ECOLOGICAL STUDIES OF ARID RANGELANDS IN SOUTH AUSTRALIA

by

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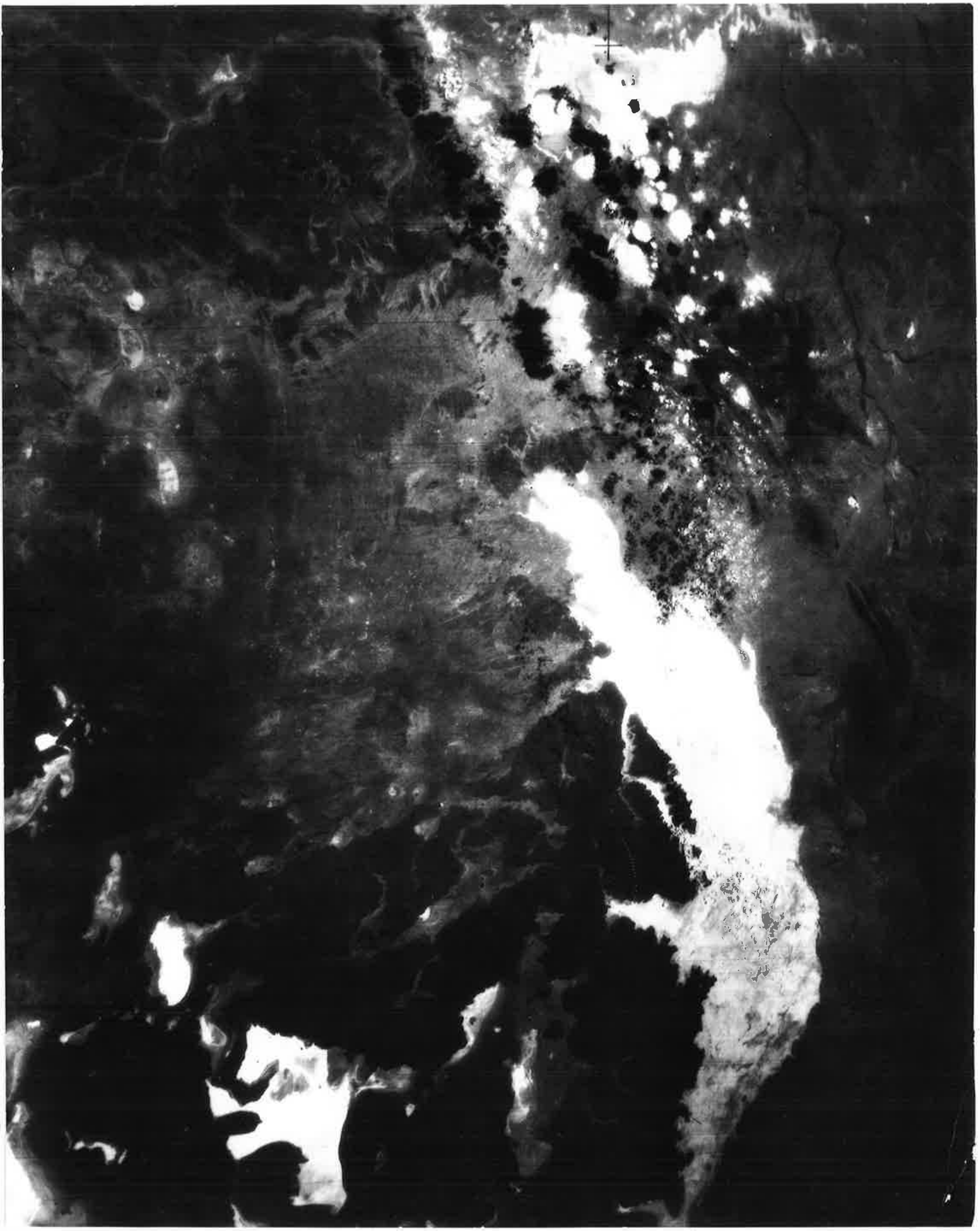
FRONTISPIECE

The study area is shown from a Skylark Rocket at a height of 270km; 9.a.m. March 27th, 1972. The photographs were taken on Panchromatic Plus X film using an F24 camera with a 127mm wide angle lens. Approximate scale is 1:1,500,000

These photographs can be correlated with maps 46 and 50 in Volume II and a description is given in Chapter 2. The most conspicuous features are the various salt lakes and the outwash plains of the Lake Eyre Basin. Other patterns are caused by the differing reflectance of the various soil types and gibber cover. Coober Pedy and part of the Stuart Highway are just visible in the top left hand corner. Scattered cloud is present.



SUMMARY

Several aspects of the ecology of arid rangeland were studied by broadscale survey over an area of about 50,000km^2 in the North-West Statistical Division of South Australia.

Re-evaluation, after 22 years, of a quantitative assessment of rangeland condition is presented. The original method using estimates of the density of bush (perennial *Atriplex* and *Kochia* species) was used, with modifications and refinements. Many problems were encountered while undertaking this work, particularly in relocating the route taken by the previous investigator. These problems were in common with other long-term studies, and an appraisal of the methods required for this type of work in general is given, based on this experience.

The results of a data analysis from three stations revealed that all had suffered significant bush loss, and in one case less than half of the original bush remains since the initial survey. Comparison of results with stocking policies reveals that the extent of bush degeneration depends on the number of stock carried on a watering point, and that a figure of 300-350 sheep has resulted in negligible bush loss on one station over the 22 year period.

A phytogeographic survey was carried out at the same time as the bush density survey. The distribution of 41 woody plant species (mainly trees and large shrubs) was mapped by observation using contiguous 3.2km sampling intervals along the traverse route.

Character plant, regeneration and mortality ratings of some species were also used. *Acacia aneura* is the only species studied which shows any significant regeneration. This only occurs in isolated localities and in some cases corresponds to areas previously burnt or flooded. The survey method permitted accurate delineation of distribution patterns for most species provided sufficient herbarium collections were made, and these were correlated with maps of known environmental variables. Influence analysis was used to detect interspecific association and to further elucidate factors affecting species distribution. A close correlation of some associates with soil types and rainfall was detected by this test.

102 permanent photographic points were set up during the survey to illustrate various shrubland communities, and tree and shrub species used in the phytogeographic survey. These are accurately located and oould be rephotographed if this survey is repeated.

Herbarium collections of flowering plants were made throughout the survey and a total of 402 identified species were collected. This collection revealed new localities for many species.

It is concluded that only methods of long-term and broad-scale inventory of rangeland condition and trend (such as the bush density survey) could provide a practical determination of the effects of management practices on the vast areas of diverse vegetation types in Australia's arid pastoral zone.

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 no material is contained herein previously published or written by any other person, except where due reference is made in the text.

Brendan G. Lay.

ACKNOWLEDGEMENTS.

This project could not have been successfully completed without the technical and professional assistance readily given by many people and organizations. In particular, the considerable financial support given to this project by the South Australian Pastoral Board and the C.S.I.R.O. Rangelands Research Unit was instrumental in completion of the study in its present form.

To my supervisor, Bob Lange, for his guidance and stimulating enthusiasm throughout the course of this work, and for his unstinting efforts to provide technical assistance in the preparation of this thesis, I am most grateful.

The ready cooperation and hospitality of many station people in the North-West greatly increased the pleasure and efficiency of the fieldwork. In this regard I would particularly like to thank Mr. & Mrs. Ron Fels of Bon Bon Station, Mr. & Mrs. Harry Russell, formerly of Bulgunnia Station, and Mr. Byron MacLachlan.

Martin Willcocks, Sue Barker, Greg Lawrence and "Buzz" Wright forsook the comforts of home for two or more weeks in the bush and thereby assisted greatly with the fieldwork.

The Analysis of Variance in Chapter 8 was carried out by Doug Ratcliff of the C.S.I.R.O. Division of Mathematical Statistics. Many discussions with him in this field proved most helpful.

I am indebted to the following for assistance given in the ways indicated:

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Credit for the final manuscript must go to Carol Wilkins, whose immaculate typing greatly facilitated preparation of the thesis. She also prepared the preliminary typescript, and assisted immeasurably in many other ways, particularly in proof-reading and duplication.

TABLE OF CONTENTS.

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SECTION I

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The chapters in this section provide a contextual basis for the original work in this thesis.

Chapter 1: gives the origins of the project and an introduction to the nature and aims of the work embarked upon.

Chapter 2: gives a description of the study area. Since it is dealing with such a large area, it is not exhaustive, but describes in detail those aspects which have most bearing on, and significance to the experimental work, its analysis and implications. Where aspects are not treated in detail, the reader is referred to published work, if available.

Chapter 3: provides a review of the literature relevant to the central themes of this thesis. (It is felt that a broader and necessarily more general review is inappropriate and unnecessary here. Barker (1972) has recently presented a broad and general review of this type.

The central themes of this thesis deal with two rather unrelated issues,

(i) long term change in vegetation subject to grazing by sheep, and

(ii) the broadscale surveying of vegetation.

Studies on the grazing factor in (i) are reviewed separately as they apply to assessment of a safe carrying capacity, which was an ultimate aim of this work.

Chapter 4: gives a review of Jessup's original survey, and the data obtained as it applies to the present investigation.

CHAPTER 1.

INTRODUCTION

This study set out to evaluate the long term effects of pastoral occupation on certain elements of the vegetation in the arid North-West of South Australia. The study's origins are rather unusual and to appreciate this, a summary of events which led up to them are set out below.

Background.

In the years 1945 - 1950 R.W. Jessup carried out a detailed, but largely qualitative and descriptive survey of the soils, geology and vegetation of a large area in the North-West of South Australia (Jessup 1951). Included in his report were details of a method for quantitative assessment of abundance of three perennial plant species on which sheep are particularly dependent in this area. He mentioned that this method could be used to detect long-term change in these species populations if his survey was repeated at a later date.

In 1968, a committee representing the C.S.I.R.O. Rangelands Research Unit, the Pastoral Board of the South Australian Lands Department, and the Head of the Department of Botany, University of Adelaide, met to discuss programmes of research worth sponsoring or initiating on arid zone problems. Consequently it was decided that Jessup's quantitative work was worthy of repetition or re-evaluation at this time, as the method appeared to have potential for broadscale assessment of vegetational change, and sufficient time would have elapsed to show up any changes which may have occurred through grazing practices. This was endorsed by Jessup himself who pointed out that his original field data books were still available, neat and legible, and an exact ground resurvey was therefore possible. It was agreed that the sponsoring of the project be undertaken jointly by the C.S.I.R.O. and the South Australian Pastoral Board, while the University would provide supervision and facilities.

An appointment within the proposed framework of implementation was finally made available at the end of 1969, with the study forming the basis for an M.Sc. degree. The writer took up this position in January 1970.

* * * *

The project was initiated, therefore, with a set aim. This was to carry out a follow-up to Jessup's survey, with a view to comparing the two sets of data, thus a quantitative assessment of vegetational changes and the effect of stocking would be obtained. At the outset it was realized that Jessup's method involved detailed vehicular survey of each Station along tracks and fence-lines, and that the present survey would involve similar work.

It was decided, therefore, that any additional work undertaken should make use of detailed ground coverage of this large area (57,000km^2). As a result, and after a few weeks of field trials, the following additional work was embarked upon.

Phytogeographic Studies

The distribution of all major tree and distinctive shrub species found in the survey area would be investigated, as well as the extent of regeneration of the more widespread and important ones. This information could then be correlated with environmental variables and the effect of stocking. The field data for this work could be collected while repeating Jessup's survey without a significant increase in actual time taken.

Herbarium Collections

As little is known of the floristics of the region and almost no verified plant collections have been made, it was decided to embark on a comprehensive herbarium collection of all flowering plants in the survey area, especially those chosen for phytogeographic studies. It was also decided to compile a reference herbarium to be available for anyone involved with this work in the future. Jessup himself made no plant collections, which limits the value of his work on floristics of the vegetation associations he described.

Permanent Photographic Points

Recognizing that this survey should be repeated in the future, it was decided to set up permanent photographic points showing individual plant species and vegetation communities characteristic of the North-West pastoral areas. These could be revisited when the survey is next repeated.

* * * *

What follows is a review of literature relevant to the survey area and to the fields of study embarked upon. The rest of this thesis covers the methods used, results and conclusions from each project, together with a final synthesis in which the place of the work in research and management of arid rangelands is discussed.

CHAPTER 2.

THE STUDY AREA

Introduction

To most effectively serve the main theme of the study it was thought necessary to place the work described in later chapters in its physical and socio-economic context.

What is presented is a summary of the features which have most bearing and relevance to the central theme, concerning the natural vegetation and the pastoral industry it supports. These are the physical features, climate, history of settlement, and management of stock in the area studied. In the latter case, the aspects most crucial to the resultant effect on the vegetation, namely paddock size and layout, sheep numbers and water supply, will be considered in greater detail.

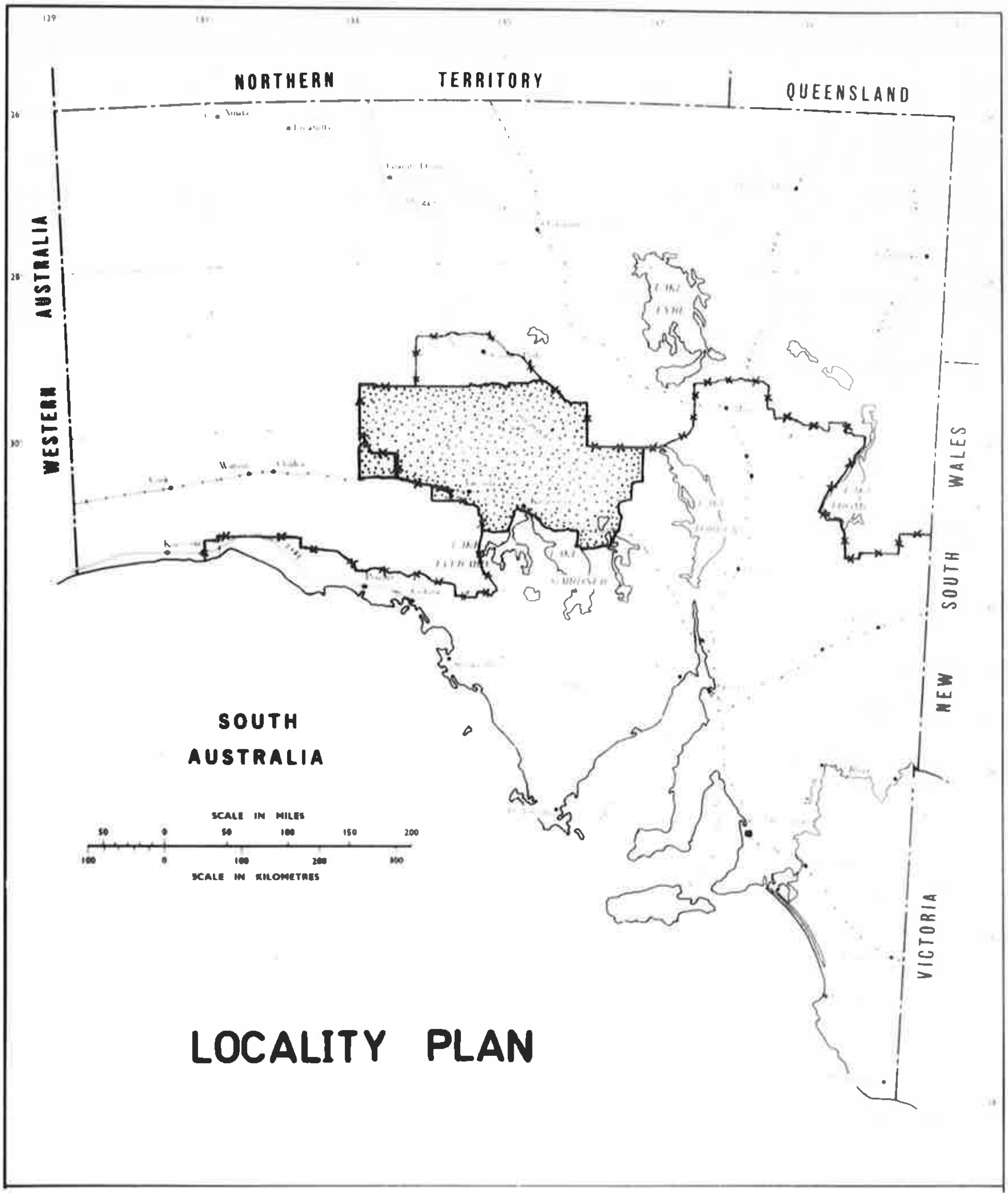
Location

The study area is located in the North-West statistical division of South Australia from near Lake Torrens westwards to the Dog (dingo proof) fence, here forming the boundary between country used for pastoral purposes and unoccupied Crown lands (Great Victoria Desert). Its approximate limits are the meridians 133° and 137°E longitude, and 29° and 31°30'S latitude. The exact location in South Australia is shown on Figure 1.

FIGURE 1

Location of the study area in South Australia.

The Dog Fence is shown thus: —x—x—x—



LOCALITY PLAN

Physical Description

Climate:

The only places where accurate climatological data, apart from rainfall, are recorded in the study area, are Tarcoola and Woomera. Average temperatures recorded on a monthly basis for these stations, and for the next nearest station (Oodnadatta to the north) are given on Table 1. The area lies within all generally accepted boundaries of Australia's arid zone (e.g. Perry, 1967) and in the world context is classified by Meigs (1958) as having an arid climate, with mild winters and no season of precipitation.

Rainfall is the only climatic variable recorded consistently at most pastoral homesteads. Averages vary between the extremes of 4.33 inches (110mm) annually at Billa Kalina Station and 8.16 inches (2.07mm) at the 416 mile siding on the transcontinental railway.

The average annual rainfall for each recording station in the area up to 1970 is represented on Map 45. Isohyets in inches are drawn in on the basis of these data only, but agree fairly well with published maps (e.g. Bureau of Meteorology, 1957). The reliability of these figures is open to question, however as there is little standardization in methods of recording, except for the few "official" stations. For example oil is used to

TABLE 1.

TEMPERATURE DATA (°C) FOR SOME STATIONS IN THE NORTH-WEST OF SOUTH AUSTRALIA

	Stations	January	February	March	April	May	June	July	August	September	October	November	December	Average	Years of record (to 1964)
Average Maximum	Woomera	34.0	33.0	30.2	25.2	19.9	17.4	16.4	18.1	21.9	26.1	29.2	31.6	25.3	14
	Tarcoola	34.6	33.7	31.6	26.1	21.6	18.2	17.9	19.9	23.8	27.3	30.8	33.3	26.6	38
	Coober Pedy	35.8	34.7	32.5	27.2	21.9	18.9	18.3	19.7	24.4	28.1	31.9	34.2	27.3	6 ?
	Oodnadatta	37.4	36.1	33.4	27.9	22.8	19.7	19.3	21.6	26.1	29.7	33.4	35.9	28.6	23
Average Minimum	Woomera	18.9	18.7	16.6	12.9	9.0	6.8	5.6	6.3	8.8	12.1	14.7	16.9	12.2	14
	Tarcoola	17.6	17.4	15.2	10.8	7.6	4.9	3.9	5.6	7.6	10.8	13.7	16.1	10.9	38
	Coober Pedy	20.6	20.0	17.2	12.8	8.6	6.9	6.7	7.2	10.0	13.3	16.4	18.9	12.2	6 ?
	Oodnadatta	22.4	21.8	19.0	14.3	9.7	6.8	6.0	7.1	10.4	14.7	18.1	20.8	14.3	23
Mean	Woomera	26.5	25.6	23.3	18.9	14.7	12.4	11.0	12.5	17.8	18.5	22.1	24.1	18.7	14
	Tarcoola	26.1	25.4	23.4	18.3	14.5	11.5	10.7	12.6	15.9	19.0	22.2	24.8	18.7	38
	Oodnadatta	29.9	28.9	26.1	21.1	16.2	13.3	12.6	14.3	18.5	22.1	25.8	28.4	21.5	23
Extreme maximum	Woomera	47.6	44.7	40.9	35.6	30.7	25.8	25.9	30.6	36.4	41.2	44.4	44.4		14
Extreme minimum	Woomera	8.3	10.3	7.9	4.9	-0.3	0.3	-0.3	-1.4	1.8	4.4	6.2	8.8		14

prevent evaporation in rain gauges on Commonwealth Hill and its Outstations, and this could help explain the higher figures for these stations. A more likely cause of the variation is the length of time for which records have been kept. Rainfall variability is typically very high in this region (Jessup, 1951; Crocker and Skewes, 1941) and it is apparent that representative averages could not be obtained with less than the accepted minimum of 30 years record. Such stations are marked on the map, and less weight was placed on them when drawing in the isohyets.

On average, the rainfall and its effectiveness in promotion of plant growth is evenly distributed throughout the year. In summer, higher intensity and amount of individual falls compensate for greater evaporation rates. Ineffectual falls for plant growth (10 points or less) are characteristic of winter rains.

Other climatic variables are typical of hot arid regions. Potential evaporation (from a free water surface) is 110 to 130" (279-330cm) annually (Gibbs, 1969). Jessup (1951) described in detail other climatic phenomena, such as winds and the occurrence and effects of local convectional storms.

Topography:

The area is characterized by almost level plains for the most part, broken by low rocky outcrops or rises, often near or associated with saltlakes and claypans of various sizes. Other topographic features include sandhills, the Arcoona Tableland or

Plateau, and the Stuart Range. This latter feature, with associated outwash plains to the north, can be seen to advantage on the frontispiece photographs. These topographic features are delineated on Map 45, which is based on information from the I.C.A.O. World Aeronautical Chart, No. 3354 (Tarcoola), 1:1,000,000 series supplemented by ground observations. A fuller description of the topographic units is included in the legend accompanying Map 45.

Drainage:

The outwash plains mentioned above form part of the internal drainage basin of Lake Eyre. The rest of the area has no well-defined drainage; small diffuse watercourses drain into salt-lakes or "swamps". Those originating from rocky outcrops or low rises often just peter out after reaching the surrounding plain. A few larger watercourses do exist, as shown on the frontispiece photographs, but some of these have never been observed to carry water, and they are not evident from the ground.

Soils:

The soils and geology for most of the study area were described and mapped in detail by Jessup (1951). However his soil classifications have not been followed up for other areas as yet. The soils map included (Map 46) is the recent work of Northcote (1966-68) who defined broader groups than Jessup's soil families while carrying out an Australia-wide survey. In general, soils are all alkaline, with either massive or free limestone or gypsum at depth. Massive concretionary limestone, usually called calcrete or travertine, is often present as a continuous layer in the soil profile, effectively preventing the penetration of moisture and plant roots to lower levels. Gypsum, in a powdered amorphous state, is present around and underlying sand dunes near claypans, in large quantities, where it is known as kopi (Jessup, 1951).

Geology:

The geology of the area is depicted on Map 47, compiled from published and unpublished information from the Mines Department, Adelaide. The surface geology is characterized by extensive sediments of Cretaceous, Tertiary and Quaternary age, variously eroded and truncated. These sediments are covered by areas of fossil soils, silicified laterites, recent aeolian sand dunes and alluvia (Jessup, 1961). Proterozoic or Archean plutonic intrusives and metamorphic outcrops, some iron-rich, are common in the south and west of the area.

Vegetation:

The only detailed vegetation survey of this area was done by Jessup (1951), his basic mapping unit being the plant association as defined by Crocker and Wood (1947). This map, covering most of the study area, is redrawn here (Map 49). He also mapped an area to the north of the redrawn area, but this was done in considerably less detail (Jessup, pers. comm.).

Other vegetation surveys have either been at a much broader scale, or dealing with an area chiefly outside the limits of the present survey. Examples of the former are Prescott (1929), Williams (1955), Cochrane (1967) and Boomsma (1969). Williams' map of vegetation regions (part of the Atlas of Australian Resources, 1955), has been reproduced here (Map 48). In general, the area is described as consisting of arid *Acacia* woodlands and perennial chenopod shrublands.

Vegetation studies in more detail have been carried out on areas adjacent to or encompassing part of this one, and include Murray (1931) - Arcoona plateau and environs; Wood (1937) - South-Eastern South Australia including south-east of study area and Bennett (1935) - Aerial reconnaissance of the Great Victoria Desert. It is of interest to note that the vegetation of the Arcoona Plateau was mapped by three separate workers, Murray, Wood and Jessup. Their respective descriptions for this area were: saltbush steppe; *Atriplex - Salicornia* association; and *Atriplex vesicaria - Ixiolaena leptolepis* association.

History of Land Usage

Pastoral Occupation:

The first documented explorations of the study area were those of Stuart, Babbage and Warburton on separate expeditions during 1858-1859 and later by Giles 1872 and 1880 (Threadgill, 1922). The earlier explorers recognised pastoral potential in parts of the area, and about the same time as Giles' explorations, Adelaide pastoralists organized their own expeditions to investigate the suitability of areas for occupation. When reports were favourable, the pastoralists applied for leases over these areas. The Government made these leases available in 100 square mile ($270km^2$) blocks, and often many of these were taken up together, and later amalgamated further into large runs. An example of this is Mt. Eba, taken up between 1874 and 1878, and containing 3929 square miles ($10,200km^2$) in 1886 (Richardson, 1925).

Following success on these pioneer runs, remaining available blocks were soon taken up, singly, or in widely separated localities. However, by the later 1890's, these small blocks had been surrendered, while leases on many of the large runs expired and were not re-applied for. This was because low wool prices and rapidly increasing losses due to dingoes did not justify the increased rent asked for on renewal of the leases. Coondambo was the only Station in the area which was not abandoned around that time.

About 1910 leases were taken up again, when rents were reduced to a reasonable level, and often comprised several of the small abandoned blocks, or subdivisions of the large runs. By that time the pastoral lease was extended from a 14 or 21 year term to the present 42 years. Since this time, and with the construction of the transcontinental railway through the area, there has been a marked stability in ownership and boundaries, apart from some amalgamation of leases in later years. A diagrammatic representation of the pastoral history of the present Bon Bon, Mt. Eba and Mt. Vivian Stations from the original Mt. Eba run is illustrated in Figure 2. This is not intended to represent a typical sequence, but rather it is a case history in the area. Details were obtained from study of original lease records and plans in the Archives of the Lands Department, Adelaide.

Development of areas further west of the above Stations did not occur until well after these had been reoccupied. It was hindered by the absence of sufficient or readily available supplies of ground water, and development proceeded slowly with the introduction of mechanization, and improvements in methods of locating and developing water supplies, particularly boring techniques and water pipelines. This could only be undertaken by lessees with considerable financial backing. It is of interest to note here that, as in the prior case, new country was offered for lease in

FIGURE 2.

Pastoral History of Mt. Eba, Bon Bon and Mt. Vivian Stations.

The larger figures are the pastoral lease numbers, and are recorded at the date when the lease was first granted. Smaller figures represent the area in square miles. A + denotes a change in the lessee.

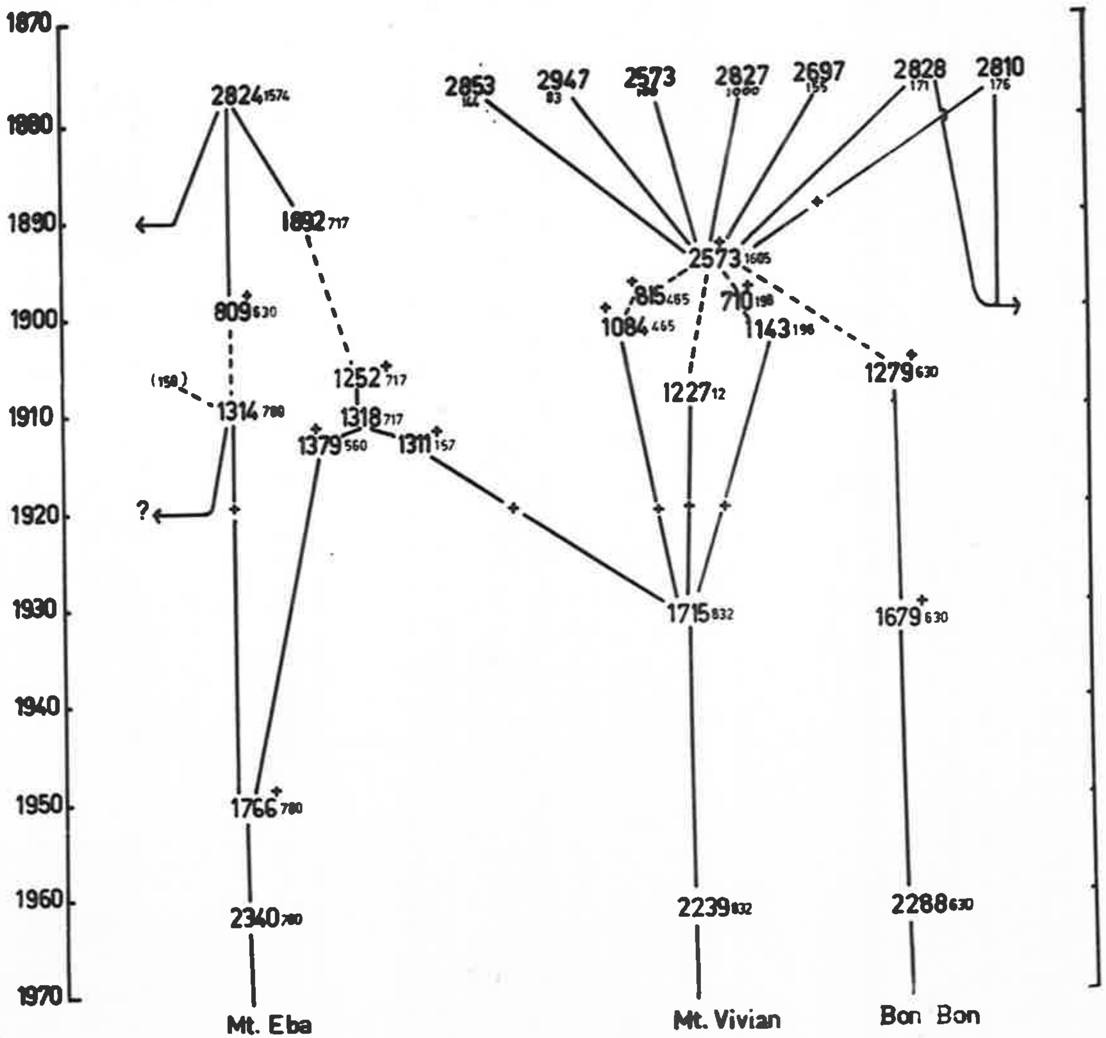


Figure 2. Pastoral History of Mt. Eba, Mt. Vivian & Bon Bon Stations.

small blocks (about 250sq. miles or 675km^2), which would, by themselves, have been uneconomic even at reasonable wool prices. Thus Commonwealth Hill was only established when it was possible, in 1946, to take up an area of about 1,000 sq. miles (2,700km^2) (B.MacLachlan*, pers. comm.).

Boundary fencing on some of the large runs in less remote areas was completed by 1890, but it was only from about 1910 onwards that vermin-proof fences were constructed around each station in the North-West. To maintain the fences in vermin-proof condition, vermin-fenced districts were established. These usually comprised several leases, whose owners shared the cost of maintaining fencing. In 1946 the dog fence, and an Act of Parliament covering it, were established, and, following eradication of dingoes and wild dogs within this fence, most individual vermin-proof fences were allowed to fall into disrepair. Sections of the dog fence have been re-located at irregular intervals since, and its present position is shown on Figure 1 and the base map of the study area (Map 1, Vol. II). Since its erection, this fence has traditionally formed the boundary between areas used for sheep grazing in fenced paddocks, and areas used for cattle grazing on an unfenced open range system.

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* B.H.MacLachlan, Managing Director, B.H.MacLachlan Pty. Ltd.

Other Land Use:

In 1912-1915 the Transcontinental Railway was constructed and undoubtedly provided a stimulus to the pastoral industry in adjacent areas and to further development there. This also provided an influx of people to the area to man fettlers camps and sidings along the route. The line also served the town of Tarcoola, near which gold was discovered in 1900. In 1911 it had a population of 106, with a regularly used route over the now trackless sand dunes south to Fowlers Bay (W. Robins,* pers. comm., 1971). The last mine was closed there about 20 years ago, but about 250,000g. of gold has been extracted from Tarcoola and from Glenloth and Earea Dam on Wilgena Station nearby.

In about 1928-1929, the sandalwood trade brought an influx of exploiters to the area. Cutters searched out large specimens of this shrub, *Santalum spicatum* R.Br. from even the most difficult terrain, and carted it to the nearest railway siding, where it then fetched about £7 per ton. Before the trade was stopped, this plant was virtually eliminated from the area (Cleland, 1930).

In 1949 the Commonwealth Government set up a rocket launching range base at Koolymilka in the North-East corner of Wirraminna Station, and built the township of Woomera to the south-east. Six years later these facilities were used in conjunction with an atomic weapons testing site near Maralinga just west of the

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* W. Robins, Owner/Manager of Carnding Well, Cooladdin and Kychering Leases, Tarcoola.

study area. Since establishment of these facilities there has been restriction of entry to the general public over most of the study area. This has not affected the pastoral industry, but has resulted in a network of graded, or in some cases sealed, roads on stations near the rocket launching site and firing range. Other features of the area in the 1940's were described by Jessup (1949).

Present Socio-Economic Geography.

Organization and Management in the Pastoral Industry:

The study area currently contains 29 pastoral leases, comprising 17 stations, or management units, with an average area of about 1000 square miles (2560km^2). However, they vary between about 250 and nearly 4000 square miles (640-10,200km^2). Ownership of the leases is now almost restricted to pastoral companies, or family partnerships with many years of experience in the arid pastoral zone of Australia. A few of these own several stations in the study area. There is no foreign ownership or interests in the area. The recent wool crisis has affected even the larger and well established stations, one of which is now under the control of a trustee company. Only six managers have a vested interest in the station under their control, the other stations having paid managers with a greater or lesser degree of control over management decisions.

Fourteen of the stations having all, or nearly all, their area within the dog fence carry sheep in paddocks of about 30sq. miles (77km^2) in area, but varying, depending on such factors as availability of stock water supplies, and vegetation type. The two stations outside the dog fence carry cattle, and are largely unfenced. As a result of low wool prices and continuing high prices for beef cattle over the last few years, several stations inside the dog fence are at present breeding up or buying in cattle, and it is intended to carry only cattle on up to half of the total area of the station (W. Morish,* pers. comm.). The effect of this change on arid shrublands previously thought unsuited to cattle, has yet to be determined, but a project to study this is currently being undertaken (T. Fatchen, pers. comm.). Stock numbers vary widely from year to year, depending on ephemeral forage available, and are illustrated for Roxby Downs Station in Table 2. Average stocking rates vary between 16 and 30 sheep or sheep equivalents† per square mile (4-12/km^2). Maximum stock numbers allowed (the "Stocking Condition") are determined by the Pastoral Board under regulations set down by the Soil Conservation Act, 1939.

Sheep are usually mustered twice a year for the operations of marking, culling, shearing and crutching. Stock are not moved

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* W. Morish, Manager, Mt. Eba Station.

† Sheep - cattle conversion in South Australia is officially 1:5.

TABLE 2.

STOCK NUMBERS ON ROXBY DOWNS STATION, 1948-1970.

The area of the Station is 781 sq. miles (1892km^2), and it has a stocking condition† of 20,000 sheep (4,000 cattle), which is 25.5 sheep or sheep equivalents per square mile.

Year	Total sheep or sheep equivalents	Stock Cattle	Stock Horses	Stocking Rate*
1948	8850	376	90	11
1949		No record		
1950	15891	619	131	21
1951	15342	581	128	20
1952	8580	195	49	11
1953	15388	311	121	20
1954	22790	140	298	29
1955	22884	164	219	29
1956	25315	720	210	32
1957	24371	660	197	31
1958	18956	350	97	23
1959	24128	200	109	31
1960	20722	254	70	26
1961	16102	172	70	20
1962	9869	132	70	12
1963	13462	140	72	17
1964		No record		
1965	11273	95	91	14
1966	13694	139	66	17
1967	13455	207	46	17
1968	15950	314	55	20
1969	21680	419	40	28
1970	19307	528	41	25
1971	15607	583	50	20

† See text.

* Stocking rate is calculated as the total number of sheep or sheep equivalents per square mile, to the nearest whole number.

otherwise, except where necessary. On some stations, however, gates are left open and the stock allowed to range at will through many paddocks (G. Rankin,[*] B. Jenkins[†], pers. comm.). Most stock losses are caused by blowfly strike and excess exposure to saline drinking water.

Stock Water Supply:

The main source of stock water is shallow ground water supplies. Because of the absence of an artesian basin, groundwater yield and quality is very variable. As this area forms part of the great Australian Shield, aquifers are always local, and usually restricted to depressions or "swamps" where replenishment is from surface percolation after heavy rain (Fisher, 1969). The freshest supplies are thus located at shallow depths, with progressively more saline supplies at deeper levels. Prolonged pumping has drained many of these aquifers, while others have become too saline for stock. The problem has been accentuated by trampling of stock on the intake area, causing compaction and sealing of the surface and preventing replenishment. Realization of this has prompted some lessees to exclude stock from these areas, or to pipe supplies to a tank located elsewhere (B.MacLachlan, R. Fels[§]; pers. comm.) .

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* G. Rankin, Part-owner / Manager, Ingomar Station.

† B. Jenkins, Manager, Millers Creek Station.

§ R. Fels, Manager, Bon Bon Station.

Due to the lack of organized drainage, and poor runoff, scope for reliable surface water catchments is limited over much of the area. The dams which do exist tend to be filled only after heavy rains, with water carrying a high silt load, while those draining the Arcoona plateau become saline as the water evaporates. Conversely, on stations in the north and east of the area, excavations are made in claypans, the hard impervious clay surfaces of which are "as efficient as an iron roof" for collecting precipitation (T. Allison*, pers. comm., 1971).

Where finance is available, the problem of lack of water supplies has been largely overcome by installation of many miles of steel, asbestos, or (more recently) P.V.C. water pipe, with tanks and troughs located regularly along it. An example is the recently laid pipeline from Mulgathing Station to Old Malbooma Station, a distance of 40 miles (64km). Malbooma was abandoned nearly thirty years previously through salting up of water supplies. Such pipelines depend on reliable, high yielding supplies which are rare in the area. The largest producer is North Wells; several wells with a combined yield of 60,000 gallons (273,000ℓ.) per day. The water is piped to about 30 paddocks over an area of 1000 square miles (2560km^2). Most equipped bores yield about 5000 gallons (23,000ℓ.) per day which is sufficient for one or two watering points in an average paddock.

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* T. Allison, Owner / Manager, Roxby Downs Station.

Towns:

At present the pastoral industry is served by Woomera, the opal mining town of Coober Pedy, and Kingoonya and Tarcoola on the Transcontinental railway. The populations of these towns are: Woomera 4069 (1970); Coober Pedy 1391 (1970); Kingoonya 139 (1966); Tarcoola, less than 100 (1966) (Bureau of Census and Statistics, 1971). The Coober Pedy figure was taken from a June census, the population during the summer being much lower. Tarcoola is currently expanding, as the initial surveying work has begun on a new route for the Port Augusta - Alice Springs railway. This will be located due north from Tarcoola through Mabel Creek Station, and will circumvent the existing creek crossings near Lake Eyre.

Communications and Transport:

Most station homesteads are connected by telephone maintained by Woomera. Outstations are connected to the head station by internal telephone. On some stations, the original roads and tracks are still used today, while others have a network of straight regularly graded roads. All mail roads are regularly maintained. Travelling stock routes and railway commonages are seldom used now in the area, most stock being moved from the station by road transport and loaded directly at the railway siding. The main through road (Stuart Highway) to Alice Springs is currently being improved from graded earth to formed gravel in parts. This will eventually render it an all weather road, to cater for a rapidly increasing volume of through-traffic, chiefly road-haulage and tourist vehicles.

Reserves etc:

At present there are no aboriginal reserves, developed tourist attractions or national parks in the area. However a section of the Stuart Range north of Millers Creek Station is currently being investigated by the National Parks Commission following recommendation in a report submitted to them by the writer. Another area being considered by the Commission is in the Great Victoria Desert just west of Commonwealth Hill Station - a long strip running north and south through several vegetation types.

Summary

In brief, the area consists of vast arid plains, low hills and sandridges, supporting a pastoral industry based on low intensity sheep and cattle grazing. The native vegetation is chiefly arid *Acacia* woodlands, perennial shrublands, and ephemeral herbage after rains. Superimposed on this is a missile firing and testing range with supporting facilities, and consequent restriction of public access.

CHAPTER 3.

REVIEW OF RELEVANT LITERATURE

In essence, this study has a bearing on three aspects of the ecology of arid vegetation. These are not directly related, due to the fact that in this study additional projects were chosen for efficiency in execution of the fieldwork associated with the follow up to Jessup's work. The aspects are:

I. Long term change in vegetation.

II. Assessment of grazing capacity.

III. Broadscale vegetation surveys.

These aspects will be discussed in turn below, and literature relevant to arid areas will be selectively reviewed. In Chapter 10, an evaluation of the present study is presented in the light of this review and the results obtained from the original work of this thesis.

I. Long term change in vegetation.

Ecological research on change in vegetation over long periods falls into categories, as in Table 3.

(i) *Short-term studies where assessment is by inference or extrapolation:*

This category will not be dealt with here in detail, except to mention examples of the type of study involved, and its advantages and limitations.

TABLE 3.

EXPERIMENTAL APPROACHES USED TO DETECT LONG TERM CHANGE IN VEGETATION

Type of study	Principle used
Short-term studies (Assessment by inference or extrapolation)	e.g.: Succession Pattern and Process Simulation
Long-term studies (Assessment by monitoring or measurement)	Assessment by regular measurement. Assessment by re-reading experiments designed for repetition at a later date. Assessment from comparisons with earlier work not designed for repetition.

Most short term studies designed to elucidate changes over a longer period are based on the concepts of Succession and Climax as delineated by Clements (1928) or with modifications. (These studies as applied to grazing effects have been reviewed to 1959 by Ellison (1960). A development of this is the concept of pattern and process (Watt, 1947). More recently, simulation techniques, usually computer facilitated, have been used to determine changes over longer periods (Goodall, 1967).

The chief advantage of these approaches is that the long term changes can be documented in a short period, and future changes can be predicted. However, at best these studies can only provide a general indication of likely change and the time taken for it to occur. This is so because invariably not all the influences which effect vegetational change are known. Even where the effects of an influence are known and their effect evaluated, it is still likely that alterations may occur in their importance and effect over a long time period.

(ii) *Long term assessment by monitoring or measurement:*
This division comprises long term studies whose conclusions are based entirely on actual data obtained during the course of the work.

(a) Experiments involving regular measurement or observation:

This class of work forms an important part of a continuing assessment and monitoring programme involving experimental areas in the arid rangelands of North America (Parker, 1954; Anderson, pers. comm., 1972). In Australia, however, there are few studies of this type. Williams (1969) reported plant density response of a semi-arid *Danthonia* grassland in New South Wales, throughout 16 years of grazing by sheep at different stocking rates. The observations were taken every year by the same observer for the entire 16 year term. Trumble and Woodroffe (1954) reported the results of a large scale grazing experiment in arid shrublands just south of the present study area. Here also, measurements were taken each year, and it is unfortunate that some of the methods used, and experimental data obtained were never published, and are unavailable.

Various experiments set up to monitor changes in the vegetation on the Koonamore Vegetation Reserve in South Australia, established in 1926, represent the most significant long term observational programme of this nature. Some of the findings from the records collected to date have been published (Osborn, Wood and Paltridge, 1935; Wood, 1936; Hall, Specht and Eardley, 1964). These papers illustrate some of the information which can be obtained from work of this nature.

(b) Experiments set up for repetition at a later date:

In the literature searched, only North American examples published in this category were found. The only Australian work known is the re-reading of some experiments and records from the early years of the Koonamore Vegetation Reserve (M. Crisp, pers. comm., 1972).

One of the most valuable experiments in this category is the work of Glendening (1952) on a Southern Arizona arid grassland. In 1932 two exclosures were set up in a cattle range, one excluding only cattle, and the other both cattle and rabbits, with an unfenced area as a control. Measurements were made of dominant shrubs, and their position mapped and grass species and density recorded. Permanent photopoints were also established. No more work was done until 1949, when the measurements were repeated, and photographs re-taken. The results were contrary to what was generally believed at the time, and showed that shrub invasion, chiefly Mesquite (*Prosopis juliflora*) occurred regardless of grazing intensity. Subsequently Humphrey (1958) reviewing this subject, concluded from past histories that absence of fires was, in fact, the most likely cause of shrub invasion of arid grassland in the United States.

Buffington and Herbel (1965) documented shrub invasion using reconnaissance surveys over a 50,000ha. area of arid grassland. These surveys, on the Jornada Experimental Range in New Mexico, were conducted in 1858, 1915, 1928 and 1963. The invasion was documented by gathering data on relative amounts of the three species concerned along the traverse routes. This work was accomplished with a minimum of time and effort as, since 1915, it was carried out with a view to future repetition.

Shreve (1929) illustrates the value of quadrat mapping of slow growing desert shrubs in assessing change in these communities in time. Phillips (1963) exemplifies the value of, and information revealed in, long term photographic documentation of change which requires little effort and minimal interpretation.

(c) Experiments based on comparisons with earlier work not designed for repetition:

There is very little available literature on this although, in assessing change through grazing or other causes, many conclusions are based on early descriptions of the area under investigation (Humphrey, 1958; Beadle, 1943). Buffington and Herbel used the original land office surveys in 1858 to compile their first map of the distribution of the relevant shrubs although they noted the limitations of this approach due to the subjective interpretations necessary to do this. York and Dick-Peddie (1969) also used these records in a general study of long-term vegetational change in New Mexico, and conclude that shrub invasion was entirely due to effects of grazing with consequent succession and erosion.

In Australia, Correll and Lange (1966) noted changes in arid vegetation by relocating photographs taken 23 years previously, and this has been done over a 40 year period on the Pearson Islands, off South Australia (Specht, 1969).

II. Assessment of Grazing Capacity.

In the context of management of arid rangelands, the concept of a maximum carrying capacity has received remarkably little investigation *per se* in the past. Virtually all work has been concerned with the effects of overgrazing, consequent soil and vegetation changes, and responses to amelioration of stocking pressure. Indeed, the concept of conservative grazing and its less overt effects has only arisen as a consequence of the well documented disastrous effects of over-grazing on every exploited rangeland on earth (Ratcliffe, 1936), and the need to establish management practices on an ecologically sound basis (Ellison, 1960; Dyksterhuis, 1958).

Most of the literature on the general subject of the effect of grazing on rangeland vegetation and soils has been well reviewed (e.g. Davies, 1955; Ellison, 1960; Moore, 1960; and Newman and Condon, 1969). These reviews have been concerned with studies on changes in vegetation as a result of grazing, rather than any which try to determine a practical level of utilization least deleterious to the long term conservation of the vegetation resource. It is this latter point, as it applies to rangelands in Australia only, which will be considered below. This is because it was generally apparent at the second U.S. - Australia Joint Workshop on Range Science* that there are few areas in North America comparable in detail with Australia's arid zone in climate and vegetation. Also, Australia's vegetation has evolved without the presence of cloven-hooved ruminating herbivores. Most studies in North America at the management level consider particular areas only, and are usually published as extension articles (W. Anderson, pers. comm.†).

In Australia, even the most basic question as to whether or not continued pastoralism in perennial shrubland vegetation is viable as a desirable or economic proposition in the long term is not determined. For example, one can quote studies

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* Proceedings unpublished as at September, 1972.

† W. Anderson, Soil Conservation Officer, U.S.D.A., Oregon, U.S.A.

showing the apparent beneficial effects of grazing (Osborn, Wood and Paltridge, 1932; Trumble and Woodroffe, 1954), on the one hand while others describe it as being untenable on a continuous basis (Barker, 1972). Certainly there are very few studies which have attempted to determine a system which seeks to reconcile maximum economic return with minimum permanent damage to the soil or vegetation. The research resources needed for such an attempt are beyond those usually available for Arid Zone research in Australia, as broadscale assessment of trend and condition is needed, due to the vast areas and extensive grazing system used. Also slow rates of change in the perennial vegetation together with longevity of individual plants and great variability in seasonal conditions would necessitate these studies being long term in nature.

Williams' work quoted earlier could be used in this way. He has applied set stocking rates to a vegetation type which although degenerate, covers a large area and has shown stability under grazing over a long period and a variety of seasons. Similarly Trumble and Woodroffe's experiment was designed along these lines (Woodroffe, 1941). Even if the results had been unambiguous (in fact they are ambiguous), the experiment would have had to be run for a longer period. Stability or any real trend in the condition of the long lived *Kochia sedifolia* vegetation community they studied was not apparent in their data.

Jessup (1951) assessed effects due to grazing over a long period, but he used indirect evidence, and his results are rather too general to be useful, especially as they were not related to stock numbers and stock distribution. Data gained on his survey, however, forms the basis of the present study (see Chapter 4). Suijdendorp (1969) in one particular area has shown that vegetation stability can be achieved by a combined grazing system and fire treatment. He has monitored it over a sufficient length of time to be sure of this.

The only significant attempt to determine the grazing capacity of large areas of rangeland is the method described by Condon (1968) and by Condon, Newman and Cunningham (1969). This method was applied to the Alice Springs area where they used C.S.I.R.O. land system categories (Perry et al., 1962) as base mapping units, and also the Western Division of New South Wales, where their own mapping units were used.

In summary, their method, as used in the central Australian survey, is as follows. Firstly the area is surveyed and the land systems, areas of relative physical homogeneity, established and described (Dickson, 1955). Once this has been achieved, a reasonable knowledge of all factors likely to influence grazing capacity in each land system is available.

A particular land system is chosen as a standard, in which both the average and drought grazing capacity is assessed as accurately as possible from past stocking records. For every other land system, or the same land system under different rainfall, each factor which affects grazing capacity e.g. soils, topography, tree density etc. is given a rating factor relative to the standard. These ratings and the asseseed stocking capacity of the standard are multiplied together to arrive at the grazing capacity. These grazing capacities are divided still further where there is variation in condition, a factor of past stocking history.

After this has been accomplished, the grazing capacity for each station is calculated on the basis of the area and condition of each land system present on the station. This represents the carrying capacity of the station if all areas are accessible to stock from stock watering points. Where this is not so, a "present stocking capacity" is calculated from all areas within a certain distance of existing waters. A drought grazing capacity is calculated mainly from tree density, which is presumed to be the main source of forage for stock during extended droughts. As a guide to management, they give stock numbers relative to the assessed grazing capacities which should be held in each year of an extended drought.

For the Western New South Wales Survey, pasture types were incorporated in the rating factors, which was not done in Central Australia due to the relative uniformity of pasture types present.

It is evident that the main drawback of this procedure is the subjectivity of the rating scales, especially where these apply to perennial vegetation. This approach would be much more tenable if it was incorporated with assessments of trends and condition based on quantitative data which are, however, unavailable. It remains to be seen whether this system actually works.

III. Methods of Broadscale Vegetation Survey.

What is presented here is an analysis of methods used in broadscale mapping of vegetation undertaken in the arid zone of Australia. Once again it is intended by this review to place relevant aspects of the present study in perspective.

Beckett (1968) in a critique of method and scale of mapping work in relation to precision and cost, provides an excellent framework for discussion. He defines three categories of survey procedure in resource inventory as follows:

(1) Grid mapping: sampling in a pre-determined pattern, and using data from sampling sites only.

(2) Free survey: location of boundaries of mapping units determined using suitable ground traverse coverage. In vegetation mapping, this is usually referred to as reconnaissance survey.

(3) Physiognomic survey: boundaries of mapping units are determined from aerial photographs, often with little or no ground check, provided information as to the nature of the units defined is available elsewhere.

Beckett's categories were presented using soils mapping as examples, but were for the purpose of delineating mapping techniques used for natural resource surveys in general.

Within the context of the above classification, all detailed maps, descriptions or notes published on the vegetation of arid regions have been at either of two levels, the plant community or the individual species. Publications at the former level may or may not include lists of species comprising the communities they define, but make up the bulk of broadscale mapping carried out. The methods used in each category will now be considered in the light of Beckett's classes.

(1) Grid Mapping:

This type of survey has not been used for broadscale mapping work, as the time and cost involved in sampling in sufficient detail has restricted its application to areas less than a few square km. However it is the method used for most surveys at smaller scale, for example in ecological studies and determination of interspecific association, e.g. Barker and Lange (1969). Data are usually collected by recording species incidence or frequency within a measured quadrat at each sampling site.

(2) *Free (reconnaissance) survey:*

This class of survey has been used in virtually all broadscale vegetation surveys carried out until about 20 years ago. Here, the basic mapping unit has been the plant community, usually at the level of association, formation or alliance, and based on the phytosociological concepts of Clements (1928). The work of Jessup in the area currently under study represents a typical example, the associations on his maps (Map 49, Vol. II) being delineated by ground reconnaissance only. These associations, as in all other work of this nature (e.g. Murray, 1931; Beadle, 1948) are defined according to one or several dominants, or character plants, whose combined distribution determines the limits of the particular association they represented. Jessup and others attempted to assign total species lists to each association. Since there is no necessary correlation between these distributions and those of the association dominants, these lists are useful only as a general guide to species distribution. However, provided the ground traverse coverage has been adequate, this method has proved the most satisfactory for vegetation mapping of reasonably accessible areas due to low cost and ease of execution.

(3) *Physiognomic (Aerial) Survey:*

As mentioned above, the value and accuracy of this method depends on either adequate ground information being already available, or a "ground truth" control survey being made in conjunction with interpretation of the aerial photographs. Published surveys of arid Australia show extreme variation in the degree of ground truth used in conjunction with aerial interpretation. For example Bennett (1935) mapped vegetation associations without any ground check over most of his remote survey area, and had no other information to base them on. As a result, the reliability of this work is open to question, and it can only serve as a rough guide to the communities present. However, the C.S.I.R.O. land system surveys (Dickson, 1955) represent a planned, integrated approach to the problem of interpretation of aerial photograph patterns. These surveys have now been completed over a large area in the North of Australia. They define vegetation communities which, together with soils, topography and climate, comprise "natural" areas with respect to these parameters.

This method has been used in a smaller area by Barker (1970). She imparted greater accuracy and detail by recording the extent and density of more than one component species in the communities of the area using a detailed ground reconnaissance and aerial photograph interpretation. It will be seen here that the application of aerial photography to the mapping of plant communities in essence enables more exact location of boundaries in araas which are not covered by ground traverse. Hence this mapping technique can be regarded as a development of the procedure using ground traverses alone. Carnahan (in Leigh and Noble, 1968), has mapped all the areas in the Australian arid zone using the vegetation community as the basic unit. The techniques used were those in the last two of Beckett's classes.

In recent work, Carneggie, Wilcox and Hacker (1971) used aerial photography in an interesting experiment to test the accuracy with which plants can be identified using low level aerial photography in monochrome, colour and infra-red false colour. However they concluded that only a few plants could be identified accurately, except where low level (110m) photography was supplemented by a ground check. Thus, although this technique is probably not viable for broadscale survey, it could be used for assessment of change in time at selected sites as these "aerial photopoints" could be re-located.

On the other hand, very high level photography for resource surveys using rockets and satellites is now being developed, chiefly by the Earth Resources Survey Section, National Aeronautics and Space Administration, U.S.A. (Carneggie, 1968). The writer was involved in an experiment of this kind using a "Skylark" rocket launched from Woomera, South Australia (British Aircraft Corporation, 1972). In this experiment, monochrome and infra-red false colour photographs were taken from a height of 200-300km over the present survey area, two of which are included as frontispiece to this volume. As can be appreciated from these photographs, ground traverse cannot usually be located accurately on them. Interpretation depends on a special ground truth survey being conducted on the basis of the patterns revealed in the photographs, or on correlation of these patterns with existing maps or survey information.

It should be noted here, that in very broad coverage vegetation maps e.g. Williams (1955), Cochrane (1967), broader regions are defined using similar life-form rather than character species composition as a criterion for classification. These regional maps are often compiled from the more detailed surveys and do not introduce new data, although this often is difficult to verify. In North America, the term "biome" is usually applied to those broader vegetation classifications defined on ecological principles (Dyksterhuis, 1958).

* * * *

It was mentioned in the foregoing discussion that broadscale surveys invariably used the plant community as a basic mapping unit. However some individual species have been mapped over portions of the arid zone because of their phytogeographic, economic or scientific interest (e.g. Cleland, 1930; Crocker and Wood, 1947).

It is almost universally accepted now that records of distribution of the plant must be verified by properly annotated and identified herbarium specimens (Chapter 7). For example, distributions of arid zone species by Hall, Specht and Eardley (1964) and Boomsma (1972) were mapped on the basis of these records.

An exception to this is the work of Rogers (1972) who mapped the distribution of some 40 species of lichen over a large area by regular spot sampling along a continuous traverse. This method will be considered further in Chapter 10, in the light of the methods used in the present survey, which now follow.

CHAPTER 4

THE ORIGINAL SURVEY.

The details here were obtained from Jessup's 1951 publication, his field data books, and from numerous discussions with Mr. Jessup himself.

Conception of "bush density" survey.

During the years 1945-1950, Jessup was engaged in a largely descriptive survey of the geology, soil groups and plant associations in a large area of the North-West division of South Australia. His plant association map is reproduced in part in this thesis as Map 48 (Volume II). While he was undertaking this survey, he searched for some rapid method of estimating the quantity and distribution of arid shrubland* vegetation in his survey area. This vegetation type forms an important drought reserve for stock over large areas of Arid Australia (Williams, 1955) and its broad occurrence in Jessup's area is shown on Map 49, Volume II.

Jessup used the term " bush" to describe the three perennial shrub species concerned and this term will be similarly applied in this thesis. The three species were *Atriplex vesicaria* Heward, "Bladder Saltbush"; *Kochia sedifolia* "Bluebush", and *K. astrotricha*, "Low Bluebush". They are shown in Plate 1.

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* Previously termed "shrub steppe".

PLATES 1 - 2

SPECIES INCLUDED IN THE BUSH DENSITY SURVEY

Most of the photographs included here and in Volume II are taken from photopoints set up during the survey (Chapter 7). Soil profiles were obtained while digging the hole for the photopoint post, while "grazing pressure" estimates were based on surrounding vegetation and amount of dung present. Authors of species noted here are given only where the plant is not listed in Appendix 1.

Plate 1, Photopoint 101: Bon Bon Station, October 1971. The three species are shown growing together. From left to right they are: *Kochia sedifolia* (Bluebush), 80cms high; *Atriplex vesicaria* (Saltbush), 50cms high, and *Kochia astrotricha* (Low Bluebush) 40cms high. Other shrubs in the foreground in the extreme left and right are *A. vesicaria*. The scale post is marked in decimetres.

Soil:	Stony clay-loam with shale at depth.
Grazing Pressure:	Light.
Rainfall:	5.6" (143mm).

Plate 2, Photopoint 70: Mulgathing Station, September 1971. The fourth species included in this survey, *Cratystylis conocephala*, is shown in a stand of *Atriplex vesicaria* stage 3. This species is rated on the same scale as *K. sedifolia*, and has a density here equivalent to stage 4-5. The trees are *Acacia sowdenii* (Myall), with a single specimen of *Casuarina cristata* (Blackoak).

Soil:	Deep sand.
Grazing Pressure:	Light.
Rainfall:	7.0" (178mm).

PLATE 1

PLATE 2

In populations of these species, he hoped that assessments could be made of changes resulting from past stocking histories and that these assessments could provide a scientific basis for the formulation of stocking controls. He observed that these species tend to form relatively uniform stands over small areas, with sharply defined boundaries. Jessup also noted that the density of these bush stands depended on both the soil type and the extent of past overgrazing by domestic stock or rabbits.

Method and Execution of Survey.

Jessup next defined stages of degeneration of these bush stands by reference to the virgin (i.e. ungrazed) conditions. Originally he recognized seven stages, representing degree of preservation on comparison with the densest stands observed. These were 100%, 80%, 60%, 40% and 20% and trace preservation as compared with the densest stands. He recorded the length of traverse passing through each stage by use of vehicle odometer, and completed a continuous traverse using this method on part of Mt. Eba and old Lake Wirrida Stations.

To enable greater reliability and accuracy in estimations of bush density to be obtained, Jessup then decided to assign numerical limits to each of his density stages. After consultation with a statistician he reduced his seven original divisions to 5 density stages plus a sixth stage representing areas with all bush gone as against areas which were naturally without bush (these were not rated).

For a unit area, or quadrat, Jessup used the wheelmarks of a vehicle driven for one tenth of a mile (0.16km) according to its odometer, across the bush stand. The outside edges of the wheelmarks were about five feet (1.6m) apart, and hence demarcated an area of about 245m^2 which Jessup gave as 2/33 of an acre. To determine the count for the particular bush stand, he drove randomly across it, and scored the bushes whose bases were on or between the wheel marks. Seedlings which were not "established" were not counted.

In calculation of numerical limits for his density stages, Jessup referred to two principal shrubland vegetation types (*Atriplex vesicaria* - *Kochia astrotricha*; *Kochia sedifolia*) as recognized by him. The numerical limits of the density stages were different for each shrub type, and are represented in Table 4. Photopoints showing examples of each density stage were set up during the present survey, and photographs from these are shown on Plates 3-14.

Several important points arise here concerning this method which are not clear from his published description. Firstly the dominant or most conspicuous bush species determined

PLATES 3 - 14

PHOTOPOINTS SHOWING JESSUP'S BUSH DENSITY STAGES.

The scale post in these photographs is at a distance of 50m. unless stated otherwise. Where a density figure is given, a count was made across the stand photographed.

Plate 3, Photopoint 85: Wilgena Station, October, 1971. Stage 1, *Kochia sedifolia* is shown, with a density of 59 bushes/250m^2. The trees at the rear are *Acacia aneura* (Mulga), while scattered *Casuarina cristata* are visible as emergents on the skyline. The soil surface supports an almost continuous lichen crust.

Soil:	20cms calcareous loam overlies 30cms calcrete.
Grazing Pressure:	Negligible by stock, rabbits present.
Rainfall:	7.0" (178mm).

Plate 4, Photopoint 68, Kychering Station, September 1971.
Stage 2, *Kochia sedifolia* is shown, with a density of 37 bushes/250m^2. The trees visible are *A. aneura*, with a few *Acacia sowdenii* (Myall) trees on the extreme right hand side in the distance. The soil surface supports a scattered lichen cover. The *K. sedifolia* plants were smaller here than those in Plate 1.

Soil:	15cms calcareous loam overlies hard calcrete.
Grazing Pressure:	Light, by cattle (note browse line in *A. aneura* groves at rear).
Rainfall:	7.6" (193mm).

PLATE 3

PLATE 4

Plate 5, Photopoint 88: Bulgunnia Station, October 1971. Stage 3, *Kochia sedifolia*, with bushes of *Eremophila rotundifolia* is shown. The trees and shrubs at the rear are *Acacia aneura* and *A. tetragonophylla*. The scattered grazed-off grass tussocks are *Neurachne munroi*.

Soil:	30cms of calcareous loam overlies 20cms hard calcrete.
Grazing Pressure:	Light.
Rainfall:	6.0" (152mm).

Plate 6, Photopoint 75: Commonwealth Hill Station, September 1971. Stage 4, *Kochia sedifolia* is shown in a largely-dead *A. aneura* woodland. A dead shrub of *A. tetragonophylla* is in the foreground on the left hand side of the photograph. The ground cover is dead tussocks of *Eragrostis* sp. and ephemeral composites.

Soil:	60cms of sandy loam overlies calcrete.
Grazing Pressure:	Negligible.
Rainfall:	6.5" (165mm).

PLATE 5

PLATE 6

Plate 7, Photopoint 96: Millers Creek Station, October, 1971.

Stage 5, *Kochia sedifolia*, near the northern limits of its distribution, is shown, with a density of about 2-3 bushes/250m^2. The smaller shrubs towards the left of the photograph in the middle distance are *K. astrotricha*. Ground cover plants are ephemeral *Bassia* spp. Mt. Paisley (243m), a residual, is visible on the right hand side in the distance.

Soil:	40cms of soft calcareous clay-loam overlies soft calcrete.
Grazing Pressure:	Slight.
Rainfall:	4.7" (120mm).

Plate 8, Photopoint 81: On W-E Pinding paddock fence, Mulgathing Station (Malbooma), October 1971.

Stage 6, *Kochia sedifolia* is shown on the left hand side (E-Pinding Paddock) with large bushes of *K. sedifolia* stage 3 on the right hand side. Both paddocks have been unstocked for about 20 years. Kangaroo tracks are shown along both sides of the netting fence. Trees and shrubs at the rear are *Casuarina cristata*, *A. aneura* and *A. tarculensis* (left hand side). Ground cover is scattered ephemeral composites.

Soil:	Calcareous sandy loam overlies calcrete.
Grazing Pressure:	Negligible by stock now (1971).
Rainfall:	7.0"(178mm).

PLATE 7

PLATE 8

Plate 9, Photopoint 100: Bon Bon Station, October 1971. Stage 1, *Atriplex vesicaria* and *K. astrotricha* are shown with a density of 180 bushes/250m^2. Scattered *K. sedifolia*, *K. pyramidata*, *K. triptera* and *Rhagodia parabolica* bushes are also present. Shrubs in the distance are *A. tetragonophylla* and *A. oswaldii* (right hand side). Extensive rabbit warrens are visible near the scale post.

Soil:	Stony clay-loam with shale at depth.
Grazing Pressure:	Light.
Rainfall:	5.6" (143mm).

Plate 10, Photopoint 98: Millers Creek Station, October, 1971. Stage 2, *Atriplex vesicaria* and *Kochia astrotricha* are shown in No. 4 Woolshed paddock, looking south-west from the post. The *A. vesicaria* is fruiting and many seedlings of this species are also present. Other ground cover plants are scattered *Ptilotus obovatus* bushes (centre foreground), with occasional *Stipa nitida* and ephemeral composites (c.f. Plate 13).

Soil:	60cms of sandy loam overlies soft calcrete.
Grazing Pressure:	Very light and intermittent.
Rainfall:	4.9" (125mm).

PLATE 9

PLATE 10

Plate 11, Photopoint 66: Parakylia Station, September, 1971.
Stage 3, *Atriplex vesicaria* is shown with a density of about 65 bushes/250m^2. The female plants are fruiting heavily, and appear yellowish in colour. Other plants present are *Craspedia pleiocephala* (Billy Buttons), and other composites, *Bassia* spp. and *Zygophyllum* sp. The trees on and around the sand dunes at the rear are *Callitris columellaris, Acacia sowdenii* and *A. aneura.*

Soil:	10cms of sand overlies clay loam.
Grazing Pressure:	Light and intermittent.
Rainfall:	5.7" (145mm).

Plate 12, Photopoint 46: Wirraminna Station, October 1971.
Stage 4, *Kochia astrotricha* from which the *Atriplex vesicaria* has been grazed out, is shown with a density of 45 bushes/250m^2. The scale post is only 25m from the photopoint post. The sparse ground cover is ephemeral composites and *Erodium* sp. A stand of *Kochia pyramidata* is visible behind the scale post. The trees on the skyline are *Acacia aneura* and *A. sowdenii.* Rabbit warrens are visible on the left hand side.

Soil:	60cms of loam overlies soft calcrete.
Grazing Pressure:	Moderate - Heavy.
Rainfall:	7.1" (180mm).

PLATE 11

PLATE 12

Plate 13, Photopoint 98: Millers Creek Station, October, 1971.

Stage 5, *Kochia astrotricha*, is shown in Moodlampnie paddock, looking east from the post. This photograph contrasts with Plate 10, taken from the same point. This overgrazed stand has a density of 7 live bushes/250m^2. The healthy bushes in the foreground are *Ptilotus obovatus*, while the ground cover is a dense sward of *Stipa nitida*. All trees visible are *Acacia aneura*.

Soil:	60cms of sandy loam overlies soft calcrete.
Grazing Pressure:	Heavy.
Rainfall:	4.9" (125mm).

Plate 14, Photopoint 91: The Twins Station, October, 1971.

Stage 6, *Kochia astrotricha* is shown 0.3miles East of Dreslys Bore. All the bush has been grazed out and the sandy topsoil has been blown into low dunes. Bushes of *Kochia pyramidata* and *K. aphylla*, which are less palatable to sheep, have remained on the drift sand. A single plant of *K. astrotricha* is visible in the left centre foreground. An *Acacia tetragonophylla* is present in the centre middle distance with the mistletoe *Lysiana* sp.

Soil:	Clay loam and soft calcrete. Previously this was probably a texture-contrast soil.
Grazing Pressure:	Heavy but intermittent.
Rainfall:	5.4" (137mm).

PLATE 13

PLATE 14

the shrub type, and hence the rating scale, but all individuals of the three species present were counted. For example, if in a *Kochia sedifolia* stand he counted 26 *K. sedifolia* and 24 *Atriplex vesicaria* bushes between the wheelmarks, his bush density rating would be recorded as *K. sedifolia* stage 1. Subdominant rateable plants (in this case the *A. vesicaria* bushes) were not indicated in the recordings. Secondly, where two differently rated species were present in almost equal amounts, as in the above example, the decision as to which one is "dominant" profoundly affects the density stage recorded. In this example, if *Atriplex vesicaria* was considered the dominant species, the corresponding density stage is *A. vesicaria* stage 4. Thirdly, the numerical limits were assigned to the density stages after Jessup had recognized these stages in the field; and this explains the unequal numerical spans of each. Fourthly, although Jessup tried to drive randomly across the bush stand, obviously he avoided large shrubs or trees, timber, warrens or other vehicular hazards. However no plants of rateable species were avoided deliberately, regardless of size, and this enabled relatively unbiassed sampling in most cases.

Once he was familiar with the shrub types and their density stages, Jessup began the survey. In stands where degeneration had occurred, he estimated the original bush density from observations of bush remains, adjacent unstocked areas, or the soil type, with which he was already familiar.

For each Station "sufficient" traverse coverage was usually obtained by travelling station tracks between stock watering points, or along fencelines. He was generally familiar with most of his traverse route and recorded only minimal route information. To ensure accuracy in estimation, Jessup estimated and then counted a series of bush stands at the beginning of each field trip. As he only had a two-wheel drive vehicle, he could not traverse rough or soft sandy areas, but presumably achieved "sufficient" coverage (see below). He began the survey in 1948 and finished in early 1949.

Analysis of Data.

From his estimates of original bush density, Jessup calculated the proportion of each of the two shrub communities which remained in 1948-49. He found that 80% of the *Kochia sedifolia* and 65% of the *Atriplex vesicaria - Kochia astrotricha* bush type remained. These percentages refer to the "bush cover" and presumably the loss refers to the stage 6 country, that is, country on which all the original bush had died or been killed by overgrazing.

Jessup then prepared bush density maps of his survey area, one of which represented the original bush density, and the other present bush density averages for the two shrub types. He compiled these as follows.

Firstly he divided the continuous traverse into convenient intervals, for example between reference points (bores, fences, dams, etc.), then he obtained an average number of bushes in his unit area over each interval. Over the total interval length (A), he dealt with each density stage by multiplying the bush number corresponding to the mid-point of that density stage (B) by the length of the stage intercepted (C) and then divided by (A). He then summed results for all density stages. In effect, he calculated the average of a series of estimates. Jessup then averaged out these averages in a manner which is not explained in his paper and still remains obscure. However some comments can be made regarding these maps after field examination of some of the boundaries shown on them.

In general it appears that his map delimited the areas with consistently higher average bush densities from areas in between, often consisting of mainly no bush with scattered occurrences of high bush density averages. For example, a large area on the eastern side of Parakylia Station was recorded as having an average *Kochia sedifolia* density of three bushes per unit area. (This region now has no rateable bush over large areas, but has many scattered occurrences of chiefly stage 1, 2 and 3 *Kochia sedifolia* and similar areas of stage 3 *Atriplex vesicaria*).

The north-east corners of Wirraminna and Millers Creek Stations, and the north-west corner of Commonwealth Hill at present contain extensive stands of *Atriplex vesicaria*, but are without either *Kochia sedifolia* or *K. astrotricha* and are bounded by areas with considerably higher average bush densities. However, Jessup has recorded these areas as *Kochia sedifolia* dominant and in two of these cases he has not given a bush density figure. One is therefore led to the conclusion that he has not included areas in his bush density maps where *Atriplex vesicaria* occurs alone. Another explanation is that these areas, being rather more rugged in parts than the rest of the area he surveyed, were not covered in enough detail to enable him to compile bush density averages.

As is probably evident from the above, it would not be possible for Jessup's survey to be repeated, and a map produced comparable with Jessup's on the basis of available published data. The critical observer must even question the value and validity of Jessup's original bush density map as an indication of location and extent of degeneration up to that time. Even if the evidence on which the original bush density was based is valid, the method is still very indirect and subjective. Also most of the boundaries are the same in both maps and, presumably due to the averaging process, no boundaries appear to follow fencelines, or Station boundaries, as one would have expected.

Conclusions.

In summary, Jessup's bush density assessment was much too general and subjective to be successfully correlated with stocking rates. However, Jessup's method is based on estimations checked by measurements and as such, now represents the basis for a valuable study to assess long term change in perennial shrubland vegetation. With known stocking rates over that time on each Station, it should be possible to assess which stocking rate or system of grazing management results in least degenerative change. One is forced to the reluctant conclusion, however, that Jessup's original field log books alone must provide the data necessary for a re-survey and comparison. The published data are inadequate for this purpose.

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S E C T I O N   I I

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The three chapters included in this section present in detail the methods used in the original work of this thesis, and the experimental results obtained from it.

Chapter 5: presents a detailed description of the attempt at re-evaluation of Jessup's bush density survey, while

Chapters 6 and 7 describe the additional work carried out at the same time.

CHAPTER 5.

JESSUP'S WORK - A RE-EVALUATION 1970-71.

Familiarization with Arid Rangeland.

At the beginning of this study, the writer had no personal experience of the study area, or of Australian arid-zone vegetation and research done on it. It was therefore evident that before maximum appreciation of the project in hand could be obtained, several months would have to be spent in a thorough familiarization of the system in which the work would be carried out. Jessup himself (pers. comm.) spent more than two years in familiarization of arid shrublands over a wide geographical range before attempting the bush density survey.

Apart from the reading of published work, this familiarization was achieved by several trips to the Koonamore Vegetation Reserve in the North-Eastern division of South Australia. The writer learned identification and method of herbarium collection of the more common species, as well as an appreciation of the long term experiments set up there to monitor changes in vegetation after the removal of stock.

Valuable contact with other scientists and their work was obtained by participation in the Third Australian Arid Zone Research Conference at Broken Hill, New South Wales, and a visit to the Fowler's Gap Research Station near there.

Familiarization with the Technique.

The first trip to the study area was made in April, 1970. Mr. Jessup and a member of the South Australian Pastoral Board, Mr. W.S. Reid (now Chairman of the Board) flew up to Bulgunnia in a chartered aeroplane, while the writer drove there by car. Three days were spent together in familiarization as follows.

As Mr. Jessup had not estimated bush density for more than twenty years, the first day was spent entirely in enabling him to remember his density stages and their numerical limits. Bush stands were estimated by him and counts made, with the writer noting the correct density stage. Mr. Jessup was surprisingly accurate with his estimations of most bush stands, with no more than about 10% error in estimation. The next two days were spent again estimating bush stands, this time with the writer and Mr. Jessup independently estimating the bush stand before the count was made. No traverses were run, as the speedometer had broken, and all estimations had to be checked by pacing.

On the fourth day, typical bush stands representing most density stages were located, and large white cloth crosses laid out in them. The chartered aeroplane which was to take Messrs. Jessup and Reid back to Adelaide that day was used to take oblique photographs of these stands from about 1,000 feet.

Technical difficulties with the camera used and the speed of the aeroplane prevented a satisfactory result from this, however.

The next three days were spent estimating and counting bush stands. By the end of that time the writer correctly estimated the density stage of about 90% of the bush stands. It should be noted, however, that not all density stages of the two shrub types rated were found on Bulgunnia Station.

Field Log Books.

From the first day spent in the study area, it was decided to maintain an accurate diary of work carried out, and to use it for direct recording of data. Consequently a series of log books were compiled in the field, kept as neatly as possible, and used for all field data collected. The purpose of this was two-fold. Firstly it enabled accuracy in later transposing of data to be attained. Secondly, it was recognised that this survey, if successful, should be repeated at a later date. With detailed directions as to methods used, and traverse route taken, the log books will provide maximum assistance to the future investigator. This point will be brought up again later.

A typical page of these log books is reproduced in Figure 3. Explanation of the various columns is given under the appropriate section below.

FIGURE 3

A typical page of the field log books used in the survey.

MULGATHING 9 contd.

61·7	NB / AMS: NB, AMS: Aves 4	75·5	NB.	84·1–84·2	BB5	89·7	BB2 (Aves 4)
61·3	NB / Aves 4	75·9	BB2	84·4	BB4 (12)	90·1	BB3 (Aves 5)
66·3	NB / NB	76·3	BB3	84·7	Ka5 // BB5	90·4	NB
66·6	FBB4 / NB	76·6	BB2	84·8	BB5	90·5	Ka4
71·1	NB / AMS: AMS	76·7	NB	85·0	NB	90·6	Ka3 (BB4)
71·2	BB4 / BB3	76·8	BB3 (BD)	85·6	BB5 (BD)	90·9	BB2
71·4	NB / BB3	77·0	NB	85·9	NB	90·8	NB
71·5	BB3	77·1	BB3 (BD)	86·0	BB5 (BD)	91·0	BB2
71·7	BB2 (Aves 5)	77·2	NB	86·3	NB	91·1	NB.
72·0	BB1 (Aves 4)	77·3	BB3.	86·5	BB3	91·4	BB2
72·1	Aves 4 (BB5)	77·8	BB5 (BD)	87·1	NB	92·1	NB
72·2	BB1 (Aves 4)	77·9	NB	87·3	NB (BD)	92·6	BB2 (Aves 5)
72·4	NB	78·0	BB3	87·4	BB3	93·5	NB
72·6	Aves 4	78·1	NB (BD)	87·9	BB5	93·6	BB3
73·0	BB1 (Aves 4)	78·4	BB3	88·7	NB	93·8	NB
73·2	BB2 (Aves 5)	79·2	BB5	88·9	BB2	93·9	BB3
73·6	BB1 (Aves 4)	79·5	Ka3 (partly) (BD)	89·1	BB3 (Aves 5)	94·1	NB
74·7	BB2	80·0	BB3 (BD)	89·2	NB	94·5	BB2 (Aves 5)
74·8	NB	80·2	Ka4 (BB4) (BD)	89·3	BB4	94·8	BB3 (Aves 5)
75·1	BB2	80·4	BB3 (Ka5) BD	89·4	BB2 (Aves 5)	94·8	BB2 (Aves 5)
75·2	BB3	80·5	BB4 (BD)	89·6	BB4	95·1	BB3 (Aves 5)
75·4	BB2	80·6	NB	89·7	BB3	95·3	NB

	1	2	3	8	18	22	23	25	31	10	30	4	12	9	35	19	16	6	24	28	11		
																							56·1 Aristarchus – Pundinga go still
58	✓		✓	✓✓	✓	✓	✓	✓	✓			✓										307 308	60·8 head – fence (4)
60	✓		✓	✓✓	✓	✓	✓		✓				✓	✓								305 306	65·8 yards turn N
62	✓		✓	✓✓	✓	✓	✓		✓			✓		✓	✓							307 308	66·1 Tank (15 Mile Tank) go NE (N then)
64	✓		✓	✓✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓						310 309	66·7 turn N→NE (4)
66	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓		✓	✓				311 310	71·0 Tank, continue NE.
68	✓		✓	✓	✓	✓	✓	✓	✓		✓			✓✓	✓			✓	✓			312 313	71·4 Cr. Four Mile Spitfire – Aristarchus, go [illegible]
70	✓✓		✓		✓	✓	✓		✓			✓	✓	✓✓						✓		313 314	76·9 Tank [illegible] – go NE still.
72	✓✓	✓			✓	✓	✓		✓			✓	✓	✓								314 315	77·3 Dunkin W – 4 mile fence, [illegible]
74	✓✓	✓			✓	✓	✓		✓			✓	✓	✓								315 316	79·1 Junction (4) (4)
76	✓✓	✓			✓	✓	✓					✓		✓✓								316 317	80·6 tank
78	✓✓	✓			✓	✓	✓					✓		✓✓								317 318	81·6 Dunkin 0·5 go back to turnoff
80	✓✓	✓			✓	✓	✓		✓			✓		✓✓		✓					✓	318 319	at 84·1 head W.
81·6	✓✓	✓				✓	✓					✓		✓							✓	319 320	87·8 fence (N-S) continue W (Dunkin W. Mallee Hen)
86	✓✓	✓				✓	✓					✓		✓		✓					✓	320 321	89·1 Gate Malleehen – Four Mile go W [illegible] on (4) still.
88	✓✓	✓				✓	✓					✓	✓	✓✓								321 322	
90	✓	✓			✓	✓	✓					✓	✓	✓							✓	322 323	91·8 Four Mile – Spitfire Mt [illegible]
92	✓✓					✓	✓					✓	✓	✓✓							✓	323 324	leave track, go N –
92·6	✓✓	✓			✓		✓					✓		✓								324 325	92·6 Mallee Hen fence, return to at head in traverse 93·4
96	✓✓	✓				✓	✓							✓								325 1%	

FIGURE 4

A typical page of the field log books of Jessup's.

Upito 1' [illegible]

Stony. "BSS" c [illegible]	.4	6.7	M	—	55
0 — 4" bright brown	.1	6.8	Angular	—	
loamy sand	.1	6.9	MS	3-6	
	.1	7.0	MS	4-6	
+ heavy [illegible]	.1	7.1	[illegible] S	3-6	
NP. [illegible]	.4	7.5	M	—	
	.1	7.6	Angular		
[illegible]	.2	7.8	MS	3-6	
	.2	8.0	MS	3	
	.2	8.2	M	—	
	.1	8.3	MS	3-5	
	.3	8.6	M	—	
	.1	8.7	MS	3	
	.1	8.8	M	—	
	.2	9.0	MV	3	
		[illegible] 9.0			
		9.1	[illegible] V	3	

[illegible]
9.9

Trial Traverses: Bulgunnia Station.

After sufficient proficiency in estimation was obtained, Jessup's re-written field notes for Bulgunnia Station were used to begin repetition of his traverse coverage of the Station. Three of his original traverses were completed, each taking one or two days continuous travelling. Where the density of a bush stand was uncertain, a count was performed by driving across the stand, close to and parallel with the traverse route, so that no extra distance was travelled.

After return to Adelaide, a graphical comparison of the two sets of data was made for sections of traverse 2 and 3 (Figures 5 and 6). It appeared that Jessup tended to "average out" bush with variable density over short distances. It was also evident that in traverse 2, which crossed much bush consisting of all three rateable species, there were differences in what each observer considered was the "dominant" species (Figure 7).

This was partly explained later by Jessup (pers. comm., 1970), who said that he used conspicuousness rather than density in deciding the dominant species. This would tend to favour *Kochia sedifolia*, on account of its size and colour.

On the next field trip it was decided firstly to repeat these trial traverses as a check in self-consistency and then to re-run these traverses again using a revised method of estimation, incorporating the points mentioned above. The results from this are shown on Figures 5-9.

Figures 8 and 9 show the same sections of traverses 2 and 3, with the results represented as "quantity units". These are calculated by multiplying the length of each stage in tenths of a mile by the density stage numbered in reverse order 5 to 1. This method does not give an accurate representation of the total bush over that interval, as there is not a linear relationship between the density stages and the numerical values they represent. However it suffices to illustrate general trends.

A comparison between the three trial traverse runs shows that repeat estimations were consistent to within ±5%. There were nearly three months between the first and last run, which would prevent any bias due to possible remembering of previous estimations, and repeating some of the traverse travelling in reverse direction would have ensured this.

FIGURE 5

Trial Traverse 3.

A section of the traverse is shown. *Kochia sedifolia* was the only bush type present.

F = fence.

R = Woolshed road.

G = Griffin bore.

D = Days Bore.

Figure 5. TRIAL TRAVERSE 3

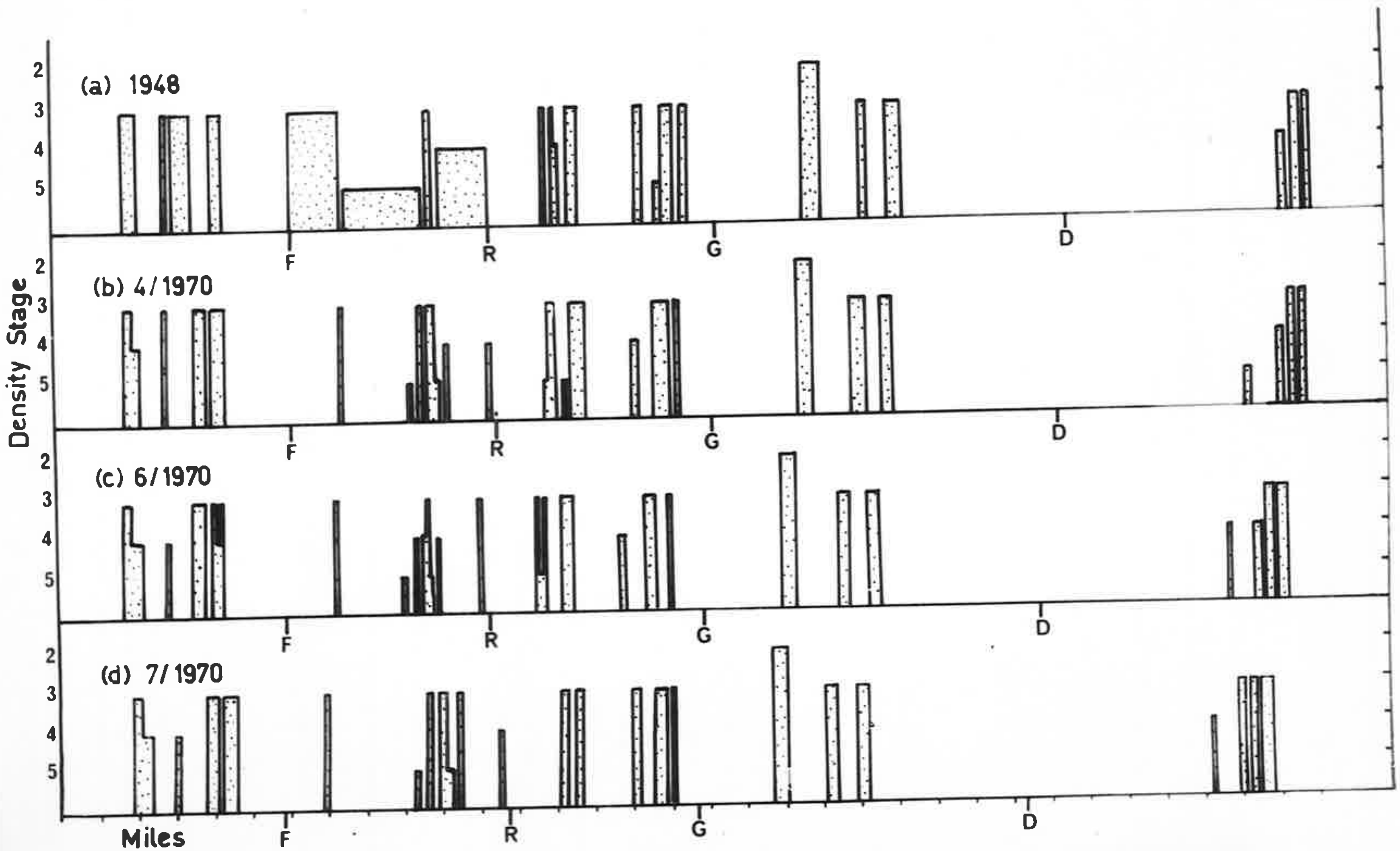


FIGURE 6

Trial Traverse 2: *Atriplex vesicaria - Kochia astrotricha.*

D = Doubtful- E. Butler fence.

F = Mulgathing boundary fence.

S = Satisfaction bore.) not recorded
) by Jessup.
B = W. Butler - W. Pegler Fence)

Figure 6 Trial Traverse 2 : A. vesicaria - K. astrotricha

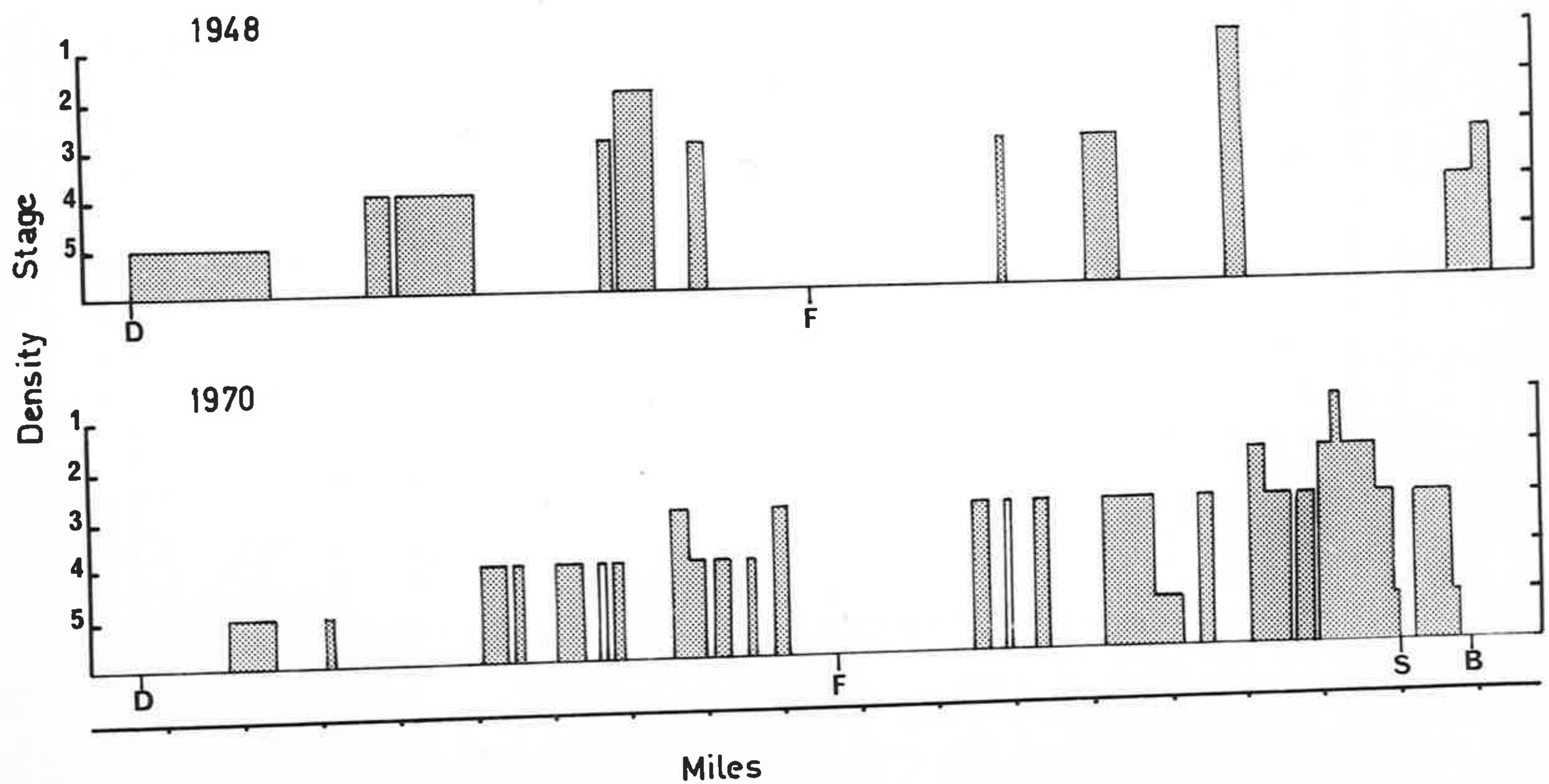


FIGURE 7

Trial Traverse 2: *Kochia sedifolia.*

Key to letters is on Figure 6.

Figure 7. Trial Traverse 2 : K. sedifolia

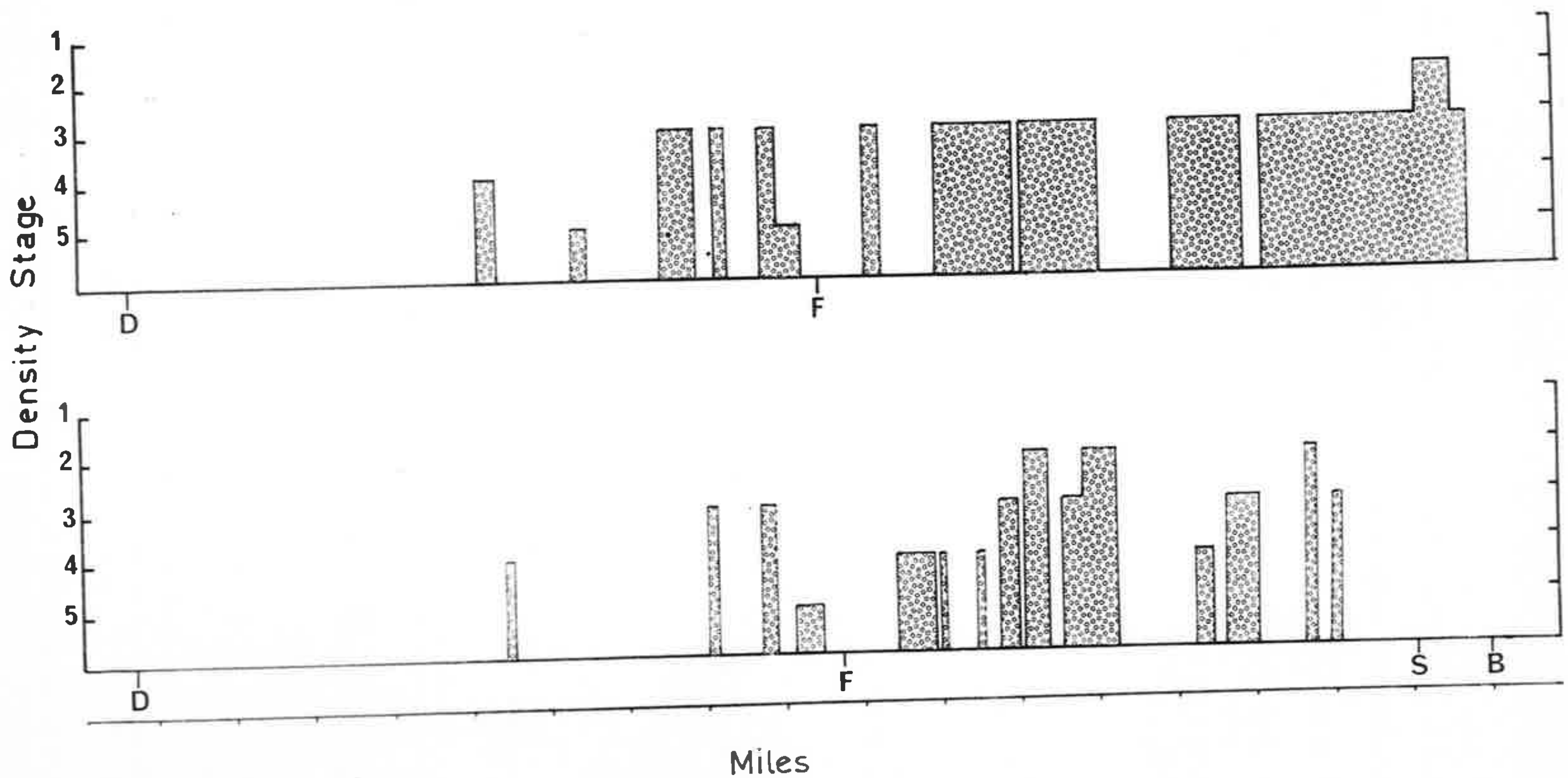


FIGURE 8.

Quantity Units: Trial Traverse 3.

Jessup's estimates and those of the three trial traverses are shown. (For key to Section letters see Figure 5).

Figure 8 Quantity Units, Trial Traverse 3

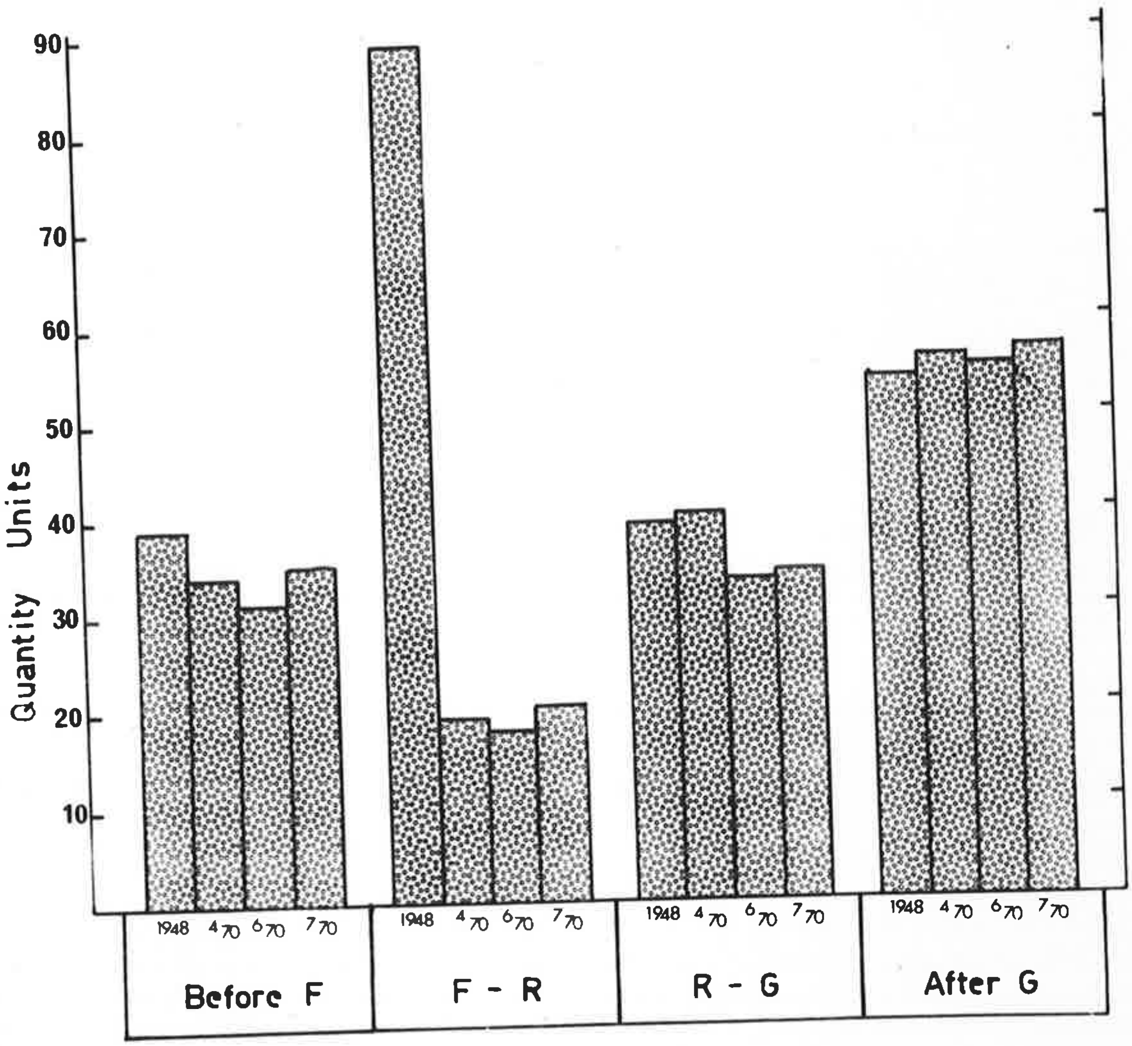
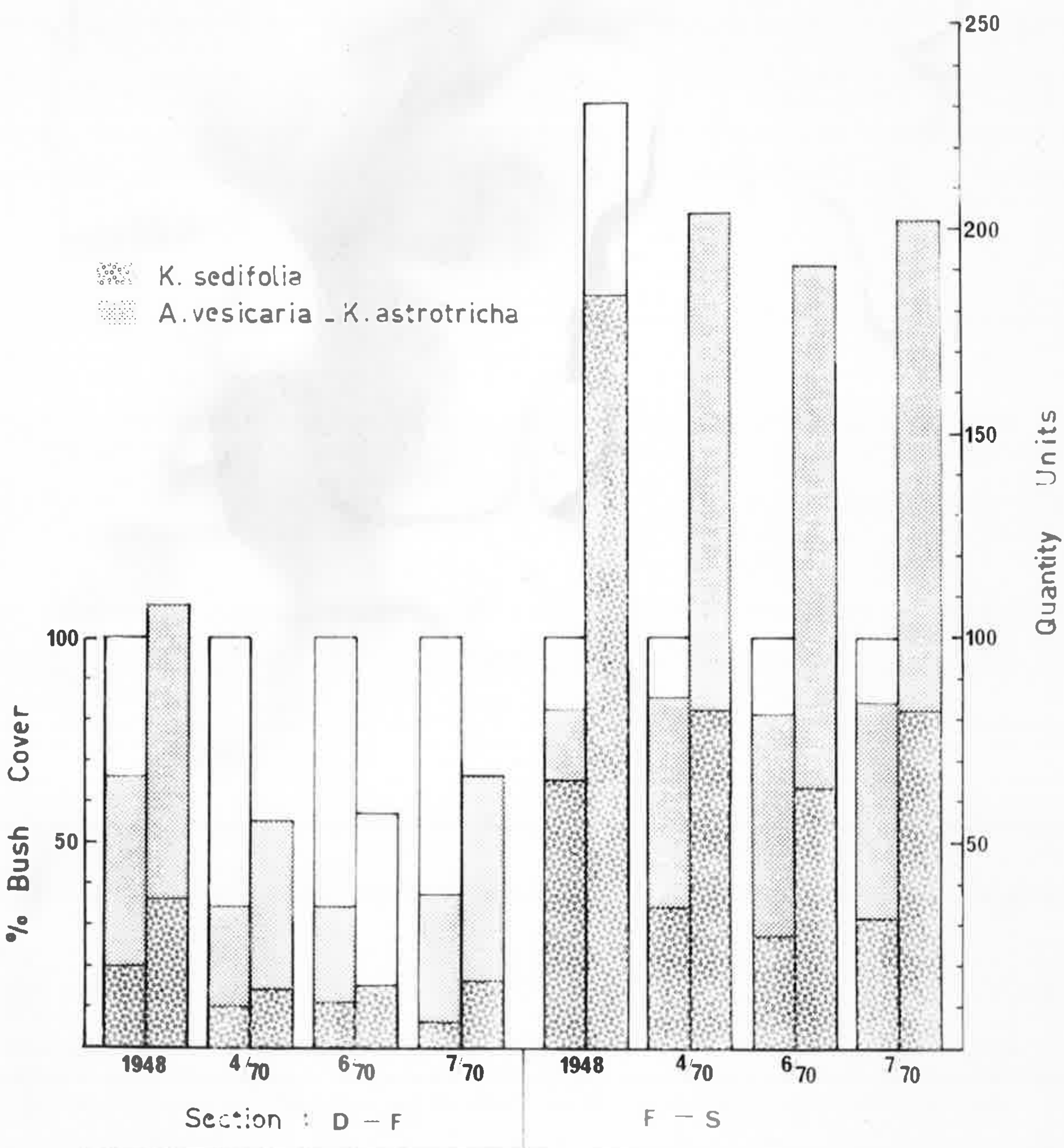


FIGURE 9.

Quantity Units and Percentage Bush Cover:
Trial Traverse 2.

The distance of the section F - S could not be checked from Jessup's notes, as he did not record Satisfaction Bore. The percentage cover, which is the first bar on the graph, is the proportion of traverse distance supporting rateable bush.

Figure 9 Quantity Units & %Bush Cover, Trial Traverse 2



Execution of Survey: Methods used and Data Obtained.

Once satisfied that the method was tenable, a standard survey procedure and recording method was adopted. This had to take account of theoretical deficiencies and practical problems in Jessup's field notes, and was finalized after the extra work to be carried out while undertaking the survey (Chapters 6 and 7) was decided upon. The remainder of Bulgunnia and the rest of the area was then systematically traversed, and the methods used are outlined below, with reference to Figure 3.

The survey was carried out on a station by station basis, using a Land Rover. Work was done on 12 extended field trips (2-5 weeks each) from Adelaide, rather than from a field base, as used by Jessup. Before commencing work on a station, the paddock plan was consulted and Jessup's traverse route located, where possible, with the assistance of the Station Manager. To permit a more uniform and complete traverse coverage, the 1:250,000 topographic map series was used to map out additional new traverses, along tracks and fencelines. At least two miles (3.2km) of traverse was located in each 10,000 yard grid square. Occasionally this necessitated running non-repeatable cross-country traverses.

Where possible, each traverse, which was numbered, began at the homestead and finished there. It was usually accomplished in one day during summer, but sometimes took two days during the shorter daylight hours of winter. At the beginning of the traverse, an indication of the area to be covered was recorded in the log book, together with the time of departure. Columns 1 to 8 (Figure 3) are used solely for the bush density estimations. The odometer readings refer to the points where the corresponding density stages end (Figure 10). Columns 9 to 30 were used for the biogeographic survey (Chapter 6), while the last column contains a detailed description of the traverse route taken and corresponding odometer readings. Sketches and a scale of "track condition and use" ratings were used to further assist the future investigator.

Jessup's bush density scales were used, with the following modifications:

(1) Where subdominant rateable species were present, their density stage was estimated and indicated in brackets. For example BB3 (Aves 5) represents a stand of *K. sedifolia* which is stage 3 because it contains some *A. vesicaria* bushes with a density equivalent to stage 5. This will help explain a future reading for this stand of, say BB4; after the *A. vesicaria* has died or been grazed out.

(2) Where there is doubt as to which shrub type is dominant, the alternative rating is also given. For example BB1/Aveska 3 represents a stand of both *K. sedifolia* and *K. astrotricha* - *A. vesicaria*. If rated as *K. sedifolia*,

it has a density stage of 1, while if rated as *K. astrotricha* - *A. vesicaria* it has a density stage rating of 3. Plate 2 shows this species with *A.vesicaria.*

(3) A fourth species, *Cratystylis conocephala,* was rated independently, using the same scale as *K. sedifolia.* This was introduced largely to avoid confusion with *K. sedifolia* which it closely resembles in general appearance at distance. However, it appears to be far more sensitive to grazing pressure than any of the other three rateable species, and may therefore provide an interesting comparison in the future. It occurs only in the far south and west of the survey area (Map 28 and photopoint 19, Volume II).

(4) Throughout the duration of the survey, counts were made of any doubtful bush stand. Figures from these counts were recorded above the appropriate rating in the field log book.

(5) No attempt was made to estimate original bush density on "new" traverse except in those areas where the bush had been recently killed out.

(6) When the traverse route ran along a fence, bush density and its limits were carefully assessed on both sides of the fenceline. Jessup only recorded this where obvious severe degeneration had occurred (for example Plate 8).

The survey took eight months continuous work, was completed in October 1971, and involved a total of 32,000 miles (51,000km) of travel. About half the work was done alone. On the rest an assistant recorded the data, which considerably increased speed and efficiency, as without one the vehicle had to be stopped before data could be recorded. A tape recorder was not used for this as the ones available were impractical under the physical conditions encountered.

Execution of Survey: - Problems Encountered.

After the first Station (Bulgunnia) was completed, several serious problems manifested themselves. Because some of these are common to other long-term work of this nature, they will be described here in detail. An approximate breakdown of the proportion of total traverse rendered useless for comparison by these problems is given on Table 5.

1. *Traverse route:*

Two main problems are concerned with location of the route taken by Jessup. Firstly, although recording the odometer readings at most reference points he passed, Jessup often failed to mention the name of the paddock fence, bore etc. concerned. This is understandable when it is realized that he did not write his notes with a view to anyone re-using them. However it resulted in a great amount of time wasted trying to locate his likely route, often unsuccessfully.

Secondly, even where the route taken was fairly clear, after more than 20 years many of the tracks he used had either completely vanished, or been obliterated by straighter roads graded since. This was particularly serious in the Koolymilka area. In this case, where the original track was still followable, a traverse was run along both routes.

Many other tracks were followable only with extreme difficulty, which in some cases involved walking ahead of the vehicle at times.

A compounding factor aggravating these problems with the traverse route was the difference in method of execution of the survey. It has already been mentioned that Jessup worked from a field base, Mt. Eba Station. As a result, many of his traverses crossed several station boundaries, and on few stations did he attempt to methodically complete a traverse coverage before beginning the next one. In the present survey, each station was effectively completed before another was tackled and traverses were restricted to one station. This difference in method resulted in some traverse being covered more than once, while other sections could not be located because of approach from a different direction.

(2) *Lost Data:*

The original data on three complete stations, Ingomar, McDouall Peak and The Twins, and on part of Mt. Eba, and Commonwealth Hill had been lost completely between the time of Jessup's survey and this present study.

(3) *Ambiguous Data:*

In a surprising number of cases, it was found on comparison that sections of original traverse were anomalous, or failed to register in any meaningful way with the present survey. Examples of this are in trial traverse 3 (Figure 5). In an apparently well preserved area, isolated large patches of *K. sedifolia* have "disappeared". This anomaly could result from a slip in recording, or a different route with the same overall length being taken. The former explanation is certainly feasible considering the near illegibility of much of the original notes (Figure 4). Another example is in Traverse 2, section 4 (Figure 6). There, although the route is specified, the bush density data reveal that bush patterns and odometer readings do not match up, presumably due to either a faulty odometer or a different route taken between reference points.

The odometer is certainly not sufficiently accurate for this type of survey, and resulted in systematic errors in distance over most traverse intervals. This is obvious when one considers that the reading of the instrument will vary both with the changes in pressure of the tyres and the amount of rubber left on them.

Only about 15% of the present survey is comparable with Jessup's as a result of these problems (Table 5), but it is hoped that the technique used on this survey will enable a future investigator to circumvent them to a large degree.

Correlation Traverses.

Although this method of estimation of bush density can be checked by actual counts, when one considers a typical field situation as presented in Figure 10, it is obvious that there are many subjective decisions which have to be made. Two of these are mentioned above, and others are:

(1) How to decide where and when a bush stand cuts out or changes in density stage;

(2) how to rate apparently dead or nearly dead bush;

(3) how to rate patchy or patterned bush;

(4) how to determine, in dense bush, what constitutes an individual for the purpose of counting.

FIGURE 10

Diagrammatic Representation of a Field Situation

Sketches similar to this have been used in the Field Log Books to assist in subjective decisions made on this survey.

The traverse route is shown on this hypothetical example by a dashed line, and 1/10 mile intervals are represented by blocks along it.

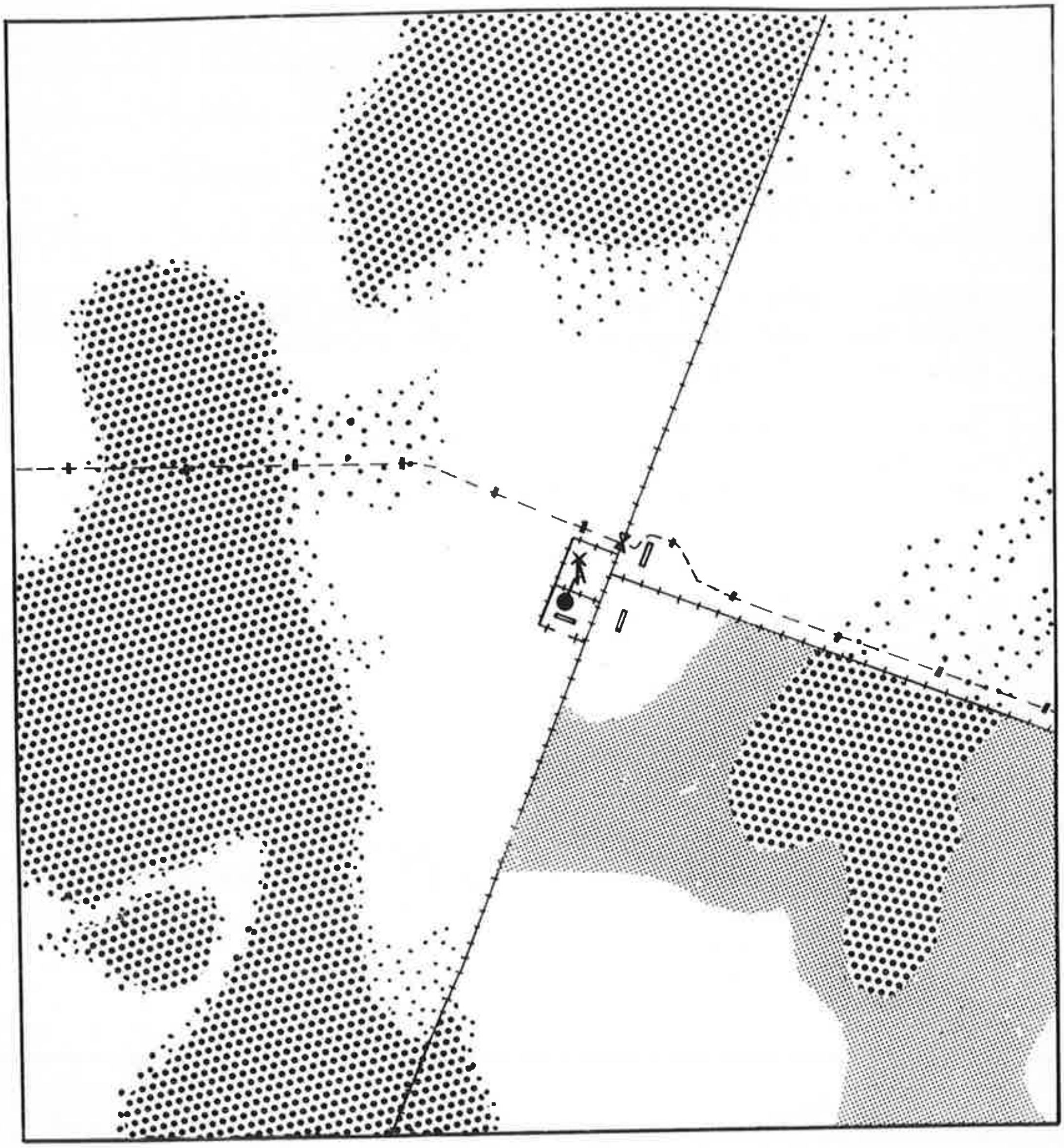
If the uniform stands illustrated are *Kochia sedifolia* stage 3 and *Atriplex vesicaria* stage 4, then the bush density recordings would run as follows (assuming the traverse runs from left to right starting at, say, 18.0.

18.0 N.B. (No bush)
18.2 BB3
18.4 BB5
18.8 N.B.

	L.H.S.	R.H.S.
18.9	N.B.	Aves 4
19.1	BB5	BB3

18.6 Jims bore.
Go through gate and E.S.E. along Jim-Peter fence.

Figure 10 Diagrammatic Representation of a Field Situation



K. sedifolia - uniform stand

A. vesicaria - " "

K. sedifolia - scattered bushes

TABLE 5

FIELD DATA PROBLEMS AND THEIR EFFECT ON PROPORTION AND LENGTH OF COMPARABLE TRAVERSE

	Miles	Km.	%
Total traverse in this survey	10,000	16,000	100
New traverse	5,500	8,800	55
Jessup's data lost	1,500	2,400	15
Jessup's route unfollowable	1,000	1,600	10
Ambiguous data	500	800	5
Comparable traverse	1,500	2,400	15

Other problems could be listed. It was therefore apparent that there may have been a consistent difference in the method and results of estimation by Jessup and the present investigator. To ascertain this, a series of three "calibration" traverses were run in all bush types from Woomera in March 1971. After sufficient familiarization, Jessup and Lay separately rated the same bush stands from a vehicle with an independent arbitrator between them. Much of the traverse was run through patchy and degenerate bush stands, and it was considered a good test of any variability in rating method between the two observers. The results are shown graphically on Figure 11 and 12. Examination reveals certain differences in method, but good agreement on amount and species of bush estimated. This is verified statistically in Chapter 8.

To partly overcome these problems for the future investigator, a series of diagrammatic field situations in which subjective decisions had to be made were shown in the field log books. (Book 1, pages 169-181, and Book 6, pages 100-110). Less common contingencies are explained at the time, or coded and referred to in the legend at the back of several of the books.

FIGURE 11

Correlation Traverses: Sections of traverse 1 and 3 are shown.

Traverse 1: Wirraminna Station.

- T = Transcontinental Railway crossing.
- L = Lake Hanson Dam.
- W = McDonald's Well.

Traverse 3: Roxby Downs Station.

- R = Red Lake turnoff.
- A = Allenby Dam.
- M = Mt. Marjory Dam.
- B = Big Marjory Tank.

Figure 11 Correlation Traverses

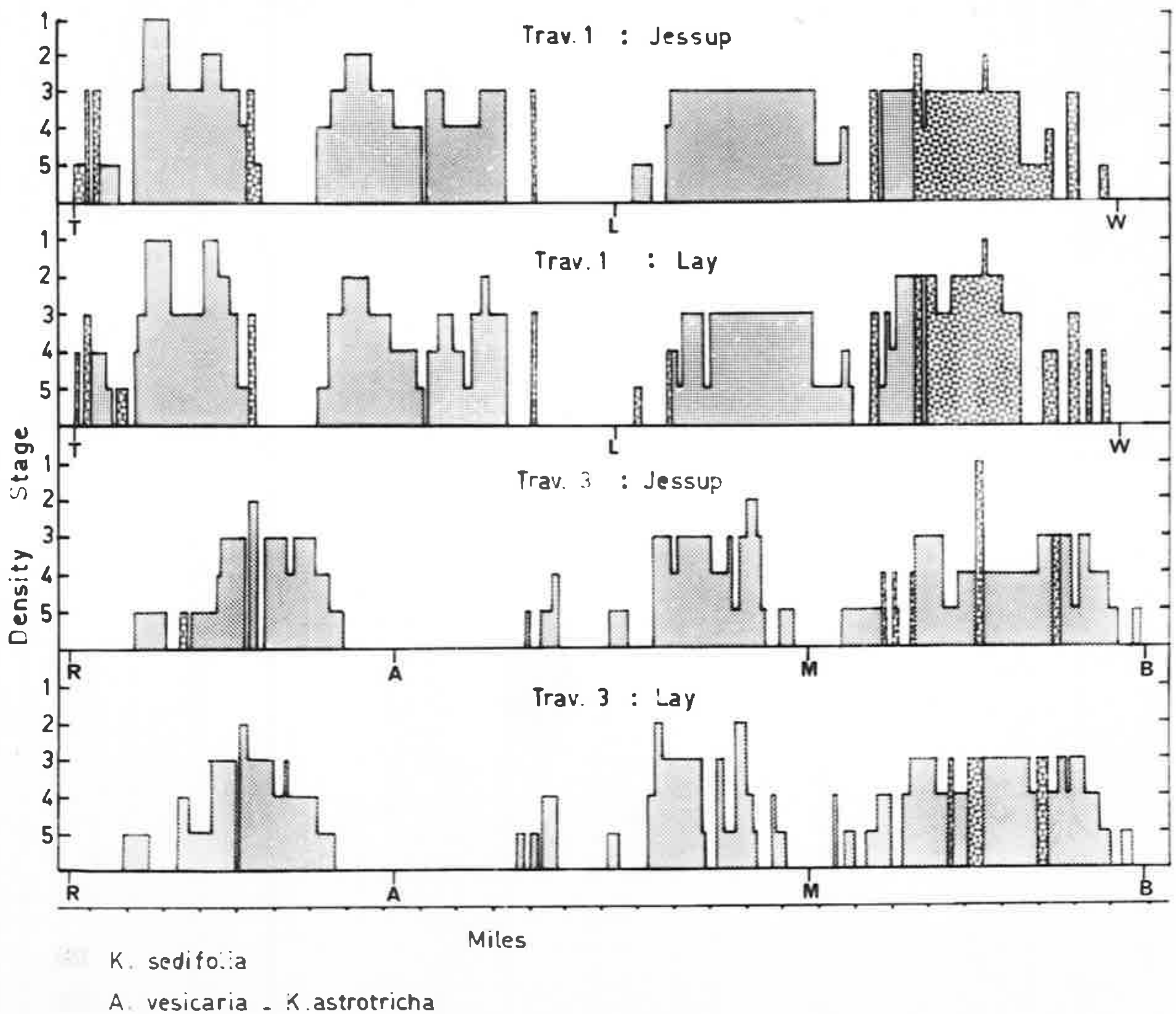
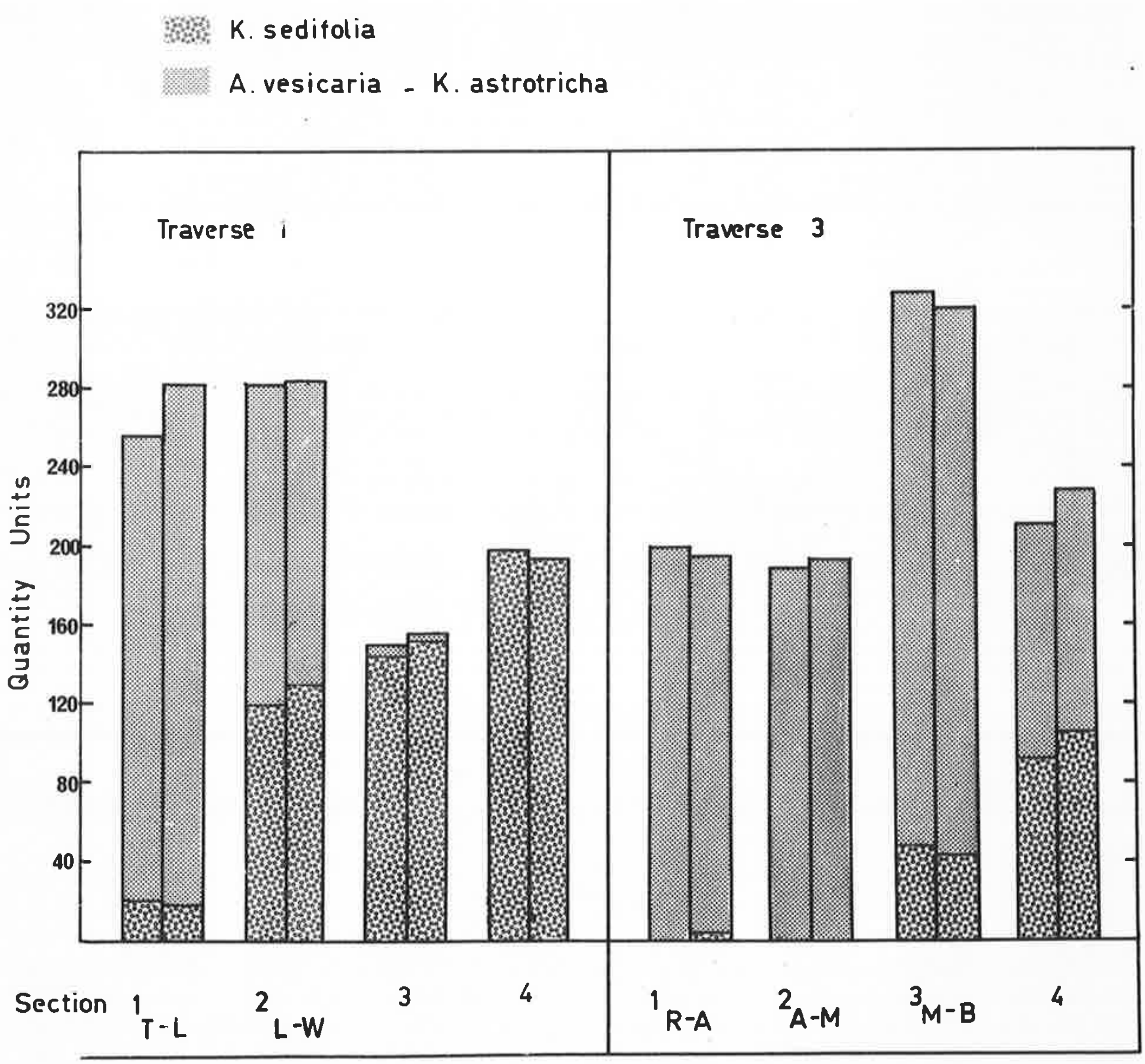


FIGURE 12

Correlation Traverses - Quantity Units.

Unlettered sections are not shown on Figure 11.

Figure 12 Correlation Traverses - Quantity Units



Summary.

After thorough familiarization, the whole of Jessup's original study area was resurveyed, Jessup's method of bush density estimation being used with modifications and refinements. Problems, which are enumerated, prevented comparison of more than about 15% of the total traverse mileage.

Traverses to check self-consistency of the present investigator and correlation of rating method with that of Jessup were performed.

CHAPTER 6.

PHYTOGEOGRAPHIC SURVEY.

Conception.

As mentioned in the previous chapter, after assessment of the viability of a general survey using Jessup's techniques, additional work was considered which could be undertaken concurrently.

It was anticipated that Jessup's work would take nearly all the field time available, so the additional work had preferably to be carried out largely from a moving vehicle. Reconnaissance mapping of vegetation communities was an obvious possibility. However, Jessup had already mapped the plant associations in most of the area and it was felt that there would be little point in re-mapping it using his subjective approach. The gathering of incidence data for particular species is a much less subjective procedure. It seemed much more worthwhile to assess the vegetation by this means than simply to repeat what Jessup had done along similarly subjective lines. Gathering such objective data is no more time-consuming than making subjective assessments, and fits in very well with the survey method being used.

Development of the Method.

Species Incidence:

While the trial traverses were being re-run (pages 54 -55), various methods of recording species occurrence and abundance were tested. The most practicable method appeared to be a systematic sampling along the traverse route and the recording of species incidence.

On an experimental traverse through the study area, various sampling techniques were tested. Initially, a method of recording conspicuous woody species at systematic sampling points along the traverse was decided upon, as it could be used both to map species distribution and to determine interspecific association. About twenty species were selected on the basis of ease of recognition and abundance. Every two miles the vehicle was stopped, and all of these species were scored for incidence. It was evident (field log book 1, pp. 29-31) that this method resulted in very low scores for most species over much of the country traversed.

Subsequently a revised method was tested. Only species readily recognized from a moving vehicle were used and the traverse was again divided into two-mile intervals. This time each species was recorded if it was seen anywhere along the particular interval. This naturally resulted in higher scores for all species and was thus thought to provide more reliable data for each.

Character Plants:

After familiarity with this method was obtained, it was decided to record intervals over which any of the species chosen was a character (dominant) plant (Adamson and Osborn, 1922). This was thought desirable when one considers that many species which occur in arid areas are quite widespread but only form minor and scattered components of the vegetation communities, while others compose dense monospecific arid woodlands. Any of the selected species which was a character plant over more than half of the interval would be recorded as such.

Regeneration:

Certain species, notably *Acacia aneura* and *A. sowdenii*, form monospecific stands over large areas, and are of great value both as topfeed forage and for prevention of soil erosion. It is generally believed that there is no significant regeneration of these species occurring over large areas under present conditions, and much has been written on requirements for successful germination and establishment (Osborn, Wood and Paltridge, 1935; Hall, Specht and Eardley, 1964; Preece, 1971) and the reasons for the lack of it (Jessup, 1951; Ratcliffe, 1936). It was therefore decided to map the extent of regeneration on the basis of number of seedlings seen over the interval.

Mortality of Acacia aneura:

Extensive areas of total or near total mortality of this species have been observed and described by Ratcliffe (1936), Condon (1949) and Lange (1966). It was therefore thought worthwhile to map these areas on the basis of the ratio of live to dead standing individuals.

Selection of Species.

The selection of the species to be used was guided by two aims. Firstly all major large shrub and tree species in the survey area would, hopefully, be included, and secondly, only those species which could be reliably determined at distance from a moving vehicle could be used. While undertaking the trial traverses many species were selected which were later found to be difficult to spot or identify in certain topography, vegetation types, or when covered in dust. Before the final trial traverse was begun, a basic list of about fifteen species had been selected. From that point on, distinctive new species were added to the list whenever they were first encountered on the traverse, providing it was certain that they had not been missed before. It became apparent later that in one or two cases the single species recorded first was actually two closely related species e.g. *Acacia aneura* and *A. brachystachya*. These species were still included because this did not affect their value if their combined distribution still had ecological significance.

Distance Limits for Species Identification.

The maximum range for reliable identification varied greatly between the species selected. However all species could be positively identified at a minimum distance of about fifty metres. An arbitrary maximum distance limit of about 800 metres was set for incidence recordings. This was primarily to avoid inclusion of a large conspicuous individual in two sampling intervals.

Method of Execution of Survey.

The method used for field data recording as in Figure 3, columns 9 to 30, is as follows. From the place the traverse began, the odometer reading was recorded at the nearest even figure above the reading at that place, provided this included an interval of at least one mile. From then on the traverse was divided into two mile intervals. For example, at a starting point with an odometer reading of 93.4 readings of 96.0, 98.0, 00.0 etc. were made in the field log book in column 9. The traverse was then commenced and every relevant species seen during that interval was noted. Thus, in common with the bush density estimations, the data were recorded opposite an odometer reading corresponding to the end of the appropriate interval. At the end of the interval, a decision as to whether or not any relevant species occurred sufficiently frequently to be considered a character plant was made. This was recorded with a double tick in the appropriate column. For ease in recording, the species were coded as memorized numbers, which could easily be called to an assistant, and a tick recorded opposite the appropriate odometer reading, without stopping the vehicle. This method was used on all traverses, throughout the survey, without further modification.

Density Measurements as a check on Character Plant and Regeneration Ratings.

It was decided to establish, by counting, the numerical limits for the subjectively estimated character plant and regeneration classes, in terms of the number of individuals per unit area of the species in question. When thoroughly familiar with these classes, intervals in which a particular species was estimated to be marginally dense enough to be classified as a character plant were noted. These intervals were then re-traversed, where practicable, with all live individuals present within a 10 yard (≈10m) strip on one side of the traverse route being counted. This "quadrat" was not marked out, but as with the bush density estimations, doubtful scores were checked. Counts were only made where there was no tendency for the traverse route to follow particular terrain, for example watercourses or treeless areas. In general the most satisfactory location for these counts was along the uncleared side of a recently constructed fence, although the side of a straight bulldozed track was often used. Counting was discontinued if stumps or evidence of other disturbance was located in the quadrat.

As well as doubtful cases, average and dense stands of these species were also counted to give some idea of the typical values involved, as no such measurements for most of these species have been published. A summary of results of density measurements is given in Table 6.

Data on seedling incidence were recorded for three species, *Acacia aneura, A. sowdenii* and *Callitris columellaris*. These three species reproduce entirely by seed and as the seedlings are characteristic in appearance and easily distinguishable, recordings were made on the basis of numbers of seedlings below a certain approximate height, seen over the interval. The exact method used for each of these species is described more fully in Volume II.

Preparation of Distribution Maps.

The details given here are primarily intended to illustrate the method used to prepare the maps included in Volume II.

TABLE 6.

DENSITY MEASUREMENTS ON CHARACTER PLANTS (INDIVIDUALS /3.2ha.)

Species	Maximum Count Recorded	Average Count for Character Plant	Threshold* Density		Number of Counts
			Average	Range	
Acacia aneura	284	114	39	27 - 53	18
Acacia linophylla	252	145	80	58 -102	7
Acacia sowdenii	64	39	13	8 - 19	21
Callitris columellaris	46	45	19	16 - 21	4
Casuarina cristata	178	110	26	12 - 41	4
Eucalyptus transcontinentalis	83	83	43	-	2

* These counts were performed where the density of a species was considered marginal between occurrence and character plant classes.

Once the survey was completed, a base map showing station boundaries, traverse route, and other features was drawn up using the field log books, paddock plans, and the 1:250,000 map series produced by the Army Survey Corps. The 10,000 yard reference grid was redrawn at a smaller scale and traverse route drawn in with respect to this. This draft was then redrawn on a tracing sheet, and the sampling intervals used in the phytogeographic survey were represented on the map by compass drawn circles along the traverse route.

These circles were drawn at the mid-point of the sampling interval. For example, the interval ending at 88.0 in column 9 on Figure 3 would be located on the map at a position corresponding to 87.0, or 0.8 miles from Durkin West - Mallee Hen paddock fence. Not all field reference points could be located on the base map used in drafting the traverse route. Where there were several intervals between reference points locatable on the base map, these were equally spaced along the traverse route between the points. To increase the uniformity of sampling point coverage, and hence lessen the probability of apparent spurious distribution patterns, some points along traverse in well covered areas, e.g. Bon Bon Station, were deleted.

The base map was then reproduced by contact print on dimensionally stable "Cronaflex" plastic film. This reproduction was then used to prepare overlays for each species.

Before this could be done, each sampling interval was numbered consecutively for each Station in the field log books (Figure 3, column 31). These numbers were then transferred to the corresponding point on a dyeline copy of the base map.

Each overlay was prepared using data transferred directly from the field log books. The relevant species column on each page was scanned until a tick for the species was recorded. The corresponding sampling point number was noted, checked for position on the dyeline copy, and then a solid circle was drawn over the corresponding point on the base map. Where a double tick was recorded for the species, this interval was not recorded, but another overlay was used to record these occurrences, representing intervals where the species occurred as a character plant.

When these were completed, additional overlays were prepared showing relevant portions of published maps which covered the area. These were prepared using a continuous enlargement light table and reference points common to both maps. Problems due to distortion and difference in projection were encountered, and where small scale maps were used, boundaries redrawn from them are only accurate to within about 15km.

When all the overlays were completed, the next step was to produce smaller scale negatives of the base map and overlays.

These were produced at foolscap size, as it was the greatest reduction possible, using dimensionally stable ester based film.

After spotting, the negatives were used to prepare aluminium masters for photolithography. Firstly sufficient base maps were printed on a Multilith machine for all the overlays, allowing 200 copies of each map for general distribution. These were produced in a light blue, so distribution patterns would be more evident. The original base map, which had subsequently been slightly corrected in preparation of the species distribution maps, was run off in black. The overlays were then printed over the blue base maps, using registration marks on the edges of each. These were printed in red, and where a second overlay was prepared for a particular species (e.g. for character plant distribution), this was printed in black. There were problems with registration here associated both with the printing machine used and with the fact that the printing paper was not dimensionally stable.

Data obtained from the Survey.

Distribution data were recorded whenever bush density traverses were run. Therefore approximately 10,000 miles or 5,000 sampling intervals were covered. However a proportion of this traverse was run along a route close to a previously run traverse (e.g. when following both old and new tracks to the same point). On these occasions, either no distribution data were recorded, or the data were abandoned during processing. Altogether about 4,300 sampling intervals are shown on the maps, and on each of these the presence, as occurrence or character plant, and extent of regeneration where applicable was noted for 41 species. These species are listed in Appendix II, and include all large shrubs and trees in the survey area with the possible exception of *Exocarpos aphyllus* and *Eremophila duttonii*.

CHAPTER 7.

FLORISTICS AND PHOTOPOINTS.

This Chapter describes additional work carried out while undertaking the survey described in the previous two chapters. As it forms no part of the survey procedure it is considered separately here.

Floristics.

After an examination of published ecological work, it was evident to the writer that any studies dealing either with the broadscale occurrence of a species, or involving poorly known taxa, rely for their value and validity on properly collected, preserved and identified specimens of these plants. These specimens, curated and stored in an herbarium, are of great value in any critical scientific study on vegetation. Their chief value can be summarized as follows:

(1) They provide a permanent record of the reliability of determinations of plants used in the study.

(2) In conjunction with voucher specimens they assist in field identification of species.

(3) They provide the only accurate means of defining the broad geographical range of any species (e.g. see Carrodus, 1962; Carrodus, Specht and Jackman, 1964; Rogers, 1971).

(4) With habit and habitat data, they provide invaluable autecological information.

(5) They can be used to document any invasion or regression of species which occurs over a very long time period.

(6) By means of these specimens only, the taxonomic relationships of all plants are evaluated.

It is certainly evident that the value of species lists meticulously prepared for plant associations in the present survey area by Jessup (1951) is considerably reduced when it is realized that these lists were compiled from field identifications, with no permanent collections being made.

For these reasons, and as there had been few plant collections from the study area (Eichler*, pers. comm. 1970), an extensive herbarium collection of all plants in identifiable condition was considered worthy of the extra time required. It would also provide a check on identifications of species used in the phytogeographic survey.

Method of Collection:

In general, the first time a plant was seen in an identifiable condition (with flowers or fruit) it was collected. This approach was used throughout the dry year of 1970. Following

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* Eichler, Hj. - Keeper, South Australian State Herbarium.

heavy rain in early 1971, ephemeral vegetation was collected mainly at sites where the vehicle had to stop for other reasons, in particular, the erection of a photopoint post.

If possible, at least two full sheets of each species were collected at each site. The location along the traverse route, grid reference on the relevant 1:250,000 map sheet, together with habit and habitat data were entered into a herbarium book opposite the appropriate collecting number. In general, common plants seen over the whole survey area were only collected once or twice, so that time would be available to collect all species seen.

After drying, one herbarium sheet of each species was incorporated into a reference herbarium at the Department of Botany, University of Adelaide, while the rest were sent to the State Herbarium of South Australia, where they were determined and incorporated.

Floristics of Survey Area:

Appendix I contains a list of all species collected in and around the survey area. It was intended to correlate this with similar lists produced by Jessup (1951); Wood, (1929); Murray (1931); Adamson and Osborn (1922) and Cleland (1935). However since all except the last two of these authors had no permanent collections, the time which would have been spent checking and interpreting name changes was not justified. However, Jessup's lists were checked and of his 257 species noted, 52 were not collected on the present survey, while 200 species collected in the present survey were either not seen by Jessup, or resulted from the splitting of former taxa.

Species in the families Asteraceae and Chenopodiaceae made up the bulk of ephemeral plants seen after winter and spring rain, while flowering ephemeral and perennial species in the family Poaceae were rather more abundant after late summer rain. Species of *Acacia* in the family Mimosaceae and *Eremophila* in the family Myoporaceae were most numerous among woody plants. The families best represented in Jessup and Lay's species lists are given in Table 7 together with the proportions of species collected by Lay in summer and winter. New localities and first occurrences for the state were recorded for a number of species in the present collection.

Species used in the Phytogeographic Survey:

In order to achieve maximum reliability of determinations of the species used in the phytogeographic survey, herbarium collections of these plants were made where possible over the whole area of their occurrence. As it happened there were several species which never flowered or fruited during the period of the survey, and it was therefore seldom possible to verify

TABLE 7.

BEST REPRESENTED FAMILIES AND GENERA COLLECTED.

Family	Species collected by		Season* of Lay's collection.					Best represented genus - Lays collection (species no. in brackets)
	Lay	Jessup	W	S	W+S	%W	%S	
Asteraceae	62	31	38	12	12	81	29	*Helipterum* (14).
Chenopodiaceae	58	56	33	19	4	69	38	*Atriplex* (18)
Poaceae	38	20	16	18	4	52	59	*Eragrostis* (6)
Fabaceae	24	10	10	11	3	54	58	*Swainsona* (10)
Myoporaceae	21	16						*Eremophila* (18)
Myrtaceae	19	7						*Eucalyptus* (8)
Mimosaceae	18	18						*Acacia* (18)

* W = Winter - May to September inclusive. S = Summer - October to April inclusive.

Note: These lists are probably not representative as only one heavy rain was recorded in summer during the survey period, and no collecting was done during January or February.

the determinations of these species. The location and collecting number of all herbarium specimens is shown for each species by red figures on the distribution maps.

Photopoints.

The value of the permanent photographic point in documentation of vegetational change is revealed in the literature reviewed in Chapter 3. In particular, permanent photographic points on the Koonamore Vegetation Reserve illustrate the information obtainable by this method over a long period.

As it was recognized that this survey will probably be repeated in the future, the installation of photopoints seemed to be a logical method of enhancing the value of this survey. Negligible additional work would be required by the future investigator if a sufficiently durable marker was erected, and adequate directions given to its location. The photographs of many early workers would be of great value now if they had taken the trouble to do this.

Selection of Site:

Because of the variation in the vegetation over the survey area it was considered impractical to attempt to set up photopoints in each distinct community encountered. In keeping with the theme of this study, photopoints were considered to be of maximum value in the long term if they showed mature specimens and regeneration of the woody species studied, incorporating examples of the broad vegetation types in the area. Various examples of the perennial shrubland communities mapped in Jessup's survey were also selected. In the former case, these photopoints would ultimately yield information on longevity of these plants largely unavailable elsewhere, while those in perennial shrublands could help to elucidate population dynamics in the field situation and under varying stocking regimes. In addition, some photopoints were set up to illustrate areas of ecological interest, for example, overgrazed areas, unstable sand dunes, and places where the Station Manager has taken steps to check erosion on overgrazed or scalded areas.

Installation:

It was originally intended to establish photopoints with steel droppers as used at Koonamore. However, following discussion and advice from pastoralists in the area (H. Russell, R. Fels, pers. comm. 1971) and to overcome problems of cartage with the limited space available in the vehicle, it was decided to use wooden posts instead, cut from local timber. Although they are considerably more cumbersome to transport and erect, they should outlast steel droppers in most soils provided the right size, condition and type of timber is used. Many fence posts are still sound after more than 50 years in the ground.

102 photopoint posts were installed throughout the survey area (Map 51, Volume II), using the following procedure.

After selection of the site, a suitably sized recently dead tree or branch of *Acacia aneura*, or *A. sowdenii* was located, and a straight length of about 2m was carefully cut to prevent splitting of the ends. Where no timber was available a post was carried in the vehicle, or, where the occasion presented itself, other materials, for example a length of railway line, were sometimes used. All bark was then removed to discourage entry of termites, and the top end roughly sharpened for accuracy and ease of placement of the camera. A hole was then dug to a depth of 40-100cms using a crowbar, and the post inserted, leaving about 150cms protruding. After filling in the hole, a thick aluminium label was stamped with the relevant details, and attached to the post using galvanized masonry nails. A typical post is shown in Plate 15 (P.P.39). The photographs were then taken, using a 1m graduated post as scale (see Volume II). An exact description of the location, camera, film, date and time of day, and details in the photograph were entered into the field log book (Book 4, pp. 145-188). The total time taken for the whole operation varied between half and two hours.

PLATE 15

AN EXAMPLE OF A PHOTOPOINT POST SET UP DURING THE SURVEY. (P.P. 40).

The post, of *Acacia calcicola*, is 140cms high.

Photography:

The most satisfactory photographic techniques were not developed at the outset, and as a result, records of the earlier photopoints consist of only a single frame of either monochrome or colour slide film. No scale post was used in the earliest photopoints, while for some later ones (up to P.P.20) a makeshift scale was used. All photographs were taken with the camera resting on the post, and the exact direction in which they were taken was recorded in the field log book.

From later photopoints, stereopairs on Ilford FP4 film were usually taken, with the camera being moved approximately 10cms to the right of the post for the second frame. Where practicable, a colour slide (Kodachrome) was taken at the same time. For all photography, 35mm single lens reflex cameras were used.

The original negatives and a set of prints are currently filed in the Department of Botany, University of Adelaide, but future records of this continuing programme will be stored with the South Australian Department of Agriculture, Gawler Place, Adelaide, South Australia.

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S E C T I O N   I I I

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This final section firstly presents a statistical analysis and discussion of a sample of the Jessup - Lay comparative bush density data and an analysis of the data obtained from the phytogeographic survey.

The last Chapter provides a discussion of results and findings of this work and their application to the general field of research in, and management of, Australia's arid pastoral country.

CHAPTER 8.

ANALYSIS OF BUSH DENSITY CHANGES 1948-1970.

Introduction.

In Chapter 5, a graphic method of illustration of comparable sections of Jessup's and Lay's bush density estimations on Bulgunnia Station was presented (Figures 5-6). The quantity units used (page 55) for comparison of sections of traverse do provide a measure of bush change. They suffer from three serious disadvantages, however, for meaningful comparison of the whole data from this survey. First, the method requires individual calculation of units present in each bush density rating, a most laborious method, impractical on the Station scale. Second, the unequal numerical intervals of the density stages prevent any meaningful estimate of change in total numbers of bushes present, and hence forage available. Third, as illustrated in Figure 5, anomalous data, if included, would seriously affect the accuracy of any overall estimates of bush change.

It was hoped that a method such as that described above would be able to give a satisfactory comparison of the data and hence an evaluation of the location and extent of bush change. Jessup's (1951) method, using his estimates of original bush density and averaging the values obtained, was unsuitable due to the limitations discussed earlier. As no such method was found suitable, it was evident that a statistical analysis involving a sampling of the data would have to be developed. The method chosen was Analysis of Variance using normalized values of the bush density ratings.

Because of the time taken to transpose the data in a form which could be used for a statistical analysis, only three stations were selected for this purpose. These were Bulgunnia, Commonwealth Hill and Mulgathing, comprising about one third of the area surveyed. 450 miles (720km) of comparable traverse were extracted from the data.

The questions which were then asked were:

(1) Is there any significant difference in the rating method and grades assigned by Jessup in 1948 and by Lay in 1970? and

(2) If there is no significant difference, what is the extent of bush loss by overgrazing on the stations over that period?

Answers to these questions were sought by analysis of the correlation traverse (page 62) and the comparable traverse data, respectively.

Selection of Data for Analysis.

The nature of the data is basically bush density grades over intervals of 0.1 miles. Therefore two problems immediately arise. The first is that bush density has been ranked from 1 (high bush density) to 6 (zero bush density), and is not in the form of counts. Fisher and Yates (1963, p. 94) provide scores for ranked data and these are used to transform the present data. The second problem is that of serial correlation among the observations. Using the traverses of section (a) below, it was found (on plotting the serial correlation against distance) that observations at approximately 2 miles apart are almost uncorrelated. Therefore this problem was handled by selecting ten observations from every 2 mile interval of comparable traverse and using these ten observations as a group. For this analysis, the ratings were considered without regard to bush type. The problems then became one of a nested (or hierarchical) classification.

Correlation Traverses.

In 1971 Lay and Jessup both travelled over the same three traverses and independently graded the same bush. The groups were chosen (as described above) and the data were transformed using Fisher's scores. Then d was calculated (d = Lay's score - Jessup's score for each observation). The model is then:

M: Difference = mean effect + group effect + error term

i.e. $d_{ij} = \mu + \alpha_i + e_{ij}$

and the hypothesis is

$H_o: \mu = 0.$

The analysis of variance (AOV) tables for the three traverses are given in Table 8.

Although, in traverse 3, the variance ratio is not significant, the Between Groups m.s. will still be used to test our hypothesis that the mean difference is zero. If the Between Groups and Within Groups S.S. are pooled, then it is found that

V(d..) = 0.000449, t = 0.566, m = 359

and hence the null hypothesis can be accepted. However, it was decided against pooling the Between and Within Groups S.S. because of the serial correlation between the observations.

The sample mean difference will be denoted by d.. and the formula for the variances V(d..) will be used as given in Ganguli (1940-41). Let t = d../ V(d..). Under the null hypothesis that the mean difference is zero, t

TABLE 8.

AOV FOR THE CALIBRATION TRAVERSES

Traverse 1.

Source	DF	Sum of Squares	Mean Square	Variance Ratio
Between groups	35	4.864	0.139	1.82**
Within groups	324	24.714	0.076	
Total	359	29.578		

Traverse 2.

Source	DF	Sum of Squares	Mean Square	Variance Ratio
Between groups	19	2.502	0.132	2.12**
Within groups	180	11.190	0.062	
Total	199	13.692		

Traverse 3.

Source	DF	Sum of Squares	Mean Square	Variance Ratio
Between groups	35	3.490	0.100	00.59 n.s.
Within groups	324	54.581	0.168	
Total	359	58.071		

has the t-distribution on m degrees of freedom where m is the number of degrees of freedom of the Between Groups sum of squares.

For traverse 1

$d_{..} = -0.006722$, $V(d_{..}) = 0.000386$, $t = 0.342$, $m = 35$.

Since t has a t-distribution on 35 degrees of freedom, the null hypothesis that the mean difference is zero is accepted.

For traverse 2

$d_{..} = -0.0132$, $V(d_{..}) = 0.000658$, $t = 0.54$, $m = 19$

and for traverse 3

$d_{..} = -0.0120$, $V(d_{..}) = 0.000277$, $t = 0.719$, $m = 35$

For both traverse 2 and traverse 3 the null hypothesis that the mean difference is zero is again accepted. Therefore it can now be reasonably stated that Jessup and Lay both agree in the grades they assign to the bush. This being so, the question of whether or not there has been significant bush change since Jessup's (1948) survey can now be assessed.

The Analysis of Change in Bush Density.

Each Station is treated separately and within each Station the observations are subdivided into paddocks and groups of ten observations within paddocks.

The grades for Jessup's and for Lay's estimates were transformed using Fisher's scores and the difference, Lay's score - Jessup's score, calculated. The model therefore is:

M: difference = mean + paddock effect + group within paddock effect + replicates within groups effect,

i.e. $d_{ijk} = \mu + P_i + g_{ij} + r_{ijk}$ $\qquad i = 1,\ldots,t$

$j = 1,\ldots,n_i$

$k = 1,\ldots,m_{ij}(=10)$

where t is the number of paddocks and n_i is the number of groups within each paddock,

$E[P_i] = 0, \quad E[g_{ij}] = 0$ and $E[r_{ijk}] = 0$

$E[P_i] = \sigma_1^2 \quad E[g_{ij}] = \sigma_2^2$ and $E[r_{ijk}] = \sigma_3^2$

The hypothesis is

H: $\mu = 0$.

i.e., there has been no overgrazing on the Station.

The AOV table used in the calculations may be written as:

Source	DF	Sum of Squares	Variance	F
Between paddocks	t-1	$\sum_{i}(d_{i..} - d_{...})^2$	V_1	V_1/V_2
Between groups within paddocks	n-t	$\sum_{i,j}(d_{ij.} - d_{...})^2$	V_2	V_2/V_3
Between replicates within groups	m-n	$\sum_{i,j,k}(d_{ijk} - d_{ij.})^2$	V_3	
Total	m-n	$\sum_{i,j,k}(d_{ijk} - d_{...})^2$		

where $n = \sum_{i=1}^{t} n_i$, $m_i = \sum_{j=1}^{n_i}$, $m_{ij} = 10n_i$, $m = \sum_{i=1}^{t}$, $m_i = 10 \sum_{i=1}^{t}$, $n_i = 10n$

$d_{...}$ = overall sample mean

$d_{i..}$ = sample mean of i^{th} paddock

$d_{ij.}$ = sample mean of j^{th} group in the i^{th} paddock

Ganguli (1940-41) states that:

$$E[d_{...}] = \mu$$

and

$$V(d_{...}) = \frac{\sum_i m_i^2}{m^2} \sigma_1^2 + \frac{\sum_i \sum_j m_{ij}^2}{m^2} \sigma_2^2 + \frac{1}{m} \sigma_3^2$$

Now V_3 will be an unbiased estimate of σ_3^2

V_2 will be an unbiased estimate of

$$\frac{m - \sum_i \frac{\sum_j m_{ij}^2}{m_i}}{n-t} \sigma_2^2 + \sigma_3^2$$

and V_1 will be an unbiased estimate of

$$\frac{m - \frac{\sum_i m_{i}^2}{m}}{t-1}\sigma_1^2 + \frac{\frac{\sum_j m_{ij}^2}{m_i} - \frac{\sum_i \sum_j m_{ij}^2}{m}}{t-1}\sigma_2^2 + \sigma_3^2$$

These 3 equations may then be solved for estimates of

σ_1^2, σ_2^2, σ_3^2, $\hat{\sigma}_1^2$, $\hat{\sigma}_2^2$, $\hat{\sigma}_3^2$.

The three Stations analysed were Bulgunnia, Commonwealth Hill and Mulgathing and the analyses for each are given below.

(1) Bulgunnia Station.

Initially Jessup's (1948) and Lay's (1970) data were analyzed separately as a 3-factor nested design to detect whether there had been any drastic changes in $\hat{\sigma}_1^2$, $\hat{\sigma}_2^2$ and $\hat{\sigma}_3^2$.

Jessup: $\hat{\sigma}_1^2 = 0.0870$ $\hat{\sigma}_2^2 = 0.1357$ and $\hat{\sigma}_3^2 = 0.2762$

Lay : $\hat{\sigma}_1^2 = 0.0559$ $\hat{\sigma}_2^2 = 0.1206$ and $\hat{\sigma}_3^2 = 0.2617$

These three quantities agree very well and hence the differences were then analysed.

TABLE 9.

AOV FOR BULGUNNIA STATION.

Source	DF	SS	MS	F	Prob.
Between paddocks	44	128.58	2.92	1.94	0.99^{**}
Between groups within paddocks	73	109.77	1.50	2.97	1.00^{***}
Between replicates within groups	1062	538.10	0.51		
Total	1179	776.45			

The VR is significant at the 1% level if Prob. >0.99

For these differences, we have d... = -0.251

$$\hat{\sigma}_1^2 = 0.0545, \quad \hat{\sigma}_2^2 = 0.0997 \quad \text{and} \quad \hat{\sigma}_3^2 = 0.5067$$

and hence the estimated variance of d...(given by equation (1)) is

$$V(d...) = \frac{42000}{(1180)^2} \hat{\sigma}_1^2 \quad \frac{11800}{(1180)^2} \hat{\sigma}_3^2 + \frac{1}{1180} \hat{\sigma}_3^2$$

$$= 0.002918$$

Letting $t = d.../\sqrt{V(d...)}$, it was known that under the null hypothesis that the mean difference is zero, t has a t-distribution on m degrees of freedom where m is the number of degrees of freedom of the Between Paddocks sum of squares.

t = -4.65 on 44 degrees of freedom. Therefore the null hypothesis was rejected even at the 0.1% significance level, and it was assumed that there had been a significant amount of bush loss on Bulgunnia Station.

The next obvious question that arises is "Which paddocks have been seriously overgrazed?". This question becomes extremely awkward to answer because a number of paddocks have only one or two groups in them and, secondly, a number of these groups contained no bush when Jessup first observed them and therefore cannot degenerate any further. (This second point is brought up again later).

This question can be answered by using the two-fold nested design within each of the 45 paddocks. Those paddocks which had been overgrazed (and their given probability levels) are:

W. TAIT	($P < 0.05$)
JIM	($P < 0.10$)
E. CHARLIE H.	($P < 0.02$)
SNEYD	($P = 0.10$)
LENA	($P < 0.10$)

(2) Commonwealth Hill Station.

This was the second station that was analysed. For Jessup's data:

$\hat{\sigma}_1^2 = 0.1285$, $\hat{\sigma}_2^2 = 0.1916$, $\hat{\sigma}_3^2 = 0.2744$

and for Lay's

$\hat{\sigma}_1^2 = 0.0891$, $\hat{\sigma}_2^2 = 0.0887$, $\hat{\sigma}_3^2 = 0.2371$

TABLE 10.

AOV FOR COMMONWEALTH HILL STATION.

Source	DF	SS	MS	VR	Prob.
Between paddocks between groups	43	109.59	2.55	1.70	0.98
Within paddocks between replic-ates.	66	98.81	1.50	4.03	1.00
Within groups	990	367.68	0.37		
Total	1099	576.09			

For these differences, d... =-0.462,

$\hat{\sigma}_1^2 = 0.0424$, $\hat{\sigma}_2^2 = 0.1126$, $\hat{\sigma}_3^2 = 0.3714$

and hence the estimated variance of d... is

$$V(d...) = \frac{35600}{(1100)^2} \hat{\sigma}_1^{\,2} + \frac{11000}{(1100)^2} \hat{\sigma}_2^{\,2} + \frac{1}{1100} \hat{\sigma}_3^{\,2}$$

Therefore t = -9.05 on 43 degrees of freedom and hence the null hypothesis that the mean is zero was rejected even at the 0.1% significance level (P<<0.1%). It must be assumed that there has been a serious amount of bush degeneration since 1948.

Again using a two-fold nested design within each of the 44 paddocks it was found that the following paddocks have shown a significant amount of degeneration:

CLAYPAN	($P < 0.01$)
RHUM	($P < 0.10$)
GALAXY	($P < 0.02$)
BLUE MOON	($P < 0.05$)
EREMOPHILA	($P < 0.10$)
ROCK HOLE	($P < 0.10$)
IBIS	($P < 0.10$)
CAMPFIRE	($P < 0.05$)

The small number of paddocks and relatively high probability levels is due to many paddocks being represented by only one or two groups, resulting in a t-distribution on 1 or 0 degrees of freedom. Of the 44 paddocks included, 11 were represented by only one group of observations, and 17 had only two groups.

(3) Mulgathing Station was the third (and final) Station analyzed.

For Jessup's data it was found:

$$\hat{\sigma}_1^2 = 0.0372 \qquad \hat{\sigma}_2^2 = 0.1549 \quad \text{and} \quad \hat{\sigma}_3^2 = 0.3052$$

whereas for Lay's data:

$$\hat{\sigma}_1^2 = 0.0617, \qquad \hat{\sigma}_2^2 = 0.1783 \quad \text{and} \quad \hat{\sigma}_3^2 = 0.3341$$

TABLE 11

AOV FOR MULGATHING STATION.

Source	DF	SS	MS	VR	Prob.
Between paddocks between groups	43	131.32	3.05	1.49	0.93
Within paddocks between replicates	65	133.29	2.05	3.26	1.00
Within groups	981	617.37	0.63		
Total	1089	881.98			

For these differences, d... = -0.178

$$\hat{\sigma}_1^2 = 0.0409, \qquad \hat{\sigma}_2^2 = 0.1421 \quad \text{and} \quad \hat{\sigma}_3^2 = 0.6293$$

and hence the estimated variance of d... is

$$V(d...) = \frac{38900}{(1090)^2}\,\hat{\sigma}_1^2 + \frac{10900}{(1090)^2}\,\hat{\sigma}_2^2 + \frac{1}{1090}\,\hat{\sigma}_3^2$$

Therefore t = -3.14 on 43 degrees of freedom and hence the null hypothesis that the mean difference is zero is rejected. ($P < 0.5\%$). It must be assumed that there has been a significant amount of bush degeneration since Jessup's (1948) observations.

Although the Between Paddocks within groups SS is not significant at the 5% level, it is at the 10% level. However, if the null hypothesis is accepted and the Between Paddocks and the Between Groups within paddocks SS are pooled to form a Between Groups SS, the following AOV table results.

TABLE 12.

AOV FOR MULGATHING STATION.

Source	DF	SS	MS	VR	Prob.
Between groups	109	264.62	2.43	3.86	1.00
Within groups	981	617.37	0.63		
Total	1089	881.98			

d... = -0.178, V(d...) = 0.002227 and hence t = -3.78 on 109 degrees of freedom and the null hypothesis that the mean difference is zero is rejected. ($P < 0.1\%$). It must therefore still be assumed that there has been a significant amount of bush degeneration since Jessup's survey.

Again, using a two-fold nested design within each of the 44 paddocks it was found that the following paddocks have shown a significant amount of degeneration.

NIGHTSHADE	($P < 0.10$)
FIONA	($P < 0.02$)
W. PINDING	($P = 0.10$)

Elimination of "No Bush" Ratings.

As it was only the problem of degeneration of bush which was of interest, it was decided to eliminate all those observations in which the bush was unlikely to regenerate. This was done for Bulgunnia Station by deleting all traverse more than 0.5 miles from a record of bush occurrence by either observer. It was found that although the level of significance increased, ($t = -6.51$ on 41 degrees of freedom), it was even more difficult to test individual paddocks for overgrazing as 17 paddocks then had only 1 group, 9 had 2 groups, 8 had 3 groups in them, and 4 paddocks vanished altogether. Further, because of an increase in the variance of the means for the paddocks only two paddocks were significant at the 5% level (E. CHARLIE H. and W. TAIT) and a further one, JIM, was significant at the 10% level. This is in marked contrast to the 5 paddocks which had their mean significantly different from zero at the 10% level. It was therefore decided not to delete those groups in which the bush was unlikely to regenerate.

Mean Bush Loss.

Finally, it was decided that it could be of interest to know the mean grade of bush when Jessup performed his traverses in 1948 and the mean grade of bush when Lay covered the same traverse. The results, together with the corresponding average bush numbers and percentage of bush remaining, are shown in Table 13.

Comments.

This analysis calculates the significance of the mean difference in the bush density ratings of Jessup (1948) and Lay (1970). It was carried out at both the paddock, and the Station levels, so as to detect any relationships between significant changes and management practices, paddock size, stock water availability and the like.

Table 13 presents a summary of the findings from this analysis. The implications of it will be discussed in Chapter 10, but several points need explanation here. The "percentage of bush remaining" (2nd last column) was calculated from the average number of bushes in the density stages in columns one

TABLE 13

SUMMARY OF BUSH DENSITY CHANGE ON THE STATIONS ANALYZED.

Station	Mean Bush Density Rating		Number of bushes/250m^2				% Bush* Remaining
			Atriplex vesicaria	*Kochia astrotricha*	*Kochia sedifolia*		
	1948	1970	1948	1970	1948	1970	
Bulgunnia	4.65	5.15	13	8	5	2	51 - 68
Commonwealth Hill	4.17	5.11	25	8	9	2	27 - 52
Mulgathing	4.14	4.50	26	18	9	6	69 - 84

* see text.

and two. This was the method used by Jessup for determining average bush density numbers on his maps (Chapter 4). However, because of the unequal numerical limits of each density stage this is most likely to be inaccurate, and in this case probably maximizes the impression of bush loss which had occurred. The actual bush loss is likely to be considerably less than this, and this is obvious from the following example. The percentage bush loss when a stand of *K. sedifolia* degenerates from stage 2 to stage 3 is only 40%, but from stage 4 to stage 5 the loss is 76%, and from stage 5 to stage 6 is a 100% loss. The true values from this analysis thus lie somewhere between the two figures given.

Table 13 values are calculated on the basis of equal cover by both rateable bush types. This is an approximation, but a large error here would not significantly affect the overall result.

The results illustrate the serious extent of bush loss on Commonwealth Hill Station, and it is of interest to note that all except one of the significantly degraded paddocks revealed on this Station are watered from two bores, No. 45 and Comet, which have an "unlimited" supply of good quality water.

CHAPTER 9.

INFLUENCE ANALYSIS ON PHYTOGEOGRAPHIC DATA

Introduction.

Influence Analysis, as used by Lange (1968) and Barker and Lange (1969) is a multivariate statistical technique of particular value in elucidating factors determining species distribution. It is a development of the general concept of interspecific association using species incidence data.

Earlier methods, developed by Goodall (1953) and Williams and Lambert (1959) are based on the idea that species in a complex vegetation can be sorted into a single set of mutually exclusive associates based on group homogeneity. The degree of association is calculated for each species pair using 2 x 2 contingency tables, with χ^2 values as the test of significance of these associations.

Lange (1968) argues that these earlier approaches are tenable only where such a single classification is the aim of the study, and is scarcely appropriate where various influences are acting independently in vegetation. The influence analysis firstly establishes the number of independent nodes of interspecific association at a given level of significance, revealing the structure of the interaction complex. These nodes are then separately back-plotted on the base map, on the basis of the combination of nodal species present at each sampling site.

Since most of the data gained on the present survey are species incidence over each sampling interval, it was felt that influence analysis may provide a clearer insight into the apparent correlation of many of the species used with certain environmental variables (see Volume II).

Method.

Each sampling interval was given a unique number, and treated as a discrete locality. For each locality, the incidence data for all the species used were recorded. The analysis, carried out as in Lange (1968), was run on the CDC 6400 computer at the University of Adelaide. Eight species, which occurred in less than 100 of the 4,300 sampling sites, were eliminated from the calculations (see Table 15).

Results.

The analysis revealed statistically significant interaction, both positive and negative, between nearly all of the species considered. Even at an absolute χ value on 1 degree of freedom of 10.0 and above ($P<<0.001$) then these species tend to link into one complex web of interaction.

However, if only the highest level interactions are considered, several independent nodes, whose structure is shown on Figure 13, appear. These negative interactions separate elements of two distinct groups of positive associates. At an absolute value of $\chi \geqslant 15$, negative associations with species No. 2 (*Acacia tetragonophylla*) separate elements of nodes 1, 2 and 3. Nodes 1 and 2 are distinct only with regard to their central species; at $\chi < 22$ they merge by virtue of highly significant positive associations between species of each node, for example species 8, 18 and 30.

Site Ordination.

Originally it was intended to back-plot the influence ratings of each sampling interval on the base map for all nodes defined. However, as none of the sampling intervals could be positioned by coordinates, it was not considered feasible to do this. Isotel maps, representing the significant features of the distribution of areas of high and low influence ratings, were drawn from the distribution maps of the component species and are hence approximate only. These maps are shown on Figures 14 to 17. For nodes 1, 3 and 4 two isotels have been drawn, representing the two poles of the node. Three isotels have been used to illustrate the complex node No. 2.

FIGURE 13

NODAL STRUCTURE

___________ positive association at $\chi \geqslant 22.0$

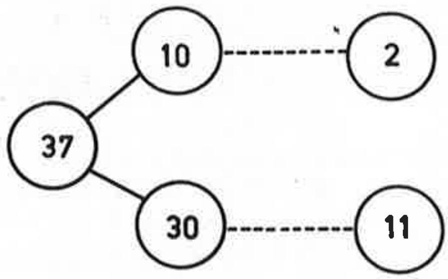
----------- negative association at $\chi \leqslant -15.0$

Key to Species.

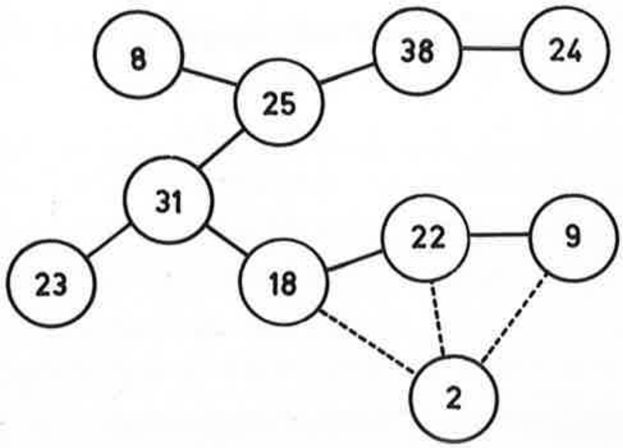
1.	*Acacia aneura*
2.	*A. tetragonophylla*
8.	*A. linophylla*
9.	*A. sowdenii*
10.	*A. ligulata*
11.	*Eremophila rotundifolia*
18.	*Santalum acuminatum*
22	*Heterodendrum oleaefolium*
23.	*Casuarina cristata*
24.	*Cratystylis conocephala*
25.	*Eucalyptus transcontinentalis*
30.	*Dodonaea attenuata*
31	*Myoporum platycarpum*
32.	*Eragrostis australasica*
35.	*Templetonia egena*
37.	*Callitris columellaris*
38.	*Acacia colletioides*

Figure 13 Nodal Structure

Node 1

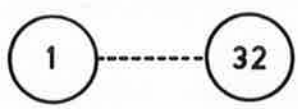


Node 2



Node 3

Node 4



Discussion:

This is the first application of influence analysis using incidence data collected in this way, or with respect to higher plants on a phytogeographical level. It is immediately obvious that most species are involved in positive or negative associations at very high levels of significance. This results from the method of sampling used, and the large size of the area surveyed, with consequent variation of environmental factors influencing species distribution.

Although most of the highly significant interactions detected by the analysis are evident on examination and comparison of the distribution maps, this analysis is of particular value in the elucidation of the broadscale phytogeographical influences affecting species distribution. It also reveals that this approach is tenable for statistical verification of apparent interspecific association at this scale.

Associations of ecological significance, however, are often not revealed. This is because a two mile (3.2km) long sampling interval can cross various distinct topographic or soil types, and hence may include species which have no real association with each other, and are only similar with respect to their broad geographic distribution. This is illustrated by an example from Table 14. Both *Cratystylis conocephala* (24) and *Acacia sowdenii* (9) were observed to occupy the swales of some southern dunefields. Their marginally significant association($\chi_{1d.f.}$ = 3.4) is a reflection of the fact that the overall distribution patterns of the two species are different. However the association between *Cratystylis conocephala* and *Acacia linophylla* (8) is highly significant (χ = 10.3) because the distribution of the former species lies entirely within that of *A. linophylla*. There is little ecological significance in this result, as *A. linophylla* occupies the crests of sand-ridges and never occurs with *C. conocephala*. This reflects the inclusion of several ridges and swales in each sampling interval over most dunefields encountered.

Within the constraints of the notion that ecological or phytogeographic significance can be placed on only the most highly significant interspecific associations detected by this test, each node is discussed below.

Node 1:

The isotel map for this node is easily explained on the basis of habitat data given in Volume II for each species. The pole representing the lowest influence values corresponds to areas of heavier soils without sand dunes. This reflects the

TABLE 14

CELL VALUES (χ) FOR NODES 1 AND 2.

2	11	10	30	37	SPECIES
	14.5	-14.9	-18.7	-13.5	2
		-11.4	-14.7	- 7.3	11
			31.4	30.2	10
				23.8	30
					37

2	8	9	18	22	23	24	25	31	38	SPECIES
	-11.9	-15.4	-17.1	-16.6	-3.3	-9.3	-12.1	-12.5	-11.9	2
		- 1.2	15.9	9.8	14.0	10.3	23.2	19.5	15.7	8
			19.9	24.5	5.4	3.4	- 2.9	6.9	0	9
				25.3	20.9	21.9	22.0	26.0	17.4	18
					20.9	12.3	14.6	21.3	11.4	22
						18.2	19.9	24.4	14.9	23
							20.8	21.3	22.5	24
								26.2	30.7	25
									19.7	31
										38

observation that the three positively-associating species only occur on deep sand or dunes, while species 2 and 11, themselves positively-associating at a high level of significance, occur on heavier or stony soils. The zone of highest influence values directly reflects the major occurrence of *Callitris columellaris* (37).

Node 2:

This complex node shows a remarkable correlation with rainfall (Volume II, Map 45), modified slightly by soil type (Map 46). Table 14 shows the reinforcement at highly significant levels of association between species of this node, which is centered on the highest rainfall dunefields, roughly corresponding to the 7" (178mm) isohyet. The other pole of the node is centered on the Stuart Range and northward, where *Acacia tetragonophylla* occurs alone, or all species vanish altogether. It roughly corresponds to areas of heavy soil type and with less than 5" (127mm) average annual rainfall.

Node 3:

This node of negative association again reflects the effects of rainfall, but also the favourable environment created by the inflow of large watercourses from the Stuart Range into dunefields on Ingomar Station. It is of interest to note that the westernmost occurrence of high influence values appears to form a narrow band, rather than the edges of a broader region. This was verified by reconnaissance south of Mt. Finke, which revealed the absence of both species there. This latter observation is also true of many of the species of Node 2 (Nos. 8, 9, 23 and 24).

Node 4:

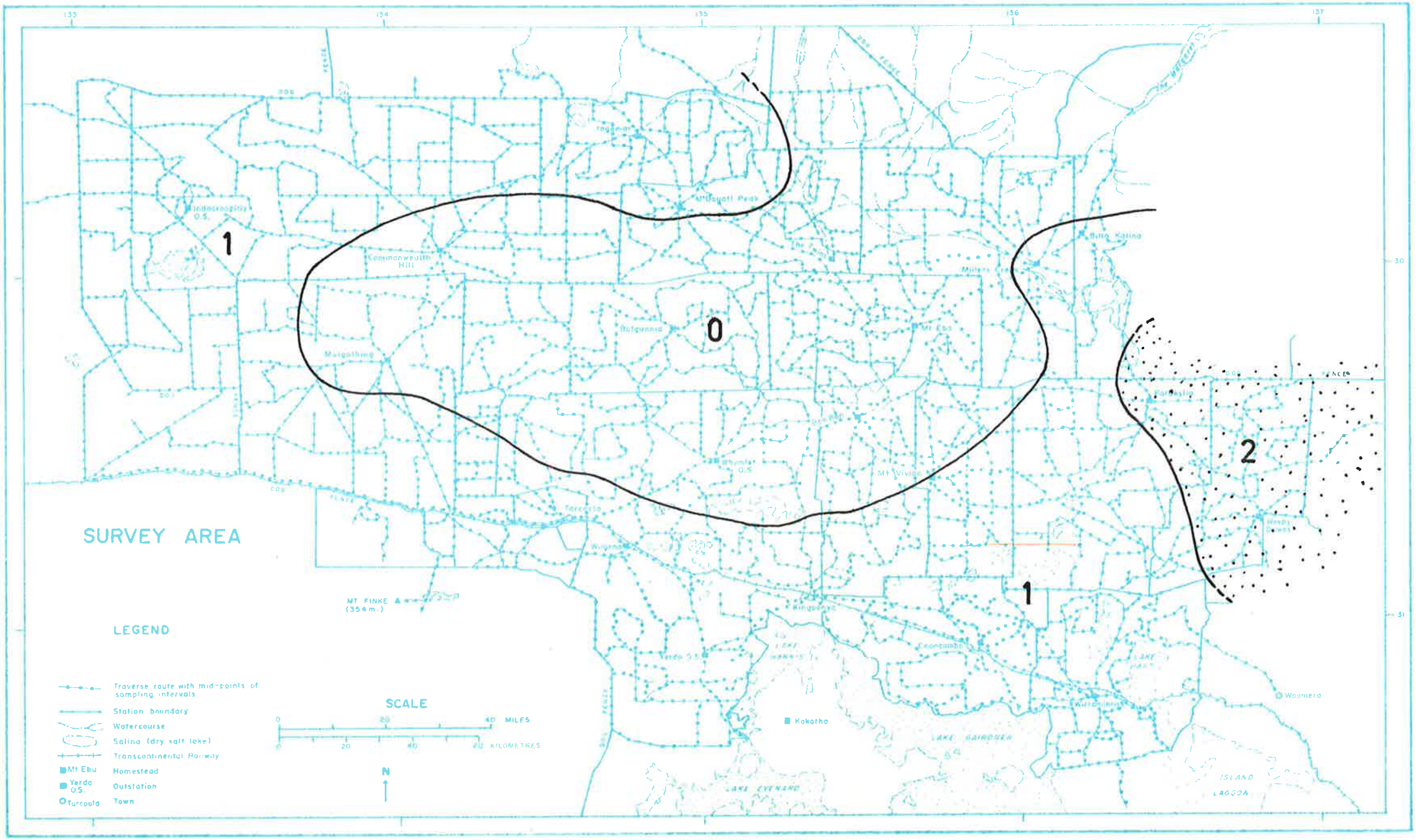
Another negative association is represented by this node, which simply demarcates those areas of stony tablelands supporting *Eragrostis australasica* (32), but from which *Acacia aneura* (1) is absent, due to the heavy textured saline soils found there (Jessup, 1951). The zones with an influence value of 1 are characterized by areas with scattered sandridges supporting *A. aneura* superimposed on tablelands and gibber plains with *E. australasica* in watercourses or depressions.

TABLE 15.

SPECIES FREQUENCY - WHOLE DATA

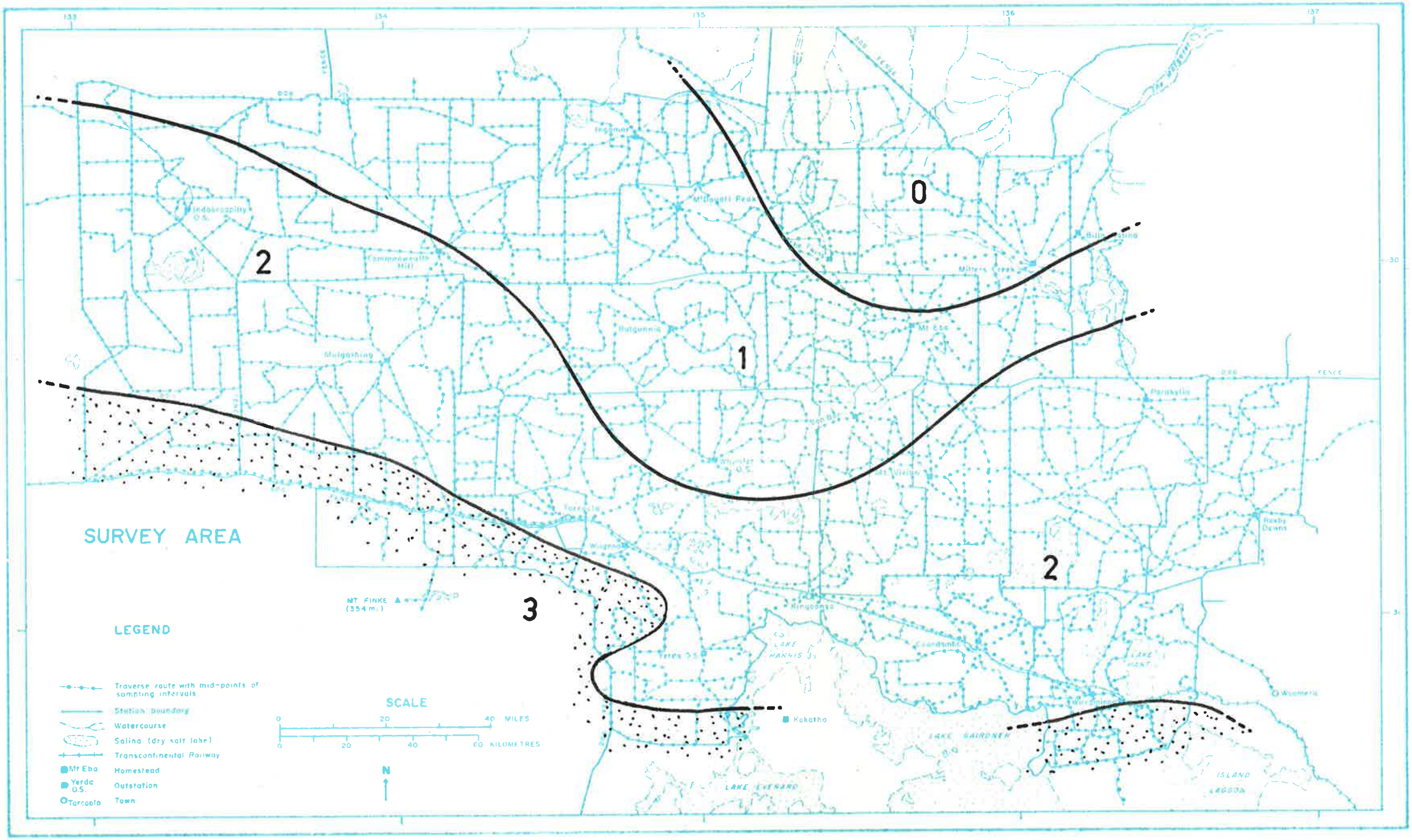
The total number of sampling intervals is 4,300. Key to the species is given in Appendix I.

Species	Frequency	Species	Frequency	Species	Frequency
1	3981	15	12	29	102
2	3033	16	502	30	906
3	1195	17	729	31	689
4	1753	18	852	32	228
5	292	19	736	33	243
6	428	20	194	34	9
7	161	21	309	35	316
8	914	22	1952	36	67
9	1530	23	1419	37	214
10	559	24	169	38	130
11	838	25	319	39	33
12	1772	26	21	40	29
13	696	27	51	41	8
14	390	28	453		


133
134
135
136
137
30
31
1
0
2
1
SURVEY AREA
LEGEND
Traverse route with mid-points of sampling intervals
Station boundary
Watercourse
Salina (dry salt lake)
Transcontinental Railway
Mt Ebu Homestead
Yerda O.S. Outstation
Tarcoola Town
SCALE
0 20 40 MILES
0 20 40 KILOMETRES
N
MT FINKE (354 m.)
Commonwealth Hill
Mt Eba
Kokatha
Woomera
LAKE GAIRDNER
LAKE EVERARD
ISLAND LAGOON

NODE 1

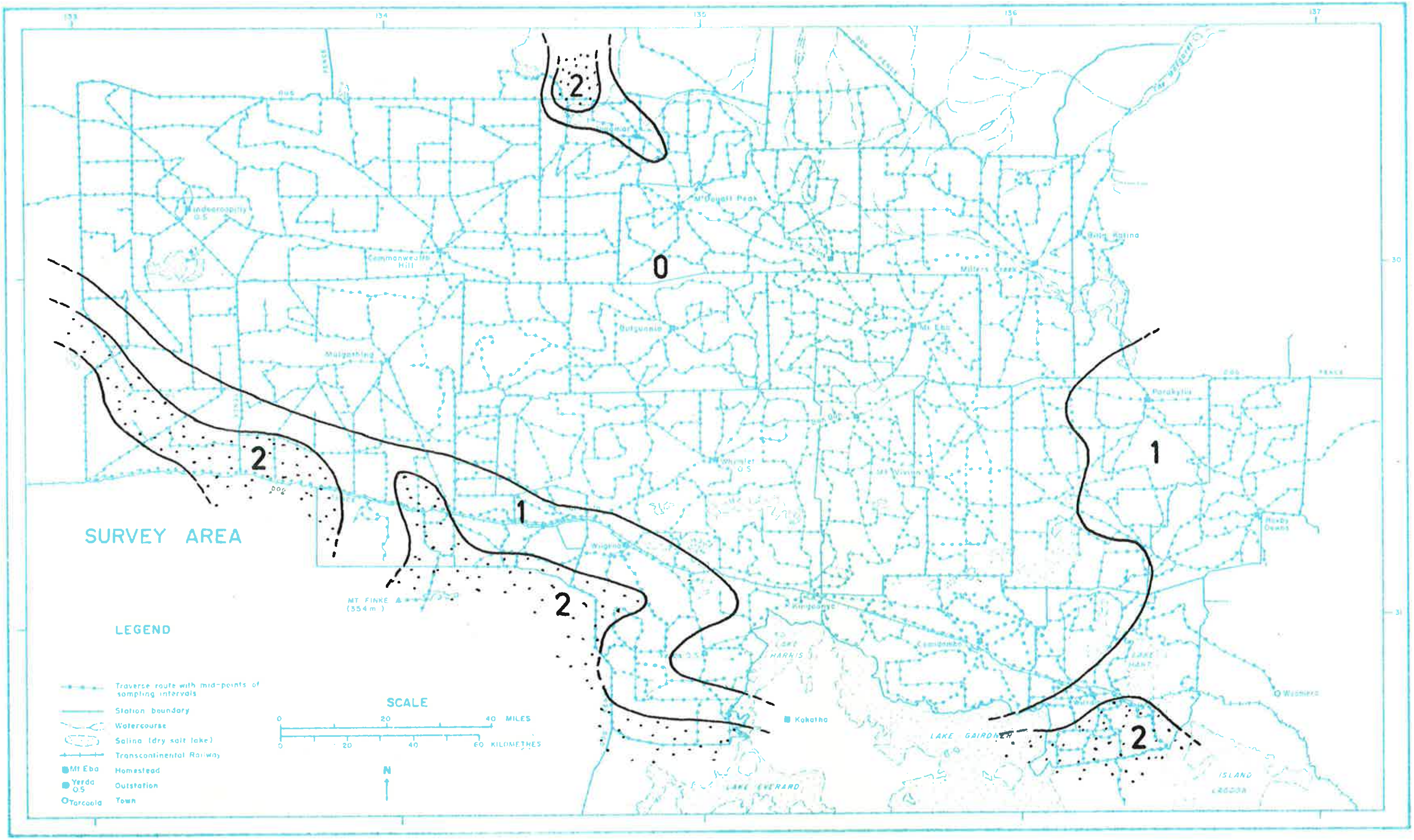
Influence Rating	Species Present				
	10	30	37	2	11
2	+	+	+	-	-
1	all other combinations				
0	-	-	-	+	+



133
134
135
136
137
0
1
2
2
3
SURVEY AREA
LEGEND
Traverse route with mid-points of sampling intervals
Station boundary
Watercourse
Salina (dry salt lake)
Transcontinental Railway
Mt Eba
Homestead
Yerda O.S.
Outstation
Tarcoola
Town
SCALE
0
20
40
MILES
0
20
40
60
KILOMETRES
N
MT FINKE
(354 m.)
Kokatha
Kingoonya
Mt Eba
Mulgathing
Commonwealth Hill
Bulgunnia
Tarcoola
Parakylia
Woomera
LAKE HARRIS
LAKE GAIRDNER
LAKE EVERARD
ISLAND LAGOON
FENCE

NODE 2

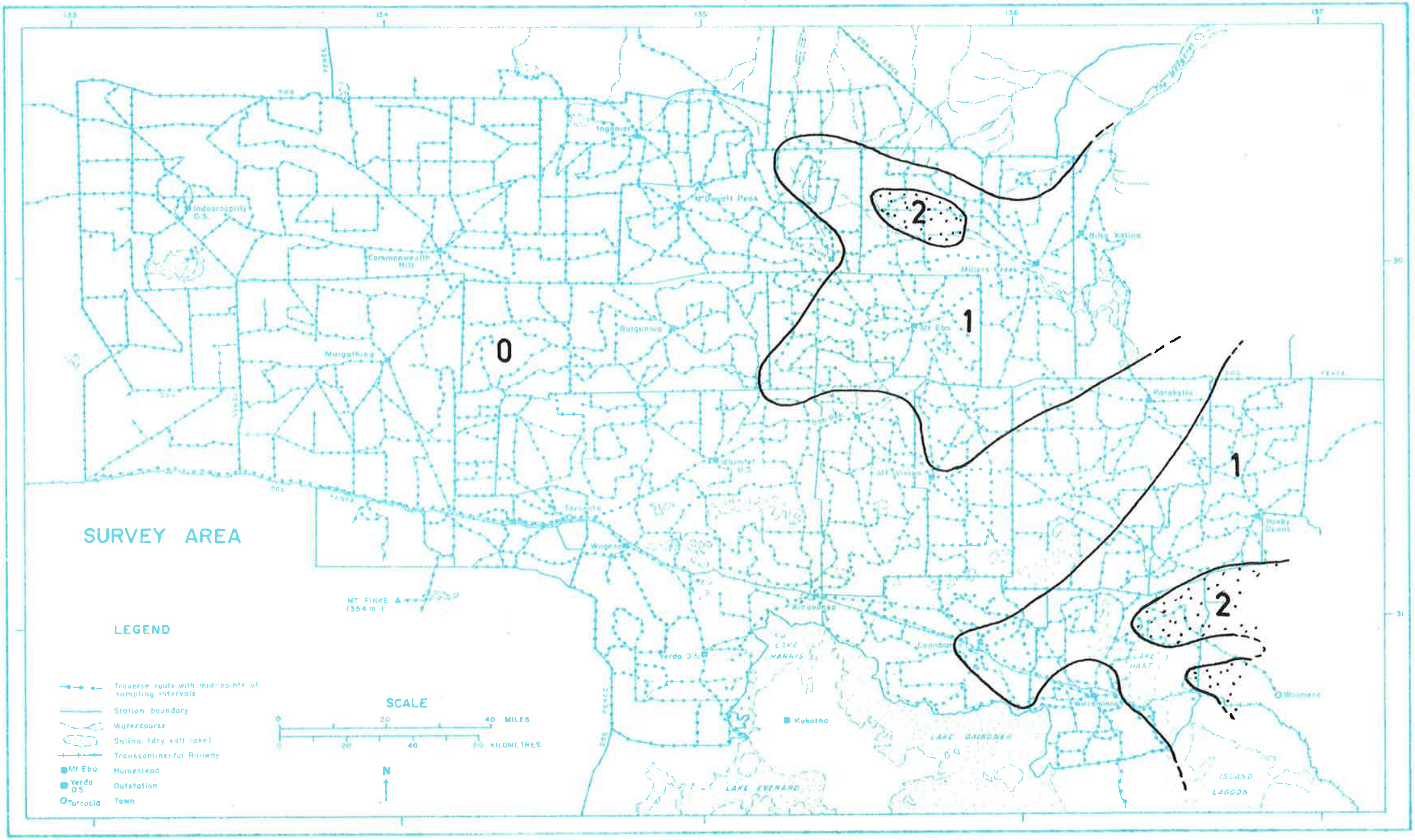
Influence ratings 0 and 3 represent the poles, while ratings 1 and 2 contain about 1/3 and 2/3 of the nodal species respectively.



SURVEY AREA
LEGEND
Traverse route with mid-points of sampling intervals
Station boundary
Watercourse
Salina (dry salt lake)
Transcontinental Railway
Mt Eba Homestead
Yerda O.S Outstation
Tarcoola Town
SCALE
0 20 40 MILES
0 20 40 60 KILOMETRES
N
0
1
2
MT FINKE (354 m)
Kokatha
LAKE GAIRDNER
LAKE EVERARD

NODE 3

Influence Rating	Species Present	
	2	35
0	+	-
1	+	+
2	-	+



SURVEY AREA
LEGEND
Traverse route with mid-points of sampling intervals
Station boundary
Watercourse
Salina (dry salt lake)
Transcontinental Railway
Mt Ebu Homestead
Yerda O.S. Outstation
Tarcoola Town
SCALE
0 20 40 MILES
0 20 40 60 KILOMETRES
N
0
1
2
1
2
Ingomar
McDouall Peak
Commonwealth Hill
Mulgathing
Mt Ebu
Millers Creek
Parakylia
Mt Vivian
Tarcoola
Wilgena
Kingoonya
MT FINKE
(354 m)
Yerda O.S.
Kokatha
LAKE HARRIS
LAKE EVERARD
LAKE GAIRDNER
LAKE HART
ISLAND LAGOON
Woomera

NODE 4

Influence Rating.	Species Present.	
	1	32
0	+	-
1	+	+
2	-	+

CHAPTER 10.

SYNTHESIS AND CONCLUSIONS.

Introduction.

This study has essentially involved two different approaches to the broadscale assessment of arid rangeland vegetation. The bush density survey is a means to a particular end, that is, the long term assessment and evaluation of change due to grazing. The phytogeographic survey on the other hand is rather an end in itself, a once-only academic exercise to elucidate phytogeographic influences affecting species distribution. It is also true that this exercise has practical value, at least in so far as it yields an improved understanding of the context of the grazing situation.

This Chapter serves to place the findings of the study in the context both of the general themes reviewed in Chapter 3, and their significance to research and management in arid rangelands.

Synthesis of Significant Findings.

The findings from the bush density survey, even though from an analysis of only three of the 17 stations covered, are clear and easily explained. Significant overall bush loss has occurred even on the two stations which appeared to be well managed, and on which no significant areas of recent bush death were observed. Not all paddocks show degeneration (e.g. see Figure 5) and data from Wilgena Station provides the most valuable indication that some stocking policies have resulted in negligible loss of bush even within 0.2 miles (0.32km) of a long-established watering point. Examples on Wilgena are Corner Bore and Bores 3, 4, 6 and 15 on the Whymlet Block. There is a similar degree of preservation of bush around some bores on the stations analyzed, for example Lloyds and Satisfaction Bores on Bulgunnia. On Commonwealth Hill, the only bores near which large areas of perennial bush have not been killed out are those with limited or highly saline supply, e.g. Two Stone and Golf Bores.

One of the most significant findings from the bush density survey was the degree of bush loss which had occurred on Bulgunnia Station. This Station appeared to be well preserved and certainly has been "conservatively" stocked over the last 20 years. Stock numbers have seldom approached the Stocking Condition of 24/square mile and yet there has been appreciable bush loss.

On the other hand, bush death on Commonwealth Hill has been severe, even to the casual observer, and the loss in only 20 years of more than half the bush on that area of the Station surveyed by both observers must be regarded as deplorable from both pastoral and ecological viewpoints. In many instances on this Station, the bush had been completely eaten out for up to 1km from the watering point.

Where such complete bush death had occurred, particularly in stands of *Atriplex vesicaria* and *K. astrotricha*, soil erosion is a serious problem on susceptible soils (Plate 14). Even where some bush remains, drift of the surface soil had occurred in all except heavily wooded areas. Certainly no perennial species had invaded these grazed-out areas. It is of interest to note here that Marshall (1970) had simulated the effect of "roughness elements" (e.g. perennial bushes) on soil stability in arid areas and the minimum protection he found necessary for this on erodable soil types was, in the case of *K. sedifolia*, a density of about middle stage 3 of ungrazed bushes on Jessup's scale (pers. comm., 1969). The protection offered by heavily grazed bush is naturally much less.

The analysis at the paddock level revealed most severe degeneration in certain paddocks, but no meaningful correlations were obtained between these paddocks and possible causative factors (see Chapter 8). This was due to inherent weaknesses in the analysis (e.g. number of sampling groups per paddock) and also because of variability in amounts and type of bush in each paddock, the location of bores in areas naturally without bush, and, most particularly, lack of information on past stocking history of each watering point. The data obtained from the bush density survey on 10 stations is still to be analyzed by the method described in this thesis. Other methods of analysis, e.g. by comparison of the proportions of stage 6 ratings, could also be used to try to obtain the most meaningful indicator of stocking pressure.

It was not possible to assess the effects of sheep or cattle stocking, if any, on the shrubs and trees studied in the phytogeographic survey (except in occasional instances). Apart from determining the distribution patterns of the species studied, information on regeneration has been obtained using a more objective approach than published to date. Generally speaking, regeneration of the three species concerned was not observed. In the case of *A. sowdenii* and *C. columellaris*, virtually no regeneration was seen throughout their range. However, the Mulga (*Acacia aneura*) is regenerating, quite densely in places, and these observations are in marked contrast to Ratcliffe (1936) who states "throughout his fairly extensive travels in the outback country, the author neither saw, nor heard of the existence of, a single young mulga surviving today unless specially protected". Much of the regeneration seen on this survey had obviously taken place before the introduction of stock (particularly on Commonwealth Hill and Ingomar Stations), and many seedlings on these Stations were entirely trimmed of leaves below the browse line. There was no overt evidence of rabbit damage, although they were present throughout the area.

Suppression of seedlings of *A. aneura* by both cattle and sheep was seen. The species is highly palatable to both these animals but seedling survival has been observed in an area heavily grazed by cattle (photopoint 69). Cattle cannot graze as closely as sheep, and this has enabled the survival of these seedlings, even though they were trimmed to within a few cms of ground level. The method used in the phytogeographic survey was most similar to that used by Rogers (1972) while studying lichen distributions. It differed mainly in that species were recorded along a continuous traverse, on a much more detailed sampling grid, and over a smaller and less diverse region. This permitted a much more exact delineation of phytogeographical and ecological factors influencing species distribution by influence analysis and correlation with environmental variables.

Broadscale Assessment of Rangeland Condition by Rapid Inventory Techniques.

The broadscale mapping techniques described in Chapter 3, as well as the work of Condon (1968) in assessment of grazing capacity could be described as methods of rapid land inventory; that is, an appraisal of composition, current status, or condition of a natural resource. These methods also include the surveys described in this thesis.

Wilcox (1972) says of this approach: "The results of surveys........must be capable of rapid assimilation and, most importantly, of comparison from year to year or period to period, without the modifying effects of observer bias, and desirably free of the mitigating effects of long term seasonal trends so frequent in arid rangelands". This statement brings out the important requirements of broadscale land inventory. These requirements are very well fulfilled in work like the bush density comparison; the major weakness of this approach has been that results are not capable of rapid assimilation (computation and analysis). Otherwise this survey conforms to the ideals of Wilcox. Both surveys described here overcome problems with observer bias and seasonal effects by providing checks for estimates, regular herbarium collections of the plants studied, and by utilizing only long lived perennials.

In this regard methods used in the United States often do not fulfil these requirements. For example the approach to range condition using proportion of increasers and decreasers in successional processes (Dyksterhuis, 1949, 1952) is usually susceptible to seasonal conditions unless perennials only are used, and probably subject to interpretive error in the determination of the category into which the species present fall. This may not reflect a weakness in their method, but more likely further serves to indicate the fundamental differences between the systems.

Long Term Studies.

The re-evaluation of Jessup's work has essentially involved a long term assessment of vegetational change in category I(ii)(c) of Chapter 3. From the discussion of the method used and problems encountered, requirements of long term experiments necessary to yield maximum meaningful data, could be determined. These requirements are briefly summarized below.

Planning of the Study;

Foresight in planning of any long term study is essential if maximum value is to be obtained from a repetition many years later. For example, the nature of the data obtained should permit simple statistical analyses or computation which is not wasteful of data and the results of which can be easily assimilated and interpreted.

Forethought should be given to likely trends or results which may be revealed by the repetition, and the parameters measured should be decided accordingly. Much criticism could obviously be placed on Jessup's work in this regard, particularly in respect to the unequal numerical spans of each density stage, which prevented accurate assessment of bush loss. It must be borne in mind, however, that his work was not designed for repetition, even though he vaguely had this possibility in mind when carrying out the survey.

The Recording of Field Data:

It need hardly be said that legible, concise and unambiguous field data recording is essential if these records are to form the basis of a repetition and comparison. However it was brought home to the writer that in a survey such as Jessup's even this is not enough, and where the period before repetition is likely to be in the order of decades, every conceivable piece of information which may be of assistance to the future investigator should be recorded. For example, while recording traverse route information, an entry such as "Travel East from Jims Well to Johns Outstation" is not sufficient. It is necessary to record this hypothetical example as follows: "Travel East from Jims Well along Jim-Bob paddock fence on seldom used winding track towards Johns Outstation". This same degree of explicitness and detail is necessary when recording the data. Failings of Jessup's data in this regard are noted in Chapter 5. It is hoped that the present survey has conformed to the above ideals within the constraints of the basic survey method used.

Type of Data Recorded:

The collection of quantitative rather than qualitative information of the parameters measured is to be preferred in any stringent scientific study. This is particularly important in long term studies where the second measurements are made by a different observer. The method used here, though based on estimations, can be checked by measurement. However apart from this check there are many decisions which have to be made and which are crucial to any comparison. When the study is based on this type of data it is imperative that a correlation test between the two observers is made. In long term work even this is far from ideal, as it cannot be stated for certain that Jessup rated the bush the same way on the calibration traverse in 1971 as he did during his survey in 1948. Other workers in this field emphasize the importance both of the training of observers where subjective decisions have to be made, and the errors obtained using different observers to do this. Quite obviously it is preferable to develop an objective approach to data recording requiring minimal interpretation or subjective error. From the literature reviewed the permanent quadrat and photographic point fulfil these requirements admirably, but are seldom applicable to broadscale studies.

Effect of Seasonal Conditions:

In arid rangelands, it is important that any long term studies to evaluate condition or trend, are based on parameters and species unaffected by the prevailing seasonal conditions. Jessup's bush density survey would appear to satisfy this requirement, but even here the prolonged dry conditions made estimation of the density of defoliated bush stands difficult, while after good rain, some bush stands tended to be obscured by ephemeral herbage and grasses. In general, measurements of the perennial component of rangeland vegetation overcome this problem, but difficulties arise when assessing rangelands supporting mainly ephemeral or short-lived perennial species. Here measurements of condition can be based on extent of soil erosion (Condon, 1968) or, on the better watered American rangelands, on proportions of increasers and decreasers in a successional process (Dyksterhuis, 1952, 1958; Parker, 1954).

Durability of Reference Points:

Finally, mention must be made here concerning a basic requirement of many long term measurements. Obviously any work involving relocation of areas or plants or even of traverse routes depends on reference points lasting the interval between measurements. When considering materials to use when such reference points are set up during the study, costs and convenience should be disregarded in favour of certain durability and ease of relocation. When using existing reference points, care should be taken to cross-reference, where possible, localities mapped using features likely to be temporary in terms of the *possible* time before re-measurement.

Implications for Administration and Management of Arid Rangelands.

Generally speaking, this study has been conducted at the management level, that is, changes measured have been analyzed at the paddock and station scale and the parameters used have been those most evident to Station Managers in this country and affected by management practices.

Before considering the application of the results from this survey, it should be emphasized here that the vegetation assessed was the component most resistant to grazing pressure, and furthermore that changes were only recorded where death of this vegetation in significant amounts had occurred. The ability of the two *Kochia* species to sprout, even when repeatedly grazed to bare stumps, also resulted in an apparent insensitivity of the method to severe overstocking. For example areas of *Kochia astrotricha* on shallow texture contrast soil were observed,which although having suffered low mortality were no more than live stumps on small mounds of soil, with the sandy soil between them having been blown away. That is, effects of overgrazing should be blatantly obvious to the Station Manager in these bush types long before a detectable change in bush density had occurred.

Undoubtedly, more sensitive methods of assessing effects of stocking are available. It is evident that assessment of stocking pressure based on biomass estimates of perennial bush would be a more sensitive measure, and work on Carnding Well (T. Fatchen, pers. comm. 1971) has revealed this.

That there has been such a significant bush loss on the Stations analyzed, illustrates the extent of overgrazing, and that permanent impairment of carrying capacity of the country has occurred. It is equally clear that many paddocks have suffered only negligible bush loss, although they had been stocked continuously over the interval between surveys. The extensive destruction of perennial bush on Commonwealth Hill Station represents a serious degree of overstocking. This is particularly true when it is realized that at least half of the area of this Station is more than four miles (6.4km) from a stock watering point, beyond which grazing effects are considered negligible (Osborn, Wood and Paltridge, 1932). It reflects the stocking policy of the lessee, who regards *Atriplex vesicaria* as a species which must be sacrificed in order to achieve adequate utilization of the pasture.

Similar widespread destruction of perennial bush was evident on other stations covered by the survey, e.g. Carnding Well and Roxby Downs, and it is of interest to note that on both these Stations the stock numbers carried have exceeded the "Stocking Condition" on several occasions (see Table 2).

It may appear from the results obtained here that any stocking will result in progressive bush degeneration. However this does not appear to be so when individual paddocks are examined (Figures 5 and 6). Bush density measurements on Wilgena Station provide the best evidence of bush response to conservative stocking policies in this rainfall zone (6-7"). This Station has been under one Manager for over 30 years, who has drawn up a plan of watering points, and the number of stock allowed on each (V. Halls,* pers. comm., 1970). Wilgena Station is rather better off for stock water than most other stations in the area and most paddocks are consequently smaller. Stock numbers are restricted to 300-350 sheep per watering point, and this has resulted in negligible bush death in the 20 years since Jessup's survey. On traverses encountering some of these long established watering points, stands of *Atriplex vesicaria* and *Kochia sedifolia* of density stages 2 and 3 were present 0.1 to 0.2 miles from the watering point. *Kochia sedifolia* was also well preserved at a similar distance from some of the watering points on Bulgunnia Station,

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* V. Halls, Manager, Wilgena Station.

particularly where water supply is limited or quality is poor. Invariably the bush near watering points on which much greater numbers of sheep have been run, even if intermittently, has been killed out for considerable distances around them. *Atriplex vesicaria* appears to be the most sensitive in this respect due to its known inability to resprout when defoliated (Leigh and Wilson, 1970).

Nowhere in the North-West did the writer find the degree of preservation of perennial vegetation as reported by Barker (1972) for areas further south. Also no perennial plant was observed to replace any of the "bush" species eaten out in the North-West. However, it is evident from the data gained here, that some degree of stability can be obtained in the vegetation under stocking, based on the perennial shrub component.

It is equally clear, that regeneration of these shrubs including *Atriplex vesicaria*, in areas from which they have been completely killed, takes place to a negligible extent, even over 20 years, and where soils have remained intact and grazing pressure relieved (Plate 8).

Conclusions.

In brief, the significant conclusions from this study are as follows:

(a) Jessup's method of broadscale assessment of the condition of arid shrublands, although insensitive to moderate stocking pressure, provides a meaningful measure of the long term effects of overstocking on the Stations analyzed.

(b) Long term experiments require utmost stringency in method of execution of fieldwork and data acquisition for successful re-evaluation at a later date.

(c) The method of phytogeographic survey used here permitted accurate delineation of the distribution patterns for most of the species used. Accurate data on the extent of regeneration of *Acacia aneura, A. sowdenii* and *Callitris columellaris*, which was previously unavailable, was also obtained. Phytogeographic implications are in accord with the theories of Burbidge (1960) concerning species in the Eremean zone she defined.

(d) Correlation of the findings from this study with past stocking history was rendered impossible in most cases, because data on stock numbers in individual paddocks, and even on the whole station are often inaccurate or unavailable. Many stations have also had a number of changes in management over the interval between surveys.

(e) From the data obtained, it is evident that stock numbers of less than 300-350 on each watering point will cause only negligible bush death over a twenty year period, provided there is at least about 20 square miles ($51km^2$) per watering point. It is certainly clear that stocking rates should be governed by the number per watering point, rather than a blanket stocking rate per square km. The findings here support the view that bush death is principally caused by high stock numbers on a particular watering point, and Commonwealth Hill Station provides a graphic illustration of such widespread degeneration over a relatively short time interval.

As pointed out by Lange (1972), from the many studies on arid rangelands in South Australia, there has been almost no spinoff to guide managers in these areas. This is in contrast with some other States, for example Western Australia, where most studies are at the management level (Western Australian Department of Agriculture, 1965). Consequently the Pastoral

Board here must determine the carrying capacity and stocking conditions on each lease on the basis of subjective assessment only. It is therefore hardly surprising that the degeneration as revealed in this study has been allowed to occur.

Recommendations for Future Research.

Only a small proportion of the data gained on the bush density survey has been analyzed as yet. It is likely that the comparison of results from the other stations will provide a greater insight into the effect of various stocking rates and management policies on perennial shrubland vegetation. Other analyses may also be profitable. It is felt that this method of assessment of the condition and trend in arid shrublands, or some other rapid inventory procedure, based on objective data from the perennial component of the vegetation, is likely to provide the most meaningful and widely applicable scientific basis for stocking policies in this country. Answers to arid rangeland problems are needed fast, but an ultimate understanding of the overall impact of the pastoral history on this vegetation type can only be obtained by stringent long-term monitoring of vegetation in the grazed paddock, and it is to this end that research efforts must be directed.

APPENDIX I

LIST OF PLANT SPECIES COLLECTED

(Housed in State Herbarium of South Australia)

AIZOACEAE 45*

Aizoon quadrifidum (F.v.M.) F.v.M.

Aizoon zygophylloides F.v.M.

Carpobrotus aequilaterus (Harv.) N.E. Brown

Gasoul crystallinum (L.) Rothm.

Glinus lotoides L.

Sarcozona praecox (F.v.M.) S.T. Blake

Tetragonia tetragonoides (Poll.) Kuntze

Trianthema triquetra Willd.

ALISMATACEAE 18

Triglochin centrocarpa Hook.

AMARANTHACEAE 42

Alternanthera angustifolia R.Br.

Alternanthera nodiflora R. Br.

Amaranthus grandiflorus (Black) Black

Ptilotus exultatus nees var. *exultatus*

Ptilotus gaudichaudii (Steud.) Black

Ptilotus obovatus (Gaudich.) F.v.M.

Ptilotus parvifolius (F.v.M.) F.v.M.

Ptilotus polystachyus (Gaudich.) F.v.M.

AMARYLLIDACEAE 30

Calostemma luteum Sims.

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* Family numbers are those used by Black (1948-65) and Eichler (1965).

APIACEAE 86 (= UMBELLIFERAE)

Daucus glochidiatus (Labill.) Fisch., Mey. and Avé-Lall.

Trachymene glaucifolia (F.v.M.) Benth.

Uldinia ceratocarpa (Fitz.) Burbidge

ASCLEPIADACEAE 94

Pentatropis kempeana F.v.M.

Sarcostemma australe R. Br.

ASTERACEAE 177

Actinobole uliginosum (A. Gray) Eichler

Angianthus brachypappus F.v.M. var. *conocephalus* Black

Angianthus burkittii (Benth.) Black

Angianthus pusillus (Benth.) Benth.

Angianthus aff. *tomentosus* Wendl.

Brachyscombe iberidifolia Benth.

Brachyscombe lineariloba (DC.) Druce

Calotis cymbacantha F.v.M.

Calotis erinacea Steetz

Calotis hispidula (F.v.M.) F.v.M.

Calotis multicaulis (Turcz.) Druce

Centipedia thespidioides F.v.M.

Ceratogyne obionoides Turcz.

Craspedia chrysantha (Schldl.) Benth.

Craspedia pleiocephala F.v.M.

Cratystylis conocephala (F.v.M.) S. Moore

Epaltes cunninghamii (Hook.) Benth.

Gnephosis eriocarpa (F.v.M.) Benth.

Gnephosis skirrophora (Sond. et F.v.M. ex Sond.) Benth.

Helichrysum ayersii F.v.M.
Helichrysum cassinianum Gaudich.
Helichrysum davenportii F.v.M.
Helichrysum podolepidium F.v.M.
Helipterum chlorocephalum (Turcz.) Benth.
Helipterum fitzgibbonii F.v.M.
Helipterum floribundum DC.
Helipterum jessenii F.v.M.
Helipterum microglossum (F.v.M.) Tate
Helipterum molle (A. Cunn. ex DC.) Wilson
Helipterum moschatum (A. Cunn.) Benth.
Helipterum pterochaetum (F.v.M.) Benth.
Helipterum pygmaeum (DC.) Benth.
Helipterum stipitatum (F.v.M.) F.v.M. ex Benth.
Helipterum strictum (Lindl.) Benth.
Helipterum troedellii F.v.M.
Helipterum sp..? aff. *troedellii* F.v.M.
Helipterum uniflorum Black
Ixiolaena leptolepis (DC.) Benth.
Ixiolaena c.f. *leptolepis* (DC.) Benth.
Microseris scapigera (Sol. ex A. Cunn.) Schultze - Bip.
Millotia myosotidifolia(Benth.) Steetz.
Minuria cunninghamii (DC.) Benth.
Minuria denticulata (DC.) Benth.
Minuria suaedifolia (F.v.M.) Benth.
Myriocephalus stuartii (F.v.M. et Sond. ex Sond.) Benth.
Olearia decurrens (DC.) Benth.
Olearia lepidophylla (Pers.) Benth.
Olearia muelleri (Sond.) Benth.
Olearia ramulosa (Labill.) Benth.
Olearia rudis (Benth.) F.v.M. ex Benth.
Podolepis canescens A. Cunn. ex DC.
Podolepis capillaris (Steetz.) Diels
Podolepis jaceoides (Sims) Voss.
Podolepis muelleri (Sond.) Davis

Rutidosis helichrysoides DC.
Senecio cunninghamii DC.
Senecio glossanthus (Sond.) Belcher
Senecio gregorii F.v.M.
Senecio aff. *lautus* Forst. f. ex Willd.
Senecio magnificus F.v.M.
Sonchus oleraceus L.
Vittadinia scabra DC.

BORAGINACEAE 96

Omphalolappula concava (F.v.M.) Brand
Plagiobothrys plurisepaleus (F.v.M.) Johnston
Trichodesma zeylanicum (Burm. f.) R. Br.

BRASSICACEAE 53 (= CRUCIFERAE)

Arabidella procumbens (Tate) Shaw
Arabidella trisecta (F.v.M.) Schultz
Blennodia canescens R.Br.
Brassica tournefortii Gorran
Coronopus didymus (L.) Sims
Lepidium oxytrichum Spraque
Lepidium rotundum (Desv.) DC.
Scambopus curvipes (F.v.M.) Schultz
Sisymbrium irio L.
Stenopetalum lineare R. Br. ex DC.
Stenopetalum lineare R. Br. ex DC. var. *canescens* Benth.
Stenopetalum sphaerocarpum F.v.M.
Waitzia acuminata Steetz in Lehm.

BRUNONIACEAE 115

Brunonia australis Sm.

CAESALPINACEAE 60 B

Cassia artemisioides Gaudich. ex DC.

Cassia helmsii Symon

Cassia nemophila var. *coriacea* (Benth.) Symon

Cassia nemophila Cunn. ex Vogel var. *nemophila*

Cassia nemophila var. *platypoda* (R. Br.) Benth.

Cassia oligophylla F.v.M.

Cassia oligophylla var. *sericea* Symon

Cassia phyllodinea R. Br.

Cassia pleurocarpa F.v.M.

CAMPANULACEAE 113

Isotoma petraea F.v.M.

Laurencia glomerata Hook.

Wahlenbergia c.f. *sieberi* A. DC.

CARYOPHYLLACEAE 47

Scleranthus pungens R. Br.

Spergularia c.f. *rubra* (L.) J. & C. Presl.

CASUARINACEAE 33

Casuarina cristata Miq.

Casuarina helmsii Ewart & Gordon

CHENOPODIACEAE 41

Arthrocnemum arbuscula (R. Br.) Moq.

Arthrocnemum leiostachyum (Benth.) Paulsen

Atriplex acutibractea Anderson

Atriplex angulata Benth.

Atriplex angulata var. *campanulatiformis* Aellen

Atriplex conduplicata F.v.M.

Atriplex eardleyae Aellen
Atriplex fissivalvis F.v.M.
Atriplex holocarpa F.v.M.
Atriplex incrassata F.v.M.
Atriplex inflata F.v.M.
Atriplex leptocarpa F.v.M.
Atriplex limbata Benth.
Atriplex nummularia Lindl.
Atriplex quadrivalvata Diels
Atriplex c.f. *quadrivalvata* Diels
Atriplex quinii F.v.M.
Atriplex spongiosa F.v.M.
Atriplex c.f. *rhagoidioides* F.v.M.
Atriplex vesicaria Heward
Atriplex velutinella F.v.M.
Babbagia dipterocarpa F.v.M.
Bassia bicornis (Lindl.) F.v.M. var. *bicornis*
Bassia brachyptera (F.v.M.) Anderson
Bassia divaricata (R. Br.) F.v.M.
Bassia eriacantha (F.v.M.) Anderson
Bassia lanicuspis (F.v.M.) F.v.M.
Bassia parviflora Anderson
Bassia paradoxa (R.Br.) F.v.M.
Bassia quinquecuspis var. *villosa* (Benth.) Black
Bassia sclerolaenoides (F.v.M.) F.v.M.
Bassia ventricosa Black
Bassia c.f. *uniflora* (R. Br.) F.v.M.
Chenopodium c.f. *cristatum* (F.v.M.) F.v.M.
Chenopodium desertorum (Black) Black
Chenopodium nitrariaceum F.v.M.
Enchylaena tomentosa R. Br.
Kochia astrotricha Johnson
Kochia aphylla R. Br.

Kochia carnosa (Moq.) Anderson
Kochia ciliata F.v.M.
Kochia concava Ising
Kochia georgii Diels
Kochia ovata Ising
Kochia pyramidata Benth.
Kochia sedifolia F.v.M.
Kochia spongiocarpa F.v.M.
Kochia tomentosa F.v.M.
Kochia c.f. *triptera* Benth.
Kochia villosa Lindl.
Malacocera biflora Ising
Pachycornia tenuis (Benth.) Black
Rhagodia gaudichaudiana Moq.
Rhagodia nutans R.Br.
Rhagodia preissii Moq.
Rhagodia spinescens R.Br.
Salsola kali L.
Threlkeldia proceriflora F.v.M.

CONVOLVULACEAE 95

Convolvulus erubescens Sims

CUCURBITACEAE 112

Citrullus c.f. *lanatus* (Thunb.) Mansf.
Cucumis myriocarpus Naud.

CUPRESSACEAE 12A

Callitris columellaris F.v.M.

CYPERACEAE 21

Cyperus iria L.

EPACRIDACEAE 87

Leucopogon cordifolius Lindl.

EUPHORBIACEAE 68

Beyeria opaca F.v.M.
Euphorbia drummondii Boiss.
Euphorbia enemophila A. Cunn. ex Hook.
Phyllanthus fuernhohrii F.v.M.
Phyllanthus lacunarius F.v.M.
Poranthera triandra Black
Rumex vesicarius L. (syn. *R. roseus* L.)

FABACEAE (= PAPILIONATAE) 60C

Aotus ericoides (Vent.) G. Don.
Bossiaea walkeri F.v.M.
Clianthus formosus (G. Don.) Ford & Vickery
Crotalaria eremaea F.v.M.
Crotalaria strehlowii F. Pritzel
Daviesia ulicifolia Andr.
Glycyrrhiza acanthocarpa (Lindl.) Black
Indigofera australis Willd.
Glycine clandestina Wendl.
Lotus cruentus Court.
Psoralea eriantha Benth.
Psoralea patens Lindl.
Ptychosema stipulare Black
Swainsona canescens (Benth.) F.v.M.
Swainsona microcalyx var. *adenophylla* (Black) Black
Swainsona microcalyx Black var. *microcalyx*
Swainsona oligophylla F.v.M. ex Benth.
Swainsona oliveri F.v.M.
Swainsona oroboides F.v.M.

Swainsona phacoides Benth.
Swainsona stipularis F.v.M. var. *stipularis*
Swainsona villosa Black
Templetonia egena (F.v.M.) Benth.

FRANKENIACEAE 79

Frankenia c.f. *connata* Spraque
Frankenia gracilis Summerh.
Frankenia sessilis Summerh.

HALORAGACEAE 85

Haloragis aspera Lindl.
Haloragis odontocarpa F.v.M.

GERANIACEAE 61

Erodium aureum Carolin
Erodium cygnorum Ness ssp. *cygnorum*
Erodium cygnorum ssp. *glandulosum* Carolin

GOODENIACEAE 114

Calogyne berardiana (Gaudich.) F.v.M.
Goodenia calcarata (F.v.M.) F.v.M.
Goodenia cycloptera R. Br.
Goodenia havilandii var. *pauperata* Black
Goodenia helenae Ising
Goodenia pinnatifida Schldl.
Goodenia subintegra F.v.M. ex Black
Scaevola collaris F.v.M.
Scaevola spinescens R. Br.

GYROSTEMONACEAE 44A

Gyrostemon ramulosus Desf.
Codonocarpus cotinifolius (Desf.) F.v.M.

LAMIACEAE (= LABIATAE) 98

Prostanthera striatiflora F.v.M.
Teucrium racemosum R. Br.
Westringia rigida R. Br.

LILIACEAE 29

Anguillaria dioica R.Br.
Bulbinopsis semibarbata (R. Br.) Borzi.
Lomandra leucocephala ssp. *robusta* Lee
Thysanotus baueri R. Br.
Thysanotus patersonii R. Br.

LOGANIACEAE 91

Logania nuda F.v.M.

LORANTHACEAE 39

Amyema gibberula (Tate) Danser
Amyema maidenii (Blakely) Barlow
Amyema miquellii (Lehm. ex Miq.) Tiegh.
Amyema preissii (Miq.) Tiegh.
Amyema quandang (Lindl.) Tiegh.
Lysiana exocarpi (Behr.) Tiegh. ssp.*exocarpi*
Lysiana murrayi (F.v.M. et Tate) Tiegh.

MALVACEAE 74

Abutilon leucoptera (F.v.M.) F.v.M. ex Benth.
Lavatera plebeia Sims.
Lawrencia spicata Hook.
Malvastrum spicatum (L.) A. Gray

Sida c.f. *cardiophylla* F.v.M.
Sida corrugata Lindl.
Sida petrophila F.v.M.
Sida tephrotricha F.v.M.
Sida trichopoda F.v.M.
Sida virgata Hook.

MARSILIACEAE 7

Marsilea drummondii A. Br.

MIMOSACEAE 60A

Acacia aneura F.v.M. ex Benth.
Acacia brachystachya Benth.
Acacia burkittii F.v.M. ex Benth.
Acacia calcicola Forde & Ising
Acacia colletioides Benth.
Acacia colletioides Benth. var. *nyssophylla* (F.v.M.) Benth.
Acacia kempeana F.v.M.
Acacia ligulata A. Cunn. ex Benth.
Acacia linophylla Fitzg.
Acacia oswaldii F.v.M.
Acacia aff. *oswaldii* (F.v.M.)
Acacia salicina Lindl.
Acacia sibirica S. Moore.
Acacia sowdenii Maiden
Acacia stenophylla A. Cunn. ex Benth.
Acacia tarculensis Black
Acacia tetragonophylla F.v.M.
Acacia victoriae Benth.

MYOPORACEAE 106

Eremophila alternifolia R.Br.
Eremophila c.f. *delisseri* F.v.M.
Eremophila duttonii F.v.M.

Eremophila exotrachys Kraenzl.
Eremophila freelingii F.v.M.
Eremophila gibsonii F.v.M.
Eremophila gilesii F.v.M.
Eremophila goodwinii F.v.M.
Eremophila latrobei F.v.M.
Eremophila longifolia (R. Br.) F.v.M.
Eremophila maculata (Ker-Gawl.) F.v.M.
Eremophila oppositifolia R.Br.
Eremophila paisleyi F.v.M.
Eremophila rotundifolia F.v.M.
Eremophila scoparia (R. Br.) F.v.M.
Eremophila serrulata (A. Cunn. ex A. DC.) Druce
Eremophila sturtii R. Br.
Eremophila willsii F.v.M.
Myoporum deserti A. Cunn. ex Benth.
Myoporum montanum R. Br.
Myoporum platycarpum R. Br.

MYRTACEAE 83

Calytrix involucrata Black
Calytrix longiflora F.v.M.
Darwinia micropetala (F.v.M.) Benth.
Eucalyptus concinna Maiden et Blakely ex Maiden
Eucalyptus aff. *concinna* Maiden and Blakely ex Maiden
Eucalyptus foecunda Schauer
Eucalyptus aff.*oleosa* F.v.M. ex Miq.
Eucalyptus pyriformis Turcz.
Eucalyptus socialis F.v.M.
Eucalyptus aff. *striaticalyx* W.V. Fitzg.
Eucalyptus transcontinentalis Maiden
Leptospermum coriaceum (F.v.M. ex Miq.) Cheel.
Melaleuca adnata Turcz.
Melaleuca glomerata F.v.M.

Melaleuca lanceolata Otto
Melaleuca leiocarpa F.v.M.
Melaleuca uncinata R. Br. ex Ait.
Thryptomene maissoneuvii R.v.M.
Verticordia wilhelmii F.v.M.

PITTOSPORACEAE 58

Pittosporum phylliraeoides DC.

PLANTAGINACEAE 107

Plantago varia R. Br.

POACEAE 20.

Aristida browniana Henr.
Aristida contorta F.v.M.
Astrebla pectinata (Lindl.) F.v.M. ex Benth.
Bromus arenarius Lindl.
Chloris pectinata Benth.
Dactyloctenium radulans (R. Br.) Beauv.
Danthonia bipartita F.v.M.
Dichanthium cericeum (R. Br.) A. Camus
Digitaria brownii (Rets.) Hughes
Enneapogon avenaceus (Lindl.) C.E. Hubbard
Enneapogon caerulescens (Gaud.) N.T. Burbidge
Enneapogon c.f. *caerulescens* (Gaud.) N.T. Burbidge
Enneapogon cylindricus N.T. Burbidge
Enneapogon polyphyllus (Domin.) N.T. Burbidge
Eragrostis australasica (Steud.) Hubbard
Eragrostis dielsii Pilger
Eragrostis eriopoda Benth.
Eragrostis falcata (Gaudich.) Benth.
Eragrostis kennedyae F. Turner

Eragrostis setifolia Nees.
Eriachne benthamii Hartley
Iseilema membranaceum(Lindl.) Domin.
Lophochloa pumila (Desf.) Bor.
Neurachne mitchellana Nees.
Neurachne munroi (F.v.M.) F.v.M.
Panicum decompositum R. Br.
Paractaenum novae-hollandii Beauv.
Paspalidium basicladum Hughes
Poa aff. *fordeana* F.v.M.
Setaria dielsii Herm.
Stipa c.f. *eremophila* Reader
Stipa falcata Hughes
Stipa nitida Summ. et Hubbard
Stipa platychaeta Hughes
Stipa variabilis Hughes
Tragus australianus S.T. Blake
Triodia lanata Black
Triraphis mollis R. Br.

POLYGONACEAE 40

Muehlenbeckia cunninghamii (Meisn.) F.v.M.
Polygonum aviculare L.
Polygonum plebeium R. Br.

POLYPODIACEAE 2

Cheilanthes lasiophylla Pichi-Sermolli
Cheilanthes tenuifolia (Burm. f.) Swartz

PORTULACACEAE 46

Calandrinia corrigioloides F.v.M. ex Benth.
Calandrinia disperma Black
Calandrinia eremaea Ewart

<u>PROTEACEAE 36</u>

Grevillea huegelii Meissn.
Grevillea nematophylla F.v.M.
Grevillea pterosperma F.v.M.
Grevillea stenobotrya F.v.M.
Grevillea treueriana F.v.M.
Hakea leucoptera R. Br.
Hakea multilineata Meissn.

<u>RANUNCULACEAE 49</u>

Myosurus minimus L.

<u>RUBIACEAE 108</u>

Pomax umbellata Sol.

<u>RUTACEAE 65</u>

Eriostemon linearis A. Cunn. ex Endl.
Phebalium bullatum Black.

<u>SANTALACEAE 37</u>

Exocarpos aphyllus R. Br.
Santalum acuminatum (R. Br.) A. DC.
Santalum lanceolatum var. *angustifolium* Benth.
Santalum spicatum (R. Br.) A. DC.

<u>SAPINDACEAE 71</u>

Dodonaea attenuata A. Cunn.
Dodonaea lobulata F.v.M.
Dodonaea microzyga F.v.M.
Dodonaea stenozyga F.v.M.
Dodonaea viscosa L.
Heterodendrum oleaefolium Desf.

SCROPHULARIACEAE 100

Morgania glabra R. Br. sensu Black
Peplidium muelleri var. *longipes* Black

SOLANACEAE 99

Anthotroche truncata Ising
Duboisia hopwoodii F.v.M.
Lycium australe F.v.M.
Nicotiana velutina Wheeler
Solanum ellipticum R. Br.
Solanum orbiculatum Dun.
Solanum petrophilum F.v.M.
Solanum quadriloculatum F.v.M.

THYMELAEACEAE 81

Pimelia microcephala R. Br.
Pimelia simplex F.v.M.

VERBENACEAE 97

Dicrastylis beveridgei F.v.M.

ZYGOPHYLLACEAE 64

Nitraria schoberi L.
Tribulus terrestris L.
Zygophyllum s.p. aff. *ammophilum* F.v.M.
Zygophyllum aurantiacum (Lindl.) F.v.M.
Zygophyllum c.f. *aurantiacum* (Lindl.) F.v.M.
Zygophyllum aurantiacum var. *eremaeum* (Diels) Eichler
Zygophyllum c.f. *crassissimum* Ising
Zygophyllum howittii F.v.M.

APPENDIX II.

SPECIES USED IN THE PHYTOGEOGRAPHIC SURVEY.

Acacia aneura F.v.M. ex Benth.	Mulga
Acacia brachystachya Benth.	Umbrella Mulga
Acacia burkittii F.v.M. ex Benth.	
Acacia calcicola Forde and Ising.	Scrub Myall
Acacia colletioides Benth.	Wait-a-while
Acacia kempeana F.v.M.	Witchetty Bush
Acacia ligulata A. Cunn. ex Benth.	
Acacia linophylla Fitzg.	Sandhill Mulga
Acacia oswaldii F.v.M.	
Acacia salicina Lindl.	Broughton Willow
Acacia sowdenii Maiden	Western Myall
Acacia tarculensis Black	Granite Wattle
Acacia tetragonophylla F.v.M.	Dead Finish
Acacia victoriae Benth.	Prickly Acacia
Bossiaea walkeri F.v.M.	
Callitris columellaris F.v.M.	Cypress Pine
Casuarina cristata Miq.	Blackoak
Codonocarpus cotinifolius (Desf.) F.v.M.	Desert Poplar
Cratystylis conocephala (F.v.M.) S. Moore	Flowering Bluebush
Dodonaea attenuata A. Cunn.	Hopbush
Eragrostis australasica (Steud.) Hubbard	Canegrass
Eremophila longifolia (R.Br.) F.v.M.	
Eremophila paisleyi F.v.M.(Narrow-leaved form)	
Eremophila rotundifolia F.v.M.	

Eremophila scoparia (R.Br.) F. v.M.	Broombush
Eremophila sturtii R.Br.	Turpentine Bush
Eucalyptus microtheca F.v.M.	Coolabah
Eucalyptus pyriformis Turcz.	Ooldea Mallee
Eucalyptus transcontinentalis Maiden	
Grevillea nematophylla F.v.M.	Water Bush
Grevillea stenobotrya F.v.M.	
Hakea leucoptera R.Br.	Needlebush
Heterodendrum oleaefolium Desf.	Bullock Bush
Melaleuca lanceolata Otto	Moonah
Melaleuca uncinata R.Br. ex Ait.	Tea Tree
Myoporum platycarpum R.Br.	False Sandalwood
Pittosporum phylliraeoides DC.	Weeping Pittosporum
Santalum acuminatum (R.Br.) A.DC.	Quandong
Santalum lanceolatum R.Br. var. *angustifolium* Benth.	Wild Plum
Sarcostemma australe R.Br.	Tableland Caustic Bush
Templetonia egena (F.v.M.) Benth.	
Triodia lanata Black.	Porcupine Grass

* * * *

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