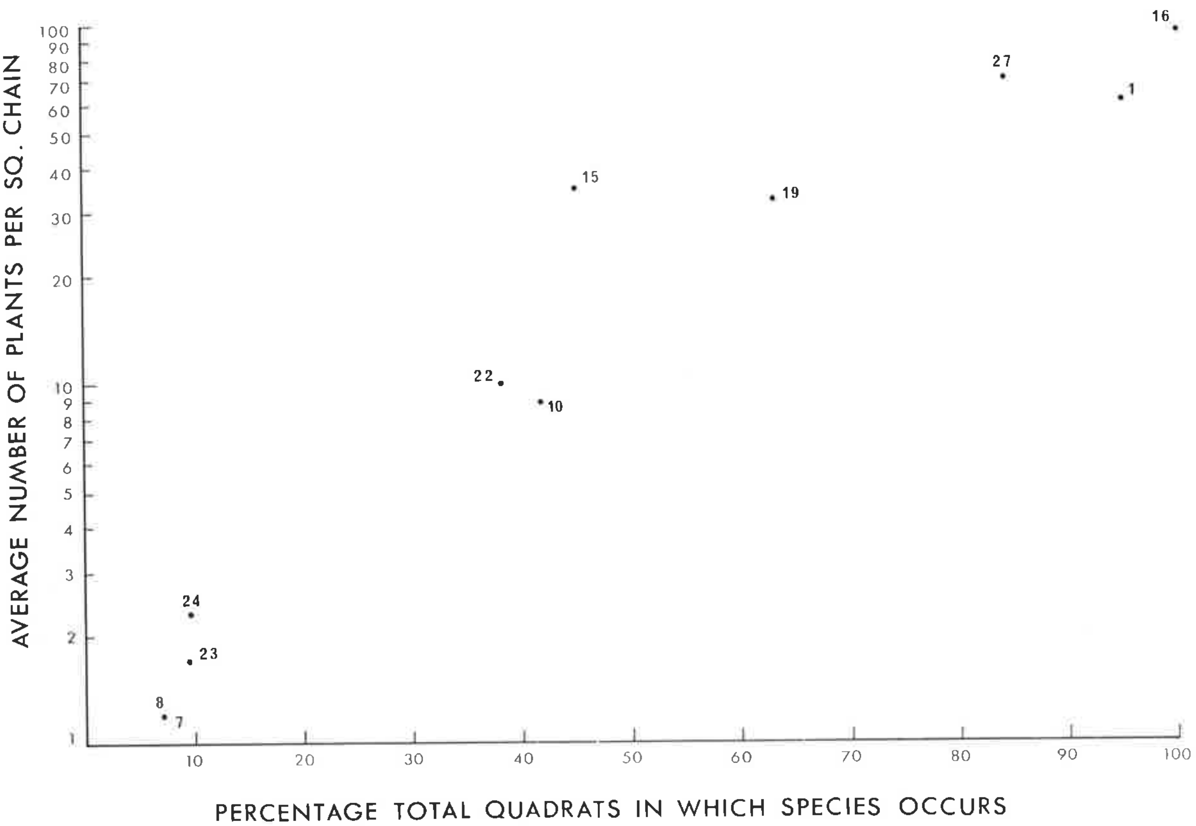
In these paddock corners, therefore, stock have had no effect

FIGURE 29

Dispersion of species in Two-Mile Paddock at Winter Trough

(excluding species having densities of less than one per square chain)

1. *Atriplex vesicaria*
8. *Bassia sclerolaenoides*
9. *Bassia biflora*
10. *Chenopodium desertorum*
15. *Kochia pyramidata*
16. *Kochia sedifolia*
19. *Kochia georgei*
22. *Enchylaena tomentosa*
27. *Bassia obliquicuspis*


AVERAGE NUMBER OF PLANTS PER SQ. CHAIN
100
90
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4
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50
60
70
80
90
100
PERCENTAGE TOTAL QUADRATS IN WHICH SPECIES OCCURS
16
27
1
15
19
22
10
24
23
8
7

TABLE 52

THE SPECIES SAMPLED IN THE WINTER TROUGH CORNER OF BARBER'S PADDOCK
with their average density per square chain* and the percentage of total samples in which they occur+

Species	Density*	Frequency+
1. *Atriplex vesicaria*	61.1	95.2
7. *Bassia patenticuspis*	1.4	7.1
8. *Bassia sclerolaenoides*	1.1	7.1
9. *Bassia biflora*	0.2	1.2
10. *Chenopodium desertorum*	8.9	41.7
12. *Marrubium vulgare*	0.9	1.2
15. *Kochia pyramidata*	35.2	45.2
16. *Kochia sedifolia*	96.5	100.0
18. *Kochia excavata*	0.4	1.2
19. *Kochia georgei*	32.5	63.1
21. *Kochia tomentosa*	0.2	1.2
22. *Enchylaena tomentosa*	10.5	38.1
23. *Rhagodia spinescens deltophylla*	1.7	9.5
24. *Lycium australe*	2.3	9.5
26. *Frankenia pauciflora*	0.2	1.2
27. *Bassia obliquicuspis*	71.7	84.5
43. *Casuarina cristata*	0.4	2.4

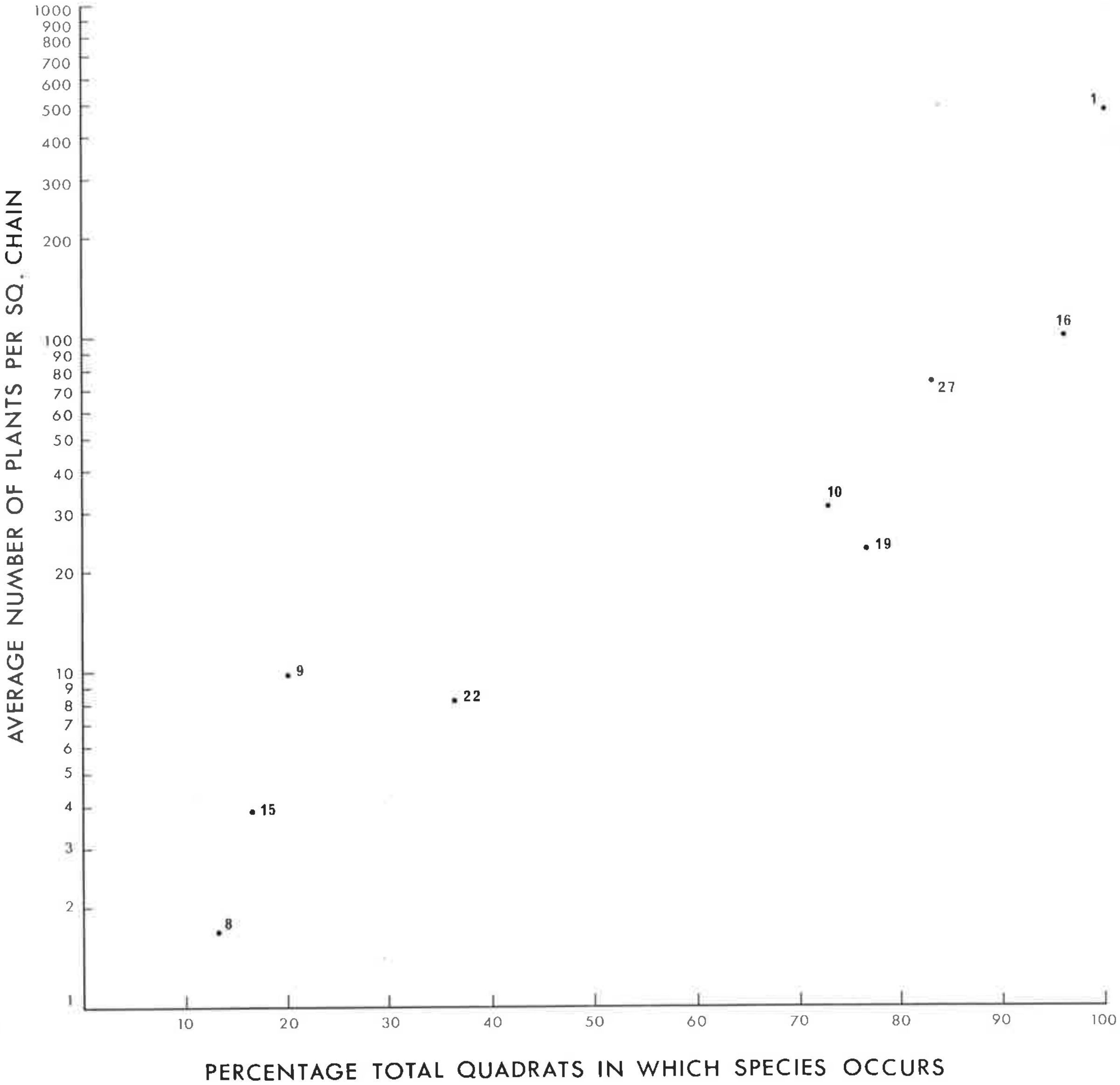
on the indicence of species, such as to cause significant positive or negative interactions between species.

FIGURE 30

Dispersion of species in Barber's Paddock at Winter Trough

(excluding species having densities of less than one per square chain)

1. *Atriplex vesicaria*
7. *Bassia patenticuspis*
8. *Bassia sclerolaenoides*
10. *Chenopodium desertorum*
15. *Kochia pyramidata*
16. *Kochia sedifolia*
19. *Kochia georgei*
22. *Enchylaena tomentosa*
23. *Rhagodia spinescens* var. *deltophylla*
24. *Lycium australe*
27. *Bassia obliquicuspis*



AVERAGE NUMBER OF PLANTS PER SQ. CHAIN
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50
60
70
80
90
100
PERCENTAGE TOTAL QUADRATS IN WHICH SPECIES OCCURS
1
16
27
10
19
9
22
15
8

ANALYSIS OF THE TOTAL DATA FROM THE AREA BETWEEN TWO-MILE DAM AND WINTER FLAT

RESULTS AND DISCUSSION

Vegetation pattern : the effect of stocking on plant populations

Incidence data

All the data pertaining to the Two-Mile - Winter Flat area (sampled by 1025 quadrats) were subjected to influence analysis. The single node is so identified at $\chi \geq 4.0$ is shown in Fig. 31. It is a complex one and it is necessary to split it into several component parts for the full expression of the interactions it contains.

Consideration of *Enchylaena tomentosa* (22), *Rhagodia spinescens* var. *deltophylla* (23) and *Lycium australe* (24) having mutual positive association, was deferred for reasons stated in previous sections.

* *

One of the very powerful groups of interactions in the node consists of mutual positive associations between *Bassia patenticuspis* (7), *Kochia tomentosa* (21) and *K. pyramidata* (15). These all dissociate with *Atriplex vesicaria* (1). The very high χ levels displayed by

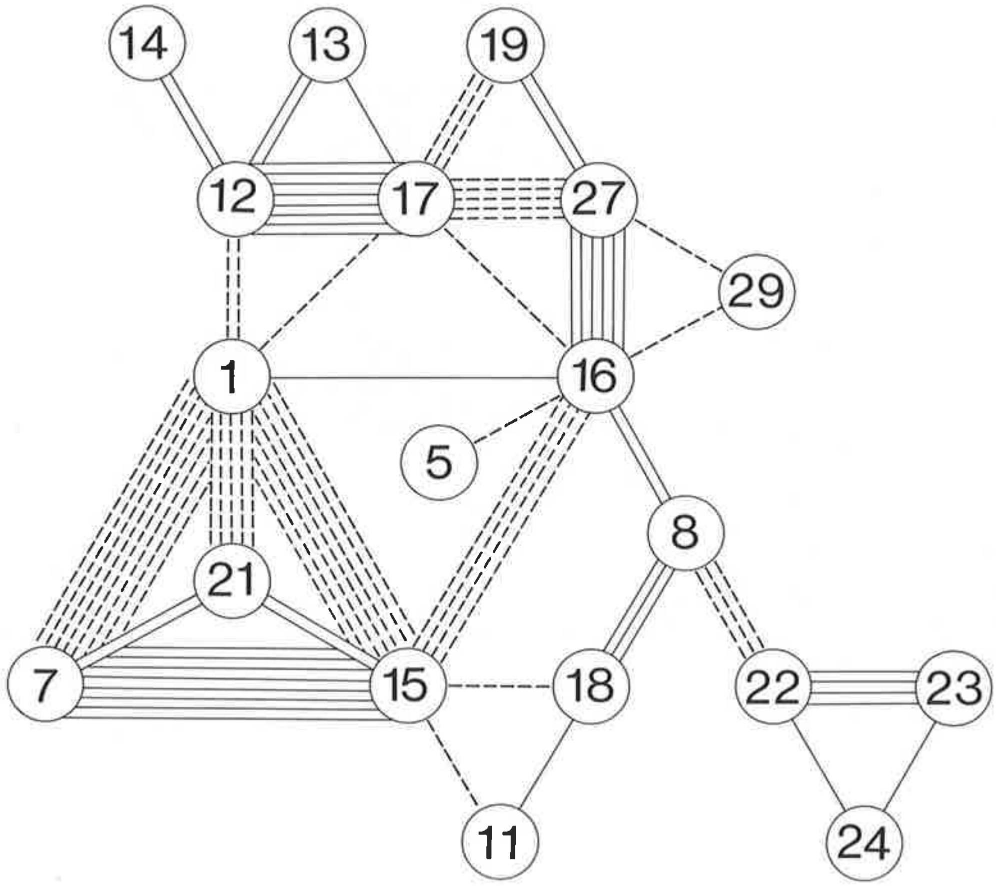
FIGURE 31

Node of associated species in the total analysis of the Two-Mile - Winter Flat data

—— indicates association, positive association
---- indicates dissociation, negative association

(1) *Atriplex vesicaria*
(5) *Atriplex eardleyae*
(7) *Bassia patenticuspis*
(8) *Bassia sclerolaenoides*
(11) *Chenopodium ulicinum*
(12) *Marrubium vulgare*
(13) *Inula graveolens*
(14) *Carthamus lanatus*
(15) *Kochia pyramidata*
(16) *Kochia sedifolia*
(17) *Kochia brevifolia*
(18) *Kochia excavata* var. *trichoptera*
(19) *Kochia georgei*
(21) *Kochia tomentosa*
(22) *Enchylaena tomentosa*
(23) *Rhagodia spinescens* var. *deltophylla*
(24) *Lycium australe*
(27) *Bassia obliquicuspis*
(29) *Centipeda thespidioides*

NODE 1.



this group are shown in Table 53. It can also be seen that *K. tomentosa* has a relatively low frequency. The other three species were coded for mapping as in Table 54, and on the completed map the incidence of *K. tomentosa* was shown by means of a symbol (see Map 28).

The principal focus of the influence ratings over the whole area is at Two-Mile Dam with similarly high influence ratings extending towards the Two-Mile Plain. A less extensive focus of influence ratings is seen at Barber's Dam, where the isotels spread

TABLE 53

SIGNIFICANCE LEVELS OF INTERSPECIFIC ASSOCIATIONS BETWEEN SPECIES LINKED INTO NODE 1a OF TWO-MILE - WINTER FLAT DATA
Cell entries are χ values (positive or negative) on one degree of freedom

Kochia pyramidata	*Bassia patenticuspis*	*Kochia tomentosa*	*Atriplex vesicaria*	
%f = 53.9	42.3	7.4	65.7	
	+ 13.2	+ 7.1	− 11.8	*Kochia pyramidata*
		+ 7.3	− 12.2	*Bassia patenticuspis*
			− 10.0	*Kochia tomentosa*
				Atriplex vesicaria

TABLE 54

POSSIBLE INCIDENCE COMBINATIONS OF NODE 1a SPECIES IN TWO-MILE - WINTER FLAT DATA with observed frequencies (f) and influence ratings (IR)

	K. pyramidata	*B. patenticuspis*	*A. vesicaria*	f	Recoding			IR
	+	+	+	123	+	+	-	2
	+	+	-	217	+	+	+	3
	+	-	+	150	+	-	-	1
	+	-	-	57	+	-	+	2
	-	+	+	67	-	+	-	1
	-	+	-	28	-	+	+	2
*→	-	-	+	333	-	-	-	0
	-	-	-	50				*
	Σ = 1025							

up the watercourse on either side of the dam. Weaker influence ratings pick out Winter Flat, the trough area and the minor watercourses in Winter and Kirrani Paddocks.

The presence of *B. patenticuspis* and *K. pyramidata* and the absence of *A. vesicaria* account for the pattern near the dams in Two-Mile and Barber's Paddocks; the predominance of *A. vesicaria* without these two species elsewhere constitutes the opposite pole of the influence. All three species occur together on Winter Flat, whilst *K. pyramidata* and *A. vesicaria* tend to be present at the trough in Winter Paddock. To illustrate this more specifically, Maps 31, 34 and 36 display the incidence of species involved in this node.

It is possible that the pattern focussed on Two-Mile Dam is the result of past overgrazing, although it must be recalled that there are possible topographic and edaphic factors involved here also. It is similar to that at Barber's Dam, where the pattern is almost certainly brought about by intense stock activity close to the dam. It is noticeable that the strong pattern extends further up the watercourse in Barber's Paddock than in Two-Mile. This is because *A. vesicaria* is absent more often on the Barber's Paddock side of the dam, whereas incidence of *B. patenticuspis* and *K. pyramidata* is similar on both sides of the dam. This effect is brought about by more intense stock pressure in Barber's Paddock where sheep can only water at Barber's Dam, whereas they have a choice of two water-points in Two-Mile Paddock.

Before concluding this discussion of Node 1a, it must be said that the cause of the pattern at Winter Trough is a matter for conjecture; it may result from stock activity.

* *

Returning to the original node in Fig. 29, it is clear that *Marrubium vulgare* (12) and *Kochia brevifolia* (17) are very strongly associated, as are *B. obliquicuspis* (27) and *Kochia sedifolia* (16). Powerful dissociation exists between *K. brevifolia* and *B. obliquicuspis*. *Marrubium* also dissociates more weakly with *A. vesicaria*. Other species linked to these major ones in the upper half of Fig. 29, are *Inula graveolens* (13), *Carthamus lanatus* (14) and *K. georgei* (19). For the purposes of depicting a further vegetation pattern the major piosphere invaders, *K. brevifolia* and *M. vulgare* were ranked against *B. obliquicuspis* and *K. sedifolia*, the other species mentioned above being ignored. The interactions of the species thus constituting Node 1b are shown in Table 55; the codes for mapping are in Table 56 and the result is shown in Map 29.

The pole combination containing *M. vulgare* and *K. brevifolia* is most extensive at Barber's Dam and particularly in Barber's Paddock. This combination is restricted to two quadrats at Two-Mile Dam; extensive IRs of 2 at Two-Mile result from the presence of *Marrubium* with *B. obliquicuspis* in the drain leading from the Plain.

K. brevifolia, but not *Marrubium* occurs in Winter and Kirrani Paddocks near the trough, so pattern is not so marked here. Watercourses and Winter Flat are identified by quadrats having either one of the associates at the other pole of the influence, *K. sedifolia* and *B. obliquicuspis*. The occurrence of these two

TABLE 55

SIGNIFICANCE LEVELS OF INTERSPECIFIC ASSOCIATIONS BETWEEN SPECIES LINKED INTO NODE 1b OF TWO-MILE - WINTER FLAT DATA
Cell entries are χ values (positive or negative) on one degree of freedom

Marrubium vulgare	*Kochia brevifolia*	*Bassia obliquicuspis*	*Kochia sedifolia*	
%f = 9.9	8.5	82.4	80.0	
	+ 13.1	- 3.6	- 4.1	*Marrubium vulgare*
		- 9.3	- 6.0	*Kochia brevifolia*
			+ 11.6	*Bassia obliquicuspis*
				Kochia sedifolia

together accounts for the majority of the area in all paddocks.

The pattern caused by the invading species close to the water-points is undoubtedly a piosphere effect, as noted in the individual analyses at Two-Mile and Barber's Dams. The incidence of the piosphere invaders for the water-points under consideration may be compared in Maps 38 and 39.

* *

TABLE 56

POSSIBLE INCIDENCE COMBINATIONS OF NODE 1b SPECIES IN TWO-MILE - WINTER FLAT DATA with observed frequencies (f) and influence ratings (IR)

	M. vulgare	*K. brevifolia*	*B. obliquicuspis*	*K. sedifolia*	f	Recoding				IR
	+	+	+	+	13	+	+	-	-	2
	+	+	-	+	12	+	+	+	-	3
	+	+	+	-	6	+	+	-	+	3
	+	+	-	-	14	+	+	+	+	4
	+	-	+	+	31	+	-	-	-	1
	+	-	-	+	8	+	-	+	-	2
	+	-	+	-	15	+	-	-	+	2
	+	-	-	-	5	+	-	+	+	3
	-	+	+	+	15	-	+	-	-	1
	-	+	-	+	3	-	+	+	-	2
	-	+	+	-	2	-	+	-	+	2
	-	+	-	-	21	-	+	+	+	3
*→	-	-	+	+	685	-	-	-	-	0
	-	-	-	+	45	-	-	+	-	1
	-	-	+	-	87	-	-	-	+	1
	-	-	-	-	63					*
					Σ = 1025					

The last group of species selected to display pattern involves the dissociation of *K. pyramidata* (15) with *K. sedifolia* (16) *K. excavata* (18) and *Chenopodium ulicinum* (11) and the positive association between *K. sedifolia* and *B. sclerolaenoides* (8), *K. excavata* and *C. ulicinum*.

Table 57 shows their interactions. Although *C. ulicinum* has a higher incidence than *K. excavata*, its interactions are less

TABLE 57

SIGNIFICANCE LEVELS OF INTERSPECIFIC ASSOCIATIONS BETWEEN SPECIES LINKED INTO NODE 1c OF TWO-MILE - WINTER FLAT DATA
Cell entries are χ values (positive or negative) on one degree of freedom

Kochia pyramidata	*Bassia sclerolaenoides*	*Kochia excavata*	*Chenopodium ulicinum*	*Kochia sedifolia*	
%f = 53.9	25.3	7.9	10.2	80.0	
	− 2.6	− 6.0	− 5.5	− 8.5	*Kochia pyramidata*
		+ 8.8	+ 5.0	+ 7.3	*Bassia sclerolaenoides*
			+ 6.2	+ 4.0	*Kochia excavata*
				− 4.3	*Chenopodium ulicinum*
					Kochia sedifolia

significant, so it was rejected for coding (Table 58) and mapping. The quadrats containing *C. ulicinum* were plotted separately on the map (Map 30) by means of a symbol.

TABLE 58

POSSIBLE INCIDENCE COMBINATIONS OF NODE 1c SPECIES
IN TWO-MILE - WINTER FLAT DATA
with observed frequencies (f) and influence ratings (IR)

	K. pyramidata	*B. sclerolaenoides*	*K. excavata*	*K. sedifolia*	f	Recoding				IR
	+	+	+	+	9	−	+	+	+	3
	+	−	+	+	6	−	−	+	+	2
	+	+	−	+	88	−	+	−	+	2
	+	−	−	+	268	−	−	−	+	1
	+	−	+	−	1	−	−	+	−	1
	+	+	−	−	9	−	+	−	−	1
*→	+	−	−	−	164	−	−	−	−	0
	−	+	+	+	45	+	+	+	+	4
	−	−	+	+	18	+	−	+	+	3
	−	+	−	+	98	+	+	−	+	3
	−	−	−	+	278	+	−	−	+	2
	−	−	+	−	1	+	−	+	−	2
	−	−	−	−	40					*
					Σ = 1025					

Map 30 shows that because of the relatively low incidences of the species at one pole *(K. excavata, B. sclerolaenoides* and *C. ulicinum)* the picture displayed by this node is not as clear as that of Nodes 1a and 1b. The isotels tend to contain small patches rather than delimit large areas.

Nevertheless the layout does identify the watercourse features and Winter Flat and Two-Mile Plain, which are also picked out by Nodes 1a and 1b. In addition, Node 1c IRs of 4 and 3 identify higher ground north-west of Two-Mile Dam and north-east and north-west of Barber's Dam watercourse and south of Winter Trough. This is due to the presence of *K. sedifolia* in combination with either or both of *B. sclerolaenoides* and *K. excavata.* It can be seen that the incidence of *C. ulicinum* reinforces this set of interactions.

As *K. pyramidata* (a possible piosphere plant) is present in all watercourses as well as near all water-points, the influence affecting the species of this node appears to be a purely topographic one.

Density data

Data collected as in Barrett's Paddock, included juvenile populations of the principal shrub dominants according to Table 16. The results are depicted in Maps 34-37 inclusive. The juvenile populations of *A. vesicaria* and *K. sedifolia* are not shown as they did not appear to be of any significance. The juvenile populations of *K. pyramidata* consist mainly of young plants, which are those shown on Map 37. The lack of seedlings is attributed to a dry season prior to sampling.

* *

Looking first at the population densities of *A. vesicaria* in Map 34, it is immediately obvious that the area extending from Two-Mile Dam out on to Two-Mile Plain is practically devoid of saltbush. Some denser populations occur on the Two-Mile Plain, but populations decrease again on the southern rim of the Plain bordering Barber's watercourse. Reference to Map 33 shows that this is where *K. excavata* is most consistently present. This effect is continuous through the fence into Barber's Paddock. South of the Barber's Dam watercourse, *K. excavata* is not consistently present and in Two-Mile Paddock the density of *A. vesicaria* appears to be only slightly lower where *K. excavata* occurs. In Barber's Paddock, however, populations of saltbush are as low on the south side of the watercourse towards Winter Trough as they are to the north of the watercourse.

In spite of the variations associated with the presence of *K. excavata* in some parts of the general region near Barber's Dam it appears as though populations of *A. vesicaria* are smaller in Barber's Paddock than in Two-Mile.

The situation close to Winter Trough is shown clearly by Map 34, Inset C. In Barber's Paddock where stock cannot get to water at Winter Trough, population sizes are low within 250 yards of the corner. In Two-Mile Paddock on the other hand, *A. vesicaria* is very dense even 25 yards from the base point. In Kirrani and Winter Paddocks, where sheep can water at the trough, populations are small or absent within 100 yards of the trough, but 150-200 yards distant they are as high as elsewhere in the paddock.

The easiest distribution to account for is the pattern at Winter Trough. It is well known, though not authoritatively documented, that sheep tend to graze downwind. In this region the prevailing wind is a south-westerly one, and as the trough in Kirani and Winter Paddocks is on the north side of the paddock, sheep would graze away from it having had a drink. In Barber's Paddock sheep grazing downwind from Barber's Dam finish up in the corner by the Winter Trough, and because they can smell water, some sheep tend to stay there. In Two-Mile Paddock sheep grazing towards the southern end of the paddock avoid the corner by Winter Trough.

Such data provide clear evidence of the damage which is caused by sheep "hanging" near a water-point they cannot reach. It is probable, however, that even if sheep in Barber's Paddock could drink at Winter Trough, they would still spend more time by the trough than sheep in Winter and Kirrani Paddocks. The cross-fence comparison of Winter and Kirrani Paddocks with Barber's provides further interesting information on this aspect of sheep behaviour. Although severe stock pressure has removed much saltbush close to the trough in Kirrani and Winter Paddocks, the high stock pressure is evidently not sustained long enough for all populations to be reduced within the 250 yard radius. On the north side of the fence, however, populations of *A. vesicaria* have not completely disappeared, but lower stock pressure (for presumably not every sheep in Barber's Paddock will always find its way to the southern corner) sustained for long periods has a noticeable effect on population size for, say, 600 yards from the trough corner. It is difficult to assess this distance as a reduction in population sizes along the northern radii could be confused with a piosphere effect at Barber's Dam. Cross-fence comparison along the westerly radii suggests the 600 yard limit.

At Barber's Dam it is believed that the low populations are a result of stock activity, that is, they reflect a true piosphere effect. South of the dam populations are low or absent up to 900-1000 yards. However, west of the dam, populations start increasing at 500 yards distant. This is probably due to the greater tolerance to stock of populations in the watercourse, where additional moisture would enable plants to renew growth relatively readily after grazing and trampling.

North of the dam populations are again small or absent up to 1200 yards from the dam. This is undoubtedly part of the piosphere effect, though it has been accentuated by the low populations which seem to be characteristic of the southern rim of the Two-Mile Plain. This conclusion is derived from the cross fence comparison with Two-Mile Paddock, where populations, though small, are not so consistently absent as in Barber's Paddock.

The piosphere effect at Barber's Dam as displayed by densities of *A. vesicaria* appears to be more marked in Barber's Paddock than in Two-Mile, where populations are nevertheless low close to the dam. This difference between the two paddocks is undoubtedly due to the fact that sheep in Barber's Paddock are obliged to water at the dam, whereas those in Two-Mile have a choice of water-point.

North-east of Barber's watercourse, from the rim of the Two-Mile Plain to Two-Mile Dam *A. vesicaria* either has low population densities or is absent. This is very difficult to account for. On Quondong Station, *K. excavata* populations are extremely high and those of *A. vesicaria* low (see Table 13), whereas on Middleback Station, *A. vesicaria* is prevalent and *K. excavata* rare. The localised areas in Two-Mile, where the *Kochia* is present also contain *Atriplex acutibracta*, another constant species in Ki Ki. There would thus seem to be similarities in the vegetation in parts of Two-Mile Paddock and Ki Ki, and it is likely that these are based on edaphic factors. It is believed that *K. excavata* and *A. acutibracta* are plants of highly calcareous areas whilst *A. vesicaria* is not.

It was suggested on p. 175 that the *K. excavata* populations in

Two-Mile may be the relic of a past continuous cover, such as that in Ki Ki. The same argument could be applied to *A. vesicaria*; the two high populations in the north-east corner of Barber's Paddock and in Purpunda Paddock suggest this.

With the present data the problem is impossible to resolve. In view of the heavy stocking Two-Mile Paddock is said to have had and the palatability of the two plants under discussion, populations of both of them were probably slightly higher than they are now, but were probably not as high as those of *A. vesicaria* found elsewhere in the sampled area or as high as those of *K. excavata* in Ki Ki.

* *

Map 35 shows population densities of *K. sedifolia*. These are fairly even throughout Barber's and Two-Mile Paddocks. It is absent or has small populations where *K. tomentosa* is present close to Two-Mile Dam, in the basin of the Two-Mile Plain and in Barber's watercourse.

In Kirrani and Winter Paddocks *K. sedifolia* is more frequently absent, and especially on Winter Flat (see Plates 21 and 22) and in the minor washes which dissect the area. A notable and inexplicable feature is the lack of *K. sedifolia* near the trough in these two paddocks, compared with Barber's and Two-Mile Paddocks. This may be an effect of the drain along the fenceline, but why this should have more effect on the south side of the fence than on the north cannot be explained. It is possible, though unlikely, that *K. sedifolia* has succumbed to intense stock pressure near the water-point; if so one would have expected *A. vesicaria* also to be absent.

* *

Maps 36 and 37 show population densities of mature and young plants repsectively of *Kochia pyramidata*. Populations of mature plants are very high close to Two-Mile Dam, and in the Barber's Dam watercourse some distance from the dam; close to the dam populations are rather smaller. At the southern end of the study area, populations are negligible, except near Winter Trough where they are concentrated within 250 yards of it, especially in Kirrani and Winter Paddocks but also in Barber's; only two individuals are present, however, in Two-Mile Paddock.

Young plants show the same general distribution. More specifically, there are very large populations of young plants close to Two-Mile Dam, in the drain leading to the dam from Two-Mile Plain, close to Barber's Dam in Two-Mile Paddock, and close to the trough in Kirrani and Winter Paddocks. These observations support the inference made from the Barrett's data, that juvenile *K. pyramidata* populations seem to be stimulated by conditions in the close vicinity of a water-point. Attention is, however, drawn to the relatively low populations of young plants near Barber's Dam in Barber's Paddock; this will be explained later.

In the corner of Barber's Paddock by the Winter Trough moderate populations of young *K. pyramidata* are present, although they are not over the fence in Two-Mile Paddock. This again must be the effect of stock "hanging" near water, and provides clear evidence for the stimulation of *K. pyramidata* by stock activity. Reference to Plates 23 and 24 shows how the population of *K. pyramidata* seems to have increased along the vermin-proof fence in Barber's Paddock, during the last 17 years.

On account of this apparently aggressive nature of *K. pyramidata*, noted also in Barrett's Paddock, it is possible that the present occurrence of the plant over much of the northern half of Two-Mile Paddock is the result of stock pressure, populations originally spreading from established ones in Two-Mile watercourse.

* *

Population densities of the two principal perennial piosphere species, *Kochia brevifolia* and *Marrubium vulgare*, are shown in Maps 38 and 39. Those of *K. brevifolia* are very localised and are high in only three or four quadrats throughout the area. Its persistence in the inner piosphere area here, as in Barrett's, cannot be explained solely by the observations gained from these analyses.

Marrubium is also persistent in the inner piosphere area, but has spread to various other parts of the sampled area. The notable features of its population size are its high densities in the artificial drains leading to Two-Mile Dam and, as can be seen from Plate 18, near Barber's Dam in Barber's Paddock. A small invading population at Winter Trough is undoubtedly the "focus of infection" for spread of the species here.

As mentioned previously, this plant appears to thrive in drift sand collecting in drainage lines. This is the case in the Two-Mile Dam area, as in Barber's Paddock where water draining into the dam from the west has deposited large quantities of sand in the watercourse. The deposition results from the combined effects of the soil surface being broken by sheep and the increased run-off brought about by soil compaction. Sand is not deposited on the downstream side of the dam and consequently populations are smaller in Two-Mile Paddock. Detritus, and hence sand also, has piled up against the mesh vermin-proof fence providing a suitable substrate for *Marrubium* near the Winter Trough.

Whether *Marrubium* could continue to colonise areas remote from the situations detailed above is not predictable. Most isolated populations consist of single individuals. Where well established, the plant will persist and in some areas it will compete with and replace populations which might otherwise provide useful fodder.

For instance, the relatively low densities of young plants of *K. pyramidata* in Barber's Paddock near the dam (commented upon on p. 151), may result from their unsuccessful competition with *Marrubium*.

CONCLUSIONS

The data contained in this chapter parallel the preliminary observations made in Barrett's Paddock. Topographic patterns have been identified as have the species responsible for displaying them; such patterns can be distinguished from the piosphere pattern resulting from stock pressure.

Some of the invading species confined to the water-point areas are the same as those in Barrett's, namely *Kochia brevifolia*, *Bassia paradoxa*, *Atriplex spongiosa* and *A. eardleyae*, although all these species were not found at all the water-points just described. The behaviour of *Kochia pyramidata* and *Bassia patenticuspis*, which were not confined to the water-point suggests that they are also invading the inner piosphere area.

Other invaders were only noted in the Two-Mile - Winter Flat area and these are *Marrubium vulgare*, *Carthamus lanatus* and *Inula graveolens*. The most important of these alien weeds is *Marrubium*. *Atriplex stipitata* appears to be an invader of the inner piosphere area in Winter Paddock, but this may not be a result of stock activity here.

The environment close to water-points has been modified such that these populations can develop, once the initial plants are established; the soil surface is broken up, lower soil layers are compacted and inputs of organic matter and mineral nutrients are increased. Why the piosphere invaders should thrive under these conditions is unknown. Some possible explanations are sought in Chapter XIV, which attempts to describe the general ecology of some of these species.

Plants which have been caused to disappear from heavily stocked regions in the study area are *Atriplex vesicaria*, possibly *Kochia excavata* and *Bassia obliquicuspis*. The first two have certainly been grazed out in places, as well as being trampled. The spiny *Bassia* is probably not grazed, but may be trampled out near water, although *B. patenticuspis* with a similar growth form survives there.

It seems unlikely that the environmental modifications mentioned above would be sufficient to directly cause the disappearance of species near a water-point, although invading species affected by the changed environment must compete with existing ones. In the piospheres examined, however, invading species are mostly confined to the immediate vicinity of the water-point, so any competitive effects would also be restricted.

The strength and extent of the influences which centre on water-points may be a reflection of their relative ages or the amount of use they get, as it takes time or heavy stocking to induce interspecific relationships which are detectable by incidence. The map for Nodes 1a and 1b of the total analysis could be said to show this effect, Two-Mile Dam having the greatest extent of pattern and Winter Trough the least.

Some of the stock effects noted here, clearly reflect fence layout. Those between Barber's and Two-Mile Paddocks must date from 1932 when the fence was erected; that between Barber's/Two-Mile and Winter/Kirrani probably date from 1930 when the trough was installed, although factors operative prior to this date should not be overlooked.

Comparison between Plates 21 and 22 and between 23 and 24 suggest that for periods in the past stocking has been rather heavier than it is now, and that recovery has been taking place.

CHAPTER XII

ASSESSMENT OF FIELD INVESTIGATIONS

INTRODUCTION

In this chapter the outcome of the principal field investigations is discussed. First, the success of the methods used is evaluated and then the results are assessed, with particular emphasis on the plants affected by the piosphere situation. The two following chapters then discuss the ecology of some of them.

THE METHODS EMPLOYED

Radial sampling grid

Such a grid may be criticised for the fact that it involves differential sampling. The arguments against this point have been mentioned at various stages in the previous text, and they are now drawn together.

As the piosphere situation has a natural radial bias (sheep having to converge on a water-point and then disperse radially) a radial grid was deliberately selected as being the best to bring out a piosphere effect on the vegetation; clearly one does not choose a sampling grid which is likely to suppress the pattern sought. It could be said that the use of such a grid would impose bias by increasing the proximity of the quadrats close to the focus.

The most serious way in which this bias might operate is that species occurring close to the water-point register their presence (or absence) in a larger number of quadrats than they might in an even grid. This means that when subjected to influence analysis, interactions between species will achieve a greater degree of significance than they would otherwise. However, the analyses used in this study were not prejudiced by this form of sampling, as the radial grid does not generate "pattern" where it does not exist. Indeed, the crowding of quadrats into close proximity with each other was necessary to pick out the details of the gradations of change occurring.

The radial grid is obviously not the best to use for identifying background pattern, but it succeeded in doing so adequately for distinguishing piosphere patterns from others in a paddock.

Incidence data and influence analysis

Incidence data collected in this investigation have been one of the main sources of information. The use of influence analysis for handling these data has a number of good features, but some weak ones too.

To its credit, the technique is a relatively straightforward one to operate. The outcome can be mapped, and although mapping can be a lengthy and tedious procedure, the result is suitable for correlation with physiographic and other features.

However, the dictionary order coding for quadrats and the delimitation of similarly classified quadrats by isopleths (isotels) may be open to criticism. The constituents of the two poles are always known. For example *Kochia pyramidata* and *Bassia patenticuspis* may be at one pole, with *K. sedifolia* and *B. sclerolaenoides* at the other. However the constituents of the various intergrades between these two extremes are numerous and indistinguishable in the mapping scheme employed here. As to whether *K. pyramidata* with *K. sedifolia* or *B. sclerolaenoides* is causing a certain influence rating can only be distinguished by reference to further maps depicting the incidence of these species. This may lead to difficulties in interpretation.

Isotels with their respective shading types must, therefore, only be taken as guides to focus the readers attention on certain general areas where quadrats are similarly classified. This is not to say that the areas between the quadrats would necessarily have the same species composition, although the chances of them being so classified would be reasonably high.

Irrespective of these criticisms, the technique has yielded the results sought. As specifically required of it, the technique has identified both the plants affected by piosphere conditions, and the plants depicting topographic pattern. These different influences must be recognised and distinguished before comments regarding the effects of stocking can be made. The technique has enabled this to be done with ease. The strategy has also identified some populations of moderate frequencies which do not appear to have been affected much by any influence; that is, they are inactive or insensitive species.

Density data and proportional circles

Although density data were collected for all species, they were only suitable for effective ecological interpretation in respect of perennial populations. Non-perennials such as *Atriplex eardleyae*, *A. spongiosa* and *Bassia* sps., which capitalise on favourable growing conditions, are less likely to show any meaningful trends in density, as their populations are transient, both in time and space.

Densities of the principal perennials in the areas studied have, however, yielded much information additional to that gained from the incidence data. Here again criticisms may be levelled at the technique: Apart from the Weary data, densities were not subjected to statistical analyses, but were presented in map form as proportional circles, from which they could be visually correlated with topography and edaphic features. In such maps perception of population size is dependent on the eye of the observer, and obviously a bias is imposed by the radial grid, populations appearing to get more numerous and larger as the grid converges. However, even in the innermost parts of the sampled area, where circles touch or overlap, this bias is considered to be unimportant, provided the observer is aware of the discrepancies which might occur from injudicious interpretation of such maps.

In complicated situations such as those studied, much more can be gained from mapped results than from statictical tests, as such situations are beyond the useful application of simple statistical techniques.

THE VEGETATION POPULATIONS SAMPLED

In Chapters IX, X and XI each section describing the results of the individual piosphere analyses began with a brief general description of the populations sampled. Of the nine separate sampled areas only Ki Ki and the corners of Barber's and Two-Mile Paddocks near the Winter Trough showed any degree of homogeneity. The remainder showed irregular distributions with species either very clumped or very scattered, their behaviour often varying from one sample area to the next, as can be seen from Table 59. Heterogeneity is a sign that some influences are operating on the vegetation and as shown in the previous chapters these may be topography, soil type or stock activity.

Where the effect of stock activity is being investigated, it is evident that as stock range widely in search of fodder the chances of finding a study area which is large enough, yet homogeneous in terms of topography and soil, and hence vegetation, are fairly remote. One of the criteria used for selecting the first three areas (Weary, Ki Ki and Barrett's) was their apparent homogeneity. This criterion was less important in the selection of the Two-Mile - Winter Flat area, because in spite of the care taken, it was found that Barrett's was heterogeneous away from the water-point. Nevertheless obvious variations in the Two-Mile - Winter Flat area were avoided as far as possible, for there is no point in introducing conspicuous heterogeneity when searching for subtle pattern.

It must continually be borne in mind that there are major differences in the general vegetation associations of Quondong Station and Roopena Station (which includes the Barrett's and Two-Mile - Winter Flat area). Quondong possesses very calcareous soils associated with an old dune system, which, in general, supports dense black oak, *Kochia sedifolia*, *K. excavata*, *Atriplex acutibracta* and *Bassia diacantha*. There is little *A. vesicaria* and *K.*

TABLE 59

COMPARISON OF THE AVERAGE DENSITIES PER SQUARE CHAIN OF THE SPECIES SAMPLED IN THE PIOSPHERES STUDIED

	SPECIES	WEARY	KI KI	BARRETT'S	TWO-MILE	BARBER'S (T-M Pdk.)	BARBER'S (B's Pdk.)	WINTER	KIRRANI
	Bassia divaricata	0.4	-	-	-	-	-	-	-
	Cratystylis conocephala	7.7	-	-	-	-	-	-	-
	Grevillea huegelii	0.66	-	-	-	-	-	-	-
	Templetonia egena	0.88	-	-	-	-	-	-	-
	Zygophyllum aurantiacum	6.8	-	-	-	-	-	-	-
	Acacia colletioides	2.0	3.0	-	-	-	-	-	-
	Cassia nemophila var. *nemophila*	8.5	2.4	-	-	-	-	-	-
A	*Cassia nemophila* var. *platypoda*	-	0.7	-	-	-	-	-	-
	Cassia nemophila var. *zygophylla*	0.4	0.7	-	-	-	-	-	-
	Dodonaea attenuata	-	0.3	-	-	-	-	-	-
	Eremophila glabra	0.2	0.2	-	-	-	-	-	-
	Eremophila sturtii	-	1.2	-	-	-	-	-	-
	Olearia muelleri	8.1	0.5	-	-	-	-	-	-
	Rhagodia spinescens var. *spinescens*	2.4	1.4	-	-	-	-	-	-
	Scaevola spinescens	1.3	1.2	-	-	-	-	-	-
	Sida corrugata	-	0.3	-	-	-	-	-	-
	Acacia oswaldii	0.2	-	-	-	-	0.05	-	-
	Babbagia acroptera	0.44	-	7.4	-	-	-	-	-
	Bassia paradoxa	19.1	-	13.8	0.1	2.2	-	-	-
	Bassia brachyptera	2.42	-	0.4	-	-	-	-	-
	Eremophila scoparia	4.4	-	-	-	-	-	-	0.3
	Exocarpos aphyllus	0.4	-	0.2	-	0.06	-	-	-
	Kochia triptera	9.2	-	-	-	0.4	-	-	-
	Nitraria schoberi	1.1	-	0.05	-	-	-	-	-
	Myoporum platycarpum	0.88	-	0.05	0.05	-	0.05	0.1	-
	Ptilotus obovatus	0.66	-	-	0.05	-	0.05	-	-
	Salsola kali	0.2	-	0.7	-	0.2	-	-	-
	Zygophyllum iodocarpum	0.66	-	1.0	-	-	-	-	-
	Atriplex stipitata	2.0	0.3	-	0.7	9.1	1.6	16.1	-
	Bassia diacantha	120.0	600.2	4.6	0.1	-	2.8	0.1	-
	Bassia obliquicuspis	0.87	195.9	89.4	344.0	406.2	285.9	273.8	80.8
B	*Bassia sclerolaenoides*	3.1	157.0	100.8	52.9	43.5	29.6	28.0	1.1
	Cassia nemophila var. *coriacea*	5.7	4.9	0.3	-	0.2	0.1	-	-
	Casuarina cristata	16.5	2.4	2.2	-	-	0.4	0.3	1.4
	Enchylaena tomentosa	18.9	19.0	64.8	6.9	20.3	13.5	15.7	13.6
	Kochia excavata var. *trichoptera*	643.0	1692.5	1.5	3.8	12.3	3.1	0.9	-
	Kochia georgei	7.7	8.5	46.0	34.5	37.2	23.9	46.5	35.3
	Kochia sedifolia	175.8	86.8	92.9	54.3	104.5	66.2	38.9	42.9
	Lycium australe	2.9	-	3.3	3.3	3.1	3.6	0.1	-
	Rhagodia spinescens var. *deltophylla*	2.6	17.6	7.7	2.2	9.1	4.7	3.8	3.3
	Atriplex acutibracta	-	36.8	-	0.4	2.8	-	0.2	-
	Atriplex vesicaria	-	14.9	238.9	8.1	145.6	76.8	305.1	380.1
	Bassia patenticuspis	-	26.5	17.8	453.3	195.2	47.1	27.7	0.1
	Chenopodium desertorum	-	0.2	11.6	6.2	14.7	5.8	5.5	5.6
	Chenopodium ulicinum	-	2.1	2.4	4.2	8.1	4.1	-	-
	Heterodendrum oleaefolium	-	0.2	0.7	0.05	0.2	0.2	1.0	0.7
	Kochia pyramidata	-	0.3	59.6	231.1	64.4	33.8	31.1	41.6
	Acacia sowdenii	-	-	0.2	0.05	0.5	0.2	0.1	0.4
	Atriplex eardleyae	-	-	5.0	6.0	-	-	-	-
	Atriplex spongiosa	-	-	19.4	10.0	0.06	-	4.8	-
	Bassia biflora	-	-	9.1	0.4	0.5	0.7	-	0.5
	Bassia lanicuspis	-	-	0.2	-	-	-	-	-
	Frankenia pauciflora	-	-	4.1	-	-	0.7	-	0.9
	Kochia astrotricha	-	-	4.1	0.05	-	-	-	-
	Kochia brevifolia	-	-	31.1	3.6	2.6	15.1	1.3	3.2
	Kochia tomentosa	-	-	0.05	12.0	0.3	0.05	-	-
	Marrubium vulgare	-	-	0.1	14.5	4.0	142.2	-	-
	Malacocera tricornis	-	-	0.7	-	-	-	-	-
	Santalum acuminatum	-	-	0.05	-	-	0.05	-	-
C	*Sida intricata*	-	-	0.6	0.9	-	-	-	-
	Zygophyllum compressum	-	-	0.8	-	-	-	-	-
	Carthamus lanatus	-	-	-	6.2	0.1	0.05	-	-
	Centipeda thespidioides	-	-	-	5.1	-	-	-	-
	Inula graveolens	-	-	-	4.9	0.3	3.9	-	-
	Marsilea drummondii	-	-	-	10.9	-	-	-	-
	Solanum sp.	-	-	-	2.5	-	-	-	-
	Verbena officinalis	-	-	-	1.8	-	-	-	-
	Vittadinia triloba	-	-	-	2.6	0.6	-	-	-
	Chenopodium murale	-	-	-	-	0.2	-	-	-
	Blennodia trisecta	-	-	-	-	-	-	0.1	-
	Eremophila oppositifolia	-	-	-	-	-	-	0.1	-

A - species only found in Quondong study areas
B - species found in both Quondong and Roopena study areas
C - species only found in Roopena study areas

pyramidata. Roopena has an open myall woodland with *K. sedifolia*, *A. vesicaria* and *K. pyramidata*; the Quondong species do, however, occur in localised areas where it is believed that much limestone is present or is near the soil surface.

The details of the range of species found in the various sampled areas are shown in Table 59, from which comparisons can be made. Some species are common to both areas, but their relative importance in each area can only be judged by reference to the figures; for example those of *K. sedifolia*, *K. pyramidata*, *A. vesicaria*, *A. acutibracta*, *K. excavata*, *B. diacantha*, *B. sclerolaenoides*, *Chenopodium ulicinum*. Others occur only on Quondong, for example, *Olearia muelleri*, *Cratystylis conocephala*, *Acacia colletioides*, *Eremophila sturtii*, *Grevillea huegelii*. Some are found only at Roopena e.g. *Bassia biflora*, *Frankenia pauciflora*, *Marrubium vulgare*, *Acacia sowdenii*, *Malacocera tricornis*. However, these are minor constituents of the total flora and although *O. muelleri*, *C. conocephala*, *B. biflora*, *M. tricornis* appear to be highly palatable to sheep, they are not major fodder plants.

Within these two principal areas there are also variations. At Quondong, Weary Paddock has overall a richer flora than Ki Ki, but each area has some species the other lacks. On Roopena, Barrett's, Two-Mile and Barber's Paddocks have the richest floras, Winter and Kirrani being poor in comparison. Undoubtedly some of the diversity in the floristically richer areas is brought about by species invading the water-point area, but it does not entirely account for the paucity of the Winter and Kirrani floras; the gneissic outcrop and Nonowie fault must exert an edaphic influence here.

THE EFFECTS OF STOCK ON PLANT POPULATIONS

A number of groups of associated species have been identified from the incidence data, by means of influence analysis. In general terms, species of a general vegetation association e.g. *K. sedifolia, A. vesicaria, B. sclerolaenoides, B. obliquicuspis, K. excavata, C. ulicinum* have formed groups of positive associates which dissociate with a further group of positive associates, found near water-points or in watercourses. It was thus relatively straightforward to pick out the species implicated in the piosphere effect by their positive or negative correlation with water-points. Such methods also picked out some species which were unrelated to any pattern, whether natural or induced by stock.

Density data reiterated the results of influence analysis, but also provided much additional information about the way plant populations were being affected by environment or stock.

Species which were found to be correlated positively with the water-points and the more important negative correlates are listed in Table 60. The behaviour of these species will be discussed separately.

One of the more consistent negative correlates is *Kochia sedifolia* which is absent near Weary Dam, in Two-Mile Dam watercourse, at Winter Trough and Kirrani Trough; it has relatively small populations in the watercourse near Barber's Dam. This is almost certainly due to topography and soil as heavy stocking in Barrett's does not appear to have diminished the population there. This is also thought to be the case for *Bassia obliquicuspis*. The absence of *Cratystylis conocephala* and *Bassia diacantha* near Weary Dam is also attributed to topographic effects.

Atriplex vesicaria on the other hand has certainly disappeared from the vicinity of Barrett's Trough, Barber's Dam and along the Barber's/Two-Mile Paddock fence as a result of stocking. The bush is palatable to sheep and has brittle stems which are easily broken by trampling; if completely defoliated it is unable to regrow. These observations confirm those of other workers, and such a change in population structure must be regarded with some concern as it is a deleterious one; both fodder and ground cover are being lost.

The positive correlates, that is, the invaders, are more numerous. Some of the twelve listed for Two-Mile Dam can be disregarded as they are thought to have been there originally, e.g. *Verbena officinalis, Marsilea drummondii, Centipeda thespidioides*

TABLE 60

SPECIES INVOLVED IN THE PIOSPHERE EFFECT AT THE EIGHT WATER-POINTS SAMPLED							
WEARY	KI KI	BARRETT'S	TWO-MILE	BARBER'S (Two-Mile Pdk.)	BARBER'S (Barber's Pdk.)	WINTER	KIRRANI
Negative correlates							
Kochia sedifolia	-----	-----	*Kochia sedifolia*	-----	-----	*Kochia sedifolia*	*Kochia sedifolia*
-----	-----	-----	*Bassia obliquicuspis*	*Bassia obliquicuspis*	-----	-----	*Bassia obliquicuspis*
Bassia diacantha	-----	-----	-----	-----	-----	-----	-----
-----	-----	-----	-----	*Atriplex vesicaria*	*Atriplex vesicaria*	-----	-----
Cratystylis conocephala	-----	-----	-----	-----	-----	-----	-----
Positive correlates							
Bassia paradoxa	-----	*Bassia paradoxa*	(*Bassia paradoxa*)	*Bassia paradoxa*	-----	-----	-----
-----	-----	*Bassia patenticuspis*	*Bassia patenticuspis*	*Bassia patenticuspis*	*Bassia patenticuspis*	-----	-----
(*Kochia brevifolia*)	-----	*Kochia brevifolia*	*Kochia brevifolia*	*Kochia brevifolia*	*Kochia brevifolia*	(*Kochia brevifolia*)	*Kochia brevifolia*
Kochia triptera	-----	-----	-----	(*Kochia triptera*)	-----	-----	-----
-----	-----	*Kochia pyramidata*	*Kochia pyramidata*	*Kochia pyramidata*	*Kochia pyramidata*	*Kochia pyramidata*	*Kochia pyramidata*
Kochia georgei	-----	*Kochia georgei*	-----	-----	*Kochia georgei*	-----	-----
Atriplex stipitata	-----	-----	-----	(*Atriplex stipitata*)	-----	*Atriplex stipitata*	-----
-----	-----	*Atriplex spongiosa*	(*Atriplex spongiosa*)	(*Atriplex spongiosa*)	-----	*Atriplex spongiosa*	-----
-----	-----	*Atriplex eardleyae*	*Atriplex eardleyae*	-----	-----	-----	-----
Enchylaena tomentosa	-----	-----	*Enchylaena tomentosa*	*Enchylaena tomentosa*	*Enchylaena tomentosa*	-----	-----
Rhagodia spinescens incl. var. *deltophylla*	-----	-----	*Rhagodia spinescens*	-----	-----	-----	-----
-----	-----	(*Marrubium vulgare*)	*Marrubium vulgare*	*Marrubium vulgare*	*Marrubium vulgare*	-----	-----
-----	-----	-----	*Inula graveolens*	(*Inula graveolens*)	(*Inula graveolens*)	-----	-----
-----	-----	-----	*Carthamus lanatus*	(*Carthamus lanatus*)	(*Carthamus lanatus*)	-----	-----
-----	-----	-----	*Verbena officinalis*	-----	-----	-----	-----
-----	-----	-----	*Marsilea drummondii*	-----	-----	-----	-----
-----	-----	-----	*Centipeda thespidioides*	-----	-----	-----	-----
-----	-----	-----	*Sida intricata*	-----	-----	-----	-----

Species in brackets are those with observed small populations in the inner piosphere or those with increased densities in the inner piosphere, but not involved in influence analysis nodes and possibly also, *Sida intricata*.

Of those remaining *Kochia brevifolia* is the most consistent. Although not recorded at Weary, later inspection showed that the species is definitely present within the unsampled first 200 yards. Apart from Ki Ki, therefore, this species was present in every piosphere. It does, however, have a fairly restricted radial distribution and has been observed only twice away from the water-point and then under trees. Although it is a perennial and has a suckering rootstock its capacity for spreading into other parts of the paddock will be determined by the facts that it is grazed by sheep and therefore may be at a competitive disadvantage, and that it appears to have poor drought tolerance, often being completely defoliated after a dry period. It is not, therefore, regarded as sufficiently aggressive to cause concern, though its presence is taken to denote degradation.

Kochia pyramidata is also a perennial invader of the inner piosphere area, though it is found elsewhere in paddocks and seems to reach its maximum development in watercourses. Although it does not sucker, it is a free seeding species and appears to behave aggressively in the piosphere situations described. This behaviour is clearly related to stock activity, as is shown by its behaviour in the Winter Trough corner of Barber's Paddock, where sheep "hang". In Barrett's the plant is spreading from a small watercourse a short distance from the trough; at Two-Mile and Barber's Dams populations associated with the watercourses appear to be stimulated close to the dams, and have also spread on to the Two-Mile Plain.

Again, this is taken to be a retrograde condition; sheep do eat *Kochia pyramidata*, though it appears to be less highly regarded as a fodder plant in South Australia than in New South Wales.

Marrubium vulgare is an alien weed, which although a perennial is dormant during dry periods in the arid zone. It is a free seeding species, with a persistent rootstock; it grows rapidly when provided with moisture to give a plant with a coarse bushy habit. It is able to crowd out other species, especially young plants. The effects of this at Barber's Dam can be seen from Plate 18. The burry fruits are a wool contaminant and seeds are spread to other parts of the paddock as in Two-Mile Paddock. It has no fodder value.

Marrubium is obviously a very important and undesirable invader of the inner piosphere, and there seems no reason why it cannot persist and continue to colonise other regions. It obviously favours sites which have been disturbed by the digging of drains.

Atriplex stipitata was identified as a piosphere species at Weary Dam and in Winter Paddock. As it is an invader its unpalatability to stock means that its likely to persist. However, like *K. pyramidata* it is not confined to the inner piosphere area but occurs also in the north-east corner of Weary Paddock, in Ki Ki and on Winter Flat. It is a perennial but does not seem to be an aggressive one. *Kochia triptera* behaves similarly at Weary and with *A. stipitata* would provide ground cover for areas denuded of palatable vegetation.

Kochia georgei, a piosphere plant at Weary, is relatively weakly correlated with the water-point at Barrett's, Two-Mile and Barber's, but negatively so at Winter and Kirrani. Although a constituent of these influence analysis nodes, the species was usually rejected for coding and mapping on account of its discontinuous distribution. Map 24, Node 1a at Barber's Dam in Barber's Paddock shows that it tends to follow the watercourse, which would account for its presence near dams. It is generally regarded as a palatable species, which implies that its persistence near a water-point is anomalous behaviour.

The remaining perennial species for discussion are *Enchylaena tomentosa* and *Rhagodia spinescens*, which are also found away from the water-point, but generally in the shelter of trees or larger shrubs. Either or both of these species are correlated with the water-point at Weary, Two-Mile and Barber's from which observation it could be inferred that these species are unpalatable. However, it has been suggested by Leigh and Mulham (1965) that these species are palatable, *R. spinescens* having been grazed out of many areas of the Riverina, and *Enchylaena* being present only in lightly grazed areas. Clearly unpalatability must not be taken as an absolute criterion for survival of species near a water-point. Palatability has to be regarded as a relative term, fodder preferences of stock being determined by the choice available.

The rest of the species in Table 60 are all non-perennial. *Inula graveolens* and *Carthamus lanatus* are alien weeds, which occur infrequently at Two-Mile and Barber's Dams and are probably very dependent on the modified environment there for their survival, so are unlikely to spread away from these areas. Some or all of the remainder, *Bassia paradoxa*, *B. patenticuspis*, *Atriplex spongiosa* and *A. eardleyae* are found at the water-points in all the piospheres except Ki Ki. *A. eardleyae* appears to favour local water catches, which would account for its presence at Two-Mile, but not for its presence at Barrett's Trough where there is no catchment. *Bassia paradoxa* and *A. spongiosa* also occur close to water, although in Barrett's *B. paradoxa* would appear to be spreading away from this point.

Bassia patenticuspis is also found away from water-points, as in Ki Ki Paddock, on Two-Mile Plain and Winter Flat but in Barrett's it is associated with the water-point only and must have been brought into this region. It is possible too that the species was not as widespread on Two-Mile Plain as it is now.

Of all the principal shrub components listed in Table 59 only one with consistent frequency did not show pattern. This was *Chenopodium desertorum* which from its eaten appearance and its high incidence in the unfrequented corner of Two-Mile Paddock at Winter Trough must be grazed. It is possible that like *Kochia georgei*, the shifts are as yet relatively slight, and may not be discernible. It is also possible that it displays a pattern unlike that of any other species, and thus would not have any positive associates.

Finally, the reader must be reminded of the behaviour of *K. excavata* at Quondong. This has been discussed in detail in Chapter X, and the investigations at Roopena did not throw any further light on the phenomenon. The behaviour of *K. excavata* at Roopena merely indicated that it occupied special sites in the general vegetation association, its populations being too small to demonstrate any other pattern.

DISCUSSION

The techniques used have shown that within the very variable plant populations described, only one species (*A. vesicaria*) is disappearing close to water-points directly as a result of sheep stocking. Two (*K. pyramidata* and *B. patenticuspis*) and possibly six (with *E. tomentosa*, *R. spinescens*, *K. triptera* and *A. stipitata*) are spreading from other parts of the paddock into the water-point area, where their populations seem to be stimulated. Seven (*B. paradoxa*, *A. spongiosa*, *A. eardleyae*, *K. brevifolia*, *C. lanatus*, *I. graveolens* and *M. vulgare*) are invading from outside the paddock area. Obviously the species involved in identifying the water-point in the individual piosphere will depend to some extent on the vegetation association in which the piosphere is situated, as this will determine what populations are there to be stimulated or destroyed by stock pressure close to a water-point. The appearance of species from outside the paddock area results from the modification of the environment by stock and possible reasons for this invasion will be examined in Chapter XIV.

As detailed in the previous paragraphs some of the plants involved are non-perennials. These register the change in environment due to the piosphere very readily as they can complete a life cycle rapidly. This permits them to have several population changes in a short period of time, and they can act as early indicators of the changing environment. The particular species noted in these investigations were not especially aggressive, and are therefore relatively unimportant in terms of degradation; they do provide some cover, if only temporary, for friable soil. However, other non-perennials invading other types of vegetation association may not be so benign.

The perennial species are slower to react to the environmental modification, but they may depict irreparable changes occurring over a long period of time. Consequently reactions which occur in perennial populations must be regarded with concern. Such changes which have been noted in these investigations could be regarded as relatively slight. The only perennial shrub which has definitely been shown to be disappearing is *Atriplex vesicaria*. The spread of *K. pyramidata* into water-point areas is retrograde but the species provides both ground cover and fodder. It could be said that at Roopena *A. vesicaria* is being replaced by *K. pyramidata*; in terms of overall denudation the effect of stock is thus negligible. However, when an aggressive crowding plant like *Marrubium* occupies niches previously occupied by native fodder shrubs, then there must be some concern.

From the Barrett's Paddock data, *K. sedifolia* does not appear to be as aggressive as *K. pyramidata*, consequently stocking will prevent its regeneration. Where other perennial plants (e.g. *K. pyramidata, K. triptera, A. stipitata*) are not there to take its place, denudation will result.

CHAPTER XIII

COMMENSAL RELATIONSHIPS BETWEEN SPECIES

INTRODUCTION

During the course of these investigations the positive association between *Enchylaena tomentosa* and *Rhagodia spinescens* var. *deltophylla* has been commented upon. From influence analysis data, the relationship was observed in Ki Ki Paddock and in the Two-Mile - Winter Flat area. Examination of the field situation revealed that this was due to their occurrence very often (but not always) together under trees and large bushes. This phenomenon has been noted by others; P. Latz (pers. comm.) says "I have seen *Enchylaena tomentosa* in a variety of habitats all over the Centre (including the western desert) but always in the shade of a tree in its litter zone. *Rhagodia spinescens* is often in association with it (perhaps not as widespread)." Leigh and Mulham (1965) state that *R. spinescens* ".... is now mainly along fence lines, near telephone posts, and under trees. This appears to be the consequence of the distribution of the sticky fruits by birds."

The nature of such possible relationships was tested in the following way.

METHOD

The three principal tree species at Roopena were selected for study, and sampling was based on 180 trees of *Acacia sowdenii*, 105 trees of *Heterodendrum oleaefolium* and 75 trees of *Casuarina cristata*. Within a stand of any of these trees the presence or absence of the following species was noted under individual canopies; *Enchylaena tomentosa*, *Rhagodia spinescens* var. *deltophylla*, *Kochia sedifolia*, *Atriplex vesicaria*, *Chenopodium desertorum*, *Kochia georgei*, *K. pyramidata*, *K. brevifolia* and *Chenopodium ulicinum*. Between one tree and the next a random area equivalent to that covered by a tree canopy was similarly sampled. Data concerning shrubs which grew under trees and not in the open were thus accumulated.

The above procedure was repeated in the Two-Mile and Barber's watercourses, where populations of *E. tomentosa* and *R. spinescens* were noticed to be particularly consistent. Here no distinction was made between tree species as the trees did not grow in specific stands. The 40 trees sampled in the watercourses included *Acacia burkittii*, *A. sowdenii*, *A. oswaldii*, *Heterodendrum oleaefolium*, *Myoporum platycarpum* and *Exocarpos aphyllus*.

The four sets of data (for the 3 non-watercourse populations of *A. sowdenii*, *Heterodendrum* and *Casuarina* and for the watercourse samples) were subjected to homogeneity tests, which take a form equivalent to the 2 × 2 contingency test, calculating χ^2. To make the 4 sets of data strictly comparable, N for the large sets of data (the non-watercourse populations) was reduced to the size of the watercourse data, which had the smallest value of N (= 80). The results of the test are shown in Table 61.

RESULTS AND DISCUSSION

The significance levels show that the relationship between trees and the two species, *Enchylaena tomentosa* and *Rhagodia spinescens* var. *deltophylla*, is a real one. Particularly high significance is displayed by *Enchylaena* on account of its very common occurrence, *Rhagodia* was more often absent in the samples. The large canopies of myall (approx. diameter 25 feet) produce results for *Enchylaena* which are more significant than the smaller canopies of black oak (15 feet) and bullock bush (10 feet).

In the watercourses, however, the effect of trees on the distribution of the two species is apparently reduced. *Rhagodia* is not significantly dependent on trees, although *Enchylaena* is, but with a much lower χ^2 value than it has out of the watercourses.

Leigh and Mulham (1965) suggest that such distributions result from birds spreading seed; Latz, by mentioning "litter zone" implies that litter may have something to do with the phenomenon.

TABLE 61

RESULTS OF HOMOGENEITY TESTS FOR TREE AND SHRUB ASSOCIATION showing χ^2 values and probabilities				
	Casuarina cristata	*Acacia sowdenii*	*Heterodendrum oleaefolium*	Watercourses
Enchylaena tomentosa	50.59 $p \ll 0.1\%$	64.79 $p \ll 0.1\%$	51.34 $p \ll 0.1\%$	19.12 $p < 0.1\%$
Rhagodia spinescens	43.45 $p \ll 0.1\%$	40.57 $p \ll 0.1\%$	29.61 $p \ll 0.1\%$	0.89 NS
Kochia sedifolia	0.0 NS	0.14 NS	0.31 NS	0.21 NS
Atriplex vesicaria	0.03 NS	0.01 NS	0.51 NS	5.08 $1\% < p < 5\%$
Chenopodium desertorum	0.0 NS	0.66 NS	1.72 NS	0.0 NS
Kochia georgei	3.03 NS	7.14 $0.1\% < p < 1\%$	1.35 NS	5.25 $1\% < p < 5\%$
Kochia pyramidata	0.39 NS	1.09 NS	0.58 NS	4.78 $1\% < p < 5\%$
Kochia brevifolia	0.0 NS	0.10 NS	-	0.0 NS
Chenopodium ulicinum	-	0.89 NS	-	-

An additional reason can now be put forward. On account of the lower dependence of these species on trees when they occur in watercourses, it is suggested that elsewhere they grow under trees for the additional moisture which is gained from increased rainwater run-off. Specht (1957) has shown what effect this has in the sclerophyll vegetation of Dark Island Heath, South Australia. Slatyer (1961, 1965) points out that the stem flow in mulga can amount to 40% of total rainfall received on a horizontal projection of a tree canopy. A rainfall of 15-20 mm (about 75 points) contributes 100 litres (about 20 gallons) to the soil water storage adjacent to the bole.

The tree canopy of *A. sowdenii* would reduce considerably the incidence of direct insolation, thus reducing evapotranspiration of communities under the tree; litter would also reduce evaporation from the soil. *Enchylaena* and *Rhagodia* are not believed to be shade plants, as they occur in the open in watercourses, and also because little shade is thrown by canopies of black oak and bullock bush.

Nutrient cycling may be more rapid under trees than elsewhere (see Rixon, 1970), but this is not known to be so in watercourses.

CONCLUSIONS

It has been shown that the dependence of *Rhagodia* and *Enchylaena* on trees is a real phenomenon. It is further suggested that this is because of improved water relations under tree canopies rather than for shade or additional nutrients. Water inputs into the soil would also be improved under shrubs, like *Cassia* and *Lycium*, relationships which have been picked out by influence analysis.

If the requirement for extra water is a reality, and there are no other factors involved, the behaviour of these species in the arid zone may have interesting biogeographical implications. Perhaps they were formerly dispersed throughout the community under a less stringent climate.

CHAPTER XIV

GENERAL ECOLOGY OF SOME PIOSPHERE PLANTS

The behaviour of some of the invading species of the piosphere is inexplicable in terms of the observations made in the preceding chapters. Not all the species are confined to the arid areas, so an attempt is made here to describe aspects of their general ecology to seek some possible reasons for their occurrence in piospheres. Apart from the author's own observations, information is derived from a number of literature sources and from the herbaria of Western Australia, Queensland, Northern Territory, South Australia and C.S.I.R.O. Division of Plant Industry.

The species selected for description are:-

Bassia paradoxa	*Atriplex stipitata*
Bassia patenticuspis	*Kochia brevifolia*
Atriplex eardleyae	*Kochia pyramidata*
Atriplex spongiosa	*Marrubium vulgare*

and their distributions are shown in Maps 40 and 41. It is notable that there is little information in the literature or herbarium material regarding plant habitats.

Bassia paradoxa

This non-perennial species is strictly a plant of the arid zone apart from one occurrence near Port Wakefield (S.A.) (see Map

40). Information consistently found on herbarium sheets suggests that it grows predominantly in sand or gravelly loam, particularly where soil moisture is likely to be relatively high; for example at the base of sandhills (in the Simpson Desert), sandy creek banks, gibber plains and on the fringes of swamps. Leigh and Mulham (1965) state that the plant is not widely distributed in the Riverina and this is presumably because of the clay soils there.

Jessup (1951) points out that where overgrazing has occurred this species increases; he gives instances of its colonisation of sand mounds where scalding has taken place. *B. paradoxa* was found to be common on the previously heavily stocked northern half of Quondong Station.

Bassia patenticuspis

This species is also a non-perennial, again confined to the arid zone south of 23°S, except for one more northerly location in the Northern Territory; it also appears to be a species of sandy soils, where run-on water is likely to be available in creek beds and flood outs.

Jessup (1948) suggests that high frequency of *B. patenticuspis* is the single best indicator of excessive stocking.

Atriplex eardleyae

A. eardleyae has the synonym *A. campanulata* and omission of material under this name probably accounts for the sparseness of the data shown on the distribution map. The herbarium material grew on a range of soil types from sandy loam to clay, but usually in areas subjected to flooding from time to time.

Atriplex spongiosa

Jessup (1948) regards this annual species as specific to watercourses. Habitats noted by herbarium collectors are predominantly sandy ones, although stony flats and claypans are occasionally mentioned. Leigh and Mulham (1965), however, say that in the Riverina it is found "mainly on the clay soils of the saltbush plains, but it occurs less frequently on loam and sandy soils". Jessup (1951) reports that *A. spongiosa* increases under heavy stocking.

Atriplex stipitata

This species of *Atriplex* appears to have a very restricted distribution in the arid zone, confined to the region south of 28°S. Jessup (1948) reports that *A. stipitata* is rare where rainfall is less than 8" per annum. Hall, Specht and Eardley (1964) say that Koonamore in the north-east of the State represents the drier end of the distribution of *A. stipitata*. These authors have correlated distribution with climatic factors. They say that the mean monthly temperature range for *A. stipitata* is 59°-60°F which they think is relatively low, and the P/SD index is 1.7, relatively high compared with other species at Koonamore.

Information on herbarium sheets indicates that it grows in sandy or gravelly areas. Wood (1937), who calls this the "mallee saltbush", says it is a plant of the drier parts of the semi-arid mallee, and that compared with *A. vesicaria* it is found on sandier soils "with better water relations".

Beadle (1948), referring to plants of the mallee near and to the west of the Murrumbidgee, says that "*A. stipitatum*" is moderately palatable. Others (Wood, 1937 and Jessup, 1948) regard it as unpalatable and practically useless as a fodder.

Kochia brevifolia

This also has a southerly distribution (Map 41) apart from two doubtful records in Northern Territory and Queensland. It also occurs in coastal high rainfall localities in South Australia and Western Australia.

It has no preference for soil types, but in arid areas grows where it receives run-off water, in creek beds, swamps and along roads. Murray (1931) records it colonising claypans on the Lake Torrens Plateau.

Jessup (1948), referring to the north-east of South Australia, says that although *K. brevifolia* is not confined to watercourses, it shows its maximum development there. Beadle (1948) appears to regard *K. brevifolia* as an important pasture species, "the heavy grazing of the bluebushes leads to their complete removal, the order of disappearance being *K. sedifolia, K. brevifolia, K. planifolia, K. pyramidata*". As the author has never observed *K. brevifolia* forming anything other than a small local community it is possible that the species has been confused by Beadle with *K. tomentosa*.

Kochia pyramidata

K. pyramidata is again a widespread plant of the arid zone but confined to South of 26°30'; like *K. brevifolia* and *A. stipitata* the east and west localities appear to be clearly disjunct. Herbarium sheets indicate that it grows on a range of soil types from sand → sandy loam → clay loam.

Jessup (1948) says the plant (like *K. brevifolia*) although not confined to watercourses reaches its maximum development here; it is a free seeding species and is regarded by him as a plant of no value, except in drought.

Beadle (1948) uses it as an indicator of alkaline soils of light texture (with *Acacia loderi, Kochia planifolia* and *K. sedifolia*) but says that *K. pyramidata* is found on deep sandy soils in which the limestone lies at a depth of 4 feet or more below the surface, whereas *K. sedifolia* occurs where limestone is 1-2 feet below the soil surface. On scalded areas where there is drift sand recolonisation occurs as the rate of absorption of water by sand is high, and young *K. pyramidata* is frequently present in these situations. Beadle regards communities of *Kochia* spp. on sand as undoubtedly seral.

Marrubium vulgare

This perennial is native to Southern Europe, Asia and Africa, and is a declared noxious weed in South Australia. Its distribution (Map 41) shows a wide climatic range.

It grows in sandy habitats as reported on herbarium sheets and by Leigh and Mulham (1965). Beadle (1948) states that it may assume complete dominance in grazed *Eucalyptus woollsiana* communities in the eastern Riverina (near Wyalong). Jessup (1948) notes that the weed is found principally in watercourses in north-eastern South Australia, though it is relatively unimportant here.

It is possible that *Marrubium* behaves as a non-perennial in more arid areas, but as the plant is unpalatable it fruits readily, the fruits being spread in the fleeces of sheep.

DISCUSSION

The evidence presented in the preceding paragraphs tie in with the author's own observations. The factors which seem to be common to the habitats of all the species described is the presence of sand and the possibility of receiving run-on water. Both these conditions would be satisfied in watercourses, and this is indeed where much of the herbarium material from the most arid areas was found. Thus, *Bassia paradoxa, B. patenticuspis, Atriplex eardleyae, A. sponsiosa, Kochia pyramidata* are all regarded as plants of natural watercourses, washes or creeks in the arid zone. *A. stipitata*, apparently a plant of sandy semi-arid mallee is probably dependent on the watercourse or wash habitat for its existence in truly arid areas. *Kochia brevifolia* and *Marrubium vulgare*, also found in the humid zones of Australia, are probably similarly dependent on sandy watercourses for their existence in the arid zone.

Such considerations suggest reasons for the occurrence of all of the above species close to a water-point, apart from the obvious one that dams are generally sited in watercourses.

Wherever stock move, and especially close to water-points, the compacted subsoil becomes impenetrable to water as are the clay floors of some watercourses, the ground surface is broken and the finer soil fractions are removed by wind erosion. Larger sand particles remain, and may subsequently be transported either by wind or water. If a water-point is downslope, sand may be deposited close to it, as on the western side of Barber's Dam. However gradual the natural slope of an area, the effect of stock is to accentuate natural drainage lines; in fact, the regular use of stock pads will create new ones. Thus where stock are present, the more rapid erosion processes which originally would have been confined to watercourses are extended to other parts of paddocks. Consequently the plants associated with natural watercourses must be expected to occupy these newly created drains, where compaction encourages water to run rather than soak in, and where drift material may alternately be removed and redeposited. Such situations are found close to water-points in particular, even where a natural drain did not previously exist, for instance in Barrett's Paddock; all the species mentioned in this chapter except for *A. stipitata* are invading the piosphere area there.

Because of the changed, possibly improved, water relations of the soil in these areas, plants such as *Enchylaena* and *Rhagodia* (shown in the previous chapter to grow under trees, where they receive additional water) may also be expected to occur close to water-points. Their populations are certainly stimulated close to the dams in the watercourses at Two-Mile and Barber's, as shown by the results of influence analysis, and it is possible that part of this effect results from stocking.

The situation where plants of watercourses or washes invade disturbed areas beyond watercourses (as at Barrett's) raises interesting questions regarding succession and climax; these points are outside the present discussion, but depending on whether watercourse habitats are regarded as more mesic than "interfluve" areas or vice versa, the observed shifts represent either retrogression or advance in successional sequence.

A further factor which ought not to be overlooked is soil salinity. It could be, for instance, that high urine input close to the water-point raises salinity there, favouring *Kochia brevifolia*, which has a coastal distribution. This hypothesis has not been tested, but a preliminary check would reveal whether there is a concentric zonation of salinity round a water-point.

CHAPTER XV

FINAL DISCUSSION

INTRODUCTION

The object of this thesis was to investigate in a fairly detailed way the extent and nature of changes occurring in arid pasture, by looking at the sort of degradation which is found near a water-point in comparison with more distant parts of a paddock. The details of its outcome have been discussed in previous chapters, and its relevance to the future of the arid zone will now be discussed with reference first to some immediate ecological and pastoral considerations.

Several points which can be appreciated from the contextual Review chapters must be kept in mind. First, there is the academic one that these assessments have had to be made without any firm evidence as to the original vegetation type. Early historical records are too generalised to give other than an indication that "Salsolaceous" shrubs were present or absent, and early pasture usage can only be judged by assessing the attitude of settler and administrator towards the country. Nevertheless, from the historical background given in this thesis it is possible to infer that the two sheep stations selected for study possessed vegetation in a pristine condition, which was thus used as a point of reference for the changes identified. Second, there is the practical point that although the diverse chenopod shrub vegetation of the southern arid areas is sensitive to stock pressure, pastoralism is the only form of "agricultural" land use suitable for these areas. Also, it should be understood that in spite of the fact that the economics of the wool industry are currently in a state of flux, some sheep pastoralism will continue in the arid areas of South Australia, even if it has diminished importance.

ECOLOGICAL INTERPRETATIONS

The vegetation examined showed little obvious sign of degradation (see Plates 12-20) compared with areas which have been completely denuded. There has been no complete removal of vegetation in any of the paddocks sampled. Changes in population structure are, however, there; this is the more significant because they have occurred under conservative stocking policies.

Admittedly, in the majority of cases cited in this thesis, the severest effects of stock were restricted to 200-400 yards from a water-point. However, the alteration of soil structure in the creation of watercourse habitats, which is put forward as a reason for the spread of aggressive plants like *Kochia pyramidata* and

Marrubium vulgare, suggests that persistent stocking will continue to promote such changes.

Obviously some vegetation associations are more tolerant of heavy stocking than others. For instance, populations of *Kochia excavata* (a free-seeding non-perennial, with a possible life span of 2 years), seem to be stimulated close to a water-point. Osborn, Wood and Paltridge (1932) show that the same thing happens in saltbush populations; areas within a quarter of a mile of the water-points they sampled were denuded of shrub cover, but beyond this point *Atriplex vesicaria* growth was stimulated. On the basis of these observations, they advocate intermittent heavy stocking as a management practice, but it must be emphasised here, that this can only be successful if the unstocked period is sufficiently long for the bush to recover, otherwise permanent damage will result.

On the other hand, the heavy stocking of bluebush *(Kochia sedifolia)* is likely to lead to the complete removal of perennial shrub cover, especially in the north-east of the State, where *K. pyramidata* does not take the place of *K. sedifolia* as it has in parts of the north-west. Under the conservative stocking regime at Roopena, the invasion by *K. pyramidata* has taken place very gradually, over a period of 30 years in Barrett's Paddock and 40-70 years in Two-Mile. Yet in general, too little such information is available concerning the population dynamics of shrub species to allow many predictions to be made.

It is an open question as to whether conservative stocking policies applied to vegetation which appears to be in good condition leads to a state of stability or equilibrium. In the author's opinion there can be no doubt that if stocking continues in the arid areas studied some of the characteristic shrub vegetations will continue to change. Equilibrium, if it is ever achieved, may thus involve an entirely different vegetation type. It has, for instance, been asserted that *K. pyramidata* pastures, established in western New South Wales, are in a stable state. Whether or not these pastures were always constituted by this species, will never be known. However, if *K. pyramidata* continues to spread into saltbush and bluebush pastures in parts of South Australia, then it is possible that here also equilibrium may be achieved in *K. pyramidata* dominated pastures.

Too little is known about the regeneration cycles or general population dynamics of the pastoral shrub species. For example, *Kochia sedifolia* is believed to be long lived and does not appear to seed freely, but 45 years of relief from stocking in the Koonamore Vegetation Reserve still has not encouraged monitored populations to increase (M. D. Crisp, pers. comm.). Yet the bluebush denuded area of Quondong shown in Plate 11 now contains young bluebushes, which appear to have grown since conservative stocking began in 1963. Similar conflicting reports of behaviour exist regarding tree populations, a comment which is perhaps outside the field of this thesis, but is relevant in that if trees are unable to regenerate, a number of shrubs dependent on them may also become rarer.

From an ecological point of view, this situation may be regarded as deplorable. There can be no reasonable doubt that some further vegetation types are at risk of permanent destruction or alteration by continued stocking; indeed, this will probably be their fate before an ecological understanding of such systems can be gained.

PASTORAL INTERPRETATIONS

Inasmuch as station practice modifies station condition, it must have some feed-back to management. Thus, the problems faced by pioneer managers and those of today are quite different. For instance, early pastoralism appears to have caused compaction of the ground surface, so that water runs into dams rather than soaks into the soil. This is obviously a beneficial feed-back to management in terms of stock-water storage. However, excessive stocking can result in the silting up of these dams. Managers must be aware of this, also.

The complete removal of perennial vegetation must lead to alteration of management practices, especially during drought, but provided overall perennial ground cover is maintained, a change in dominance probably does not affect pastoralists unduly. In the areas sampled on Roopena, where moderate stocking has been practised, the decline in perennial fodder may be regarded as negligible, except where *Marrubium* has invaded. Populations of the valuable *A. vesicaria* have declined but *K. pyramidata* appears to be replacing it. This plant may not be so palatable to sheep, but it is eaten and will probably become a major fodder constituent of some pastures here, as in parts of New South Wales.

On Quondong Station and similar highly calcareous areas of the north-east, *K. pyramidata* is rare. If *Kochia excavata*, which seems to be an important constituent of the pasture, is grazed out then the non-regeneration of *K. sedifolia*, its associate, will pose severe problems. Complete removal of bush has been advocated on the grounds that herbage growth is encouraged; T. J. Fatchen (pers. comm.) has found evidence in areas adjacent to Quondong suggesting that such a belief would not hold good in this region of the State.

It is clearly of paramount importance to maintain perennial cover on arid pastures, as not only does this provide fodder at all times, but also prevents erosion and contamination of fleeces by dust. Nevertheless, with falling wool prices many pastoral concerns may be led to stock their properties more heavily to offset their diminishing returns. Such a practice must be guarded against as continuous heavy stocking for only a few years, does irreparable damage, and the low quality product achieved (see Reid, 1968) will only flood an already oversupplied market.

SOME COMMENTS REGARDING THE FUTURE OF ARID AREAS

Clearly there can be no complacency about arid vegetation in South Australia, even in moderately stocked areas. Equally clear is the incompatability of the ecologist's desire to maintain floristic diversity in a balanced ecosystem, and that of the pastoral industry to maintain wool or beef production in the arid areas.

It must again be stressed that the changes observed in connection with this thesis relate to some of the best managed arid pastures of the State; conditions are very much worse under poor management, where total denudation of the landscape may take place. Even under the good management practices noted here changes will continue to occur under any stocking level which gives an economic return. No criticism can be levelled at the stocking practices involved on the properties studied, as a conscious attempt to maintain perennial vegetation is evident.

From the range of results presented, it is impossible to predict the likely form of change in vegetation structure that will eventually take place on Quondong Station, which has only been conservatively stocked since 1963. The effect of previous heavy grazing in the northern watercourse or wash country (Barker, 1970) is clear from Plate 11. It is similarly impossible to predict how long the suggested change to *K. pyramidata* dominated pastures on Roopena will take. Some of the changes in population structure, as they are now, may be reversible, although this would depend to some extent on whether the changes in soil structure are also reversible. Rogers (1970) reports that the soil lichen crust has re-developed in the Koonamore Vegetation Reserve.

It was evident from their condition in the field that some of the species of low frequency are high palatable. These were *Olearia muelleri*, *Bassia biflora* and *Malacocera tricornis*; the last two were only found straggling through other bushes. It cannot be judged whether these species were ever more frequent in these areas, but the indications are that they would probably have disappeared from more heavily stocked regions. It is also possible to say that some species, if not endangered now, very soon will be. The inevitable problem with conservative management is that a ground cover of mature bushes of a given species may be maintained for upwards of 50 years, with degradation being so gradual as to be unnoticeable. Thus, if regeneration is hindered or is not occurring, total disappearance of a species will be the eventual result. *Kochia sedifolia*, at present a characteristic shrub of many arid pastures of South Australia, is probably at risk in this respect; it is likely that *K. astrotricha* is too, although the author has little knowledge of this species. If vegetation stands are even-aged (as has been observed in tree species by R. M. Purdie, pers. comm.), then death may be more or less synchronous.

A major consideration arising from this is obviously the future management of the arid pastoral areas. It is suggested that the conflicting aims of the pastoralist and ecologist might be resolved in the following way.

It is evident now, that many pastoral leases are being relinquished as a result of the rural recession. Some, in New South Wales for instance, have been taken over as National Parks, but obviously not all stations are suitable as parks. It is suggested that these leases be allowed to remain unoccupied until such time as regenerating vegetations, particularly trees, are no longer vulnerable to stock. At the end of such a period, pastoral occupation could be resumed. The length of the period of "spelling" would necessarily vary according to the vegetation associations present; where they are woodlands, then at least 50 years might be necessary, which is only a little longer than the length of the present South Australian leases. This suggests a cycle of 50 years grazing followed by a 50 year "spell" for each pastoral lease.

Immediate objections to this idea would include those currently veing voiced following the establishment of the Oraparinna National Park in South Australia, that good fodder is being wasted and creates a fire risk, and that installations will deteriorate. Nevertheless, a management system such as this would allow ecologists to observe whether the effects of stocking, such as those reported in this thesis, are reversible; it would allow species in danger of destruction or elimination by stocking to recover; it would allow pastoral activities to continue, albeit over a reduced total area, but as this seems inevitable anyway, and has been forecast by others (see Waring, 1969) such a scheme ought not to be regarded as unrealistic.

The institution of this system would obviously require changed attitudes on the part of the Government and its administrative officers, who must be increasingly answerable for the future status of arid areas. The forced removal of pastoralists from the arid zone is not implied (although this would undoubtedly be appropriate in a few cases); some leases should not be renewed at the end of their current term in the year 2004, or when managers retire. (The present 42 year lease is deemed to cover the term of a man's working life.) The best managers for the future are the conservative ones. Ideally they should know as much ecology as animal husbandry and they should not be penalised by higher rents for possessing pasture in good condition - this seems to be a current bone of contention - but rather for overstocking pasture to its detriment.

The turning of abandoned leases into National Parks in perpetuity is not the answer. The remaining areas would still be persistently degraded, without a chance of recovery. There seems no reason why unoccupied leases (Pastoral Reserves) supervised by rangers, should not be used as recreation areas.

CONCLUSIONS

Such considerations aside, the formal conclusions which have arisen from this study are simply these:-

.. The techniques used, based only on incidence and density data, have shown that there is a definite pattern associated with a water-point by comparison with the rest of a paddock. Further, that these changes in plant population structure, occurring where stock pressure is heaviest, appear even in well-managed pastures where perennial vegetation cover is continuous right up to the dam or trough. These identified stock pressure patterns, which are readily distinguished from pattern already existing in a paddock, are regarded as degradations.

.. The species involved in the generation of pattern induced by heavy stocking have been picked out in the areas studied, and the reasons for their occurrence in the inner piosphere have been examined. They can be regarded as indicators of heavy stocking. Some of them have been noted by others, for example Jessup (1948, 1951). They are not always found in the influence analysis nodes, but mapping of either incidence or density data indicates their positive correlation with the water-point.

.. The areal extent of the degraded areas is not great. Some perennial species, often found in watercourses are spreading into areas subject to intense stock pressure, and it is suggested that this change is progressive and may indicate that the environment is changing permanently.

Some ideas which arise out of these conclusions and the preceding discussion would bear further investigation.

From a purely academic point of view, additional studies on the autecology of implicated species would lead to a better understanding of why they behave as they do under stocking. Such work ought to be related to changes in soil structure and nutrient status (see Rogers, 1970). Species distribution studies linked with autecological ones may yield interesting phytogeographical relationships, such as those alluded to on p. 257.

As the future of pastoralism in the arid zone, in some form or another, seems assured, then inspections of vegetation condition as carried out under the provisions of the Pastoral Act, must be more rigorous than they are at present. The parameters used here might be adequate; they have the advantage that the data are collected easily. Biomass measurements would be better as they give the first indication of stock pressure, but a combination of two or three of the parameters mentioned would be best. Once the species sensitive to stock are identified for any general geographical region, they will prove to be valuable indicators. It is towards the development of such a system of effective monitoring in different vegetation and soil types that research could be most profitably directed. In attempting to maintain a stable ecosystem such efforts will be for the long-term benefit of the pastoral industry.

If floristic diversity is to be sacrificed in the arid shrublands of South Australia, then the merits of different easily maintained fodder plants should be evaluated in respect of perennial productivity and also in respect of the year-round maintenance of wool quality, which must become an increasingly important factor in capturing future wool markets. *Kochia pyramidata* will probably be the easiest perennial cover to maintain under moderately heavy stocking.

The author does not consider that studies on palatability and stock behaviour have much future in applied arid zone research. Both of these features are dependent on numerous variables, and the techniques necessary to provide enough of this information for it to be useful may be sophisticated and would be costly in terms of man-hours and equipment, compared with the possible increased returns from the system. The effects of palatability and behaviour are reflected by the vegetation structure, which is more amenable to the application of simple research techniques. Although behavioural studies may be desirable for deriving a model which gives some degree of predictability for the stock-in-paddock situation, the same conclusions must surely be achieved by vegetation monitoring, which shows the actual effects of the stock-in-paddock situation. There is, after all, little the station manager can do economically to manipulate this particularly sensitive ecosystem, with its rigid boundaries and fixed water-points, except move his stock, and occasional vegetation checks will tell him when this is necessary.

It is very unlikely that a full understanding of how this ecosystem functions under controlled grazing, will ever be achieved. Probably any sustained equilibrium between pastoral activities and a diverse shrub pasture can only be effected by periodic restraints on the removal of the vegetation resource.

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