THE IMPACT OF CATTLE INTRODUCTION ON ARID SHEEPLANDS

by

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Thesis submitted for the degree of Doctor of Philosophy

University of Adelaide

February, 1975.

SUMMARY

This thesis investigates the effect on vegetation of recent cattle introduction to the arid sheeplands of South Australia. While the effects of sheep on these rangelands are well documented, those of cattle are not known. The study thus represents the initial examination of the cattle impact.

The main aim was to determine the extent to which cattle modified the existing sheep-induced vegetation pattern. For the short term, thiswas achieved by a two-year comparison of vegetations, separately grazed by cattle and sheep, on a representative station. The comparison was begun soon after the first introduction of cattle. Stocking effects were isolated from background vegetation pattern by application of the piosphere concept. Detection of pattern in density and estimated biomass of major pasture species was emphasized, with regression and Principal Components analyses being employed. The results were complicated by the exceptionally heavy and extended rains which fell during much of the observation period. The results nonetheless demonstrated that short-term stocking effects differed for sheep and cattle, but became obscured in periods of pasture growth. No basis was found for the prediction of the long-term trend from the short-term observations.

Less intensive comparisons, with both sheep and virgin sites, were used to infer long-term changes in vegetation resulting from cattle stocking. Stocking effects were isolated by examination of mapped relative abundances of species, following a

careful matching of site landscapes. The results indicated changes similar to those reported to occur with sheep stocking.

The causes of vegetation pattern and change were considered, but the research needed to allow definitive statement of these causes was beyond the scope of the study. Reports on possible factors such as stock diet and behaviour are, therefore, reviewed in detail. On the basis of these reports, it was concluded that the majority of the stocking effects observed did not result from the preferential selection of species by the grazing animal. This is contrary to common assumption.

Mechanical disturbance of soil and plants in the course of grazing was proposed as the major determinant of stock-induced vegetation change. This hypothesis was partially tested, but with equivocal result.

The implications of the outcome of this study are discussed, as regards both the future of the South Australian sheeplands and the requirements for future study.

DECLARATION

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

T.J. Fatchen

ACKNOWLEDGEMENTS

I wish to thank Dr R.T. Lange for his support during this study. Mr Andrew Brown and Mr D.H. Crane also gave much assistance through both advice and introductions at the outset. Of the many pastoralists who tolerated my presence and questions, I especially wish to thank Mr Hugh Maclachlan for his co-operation regarding the observations on Mt Victor station, and his staff, Mr and Mrs Fred Sleep, who kept a weather eye on me; Mr Walter French and sons of Pernatty station, and Mr Tom Allison and Mr Jack Allison of Roxby Downs station for their help in other field studies; and Lester Lord, Garnham Skipper, and Dudley Fuller. All the pastoralists I met showed a welcome interest and a great hospitality, and gave me no little education in the intricacies of management in the pastoral country.

My thanks must also go to Dr George Ganf and Dr Susan Barker who critically read part of the manuscript; to Daphne McEwen who typed the text; and to Deborah Fatchen, who with patience and perseverance not only withstood my preoccupations but also drafted the final diagrams.

The research was supported by a Commonwealth Postgraduate Student Award and funds from the Sandlands Bequest to the University of Adelaide.

NOTE ON PLANT IDENTIFICATION AND NOMENCLATURE

Voucher specimens of all species named in this thesis have been lodged at the State Herbarium of South Australia, Adelaide (AD) and at the Botany Department, University of Adelaide. Most identifications were verified by Dr Hj. Eichler and staff at the Herbarium. The remainder, involving vegetative specimens only, were verified by comparison with AD collections.

All names are those given by Black (1943-1957), as amended by Eichler (1965). The appropriate author citations are given in these works.

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CHAPTER 1

INTRODUCTION

1-1 CAUSE AND PURPOSE OF RESEARCH.

Significant cattle herds were introduced on South Australian arid sheeplands in 1970, after a century of almost exclusive sheep grazing (see fig. 1.1). The effect of sheep on the vegetation of these rangelands was well documented, but little was known of the effect of cattle. Ignorance of the arid environment in general, and the effect of sheep in particular, had led to injudicious stocking in the past. This in turn resulted in widespread pasture degradation and soil erosion, with concommittant losses in animal production. The introduction of cattle was regarded as having much the same potential for destruction (e.g. by Lange, 1971), in the absence of information about the animals' effect on the vegetations concerned. The research, reported in this thesis, represented the first attempt to provide the missing information. The main aims were:

1. To identify the impact of cattle on the vegetations of the arid former sheeplands; and
2. To predict the long-term trends in such vegetations under cattle grazing.

The secondary aim was: to determine the primary causes of the changes in vegetation resulting from cattle introduction.

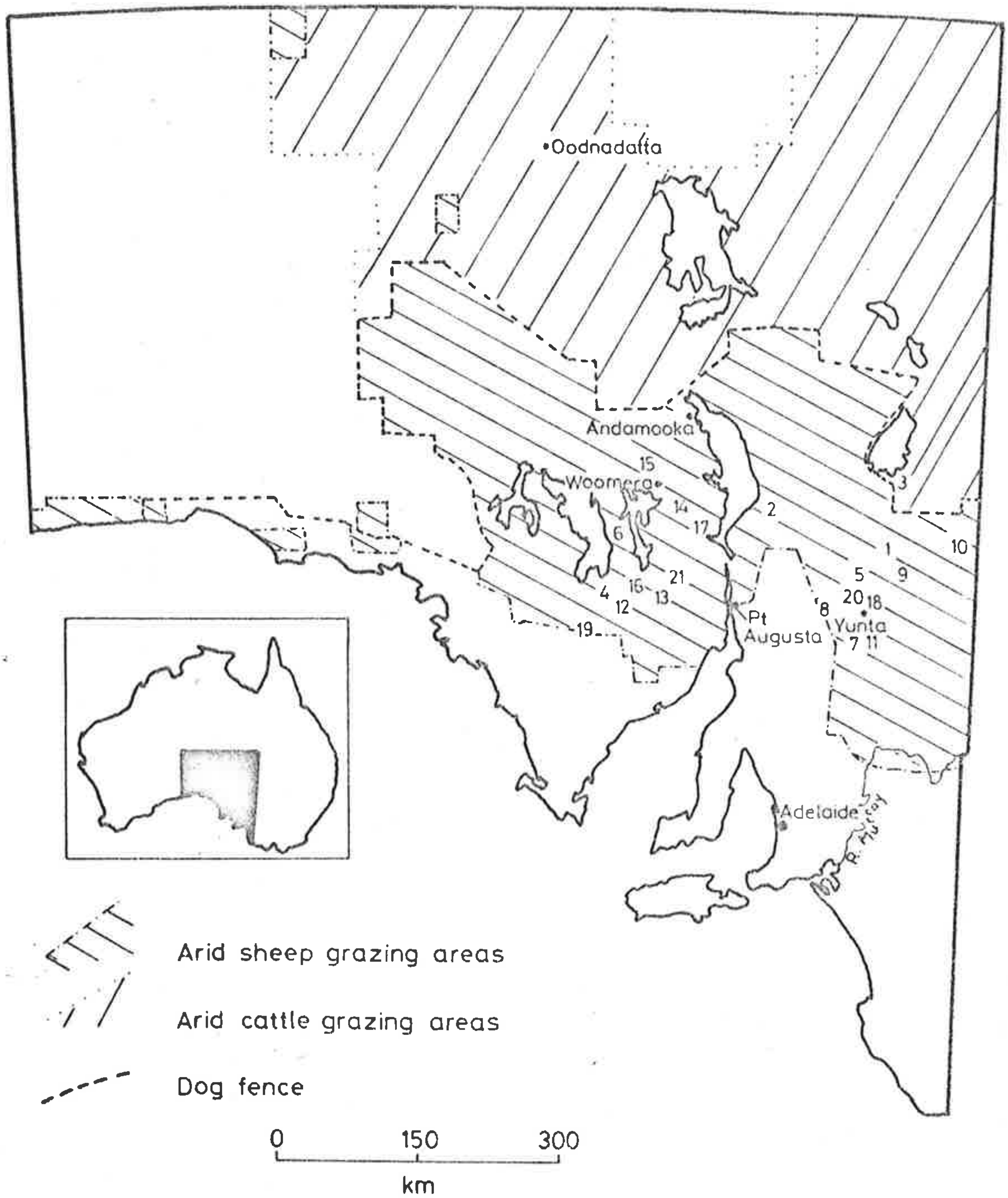
1-2 PLAN OF RESEARCH.

The research plan is shown in figure 1.2 A literature review, summarized in the remainder of this chapter, was undertaken at the

FIGURE 1.1

SOUTH AUSTRALIA
STATION LOCALITY MAP

1. Curnamona
2. Edeowie
3. Frome Downs
4. Kolendo
5. Koonamore
6. Mahanewo
7. Manunda
8. McCoy's Well
9. Mt Victor
10. Mulyungarie
11. Netley Gap
12. Nonning
13. Oakden Hills
14. Pernatty
15. Roxby Downs
16. Siam
17. South Gap
18. Teetulpa
19. Thurlga
20. Wabricoola
21. Yudnapinna



Oodnadatta
Andamooka
Woomera
Pt Augusta
Yunta
Adelaide
R. Murray
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
Arid sheep grazing areas
Arid cattle grazing areas
Dog fence
0
150
300
km

commencement of the study. Extensive reviews exist for most of the aspects discussed, and there seemed little point in rewriting these reviews. Instead, a condensed outline of the background is given, adequate for an understanding of the general situation, but details are not stressed unless they have an immediate bearing on the particular problem under investigation.

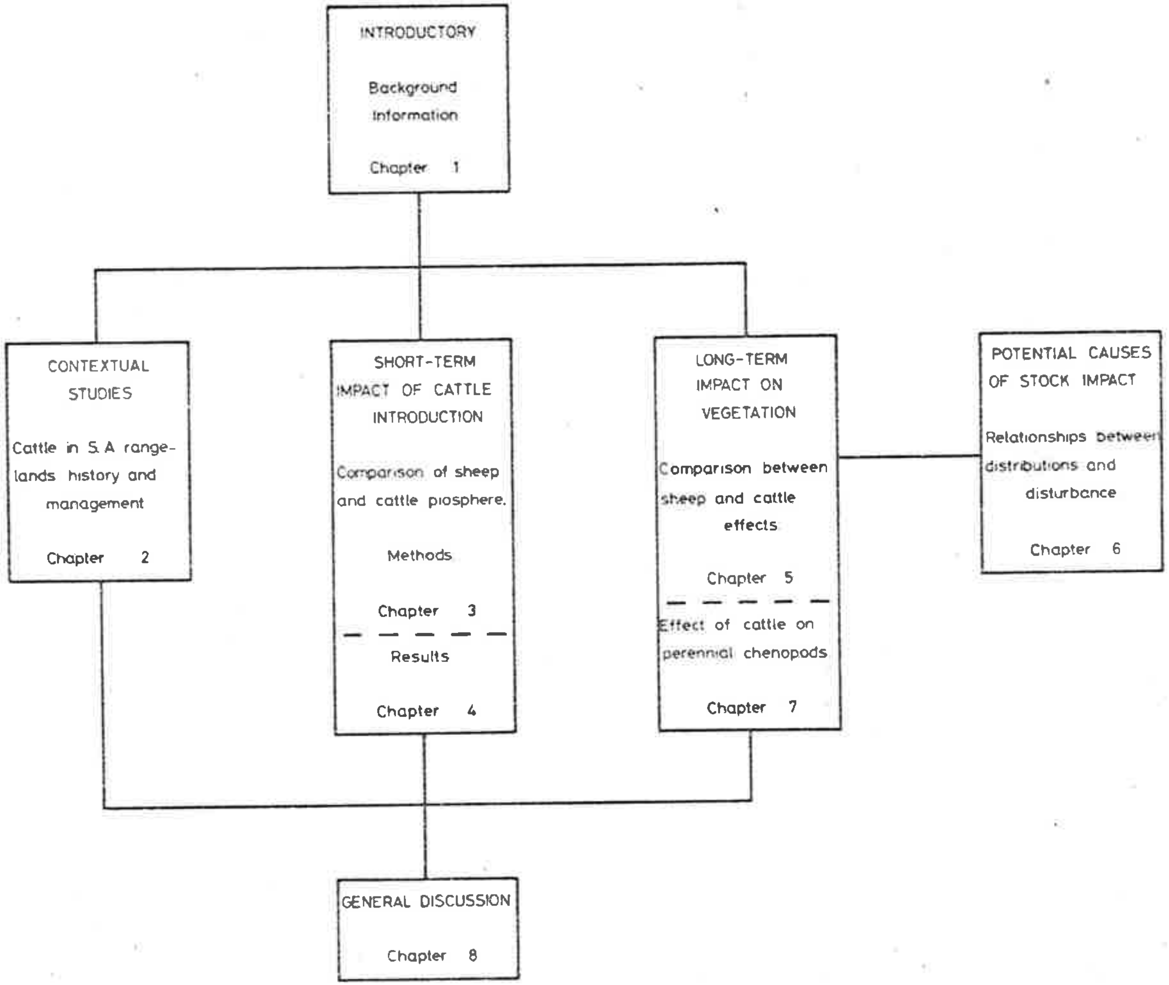
Three courses of research were necessary. Before commencing detailed investigations, information was required, on the manner in which cattle were run on former sheeplands, the pasture types on which they were run, and the pastoralists' attitudes. The information was gained during widespread travel through the sheeplands, from subjective observation and discussion among pastoralists; and is summarized in chapter 2.

The impact of cattle on vegetation was determined by a detailed comparison, over a two-year period, of two representative pastures; one newly under cattle, the other still under sheep. The results were expected to show the beginnings of long-term pasture divergences between grazing regimes, in addition to allowing identification of the immediate impact of cattle. The methods are described in chapter 3, and the results are given in chapter 4.

The outcome of long-term cattle-stocking was observed, for isolated situations where cattle had been run on former sheeplands prior to the major introduction. Trends in vegetation under cattle were inferred largely by comparisons of pasture species' abundances, between cattle-grazed sites and both sheep-grazed and virgin sites. The two main observations are reported in chapter 5. In the course of these observations, mechanical

Fig. 1.2

STUDY PLAN



disturbance (trampling of plants, and disturbance of soils) was proposed as the main determinant of long-term vegetation changes relating to stock. The study of plant distributions in relation to soil stability, reported in chapter 6, provided a partial test of this hypothesis. In addition to the observations of chapter 5, two minor studies were undertaken, to determine the long-term effect of cattle stocking on perennial chenopod species (chapter 7).

The three courses are drawn together in chapter 8, in which their overall results and implications are discussed, and the final conclusions given.

The research was aimed at problem solution, not elucidation or comparison of techniques. The various techniques and analyses were employed as means to this end. Methods were selected, from the great variety available, on the grounds of familiarity, convenience and efficiency. In some cases, equally efficient and convenient methods, other than the one used, were available (e.g. methods of biomass estimation; section 3- 3). In such cases, justification is given for the eventual choice. The amount of data gathered, and the number of analyses performed, could not be presented in full without making the thesis unwieldy. The procedures which have been adopted are:

1. Where statistical tests were performed, only those results found significant are included; the rest are stated to be nonsignificant, but no further information is given;
2. Where analyses were performed by subjective appraisal of data, the original data is included.

1-3 HISTORY AND ADMINISTRATION OF RANGELANDS IN SOUTHERN AUSTRALIA.

1-31 *Introduction.*

The vegetation of the South Australian sheeplands forms part of a suite of related associations, extending east into New South Wales and west into Western Australia. The S.A. and N.S.W. vegetations both have been grazed by sheep for over a century, and much of the research on the effect of sheep in N.S.W. is directly relevant to the S.A. situation. The States' sheeplands nonetheless have differences both in their histories and in their administrations, as outlined in the next two sections. These differences are reflected in differences in the present condition of the vegetation. Hence the research was limited to S.A., despite the similar increase in cattle on N.S.W. arid sheeplands.

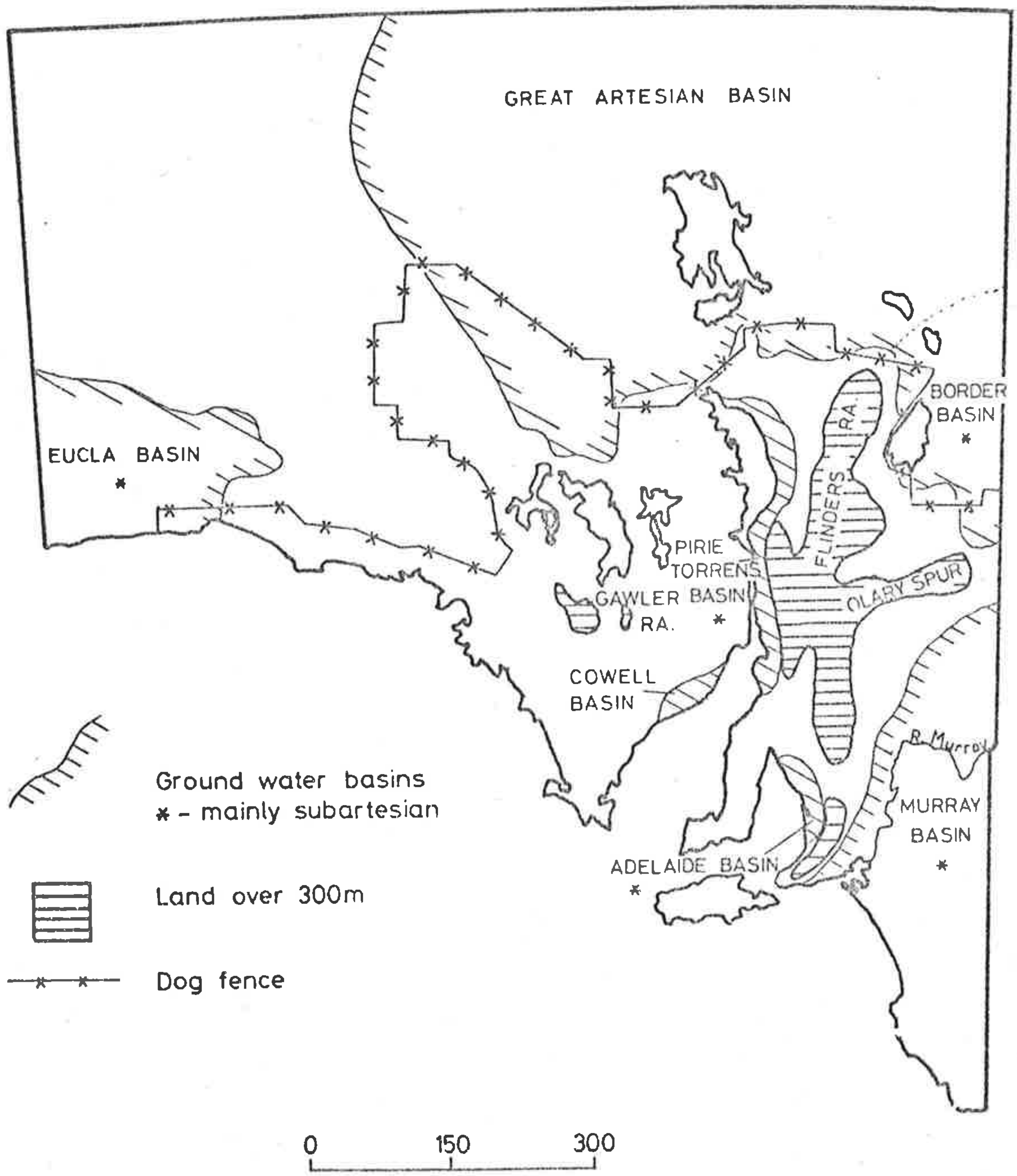
1-32 *History.*

The early history of arid N.S.W. is more fully documented than that of arid S.A. The Major reviews are Cain (1962) for the Western Division (arid N.S.W. west of the Darling River), Williams (1962) for the semi-arid Riverina (the alluvial plain bounded by the Murray and Lachlan rivers), and Heathcote (1965) for the Warrego district (northwest N.S.W. and southwest Queensland). The two major reviews for S.A. are Threadgill (1922) and Bowes (1968), both of which consider the State as a whole, not only the rangelands.

Pastoral expansion into the arid zone of both States commenced in the 1850's. Cattle were introduced occasionally, but the main emphasis was on sheep. The present boundaries of grazing lands were reached by 1870 (Roberts, 1924; Threadgill, 1922). Permanent water was freely available only in N.S.W., from springs or wells. In S.A., reliable and accessible sources were present only in the Flinders Ranges, the Olary spur, and on the edge of the Great Artesian Basin (fig. 1.3). Thus much of the grazing in S.A. was intermittent until the turn of the century, with stock removed at the onset of drought (see Barker, 1970). Provision of large surface catchments and sub-artesian bores became technically and financially feasible at this time. On the other hand, grazing in N.S.W. was continuous. Without prior experience in such country, stocking rates were set too high for pasture maintenance. Widespread destruction of the perennial shrub pastures ensued. Only in the semi-arid Riverina were the resultant pastures also perennial: elsewhere, the shrubs were replaced by ephemerals, able neither to support flocks in drought, nor to provide adequate protection against soil erosion. Pasture destruction and soil erosion reached a peak in the severe drought of the 1890's. The resulting crash in sheep population was so serious as to warrant a Royal Commission of enquiry (Roberts, 1924). The watered parts of the S.A. rangelands suffered similarly. In a contemporary account Dixon (1892) stated that damage from overstocking was "so great ... as to entail a national loss". Like statements were made even earlier, by Goyder (Surveyor-General, in S.A. Parlt. Paper No. 78, 1865-1866). However, large tracts of perennial pastures remained elsewhere, because of the intermittent stocking. Stock numbers have reached the levels of 1880-1890

Fig. 1.3

S. A. RANGELAND WATER RESOURCES



in only ten of the subsequent years (Barnard, 1969). Perry (1969) considered that this may imply a reduction of the productivity, resulting from the early overgrazing. If so, the situation presents a parallel with the Great Plains, U.S.A., where injudicious use of fragile lands also resulted in severe damage and lowered productivity (see Bennett et al, 1938).

By 1920, most of th S.A. rangelands had improved water resources which allowed continuation of stocking through droughts (e.g. as reported by the Mutooroo Pastoral Co., 1951); but the earlier experiences were not remembered. On the erroneous notion that carrying capacity is dependent only on the level of "improvements" such as fencing and water facilities, much of the stocking between 1920 and 1940 was still above the optimum for pasture maintenance. The result was again degradation and erosion (Ratcliffe, 1936). Overstocking was also causing further damage in Western N.S.W. (Beadle, 1948), exacerbated by the administration system. Since 1940, the situation has largely stabilised (Perry, 1970), although some cases remain of continuing degradation.

1-33 *Administration.*

In both areas, the original holdings were large (e.g. in S.A., blocks of 100mi^2, with lessees taking several contiguous blocks at a time--data from Richardson,1925). While leases remained large in S.A., the western N.S.W. holdings were subdivided on the basis of "living areas" early this century (Beadle, 1948). Waring (1969) outlined the need for large holdings on Australian rangelands; arid pastoralism is necessarily extensive because of the low return per unit area. From an economic viewpoint, only large holdings provide adequate returns on both labour and investment: from an ecological viewpoint, they are vital for landscape stability, permitting lighter stocking rates than small holdings for the same overall return. Reid (1968) summarized the situation, as follows. The average station areas in N.S.W. and S.A. respectively were 29,000 acres (12,000ha) and 58,700 acres (24,000ha), but sheep numbers were 5,460 and 3,410. (His figures include both arid and semi-arid ranges). The S.A. enterprises were the more efficient, with less agistment and fodder import, and smaller variation in sheep numbers, than in the N.S.W. enterprises. This resulted from both the more extensive grazing and the higher quality of the pastures in S.A.

Land tenure in most of the S.A. rangelands is by 42 year lease, with stocking limits set by Government regulation, and with provision for revocation of leases if damaged by overstocking (Pastoral Act, 1936-1969). Some cases exist of leases being foreclosed on these grounds. On the other hand, the leases of arid N.S.W. are perpetual, with little Government control, and little provision against damage (Heathcote, 1969). The provisions in S.A. have probably had some effect in maintenance of pastures, despite the nebulous character of many of the restrictions. (Lange, 1971, reports the difficulty of policing the regulations). The N.S.W. legislation has, if anything, impaired pasture conservation.

1-34 *The recent introduction of cattle on arid sheeplands.*

The S.A. arid sheeplands were separated historically into sheep and cattle ranges, with sheep in the southern rangelands, and cattle in the northern rangelands. Sheep-stocking was favoured in early settlement: an export market existed for wool, but only a small local market for beef (Roberts, 1924). Further, the merino sheep, most commonly run, could maintain production on chenopod pastures to a greater extent than the available cattle breeds (section 1-62, see also chapter 2). However, viable sheep enterprise required both the control of the wild dog (dingo), and the maximum utilisation of pastures. The construction of dog-proof and subdivisional fences, and of numerous water facilities, was feasible only in the southern rangelands; where the perennial pastures, if not abused, allowed continuity of stocking, with returns justifying expenditure. Where such development was not feasible, cattle were run. The division between the sheep and cattle areas was highlighted by the erection of the Dog Fence (fig. 1.1), consolidated from earlier vermin-proof fences by act of Parliament (Dog Fence Act, 1946). Until 1970, this fence represented a true demarcation, with most of the significant cattle herds "outside" (north)and most of the significant sheep herds "inside" (south) the fence.

The uneconomic wool prices of 1970-1971, and the resultant rural recession, led to an Australian-wide upsurge in cattle production, and a corresponding decrease in sheep production (see Thompson, 1971; also figs. 1.4, 1.5). In S.A., this was

Fig. 1.4
AVERAGE GREASY WOOL PRICE FOR S.A. 1951-1971

(Courtesy Bureau of Census and Statistics)

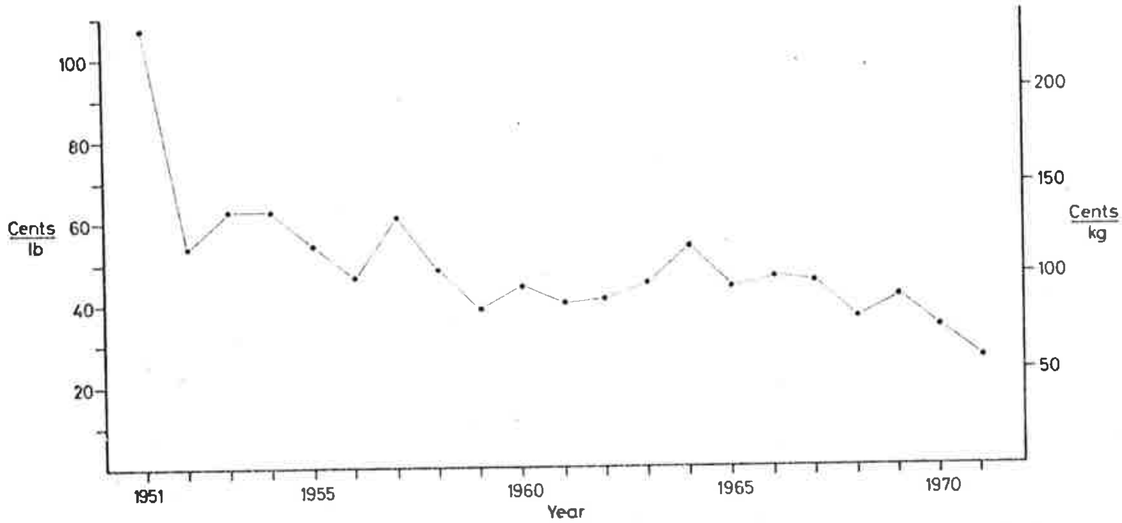
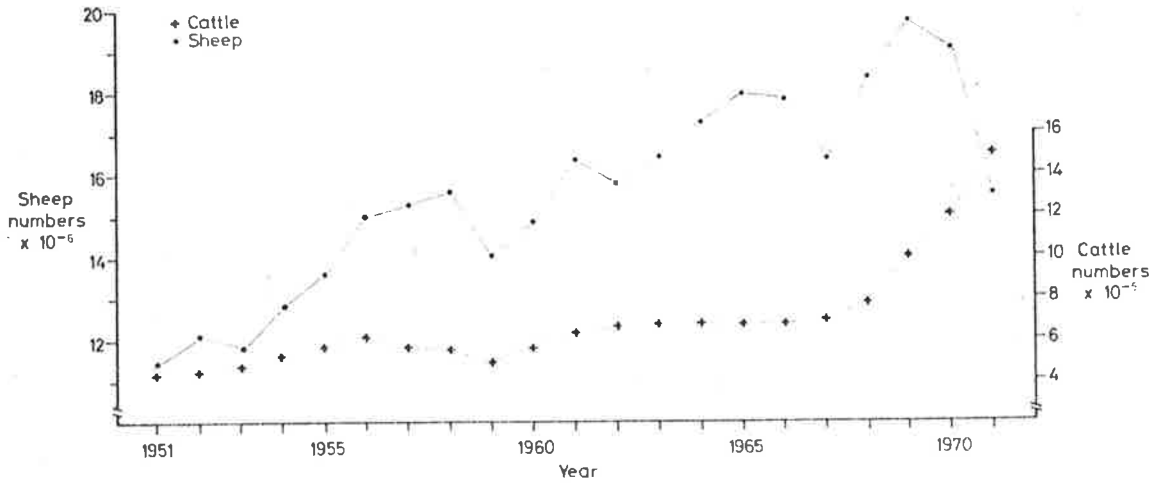


Fig. 1.5
CATTLE AND SHEEP NUMBERS IN S.A., 1951-1971 (Includes high rainfall districts)

(Courtesy Bureau of Census and Statistics)



most evident in high rainfall, and mixed farming areas, but was reflected in the arid sheeplands. Between 1969 and 1971, properties carrying cattle inside the dog fence increased five-fold (Lange, 1971). Many of the pastoralists were considering a complete switch to cattle from sheep, and most were considering cattle introduction in order to diversify their enterprise.

1-4 DEMARCATION AND CLIMATE OF SOUTH AUSTRALIAN RANGELANDS

1-41 *Demarcation.*

Goyder set the earliest boundary for the S.A. rangelands, known as "Goyder's Line of Rainfall", corresponding roughly to the 12" (300m) annual isohyet (SAPP No. 78,1865-66). This was said to divide agricultural land from land suitable only for pastoralism. Goyder appears to have used the southern limits of *Atriplex vesicaria* (saltbush) as an indicator.

Between 1930 and 1950, various precipitation/evaporation indices were used to set the limits of the arid areas, as defined by length of growing season. For instance, Trumble (1949) defined arid pastoral areas as those with a growing season of less than five months; with plant growth requiring a monthly $P/E^{0.75}$ greater than 0.3. Meigs (1953) used a similar index.

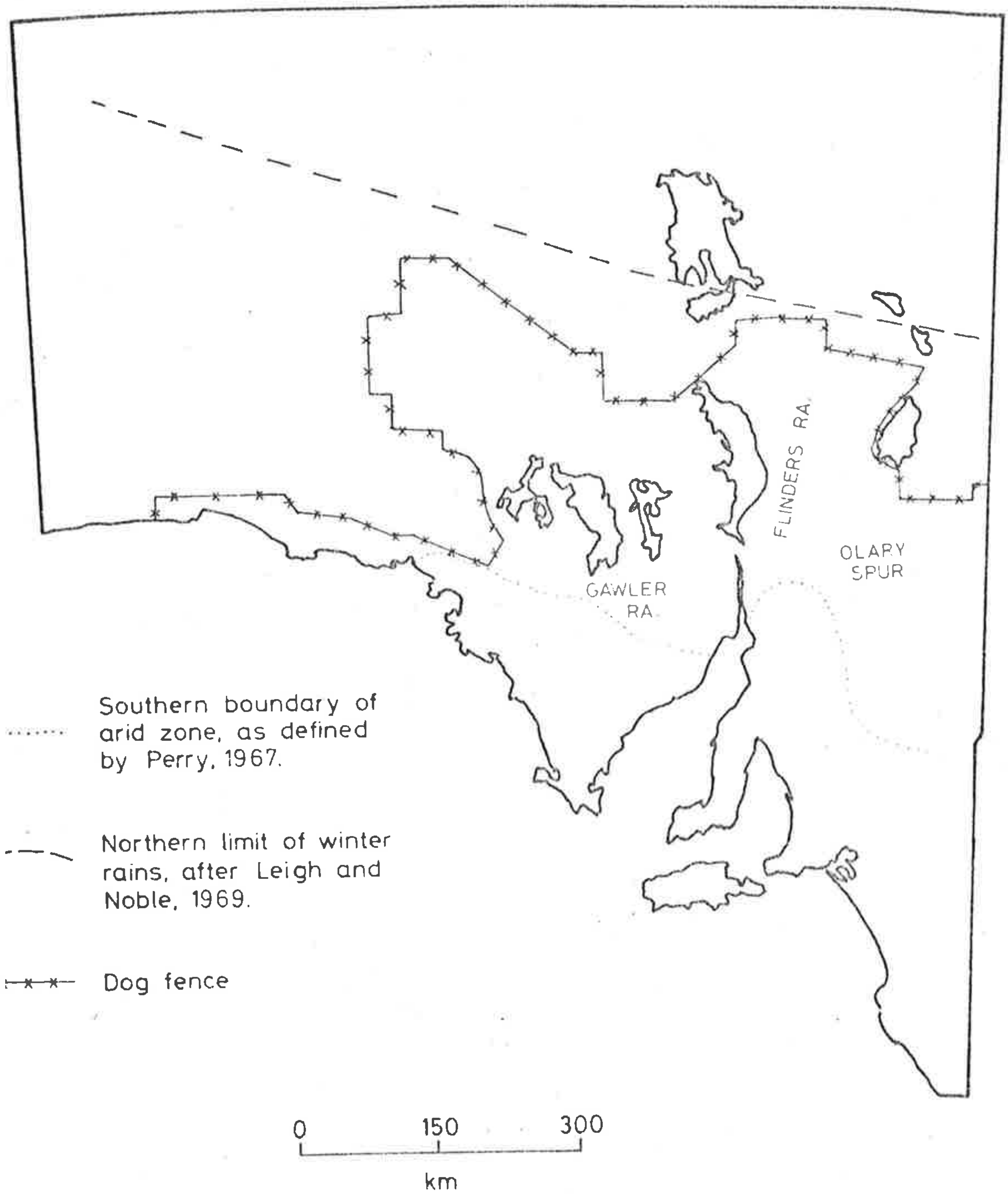
Perry's (1967) definition and demarcation of rangelands is used here. A rangeland is defined by a rainfall inadequate for economic cropping or pasture improvement. This differs from the common American definition, which embraces sub-humid areas capable of pasture improvement (Box and Perry, 1971). For S.A., Perry defined the boundary as the 250mm annual isohyet, with the rangelands occupying 87% of the State's total area (see fig. 1.6).

1-42 *Climate.*

Gibbs (1969) and Gentilli (1972) present extensive reviews on the climate of arid Australia. South Australia in particular is adequately documented in the S.A. Year Books (Bureau of Census

Fig. 1.6

DEMARCATION OF THE S.A. ARID PASTORAL ZONE



and Statistics, 1966-). The aridity of the S.A. rangelands derives from the presence of dry, subsiding air masses of tropical origin. Invasions by moist air masses increase in likelihood towards the southern and northern margins. Incursions from the south give a winter maximum rainfall in the southernmost arid areas, while monsoonal rains from the north give a summer maximum rainfall in the northernmost areas. (The foregoing is from Bureau of Census and Statistics, 1974). Between lies a broad belt with no marked seasonality in rainfall: reports are given by Osborn (1925) for Koonamore station, and Jackson (1958) for Yudnapinna station. Leigh and Noble (1969) give the approximate boundary of winter rain and summer monsoon influences (fig. 1.6).

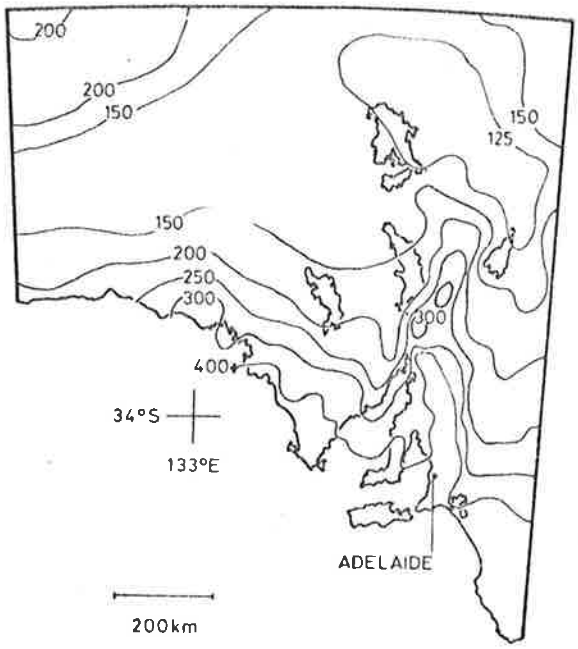
The rainfall is low and erratic. The mean annual isohyets are shown in figure 1.7. The associated standard deviation is more than 30% of the mean (Gentilli, 1971, 1972). Solar radiation inputs are high (fig. 1.8) and increase to the north. Consequently, evaporation and day temperatures are high (figs. 1.9 and 1.10). The diurnal range is of the order of 20^{o}C. (Specht, 1972).

The climate of Yudnapinna station is representative of the arid sheeplands. Jackson (1958) reported the following. The mean for the period 1884-1939 was 226mm, with minimum and maximum annual rains of 60mm in 1921 and 459mm in 1928. Over a seventeen-year period, falls of under 7.5mm in 48 hours, regarded by Jackson as "ineffective" for plant growth, accounted for almost half the mean annual rainfall. The mean annual temperature over this period was 18^{o}C., with a mean pan evaporation of ca 2,400mm. In

Fig. 1.7

S. A. MEAN ANNUAL RAINFALL

mm

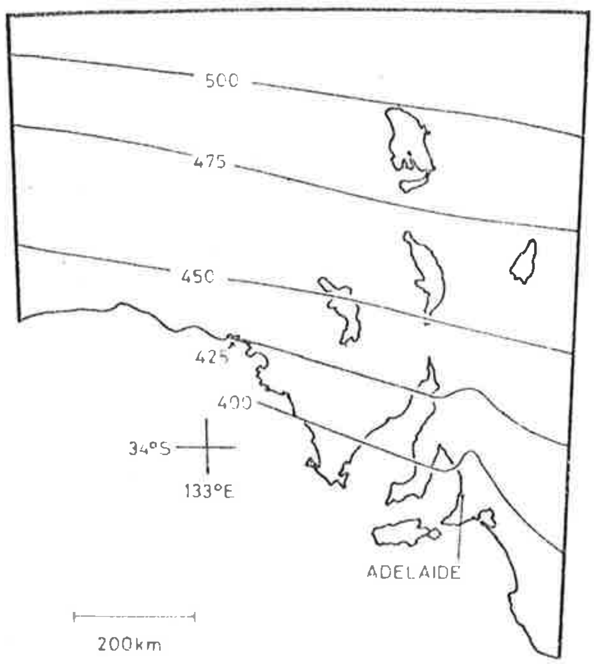


(Courtesy Bureau of Census and Statistics)

Fig. 1.8

S.A. MEAN ANNUAL SOLAR RADIATION

at the ground cal/cm^2. day

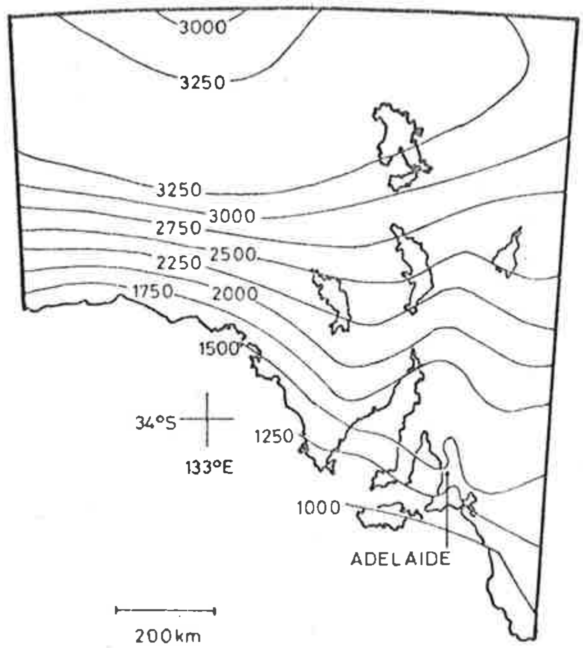


(Courtesy Bureau of Meteorology, Adelaide)

Fig. 1.9

S.A. MEAN ANNUAL EVAPORATION

mm.



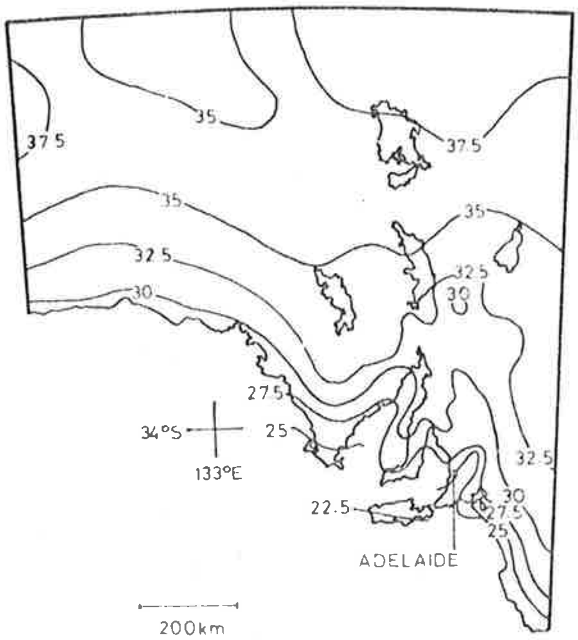
(Courtesy Bureau of Census and Statistics)

Fig. 1.10

S. A. MEAN MAXIMUM TEMPERATURE

for JANUARY

° Celsius



(Courtesy Bureau of Census and Statistics) summer, the mean daily evaporation approached 12mm.

1-5 VEGETATION OF THE SOUTH AUSTRALIAN RANGELANDS

1-51 *Main divisions.*

There are two main groups of plant communities in the S.A. rangelands: those communities with semi-succulent shrubs of the family Chenopodiaceae either as dominants or in the understorey of woodlands, and those communities with tussock or hummock grasses as dominants or in the understorey (Specht, 1972). The former extend north to the limits of winter rainfall (Leigh and Noble, 1969), and are the most common communities in the S.A. and N.S.W. sheeplands. The latter, showing affinities with the sub-tropical summer rain communities of central Australia, are also found in the S.A. sheeplands, and extend well south into the winter rainfall belt. Both groups are considered in this thesis.

The particular associations are not of prime importance here: where necessary, they are discussed in the body of the thesis. However, the following points are important. Of the semi-succulent shrubs, the most significant are the long-lived perennials *Atriplex vesicaria* (saltbush), *Kochia sedifolia*, *K. astrotricha* and *K. pyramidata* (bluebushes). These species have attracted much ecological research. For instance, autecologies are described by Osborn et al (1932), on the growth of *A. vesicaria* under stocking; Burbidge (1945) and Beadle (1952) on germination rates; Knowles (1951) and Condon and Knowles (1952) on phenology. Much of the research has been aimed at *A. vesicaria* alone (see Jones, Ed., 1970). Nonetheless, there remain serious gaps in knowledge concerning these species (Perry 1970). They originally comprised the majority of pastures of the first group of communities. Grasses of the genera *Stipa, Aristida, Eragrostis, Triodia* and *Zygochloa* comprised the pastures of the second group. *Triodia* and *Zygochloa* species are perennial, but have never been grazed to a large extent in S.A.: of the remainder, only certain *Eragrostis* species are perennial, but rarely contribute much to the pasture (Specht, 1972). Much less research, relevant to the S.A. situation, has been performed for such species.

The first group of communities is found on calcareous, gypseous or saline soils, with clay B horizons and, often, marked texture contrasts in the soil profile ("duplex" soils of Northcote, 1971). The soils are highly erodable, and the chenopod shrubs are very sensitive to overgrazing: such landscapes have suffered most under stocking (Leigh and Noble, 1969). The second group is found on less erodable deep or clayey sands; a less easily damaged landscape (Condon, Newman and Cunningham, 1969).

1-52 *Trend in grazed rangeland vegetation.*

The original vegetation of the southern Australian rangelands, including those of S.A., was considered climax, as limited by soils and microclimates (Wood, 1937). Most of the present vegetation can be regarded as a grazing disclimax (Moore, 1953b), relatively stable at present (Perry, 1969). Various paths and outcomes of pasture degradation, in S.A. and elsewhere, have been reported as follows.

Moore (1953a, 1953b) outlined grazing succession in the semi-arid Riverina. Perennial *Atriplex* pastures on light-textured soils showed succession under heavy sheep grazing, initially to *Kochia aphylla-Stipa falcata* (perennial chenopod-tall grass) pasture, after destruction of the *Atriplex*. Heavier grazing on such a pasture resulted in a *Danthonia* (perennial mid-grass) pasture, considered more productive than the original. Still heavier grazing led to an annual short-grass pasture of low productivity. On heavier textured soils, different species were involved, but the succession was also perennial chenopod pasture, to perennial grass pasture, to annual pasture under increasingly heavy stocking. Wilson and Leigh (1964) and Williams (1965) demonstrated similar successions for other communities in the Riverina.

On the more arid S.A. and western N.S.W. rangelands, the starting points (perennial chenopod pasture) and endpoints (ephemeral pasture) are similar to the foregoing, but there is no intermediate perennial grass stage. Beadle (1948) and Ratcliffe (1936), the two most extensive studies, contain many examples of grazing succession. Those here are from the more local study of Crocker and Skewes (1941), on Yudnapinna station. Heavy grazing of an open woodland with *Kochia sedifolia* (perennial bush) pasture resulted directly in an ephemeral *Bassia*-short grass pasture, of low fodder value and with little protection against soil erosion. Similarly, overgrazing of an *Atriplex-Kochia* (perennial bush) pasture, causing destruction of the bushes, led directly to an *Atriplex spongiosa* (ephemeral forb) pasture of low value.

Less research has been directed towards grazing succession in hummock and tussock grasslands, by comparison with the chenopod pastures. Research relevant to S.A. rangelands has been performed at Alice Springs, N.T., and deals with cattle grazing. Where pastures were perennial at the start of grazing, overstocking resulted in an increase of unpalatable species and a decrease in palatable species (Newman and Condon, 1969; Maconochie and Nelson, (1972). This is not homologous with the shrubland situation, where the salt- and blue-bushes are not usually the most palatable species. Perennial pastures did not necessarily show a decrease under heavy stocking of the perennial species: *Triodia,* an unpalatable perennial, was reported to increase under stocking (Newman and Condon, 1969).

Overgrazing, particularly in the first group of communities, is accompanied by severe loss of plant nutrients. In soils carrying *Atriplex vesicaria,* 27% of the total nitrogen, 21% of the total phosphorous, and 30% of the total organic matter are in the top 10cm of the profile (Charley and Cowling, 1968). The consequences of erosion following overgrazing of the plant cover are self-evident. Further, the phosphorous is largely organic in origin. A level of grazing, not resulting in erosion, nonetheless may remove a significant part of the supply. Regeneration following overgrazing is retarded by the resultant nutrient deficiencies, in addition to other soil modifications which have occurred (Beadle and Tchan, 1955). Lichen crusts are a prominent feature of many virgin soils. The lichens, in addition to stabilising the soil surface, may contribute significantly to the nitrogen balance

(Rogers et al, 1966). Stock impact is first shown in the breakup and loss of this crust (Rogers and Lange, 1971).

1-53 *Regeneration of chenopod shrublands following overgrazing.*

The Koonamore Vegetation Reserve (now the T.G.B. Osborn Vegetation reserve at Koonamore) was established in 1925, in the "worst eaten out corner" of a paddock on Koonamore station (see Osborn, 1925). Regeneration in the absence of sheep has been followed since (reports: Osborn et al, 1935; Wood, 1936; Hall et al, 1964). Of the perennial chenopods forming the original vegetation, regeneration of *Atriplex vesicaria* and *A. stipitata* was evident in 1936, and largely complete by 1964; but *Kochia sedifolia* has not regenerated, although some individuals survived the original overgrazing. Soil surfaces have stabilised, but equally slowly. Pidgeon and Ashby (1940), investigating regeneration of overgrazed commons after exclosure, at Broken Hill, N.S.W., reported that decades would be required for complete regeneration. On Manunda station (fig. 1.1), following a long and severe stocking history, regeneration was hastened significantly with mechanical aids, combined with exclosure of paddocks, from 1945. Much of the chenopod pasture has regenerated, yet certain paddocks are still largely ephemeral grasslands, and are still closed to stock (personal observation).

1-54 *Contrasted American and Australian situations.*

The extensive American (largely U.S.) rangeland research is frequently referred to here, for methodology, comparison and interpretation of trends, in structurally similar vegetations grazed by sheep and cattle. However, there are important differences in management strategy. In southern Australian arid rangelands, chenopod shrubs are of major importance. They provide an adequate forage for stock in drought (Wood, 1936; Wilson, 1966) and a major guard against soil erosion (e.g. wind erosion, as shown in the wind tunnel studies of Marshall, 1973). The ephemeral plants of degraded pastures cannot fulfil such functions adequately. Management, therefore, is aimed at maintenance of the perennial chenopods. On the other hand, management in the U.S. rangelands may benefit from the removal of similar shrubs (e.g. sagebrush,shadscale) as the resultant pasture may be perennial grass. Such grass can provide the required drought reserve and soil protection, while increasing domestic secondary production (e.g. as demonstrated by Shown et al, 1969; Bleak et al, 1965).

1-6 ASPECTS OF SHEEP AND CATTLE PERFORMANCE ON ARID RANGELANDS.

1-61 *Introduction.*

The sheep industry in the S.A. rangelands is based wholly on strong-wool production, from the S.A. strain of Merino (a larger-framed strain than found elsewhere in Australia--Brown and Hutchinson, 1973). The cattle industry is based on beef production from Hereford and Shorthorn cattle. There are no significant herds of the *Bos indicus* breeds or crossbreeds, despite their success and acceptance elsewhere in Australian rangelands (see Alexander and Carraill, 1973). Hence the following discussions concentrate on the Merino and the two British cattle breeds.

1-62 *Aspects of physiology.*

The Merino is better adapted physiologically to arid conditions, than the British breed cattle. With the protection of wool, sheep can graze comfortably in the sun: although surface wool temperatures may reach 92°C., there is little heat penetration (Macfarlane*, 1956). Excess heat is dissipated mainly by panting, which allows greater control of water loss than sweating; water is efficiently conserved in both the renal system and the intestine, resulting in low water turnover; and the metabolic rate is low (Macfarlane, 1968). By comparison, the British cattle breeds often have a coat which collects radiant energy but is not a good insulator; heat is dissipated mainly by sweating; the renal system and intestine are less efficient in water conservation (e.g. Macfarlane, 1968, cites maximum urine concentrations of 2.6 osmol./litre for Shorthorns, compared with 3.8 osmol./litre for Merinos); and both the water turnover and metabolic rate are higher than for the Merino (Macfarlane, 1968). Differences in water turnover are highlighted in table 1.1. On a comparative basis, the water turnover of the Merino was only slightly more than that of the camel, whereas the turnover in the Shorthorn approached that of the water buffalo. Even the more efficient beef breeds were not as well adapted as the Merino. Macfarlane (1964) reported that, at Alice Springs in summer, cattle deprived of water survived only four to five days, but Merinos six to ten days, further illustrating the better adapted water balance of the latter. Schmidt-Nielsen (1964) presents a more general review, which supports and expands the foregoing statements.

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* et al.

TABLE 1.1

WATER TURNOVER IN RUMINANTS

(from Macfarlane, 1968)

(a) Adult ruminants at Alice Springs, in summer after rain.

	Body solids	Total body water	Body water turnover
	%	Litres	ml/kg$^{o.82}$.day
Merino	38.5	46.7	365
Shorthorn	39.8	267	765
Camel	47.7	385	350

(b) Cattle at Darwin in wet season.

Zebu	38.6	614	361
Santa gertrudis	37.1	629	384
Shorthorn	26.1	739	484
Water buffalo	21.4	786	524

(kg$^{o.85}$ is a measure of metabolic body size, which allows comparison between species irrespective of stature).

The salt content of chenopod pastures may be very high. Lange (1967) reported levels of up to 20% by weight in some chenopods. Wilson and Leigh (1969) recorded 6.25% *Na* in *A. vesicaria,* and reported that sheep grazing this species had maximum daily sodium intakes of 200g. To cope with such a salt intake, the Merino's basic adaptation is to drink more water (to a total of 10-19 litres/day--Macfarlane et al, 1967). Wilson and Leigh reported an increment of 74ml per gram *Na* ingested. The salt intake may be further increased by saline waters. Cattle in such a situation cannot tolerate the salt levels (Schmidt-Nielsen, 1964, p203) and lose condition as a result, whereas the sheep can maintain production. This is a major reason for the lack of cattle-stocking on intact chenopod pastures.

Other aspects of physiology, also showing the superiority of the Merino over cattle in an arid environment, are discussed by Brown and Hutchinson (1973).

1-63 *Dietary selection.*

The selection of species by the grazing animal is often considered a prime cause of stock-related vegetation pattern, and so requires an extended discussion. Most research on dietary selection in Australian rangelands has dealt with either sheep or cattle: there is little directly comparative work reported. For this reason, some investigations are quoted here, from similar situations overseas, and from higher rainfall areas, as examples of the general differences and similarities to be expected in the S.A. situation. The discussion is concerned more with stock preferences than plant palatabilities. The words are often used in reports as though interchangeable; but a herbivore's preference for a particular species is determined by the relative circumstances resulting in choice, whereas palatability is a function of intrinsic properties of a plant (Heady, 1964).

A series of short term, intensive sheep grazing trials were run in a variety of associations in the Riverina (Leigh and Mulham, 1966a, 1966b, 1967; Robards et al, 1967; Leigh et al 1968; Wilson et al, 1969). Patterns of selection were similar throughout. For a perennial bush community of *Atriplex vesicaria-Kochia aphylla*, Leigh and Mulham (1966a) demonstrated a high degree of species selection by sheep, and changes in diet correlating with pasture change. In winter, *A. vesicaria* comprised 75% of the available forage, but 3.5% of the diet. Species of *Hordeum* (annual grasses) and *Medicago* (legume, annual from a forage viewpoint) comprised 5% and 12% respectively of the pasture, but 33% and 22% respectively of the diet. In summer, with die-back and grazing down of ephemerals, *A. vesicaria* comprised 78% of the pasture, but 10% of the diet, while *Sporobolus* (perennial grass) comprised 0.5% of the pasture, but 82% of the diet. In another situation, Leigh and Mulham (1967) reported that *A. vesicaria* provided 90% of the diet, in summer drought, and in the absence of most annual species. However, the winter pattern was similar to the above, species representing only 4% of the total pasture comprised 50% of the diet. Likewise, in a *Danthonia caespitosa* (perennial grass) community, annual species were preferred when present, although only a small part of the total forage. The contribution of *Danthonia* to the diet was significant only in summer drought (Robards et al, 1967).

The same pattern is reported under station conditions, with large paddocks and free-ranging sheep. Weston and Moir (1969), observing sheep grazing perennial Mitchell grass pasture in arid Queensland, reported an equivalent sequential consumption. Perennial species formed the mainstay of the diets only when annual species had diminished greatly.

A further aspect of the degree of selectivity is the higher proportion of nutrients in the diet, compared with the proportion in the overall pasture. For example, Weir and Torrell (1959) and Weston and Moir (1969) demonstrated higher crude protein and lower crude fibre proportions in the diet than in the pasture.

The preference hierarchy of cattle on Australian rangelands is similar in outline, but with marked differences in detail. Low (1973) observed free-ranging Shorthorn cattle on grass pastures at Alice Springs. Perennials were grazed only in the absence of ephemerals. Cattle showed marked preferences for particular communities, depending on the latter's state of growth (see also Low, 1972). In the same area, Chippendale (1968) showed the preference of cattle for ephemeral grasses, e.g. *Enneapogon* species. In both studies, browse formed a minor component of the diets. Chippendale reported that, even in drought, browse from perennial shrubs and trees comprised only 7-9% of the diet (c.f. the sheep browse consumption in drought, above). The same patterns are reported in diverse situations elsewhere (e.g. Clary and Pearson (1969) in the semi-arid U.S.; Harrington and Pratchett (1973) in Uganda). As with sheep, cattle intake is of a higher nutritional quality than the pasture as a whole (e.g. Galt et al, 1969; Newman, 1969).

At present, there are no direct comparisons of dietary selection, between sheep and cattle, on Australian rangelands. The probable differences must be inferred from investigations dealing with one or other animal. Since sheep and cattle studies dealt with disparate vegetations, and since selection is highly dependent on local circumstances, such comparison is adequate only for the outline of differences. Hence, the following examples are taken from the American literature, to indicate with more certainty the general differences between sheep and cattle preferences, likely to be found on the S.A. sheeplands. The differing situations preclude any detailed extension of results to the S.A. case, but the general pattern is likely to be similar.

X Van Dyne and Heady (1965a) compared dietary selection of cattle and sheep grazing a mature (dry) annual range. During observations, pasture standing crop decreased by 70%. Preferences changed significantly as the forage decreased, but not in the same manner for sheep and cattle. Their preferences were significantly different throughout, for half the forage species present. Further, sheep maintained a higher quality diet (Van Dyne and Heady, 1965b). Parallel results were reported by Cook et al (1967), in a comparison of sheep and cattle grazing on sagebrush. Some preferences were found equivalent, but on the whole the cattle preferred and mainly consumed grasses, while the sheep utilised forbs and browse to a much greater extent.

The reports on the individual herbivores, already discussed, imply that cattle and sheep would show some similarity in dietary selection on the S.A. rangelands: ephemeral plants would be grazed when present, and perennials only grazed during stress periods. However, the above indicates that there would be considerable differences in specific preferences, particularly with regard to shrubby species. This last point is of major importance for the S.A. rangelands, with their high shrub component. Harrington and Pratchett (1973) reported that cattle avoided non-grass species on the Ankole rangeland (Uganda): Galt et al (1969) on arid U.S. rangeland, and Thetford et al (1971) on semi-arid U.S. rangeland demonstrated the low proportion of browse in cattle diets by comparison with sheep: and Chippendale (1968) provided an Australian example of the low utilisation of browse by cattle. With such a pattern recurring in these diverse situations, the same should occur in the S.A. sheeplands. Hence it may be postulated that the introduction of cattle onto the sheeplands is likely to prove less deleterious to the chenopod pastures than was the former sheep grazing: the cattle are less likely to affect the shrub species.

1-64 *Aspects of ranging behaviour.*

On Australian rangelands in dry condition, stock are dependent on the waters provided. As indicated in section 1-62, cattle are more dependent than sheep. Lynch (1973) reported that merino sheep on semi-arid pasture with some green feed drank daily only when temperatures exceeded 41°C, but at three-day intervals at lower temperatures. Cattle under similar conditions normally drink daily (Lynch and Alexander, 1973), although some individuals may remain away from water for 36 hours (Schmidt, 1969). Hence the pasture utilisation is limited by the travelling ability of the animals; in dry periods for sheep, and most of the time for cattle. This partly underlies the piosphere concept (to be discussed).

There is controversy as to how far sheep and cattle graze from water, under rangeland conditions. Cattle are often reputed to walk further (e.g. chapter 2). They are known to be capable of long travel: Bonsma (1949) drove herefords and shorthorns, under hot conditions to the point of exhaustion, achieving 25km/day for the smooth coated varieties. Wooly coated animals walked no more than 8km, but such varieties are not common on the southern rangelands. Schmidt (1969) observed shorthorns under field conditions on the Barkly Tableland, N.T., in a time of high temperatures and dry, sparse pasture. 40% of cattle walked 6-7km before commencing grazing, and remained within 8.5km of water. Under extreme pasture scarcity, grazing extended to 11km from water. The majority, however, extended to a maximum distance of only 4km. Newman and Condon (1969) stated the limit of cattle grazing under similar conditions to be 5mi (8km). For comparison, Herbel et al (1967) reported cattle to extend only 3.5km from water on a New Mexico dry range.

Squires and Wilson (1971) performed a series of experiments on merino travel under semi-arid conditions (see also Squires, 1970; Squires and Hindley, 1970). Water and feed--*Atriplex vesicaria*--were separated by walkways devoid of forage. Merinos walked a daily total of 12km. Forage and water intakes were unaffected until the length of the walkways exceeded 4km. In field studies, Lynch (1967) reported similar total distances walked in semi-arid pasture, with a maximum distance from water of 3-4km. Osborn et al (1932) reported that sheep remain largely within 3km of water, with virtually no grazing beyond 6km. Ratcliffe (1936), on the other hand, described cases where vegetation was denuded by sheep, in drought, up to 5mi (8km) from water. Hence there is no certain evidence that, under station conditions, the commonly run cattle breeds will graze further from water than will sheep.

1-7 THE PIOSPHERE: STOCK INDUCED VEGETATION PATTERN

1-71 *The concept of the piosphere.*

The dependence on water supply and the limits of ranging of stock cause radial patterns in rangeland vegetation centred on the water point. Research into such patterns in southern Australian rangelands has been confined to those caused by sheep. Part of the contribution of the present research is the outlining of pattern caused by cattle.

The sheep-induced pattern was first quantified by Osborn, Wood and Paltridge (1932), who examined density pattern of *Atriplex vesicaria* in South Australia. They distinguished four concentric density zones:

1. The "A" zone, immediately around the water to a maximum of 400m; severely overgrazed and trampled (the pastoralists' "sacrifice zone");
2. The "B" zone, lying between 400m and 1600m from water, in which most grazing took place; heavily grazed, but with apparently more vigorous growth than the "A" or outer zones;
3. The "C" zone, lying between 1600m and 3600m; occasionally grazed;
4. The "D" zone, beyond 3600m from water; ungrazed, and beyond the normal range of sheep.

They emphasised that these zones were not sharply defined, varying in extent with stocking rates and paddock topography.

Valentine (1947) observed a similar radial attenuation of grazing pressure with increasing distance from water in forest range grazed by cattle (U.S.). Grass standing crops increased with distance from water, and Valentine summarized the radial patterns in terms of zones, much as above. (Herbel et al, 1967, did not detect such pattern when observing cattle on a New Mexico arid range, however).

Lange (1969) further quantified the pattern described by Osborn et al, in a scrutiny of sheep tracking and dung drop on

S.A. rangeland. The term "piosphere" was introduced to name the system of stock/plant interactions centred on the water point. Lange stated that the piosphere should be considered the basic ecological unit in rangeland grazing studies. Using the framework of this paper, Barker and Lange (1969, 1970) and Rogers and Lange (1971) have since examined the vegetation pattern in detail. The results of their studies display a more continuous variation in parameters than was suggested by Osborn et al.

Like patterns are described for other herbivores in diverse situations, where ranging is limited by the need to return regularly to a particular point. Ogden et al (1973) reported the formation of "haloes" around West Indian patch reefs as being a grazing effect. The standing crop of benthic algae increased with distance from reefs, due to grazing of the echinoderm *Diadema*. This herbivore was limited in its foraging by the need to return to reefs in daylight, to avoid predators. Another example is given by Lock (1972), in Uganda. Hippopotamus grazing maintained tussock grasses, replaced by cauline-leaved species in the absence of grazing. Grazing was limited to areas near channels and lakes, and attenuation of grazing pressure with increasing distance resulted in correlated vegetation pattern: increase in cauline-leaved species and decrease in tussock grasses. In this case, the pattern was not centred on a single point, but on wallow areas.

1-72 *The form of plant/distance relationships in the piosphere.*

In the absence of domestic grazing, an even standing crop (e.g. of biomass, density) is expected, with due allowance for background influences such as soil variation. A stocked water point in such a situation introduces a grazing pressure, varying with distance, and causing correlated pattern in vegetation. The only certain characteristic of the distribution of grazing pressure is that it asymptotes near zero beyond the range of stock. Within the piosphere, the possible distributions are numerous. The results of Osborn et al (1932) imply an exponential decrease in grazing pressure with distance, and dissimilar variation in plant density and condition (peak density in "C" zone, peak condition in "B" zone). Barker and Lange (1969, 1970) demonstrated patterns in species incidence which appear to relate, more directly, to an exponential decrease in grazing pressure, with concentric pattern most clearly defined immediately around waters. On the other hand, Lange (1969) reported linear decrease in dung drop with increasing distance (though not to the limits of grazing). As dung drop may be taken as indicative of time spent in an area (Ares et al,1972, after Harker,1960), Lange's results imply a like decrease. in stocking pressure. Rogers and Lange (1971) demonstrated a near-linear increase of lichen species frequency with distance from water, excluding the area within 200m of water, to a maximum of 2km. This is significant, since the lichens are not actually grazed, but are easily destroyed by trampling. They thus provide a clearer measure of overall grazing pressure than fodder plants, since the latter do not necessarily reflect the general pattern, due to differences in the grazing animals' preferences.

In general terms, the distribution of grazing pressure around a water point is almost impossible to determine. Reports on stock ranging behaviour only give a general indication of the areas under heaviest pressure, and the matter becomes more complicated when stock show preferences for particular areas (e.g. Low, 1972). Nonetheless, distance from water provides an *index* of stocking pressure, and so the studies in this thesis, which deal with the piosphere, consider plant parameters in relation to this index. The papers using quantitative data, Lange (1969) and Rogers and Lange (1971), show linear relationships between various parameters and distance from water: in the absence of specific information to the contrary, this linear framework has been employed here. There are other arguments in favour of a linear approach. For instance, the variation to be expected in a natural population may obscure the underlying grazing relationship. This is demonstrated in chapter 6, where various functions are fitted to quantitative data. The variances involved were such that curvilinear functions, which were thought to approximate more closely to the data, were no more efficient than simpler linear functions in accounting for the variances. Patten (1972), discussing prairie ecosystem modelling, has pointed out that "linearised models behave more like ecosystems than do non-linear ones". Further, a linear relationship remains the simplest hypothesis in the absence of information to the contrary.

Nonetheless, the search, in much of this thesis, for linear relationships between plant parameters and the index of grazing pressure is based on the reports of Lange (1969) and Rogers and Lange (1971), which have demonstrated the existence of such relationships.

1-8 THE CAUSATION OF PATTERN AND TREND.

The main components of stocking pressure on rangelands are grazing (in the eating sense) and disturbance in the course of grazing. The low stocking rates employed (rarely more than 1 sheep to 5ha, 1 beast to 10ha) minimise nutrient transfer effects, prominent at times in pattern causation on higher rainfall pasture (e.g. Sears, 1949; Hilder, 1964). A possible significant exception is the input of nutrient immediately about the water point.

In the literature, little attention has been given to the effects of disturbance, and, in particular, trampling. Trends and patterns in stocked vegetations are often considered to result purely from the eating out of more preferred species, with an attendant increase in less preferred species being due to lowered competition. For instance, in their major review on Australian rangeland vegetation, Leigh and Noble (1969) stated that

> "..extensive botanical changes have occurred in these (chenopod) shrublands following grazing and indiscriminate lopping for drought feed. This has resulted in the disappearance of the palatable shrub species, and a marked increase in other less palatable species."

In an earlier review, Beadle (1959) also considered changes resulting from stock in these terms. (However, Moore (1959) in the same publication considered trampling of equal importance to grazing). Hence, considerable emphasis has been placed on studies of dietary selection, as a means of understanding the mechanisms involved in stock-induced vegetation change.

Even in intensive grazing trials, the effects of trampling are often ignored. For example, Leigh and Mulham (1966a), in a trial already discussed, did not consider trampling at all. In similar experiments, Laycock et al (1972) have shown that trampling may account for up to 50% of forage removed by sheep.

This is not to say that trampling is always disregarded as a factor, nor is it to be taken as denigrating the undoubtedly important research into the selection aspect. Nonetheless, numerous reports make only passing reference to the role of trampling, and basically consider patterns or dynamics in terms of species palatabilities or stock preferences (Beadle, 1948, represents a prime example). The review of research into dietary selection suggests that this is a simplistic approach: the species consumed vary with time and pasture condition, and such variation renders the palatability or un-palatability of species largely irrelevant.

Two signal papers point to the importance of disturbance as a prime factor. Rogers and Lange (1971) demonstrated a clear stock impress on lichen distributions, which could only be caused by trampling. The changes imply a break-up of the soil crust, loss of the nitrogen-fixing lichens, and consequent soil changes. Such soil changes must result in correlated changes in fodder plant populations, due to the disturbance caused by stock, but not to their actual grazing. Heady (1966) investigated the effect of various wild and domestic ungulates on East African grassland. Each species influenced composition differently to some extent, in a manner accountable by differing preferences. However, the most striking correlations found were between pasture composition and stocking rate, irrespective of the particular ungulate run. Thus the spectrum of preferences, of the ungulates, had little to do with the ultimate state of the pasture. The main alternative is the trampling factor. Quinn and Hervey (1970) have shown that trampling losses, for cattle on sandhill range, increase geometrically with stocking intensity: hence there exists the mechanism to explain Heady's observations.

This thesis considers both preferential grazing selection and disturbance as possible causes of the pattern in vegetation shown to relate to stocking. The implications of its data are discussed in the course of analyses, and the two factors are discussed at length in the final chapter.

CHAPTER 2

CATTLE ON SOUTH AUSTRALIAN SHEEPLANDS

2-1 VEGETATIONS GRAZED BY CATTLE WITHIN THE DOG FENCE

Specht (1972) recognised 15 major plant associations in the arid land systems of South Australia, of which 14 occur within the Dog Fence. Cattle are run on all of these, but with varying success. Associations with a high proportion of ephemerals are most favoured, particularly those found on sand soils and flood-flats. The former contain few perennial chenopods in the pastures, The latter may be characterised by perennial chenopods (e.g. *Kochia pyramidata)*, but also contain many higher-quality fodder species, and, in addition, provide green pasture more frequently than most other associations (Wood, 1936). Sand associations are particularly important in the northwest sheeplands. In this area is an extensive sandridge system, with alternating ridges and clay-soil flats (Jessup, 1951). Prior to 1970, the few significant cattle herds in the sheeplands were run on this sand/clay system.

Very few cattle are run on intact chenopod shrubland (i.e. high density of *Atriplex* or *Kochia* species, minimal soil disturbances, and no overt pasture degradation.) Some stations, for instance Nonning (fig. 1.1), attempted cattle grazing on such pastures, but found that only store cattle--sold for canning, or to other producers for fattening--were produced. Store cattle are less profitable than fat cattle, the latter having a "finish" suitable for sale as table beef. On the other hand, stations running cattle on sand soil or floodflat pastures can expect to produce fat cattle one year in three, on average. (This is based on reports from Pernatty and

Roxby Downs stations, for the period (1940-1970). Nonetheless, where *Atriplex*-or *Kochia*- dominated pastures have deteriorated, with bushes severely thinned or altogether removed, cattle are run profitably on the resultant, largely ephemeral pastures. The emphasis on perennial pastures, and the production potential of such pastures, is summarized in table 2.1, for a selection of stations with cattle inside the Dog Fence.

An apparent anomaly in an otherwise clearcut situation is the number of stations grazing cattle on *Kochia astrotricha* associations. This association, as it appears now, has a very high ephemeral component (q.v. chapter 4). Despite Specht's (1972) mapping, showing it as a pre-settlement association, I consider it the result of pasture degradation due to stocking, for the following reasons.

1. Large tracts of an *Atriplex vesicaria-K. astrotricha* association occur where there is no history of overgrazing (Jessup, 1951). This may represent the forebear of the present association.
2. *K. astrotricha* can survive overgrazing which will eliminate *A. vesicaria* (chapter 7). Hence there is a mechanism for reducing *A. vesicaria-K. astrotricha* to the present *K. astrotricha* association.

2-2 MANAGEMENT SYSTEMS

2-21 *Management north and south of the Dog Fence*

Marked differences exist between cattle stations outside, and

TABLE 2.1

PASTURE LANDSCAPES FOR A SELECTION OF SOUTH AUSTRALIAN MIXED BEEF/SHEEP STATIONS

(a) Stations

Station	Pasture classes present	Cattle run on	First introduced	Potential for fat cattle
Curnamona	*Atriplex/Kochia* *K. astrotricha* Disclimax grass Floodflat	Floodflat	1971	yes
Edeowie	Disclimax grass	Disclimax grass	1971	yes
Kolenda	*Atriplex/Kochia* *Triodia*	*Atriplex/Kochia*	1970	no
Mahanewo	*Atriplex/Kochia*	*Atriples/Kochia*	1970	no
Manunda	*Atriplex/Kochia* Disclimax grass Floodflat	Floodflat	1970	yes
Mt Victor	*Atriplex/Kochia* *K. astrotricha* Disclimax grass Floodflat	*K. astrotricha* Disclimax grass	1971	yes
Mulyungarie	*K. astrotricha* Disclimax grass Floodflat	*K. astrotricha* Disclimax grass Floodflat	1965	yes
Netley Gap and Wabricoola	Disclimax grass	Disclimax grass	1958	yes
Nonning	*Atriplex/Kochia* *Triodia*	*Atriplex/Kochia*	1950	no
Oakden Hills	*Atriplex/Kochia* Sand/clay	Sand/clay	1970	yes
Pernatty	*Atriplex/Kochia* Sand/Clay Floodflat	Sand/clay Floodflat	1930?	yes
Roxby Downs	*Atriplex/Kochia* Sand/clay	Sand/clay	1930?	yes
Siam	*Atriplex/Kochia* *Triodia* Floodflat	Floodflat	1970	yes
South Gap	*Atriplex/Kochia* Sand/clay	Sand/clay	1930?	yes
Thurlga	Disclimax grass *Triodia*	Disclimax grass	1971	yes

TABLE 2.1 (Cont.)

(b) Pasture Classes

Class	Specht's (1972) associations	Major forage
Atriplex/Kochia	*Myoporum platycarpum* *Casuarina cristata* *Acacia sowdenii-Kochia sedifolia* *Atriplex vesicaria-Ixiolaena leptolepis* *Atriplex vesicaria* *Kochia sedifolia*	Perennial chenopods
Disclimax grass	The above associations, as degraded by overgrazing	Ephemeral grasses, herbs
Sand/clay	*Acacia linophylla-A. ramulosa* *Acacia aneura-A. brachystachya* with pockets of other associations	Ephemeral grasses, herbs
Floodflat	*Nitraria schoberi* *Eucalyptus microtheca*	Perennial chenopods, ephemeral grasses, herbs
K. astrotricha	*Kochia astrotricha*	Ephemeral grasses, perennial chenopods
Triodia	Not recognised by Specht Hills of the Gawler Rd., with *Trodia irritans*	Perennial grass

sheep stations inside the Dog Fence; both in facilities and management strategy. Cattle stations outside are unfenced except along boundaries: stock movement is controlled only by the placement of waters. On the other hand, the extensive fencing on sheep stations is the most expensive single investment. A century of subdivision of sheep stations has resulted in a large number of small paddocks; paddocks larger than 5000ha are uncommon. The watering facilities also differ to some extent, although much of the difference results from the subdivision. Many cattle stations have access to the Great Artesian or similar basins, and the main waters are deep, high capacity and very expensive bores. Few sheep stations are over major basins; instead, water is supplied by surface catchment, and small bores into local, sub-artesian aquifers. The reasons for the development of facilities on sheep stations have already been mentioned (section 1-34). In particular, the subdivision was aimed at bringing as much pasture as possible within the range of sheep. Little was aimed at pasture conservation: most of the fence lines run straight, north-south or east-west, arbitrarily with regard to pasture types (e.g. figure 3.1); while stock waters are commonly laid at the supply source, with scant regard for the erosion potential of the site.

On sheep stations, flocks are segregated for age and sex, with breeding at fixed times. This is closely similar to higher-rainfall sheep husbandry, and considerably more efficient than the open system of cattle-stocking outside the Dog Fence. The management tradition in the sheeplands is set stocking, with flock size largely determined by the number that can be carried in drought. Much of the outside cattle country is stocked intermittently, with large seasonal fluctuations. In drought, most cattle are removed: in plenty, large numbers may be run. Ratcliffe (1947) presented an account of this system of management, still closely applicable to the present situation. The reasons are biological and economic. The sheeplands still possess much perennial pasture, despite widespread degradation (section 1-3), and so continuous stocking is feasible; but the northern pastures are ephemeral to a large extent (section 1-5). Sheep can either maintain production in drought, or at least survive to produce wool profitably at the end of the drought, and so, are worth maintaining. However, cattle cannot maintain or improve their condition in drought, and the loss of condition means loss of money. If numbers above a small nucleus are retained, the pastoralist is faced with unsaleable cattle at the end of the drought: by the time their condition improves, they are too old to command good prices.

2-22 *Problems in changing to cattle from sheep.*

Perhaps the most important problem when introducing cattle to sheeplands is the setting of stocking levels. The pastoralist usually cannot use past experience, as can be done in setting sheep levels. The matter is complicated by the pasture types involved (particularly the salt content) and the quality of stock waters. Legislative guidance is limited to the Pastoral Act, which arbitrarily sets one beast equivalent to five sheep;

undefined as to age or sex. This is a much higher ratio than would be expected in terms of relative forage or water demand. To date, the decision has been *ad hoc*, with the pastoralist using his own appraisal of short-term pasture condition to check overgrazing or under-utilisation of pastures. Equivalences determined since 1970, by pastoralists in the Gawler Ranges, and indicative of the general levels elsewhere, are:

1 cow/unit area	7-8 ewes/unit area
" "	12-14 wethers/unit area
" "	2 steers/unit area

The district stocking rate is 25-30 sheep/mi^2 (1 sheep/10ha).

Sheep orientated facilities must be adjusted to cope with cattle. Internal subdivision fences are often flimsy--low, with small posts, and plain wire--and are barely adequate at times to restrain sheep, let alone cattle. Similar restrictions apply to water troughs and handling yards. The greatest nuisance, and the most expensive to rectify, is the ability of cattle to walk through sheep fences. Locating stations where cattle were restricted to set areas was a major difficulty in this study: the most common reply was that the cattle "go where they want". Very few stations have gone to the expense of strengthening fences. Rather, the two main solutions have been to shift cattle frequently to fresh pasture, or, more commonly, to create semi-open range by removing, or allowing cattle to remove, internal subdivision fences. On Mulyungarie station (fig. 1.1), several former sheep paddocks were coalesced to from one 110mi^2 (28500ha) paddock with multiple waters. On Mt Victor station (chapters 3, 4), cattle broke down intervening fences, and, despite repair efforts, created a single range from two large paddocks. The semi-open range is perhaps the best solution: some segregation of herds can be maintained, and the cattle, having set their own bounds, do not usually stray further.

A further problem in adjustment is provision of water of adequate quality for cattle. This may require extensive upgrading of surface catchments if ground water supplies are too saline. Surface catchment is not always feasible, particularly in sandy country, and is expensive.

2-23 *Cattle husbandry on former sheepland.*

Cattle husbandry inside the Dog Fence varies markedly from station to station. At one extreme, the system is no different from that of outside cattle areas, with no segregation of herds. At the other, it is akin to the sheep system, with herds segregated for age and sex, and bulls joined at set times. In very few cases do cattle and sheep share paddocks. These cases are mostly on stations with minor cattle herds (30-50 head) but large sheep flocks (several thousand head). An exception is Nonning station, with 500 beasts. On this station, cattle share large paddocks with sheep, on a ratio of 50 beasts to 1000 sheep. The management attempted higher ratios, but found that cattle condition deteriorated, possibly due to interference between the two ungulates.

2-3 PASTORALISTS' OPINIONS ON THE EFFECT OF CATTLE

Many graziers consider cattle to be less destructive in their grazing behaviour than sheep. The reasons offered by them are as follows.

1. There are fewer hooves per weight or money unit, and thus there should be less overall trampling.
2. Cattle tracking patterns are the less intense. The sheep pattern is a dense network of incised tracks radiating from water (e.g. photographs in Lange, 1969), but the cattle pattern is a very few, largely unbranched tracks, although more deeply incised than sheep tracks. This is also considered to indicate less trampling under cattle stocking than under sheep stocking.
3. The grazing habits of sheep and cattle differ: sheep are said to be destructive and uneven grazers, removing small plants completely but rarely touching rank growth; whereas cattle graze less closely and more evenly. This is a valid point. Bennett et al (1970) discuss, in such terms, the role of cattle grazing in maintaining short pasture for sheep in higher rainfall areas.
4. Cattle graze further from water than sheep, permitting a more even utilisation of pasture than would an equivalent number of sheep (but see section 1-64).

It follows that certain pastures, easily damaged by sheep, have always been regarded as potentially better suited to cattle stocking. The drop in wool prices provided the impetus to switch such pastures from sheep-stocking to cattle-stocking. For example, Edeowie station, on the outwash plains between the Flinders Ranges and Lake Torrens, carried sheep from the mid-1850's to 1970, and was heavily overgrazed. The perennial pastures were largely destroyed in the course of this grazing, but erosion was more severe than usual, due to the very friable deep loam soil. The present lessee has run cattle since 1970, more in an attempt to stop the sheep-induced erosion than in order to increase profitability. Since the introduction of cattle, the erosion has ceased; but this may have resulted more from abundant ephemeral growth in the subsequent years, than from the cattle-stocking itself.

Some pastoralists consider cattle more destructive than sheep. On Mulyungarie station, the management considered replacing the entire herd (1500 head, Herefords) with another breed: the Herefords would not graze more than 2-3km from the waters, and the pastures were clearly deteriorating. On Oakden Hills station, cattle showing similar behaviour are moved to new pastures frequently, to avoid such damage. On McCoy's Well station, cattle were introduced in 1971, but removed in 1973: although no deterioration of pastures was observed, the cattle were not ranging as far as had the sheep.

2-4 ECONOMICS OF CATTLE INTRODUCTION

The economics of the changeover to cattle have not been stressed, as they are peripheral to the present investigation. Nonetheless, they remain the cause of the situation. In the period of low wool prices, prospects for cattle introduction were buoyant (Thompson, 1971), but, even so, a changeover was not necessarily worthwhile. Table 2-2 shows budgets prepared for stations in the Gawler Ranges, by the S.A. Department of Agriculture in 1972; assuming a minimum greasy wool price of 35c/lb (77c/kg). The Gross Margins for wool production were as high as for beef production. However, a switch to cattle would also require heavy investment; in the purchase of stock, and the upgrading of facilities. In view of the comparability of returns from cattle and sheep enterprises, such investment was not necessarily justified. Since 1972, wool prices have risen to economic levels. Pastoralists intending a complete switch to cattle slowed or halted the cattle buildup when the wool price started to rise. With the collapse of beef export markets (Nov., 1974, reported in *The Australian,* Sydney, 15/11/74), no pastoralist is at present considering further increases in cattle herds. Thus it appears that the switch to cattle will not reach the scale anticipated at the start of this study (March, 1972), due to the combination of pasture limitations, practical and economic problems. Nonetheless, a reduction in the present cattle numbers on former sheep-lands is unlikely. The pastoralists of the S.A. arid sheeplands now recognise the need for at least some diversification, to insulate from market vagaries an industry originally dependent on one product.

TABLE 2.2

1972 WETHER AND STEER BUDGETS FOR GAWLER RANGES AREA
(Courtesy A. Brown, S.A. Dept of Agriculture)

WETHER BUDGET

Assumptions.

Wethers retained for 4 years.
4% deaths per annum.

Return per wether.

1. Wool: 6.5kg/hd @ 77¢/kg net of marketing charges.	$5.00
2. Sale of 21% wethers @$2.00 off shears, c.f.a., net of transport and marketing charges.	$0.42
Total return per wether	$5.42

Cost per wether.

1. purchase 25% replacements @ $3.75 on property.	$0.94
2. Operating costs: Shearing	$0.50
Crutching	$0.15
Jetting.	$0.05
3. Interest on cpital outlay of stock, 8% of $2.85 average value.	$0.23
Total variable costs	$1.87

Gross margin per wether
(return - variable costs) = *$3.55*

STEER BUDGET

Assumptions.

Gross margin per steer =
net value per steer minus foregone income from weaner.

Net value per steer.

1. Gross return, 190kg carcass @ 52¢/kg		$98.80
2. Variable costs:		
Freight, Gawler Ra. to Adelaide	$7.00	
Commission etc. @ 6% gross sales	$5.90	
Interest on capital outlay of stock, 8% of $85 average value	$6.80	
3. Deaths, 2%	$1.70	
Total variable costs	$21.40	
Net value per steer		$77.40

Weaner calf value.

= gross value - (transport + selling charges)
= 125kg x 55¢/kg - ($6.00 + $4.20) $58.80

Gross margin per steer = $18.60

In the Gawler Ranges, 6 to 7 wethers can be run in the area required for 1 steer.

CHAPTER 3

COMPARISON OF SHEEP AND CATTLE PIOSPHERES OVER A SHORT TERM: METHODS

3-1 INTRODUCTION

This chapter discusses the techniques used in comparing vegetation dynamics in a newly established cattle piosphere with those in a sheep piosphere over 22 months. The object of the study was to detect any differences in pattern or trend under the two animals. Two independent approaches were used, one quantitative and dealing with biomass and density of species, estimated from quadrats, the other semi-quantitative, using stereophotographs in an independent sampling system. Sections 3-2 to 3-5 deal with the first approach (major study) and section 3-6 with the second (minor study).

The requirements for the research were:

1. A paddock about to be, or recently, turned over to cattle;
2. A paddock still under sheep with a comparable vegetation;
3. Both paddocks remaining under the same station management, giving an empirical equivalence of stocking rates; and
4. Cattle and sheep restricted to the particular areas and not interchanged within the study period.

In 1972, only two pairs of sites fulfilling these requirements were known, viz.--on Roxby Downs station, where cattle were soon to move into a former sheep area, and on Mt Victor station, where cattle had been run on former sheepland since November, 1971 (locations; fig. 1.1). The first was not acceptable due to difficulties of access combined with a heterogenous vegetation (see chapter 5). The second offered easier access and a wider range of vegetations, more uniform in structure on the scale of sampling considered; although there was the disadvantage that the initial impact of cattle could not be observed directly.

A detailed description of the environment and landscapes of Mt Victor is unnecessary; the full discussion on the adjoining Koonamore station, given by Carrodus et al (1965) applies equally to Mt Victor station. The major features are as follows.

Mean annual rainfall (1958-1972) is 197mm, with a slight summer maximum. (Table 3-1). The observation unfortunately coincided with the heaviest rainfall on record for the area (Bureau of Census and Statistics, 1974). The major land systems (fig.3.1) are gently undulating plains and downs with duplex or gradational soils (nomenclature: Northcote,1965); with *Myoporum platycarpum, Acacia aneura, Kochia* species and *Atriplex vesicaria* as character plants, in tall shrubland or low open woodland formations (Specht 1972). There are small rocky ranges bearing chenopod shrubland (in southern areas) or *A. aneura* tall open shrubland (in northern areas). The lease was taken by the present lessee in November 1971, and cattle were introduced by him, for the first time. The plan of the station is given in figure 3.2.

A brief reconnaissance determined the most comparable piospheres, by reference to soil types, relative proportions of major pasture plants, amount and type of tree cover, and topography; within the limits of sampling anticipated (section 1-72). Figure 3.3 illustrates their salient features. The cattle paddock selected was Black Hill, mainly level with a gentle south slope. Black Hill itself, a rocky, shallow soiled insulberg rising ca 100m above the level of the plain, occupied only a small proportion of the total paddock area-- 150ha of the total 4600 ha--but dominated the landscape. A similar but lower rise was present in the eastern part of the paddock. The vegetation of these hills was an

TABLE 3.1

RAINFALL (mm) AT MT VICTOR STATION, 1958-1972

	1958	*1959*	*1960*	*1961*	*1962*	*1963*	*1964*	*1965*	*1966*
J	49	30	23	0	63	13	6	0	7
F	17	16	4	3	0	4	5	9	49
M	48	18	0	0	12	0	0	0	8
A	12	0	6	27	0	21	14	0	1
M	6	25	34	6	28	44	15	7	14
J	0	2	4	1	0	40	2	19	26
J	18	17	27	2	3	1	4	6	0
A	49	7	8	14	10	18	34	20	0
S	12	8	19	9	0	4	78	15	1
O	55	10	2	2	12	19	23	1	11
N	63	0	21	15	0	0	7	1	13
D	20	25	5	16	67	12	10	8	75
	349	*158*	*153*	*95*	*195*	*176*	*198*	*86*	*295*

	1967	*1968*	*1969*	*1970*	*1971*	*1972*	*Monthly means*	*Proportion Of annual mean*
J	11	87	34	0	0	143	31	.16
F	16	0	44	0	26	14	14	.07
M	2	0	33	2	105	0	15	.08
A	0	48	6	62	29	2	15	.08
M	6	40	16	0	17	10	17	.09
J	0	19	12	5	16	5	10	.05
J	0	23	38	0	38	7	12	.06
A	3	8	3	28	19	18	16	.08
S	10	0	9	62	26	4	17	.09
O	4	0	9	18	0	16	12	.06
N	0	9	5	78	36	1	17	.08
D	0	10	0	11	27	2	19	.10
	52	*244*	*209*	*266*	*339*	*222*	*197*	*1.00*

FIGURE 3.1

VEGETATION SYSTEMS ON MT VICTOR STATION

1. HILL SYSTEM: skeletal sandy soils.

1a Low shrubland: *Atriplex vesicaria*

1b Tall open shrubland: *Acacia aneura* with *A. tetragonophylla*

2. FLOODPLAIN SYSTEM: deep loams.

2a Low shrubland: *Kochia pyramidata* with *Nitraria schoberi*

2b Tall shrubland: *Acacia victoriae* with *K. pyramidata, K. brevifolia*

3. SOUTHERN PLAINS SYSTEM: texture contrast soils.

3a Low shrubland:

- 3ai. *A. vesicaria*
- 3aii. *A. vesicaria* and *Kochia astrotricha*
- 3aiii. *Kochia sedifolia*
- 3aiv. *K. astrotricha*

3b Ephemeral herbland: grasses and *Bassia* species.

3c Low open woodland:

- 3ci. *Myoporum platycarpun*
- 3cii. *Casuarina cristata*
- 3ciii *M. platycarpum* and *A. aneura*
- 3civ. *A. aneura* and *Cassia nemophila*

4. NORTHERN PLAINS SYSTEM: sandy gradational soils.

4a Low shrubland:

- 4ai. *K. astrotricha*
- 4aii. *A. vesicaria* with *K. astrotricha*

4b Ephemeral herbland: grasses.

4c Low open woodland:

- 4ci. *Acacia aneura*
- 4cii. *Eremophila duttonii* with *E. sturtii*
- 4ciii. *Casuarina cristata*

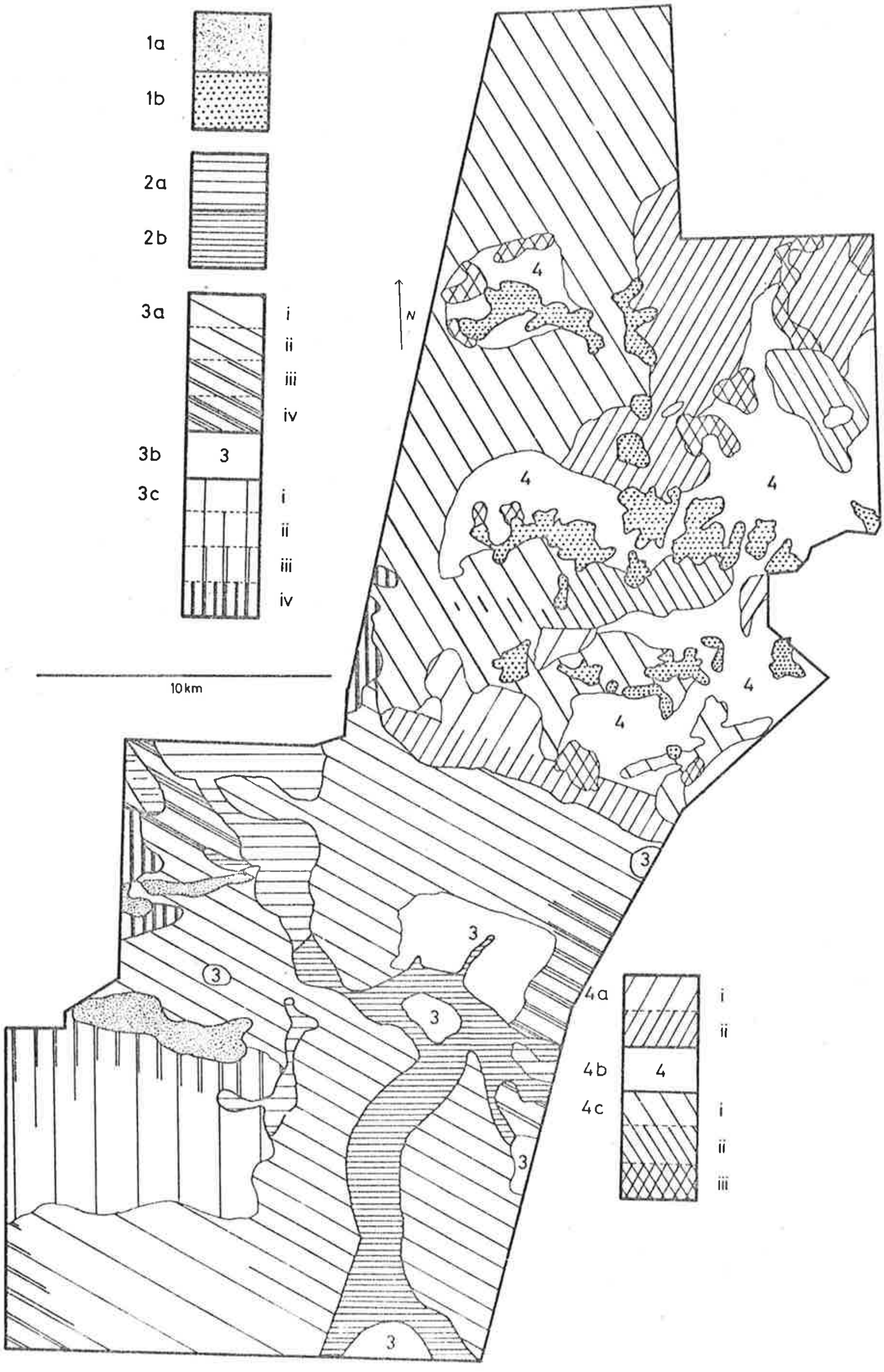

1a
1b
2a
2b
3a
i
ii
iii
iv
3b
3
3c
i
ii
iii
iv
10 km
N
4
3
4a
i
ii
4b
4
4c
i
ii
iii

Fig. 3.2
MT VICTOR STATION
PADDOCK PLAN

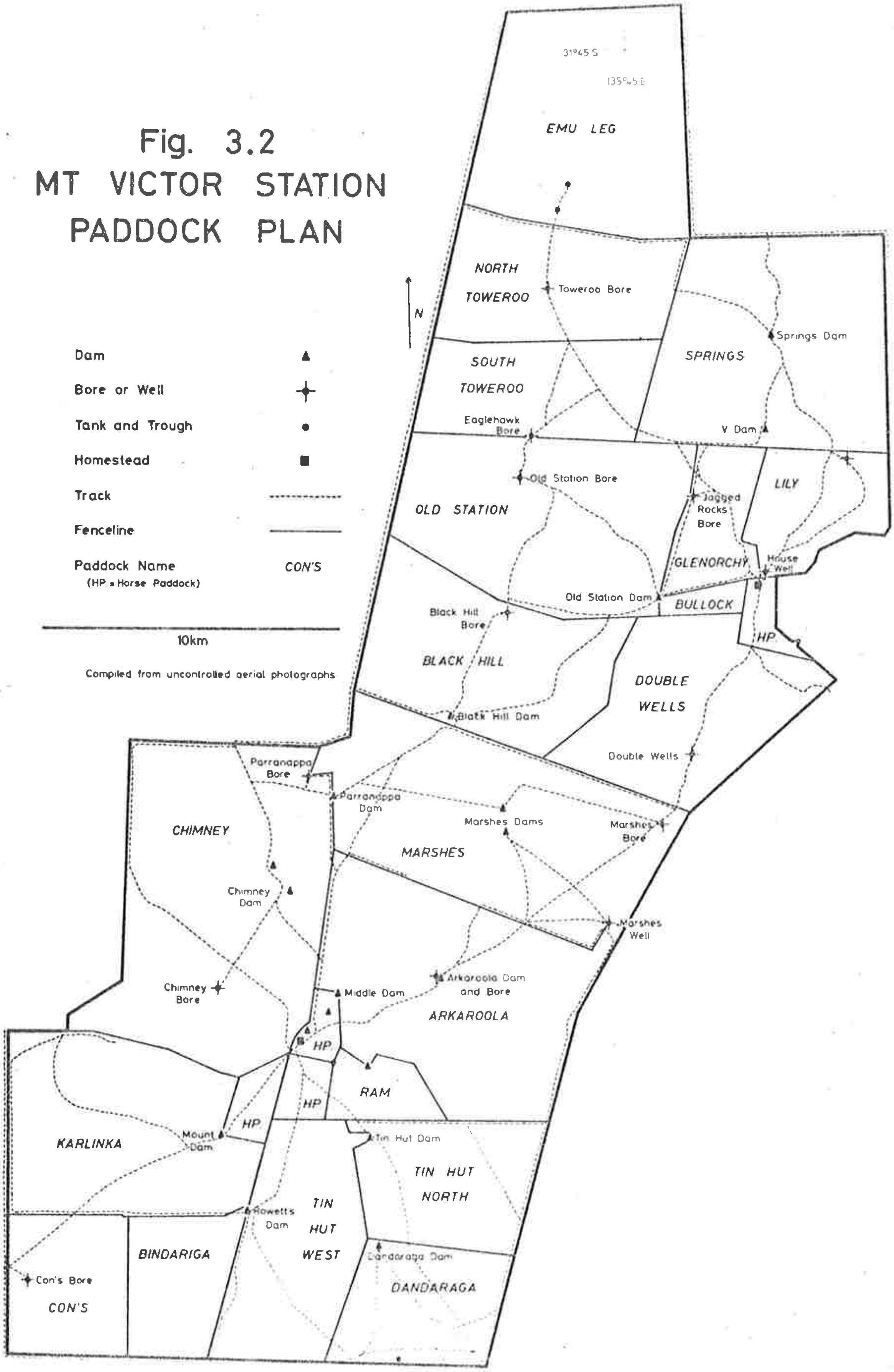
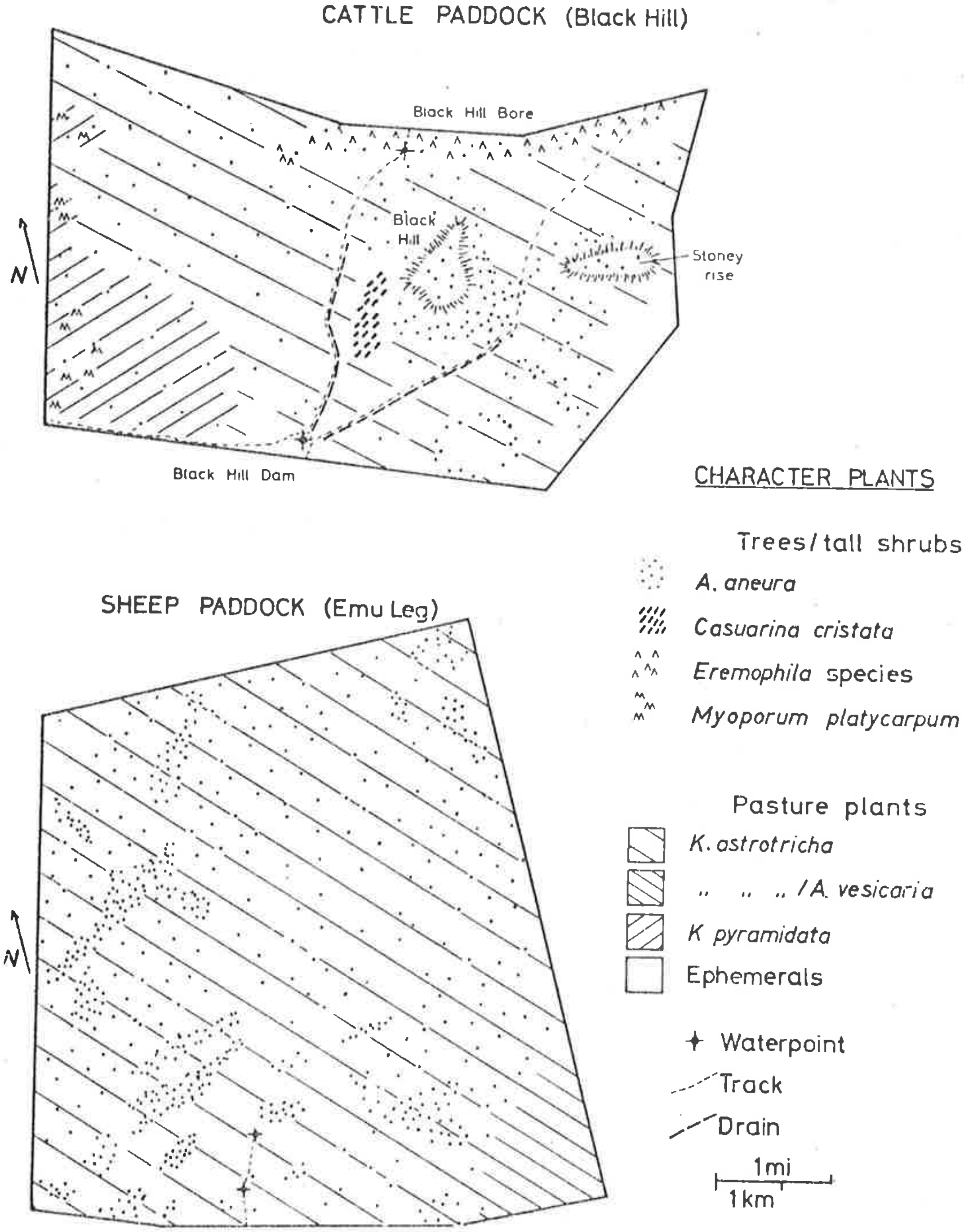


Fig. 3.3
VEGETATION AND LANDFORM
OF STUDY PADDOCKS



Acacia aneura-A. tetragonophylla tall open shrubland, with a grass understorey. The level areas, with gradational soils, were covered mainly by *Kochia astrotricha* low open shrubland, with scattered groves of *A. aneura*. However, the south-west corner had *M. platycarpum-A. aneura* low open woodland with *Kochia pyramidata* understorey. The paddock was served by two well-separated waters, on the southern and northern fences.

The deciding factor in the choice of the paddock was the position of the southern water, Black Hill dam. Here, the bush grew to within 200m of the water, much closer than other situations observed. This allowed analysis of gradients in this major pasture species, from the immediate vicinity of the water to the limits of sampling. (The importance of the bluebushes in S.A. rangelands was discussed in section 1-5.) Further, the dam was not placed in a watercourse, with the concomittant soil and vegetation discontinuities, but was fed by large drains, utilising the general southerly slope of the area. Thus it could be regarded the same as a pipeline trough, placed arbitrarily with relation to soils and vegetation (c.f. Barker and Lange, 1969).

The sheep paddock , Emu Leg, had uniform topography, soils and vegetation. It was flat with a gentle northerly slope, had gradational soils the same as those in Black Hill, and had a low shrubland of *K. astrotricha* with groves of *A. aneura*. The density of the latter increased to the north. The paddock had two waters, each with encircling vegetation similar to that around Black Hill dam, though with slightly more *A. aneura*. Each water was a trough supplied by pipeline, arbitrarily placed with regard to soil vegetation, and sited less than 1km apart near the south fence. Plates *1,2,3,4* show

PLATE 1.

Black Hill Paddock, Mt Victor Station. *Kochia astrotricha* shrub pasture (A), with the grasses *Enneapogon avenaceus* and *E. cylindricus* (B). Trees are *Acacia aneura.* 13/2/74

PLATE 2.

Black Hill Paddock, Mt Victor Station. *Kochia pyramidata* shrub pasture (A), with *Acacia aneura* (B). Grasses are *Enneapogon* species.

13/2/74


B
A

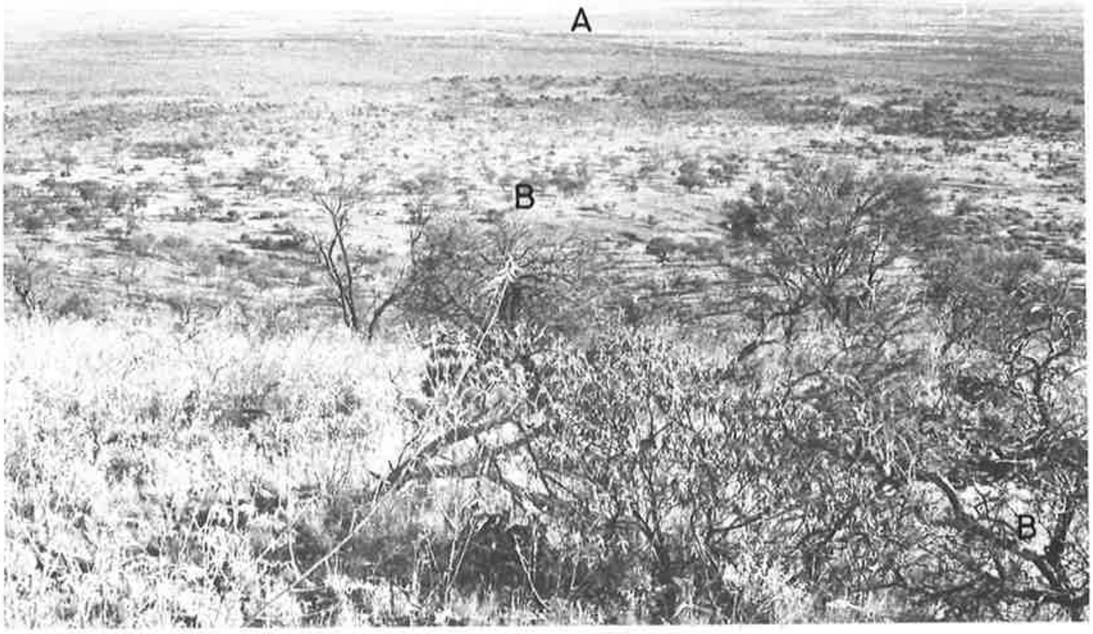

B
A

PLATE 3.

Black Hill Paddock, Mt Victor Station. On Black Hill, looking toward Black Hill Dam (A). Grass pasture on skeletal soil, with the tree *Acacia tetragonophylla* (B). 13/2/74

PLATE 4.

Emu Leg Paddock, Mt Victor Station. *Kochia astrotricha* shrub pasture (A), with the grasses *Enneapogon avenaceus* and *E. cylindricus* (B), *Stipa nitida* (C). Trees are *Acacia aneura*. 13/2/74


A
B
B


C
A
B

representative views of the vegetation.

The major problems in comparing the two were:

1. The presence of Black Hill in the cattle paddock--the vegetation heterogeneity this caused was avoided by restricting sampling to the *K. astrotricha* type, but the hill may have introduced other variation by influencing cattle movement.
2. The presence of juxtaposed waters in the sheep paddock versus a single water in the equivalent position in the cattle paddock--this situation was further complicated by failures and the eventual closing down of one of the waters.
3. The large scale heterogeneity of the cattle paddock vegetation--while this was excluded from the actual sampling, it yet may have influenced utilisation of certain parts of the pasture. Necessarily, this would alter the magnitude of stocking effects in a way not present for the sheep case.

Nonetheless, the two situations were the most satisfactory available. Because of the unavoidable differences between paddocks, emphasis was placed on detailed analysis of effects within paddocks, with a more general comparison between paddocks. The direction of differences was sought rather than absolute magnitude.

3-2 APPROACH TO THE MAJOR STUDY (SAMPLING BY QUADRATS)

Observations were made over 22 months, from September 1972 to August 1974. Eight observations were made for each paddock, at approximately three-month intervals, following a pilot observation in the cattle paddock. Further observations were attempted in May,

TABLE 3.2

DATES OF OBSERVATIONS ON MT VICTOR

Given as the mid-date for each trip, with the interval between observations.

TRIP	*DATE*		*INTERVAL (days)*	
	Cattle	Sheep	Cattle	Sheep
(Pilot) 0	6-7-72	-		
			90	-
1	4-10-72	2-9-72		
			57	94
2	30-11-72	4-12-72		
			80	72
3	18-2-73	15-2-73		
			74	75
4	4-5-73	1-5-73		
			89	86
5	29-7-73	26-7-73		
			100	100
6	6-11-73	3-11-73		
			104	104
7	19-2-74	15-2-74		
			165	172 *
8	3-8-74	6-8-74		

* No access between trips 7 and 8.

June and early July, 1974, but access was impossible due to exceptional rains. Table 3.2 gives the mid-dates for each observation. The first in each paddock were not at equivalent dates, because of the extra time required for initial setting-up.

For the limited period, in an area of erratic climate and plant growth, it was vital to concentrate on features likely to yield precise information for the effort expended; as follows.

1. Only those patterns and changes were sought, which could develop in 22 months: patterns relating to past stocking history (e.g. in the density of long-lived perennials) could not be regarded as germane to the present problem.
2. The study was restricted to the dominant vegetation type, as characterised by *K. astrotricha,* to minimize variation introduced by large scale pattern.
3. The most time consuming, but most sensitive, measures were used only on species visibly forming the bulk of the pasture.
4. Sampling was restricted to a maximum of 3km from the nearest water, following the rationale of section 1-72.
5. While the major control of the observation was inherent in comparison of the two piospheres, a limited number of exclosures were planned as separate control, to check vegetation dynamics between paddocks in the absence of grazing.

3-3 PASTURE POPULATIONS STUDIED AND PARAMETERS ESTIMATED

3-31 *Major species.*

Major species were defined as those which visibly contributed the bulk of the standing pasture. In both paddocks, they were the perennial bluebushes *Kochia astrotricha* and *K. pyramidata*, and the ephemeral grasses *Stipa nitida*, *Enneapogon avenaceus*, *E. cylindricus* and *Aristida contorta*. The *Enneapogon* species contributed at least half the standing biomass of the pasture for most of the period.

These species provided an excellent basis for interpretation of pattern due to preferential grazing selection. They allowed a three-way comparison, of bush with grass, bush with bush, and grass with grass. They are more fully documented than many other common arid pasture plants, although such basics as phenology, population dynamics and the like are still largely unknown. For sheep, *K. astrotricha* and *K. pyramidata* are regarded as highly palatable and unpalatable respectively in most assessments (e.g. Jessup, 1951): similarly, the grasses provide a sliding scale from the supposedly highly palatable *Stipa* to the rarely grazed *Aristida* (Osborn et al, 1931; Jessup, 1951). Parameters estimated for these major species were density, and above-ground leaf biomass.

Density is a much used and easily interpreted parameter (Grieg-Smith, 1964). In the present study, it is defined as the number of individuals per hectare, gained from an initial count of individuals per quadrat. It is limited in its use by the rigour of definition of the unit to be counted (Walker, 1970). Grieg-Smith quotes several counting methods using both plotless and quadratting techniques. Estimations may be used rather than direct counts, e.g. visual assessment from a vehicle transect

(Jessup, 1951) or from line transects (McIntyre, 1953). Direct counts are obviously superior to estimates, but, even so, Lyon (1968) points out that the variances associated with any of the particular methods are "less than satisfactory" when applied to shrubland similar to the present case. Quadratting will give lower variances than plotless methods, and narrow-rectangular quadrats give a lower variance than the more usual square. (Wight, 1967, draws similar conclusions with regard to biomass). Such a shape will reduce variances by cutting across any patterns caused by contagious distributions at the level of the individual (discussions on such distributions are given by Anderson, 1971, for an Australian situation, and Grieg-Smith and Chadwick, 1965, for an African situation).

Definition of individuals of *K. pyramidata, Stipa* and *Aristida* presented no problems in the field; the first was present as a discrete bush, the latter two as discrete bunches, and these units were scored as individuals. Both of the *Enneapogon* species were present also as discrete bunches, but care was needed to distinguish the separate bunches when present in quantity. Further, the two species were difficult to separate without flowerheads, particularly after prolonged grazing. As this may have led to serious confusion, the two species were pooled for counting and estimation purposes, as *Enneapogon* spp..*

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* M. Crisp (Ph.D. Thesis, Botany Dept., University of Adelaide, 1975) has informed me that the two species share a similar habitat on the Koonamore Vegetation Reserve; and that cross-fence comparisons between protected and grazed areas indicate that stock effects are of the same order and direction for both.

Individual definition was difficult for *K. astrotricha*. In this study, an individual was defined as a more or less continuous canopy formed by one or several shoots on a common mound. The difficulties arose because mounds were often formed around stems emanating from different rootstocks, or separate mounds associated with two stems from the same rootstock; and a continuous canopy could be formed by stems from different rootstocks. The above definition was considered the best compromise in an untractable situation. For consideration of the short term dynamics of the long lived species, separate counts were made for juvenile bushes. These were defined as both true seedlings, and small shrubs with secondary thickening, less than 10cm in height or diameter.

Biomass is an appropriate parameter to measure, from a grazing viewpoint, as it is usually more immediately affected by grazing than density. Further, it is more readily interpreted than other sensitive measures of abundance, such as aerial cover or basal area. The most straight-forward measurement is by destructive harvest; unreasonable beyond a certain point, in terms of both the time required and the disturbance caused in the target populations. For extensive measurement, estimation methods, calibrated by limited harvest, must be used.

There are numerous techniques available. For example, Hutchings and Schmautz (1969) discuss a method which expresses the visual estimation of quadrat biomass in relation to a nearby standard, later harvested; Mannetje and Haydock (1963) describe a system of ranking species by estimated weight; Robel et al (1970) use a visual obstruction technique; Robards et al (1967) describe a direct visual assessment, based on training by assessment and harvest; and Campbell and Arnold (1973) describe a similar system, and also discuss the use of capacitance meters. With the possible exception of the capacitance measures, all the methods are reported to work successfully within the pasture types concerned. The list of methods is by no means exhaustive (for others, see Morley et al, (1964), and Walker, (1970)). However, the reports indicate that any method is likely to be effective, provided that adequate control and training is maintained.

The method used here was a modification of the early and very simple system of Pechanec and Pickford (1937). In their method, the biomass of an individual is estimated as a multiple of a hand-held specimen of known biomass, and accuracy is maintained by repeated training (estimation followed by harvest). It has been used successfully in S.A. rangeland situations by final year undergraduate students (Dept. of Botany, University of Adelaide), and was extensively used by me, with acceptable results, in an earlier study.* Its advantages are the ease, speed and simplicity of estimation.

In the present study, the following procedures were used:-

1. Leaf biomass (wet weight) was estimated. For grasses this was defined as the total standing crop, dead or alive, over 1cm above the ground (as cut with shears). For the two bush species it was defined as the proportion

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* Fatchen, T.J. (1971); Measures of vegetation and stocking effects on South Australian pastoral stations. Honours Thesis, Dept. of Botany, University of Adelaide.

of above ground biomass, dead or alive, removed by hand-stripping leaves (thus excluding the bulk of the woody branches from estimation).

2. A single hand-held specimen was used for each species on each day's run.
3. The first hour of each day was occupied in training (longer for the initial observations) and training was continued for each species until three consecutive estimations fell within the desired accuracy. Spot checks on species were made at intervals during the day.
4. The maximum error allowable was set at 15%. (Other studies, particularly those of Trumble and Woodroffe (1954) and Leigh and Mulham (1966a,b) have aimed at higher accuracy. However, the effort expended to gain increased accuracy is very great, and observer fatigue has a much greater effect within finer error limits, as shown by Morley et al (1964). Results indicate that the variations in biomass of target populations both in time and space were such as to render the error at each sampling point insignificant by comparison. Hence field estimates were treated in analyses as measurements without error.
5. Estimations were scored for groups and not individuals. This allowed a carry-over of estimation from one individual to the next, thus reducing relative error when the individual's biomass was not an exact multiple of the hand-held specimen. Grasses were estimated in five arbitrary blocks per quadrat, bushes in groups of three to five

individuals, and the scores for the particular species summed to give the quadrat bulk estimate.

6. During each observation, a calibration run was carried out for each species, to provide information on accuracy over a number of measurements with no intermediate checks. The run was made at the end of the day, when fatigue was greatest. Twenty groups of individuals of the particular species were estimated in one run, with no preliminary or intermediate training and harvest. At the end of the run, all groups were harvested and weighed. (*K. pyramidata* had to be checked by estimating parts of individuals or small individuals: the size of most individuals made stripping of groups for calibration impractical in terms of time).

   Runs for all species, all times, are given in figures 3.4 to 3.8. Most estimates lay within the 15% error limits, but there were occasionally widely varying estimates. Morley et al (1964) suggest that these result from fatigue, and are probably unavoidable. *K. pyramidata* estimations showed the most frequent discrepancies; this is ascribed to the thicker foliage of the species obscuring the leaves below the canopy. This, combined with the large size of many individuals, may have led to a significant proportion of inaccurate estimates.

7. The hand-held specimens to be used for a day's estimation were selected at the beginning of the day from the general area of the run. This avoided specimens from, for example,

Fig. 3.4
BIOMASS ESTIMATIONS AND ACTUAL WEIGHTS FOR S. NITIDA

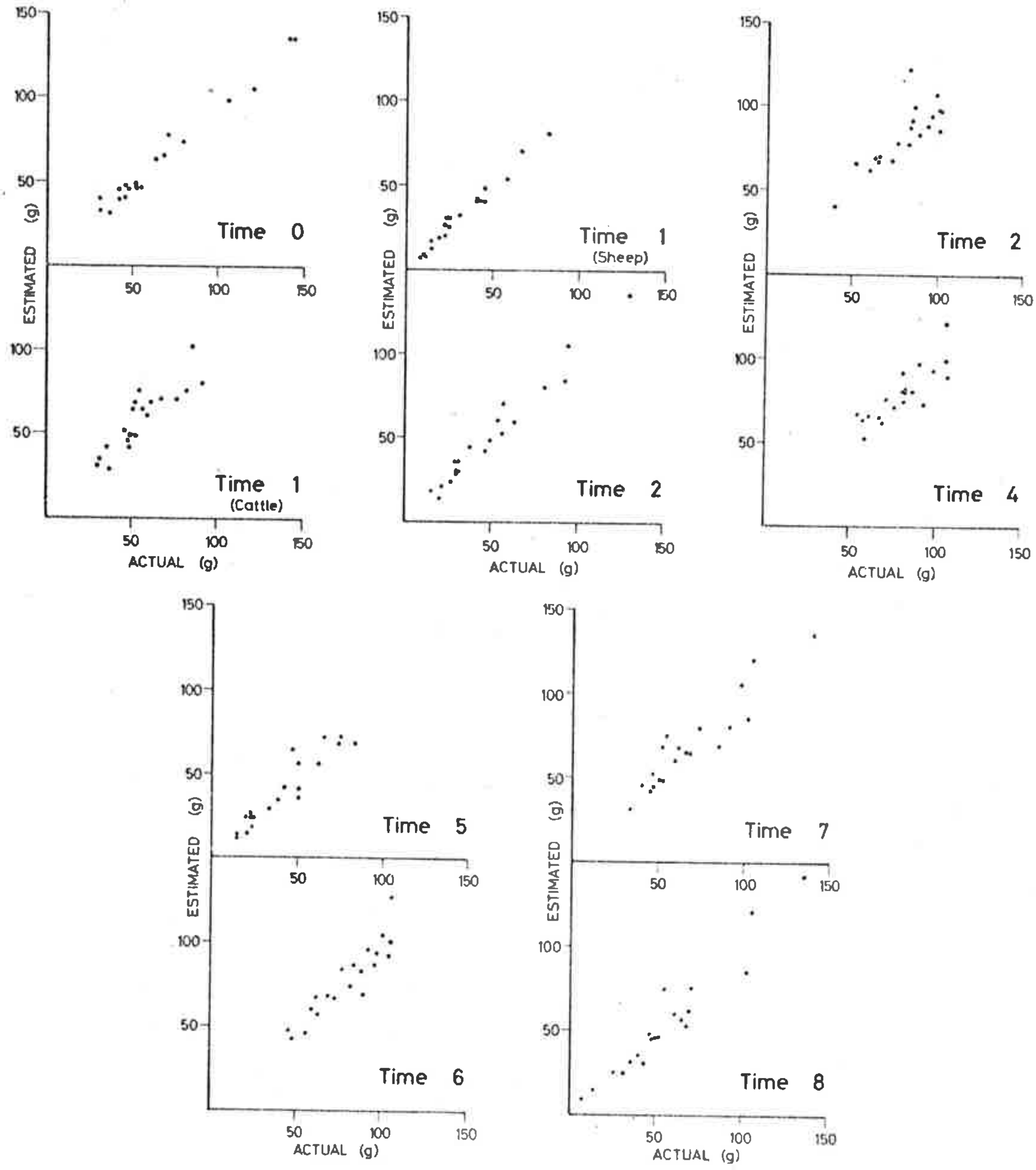


Fig. 3.5
BIOMASS ESTIMATIONS AND ACTUAL WEIGHTS FOR ENNEAPOGON SPP.

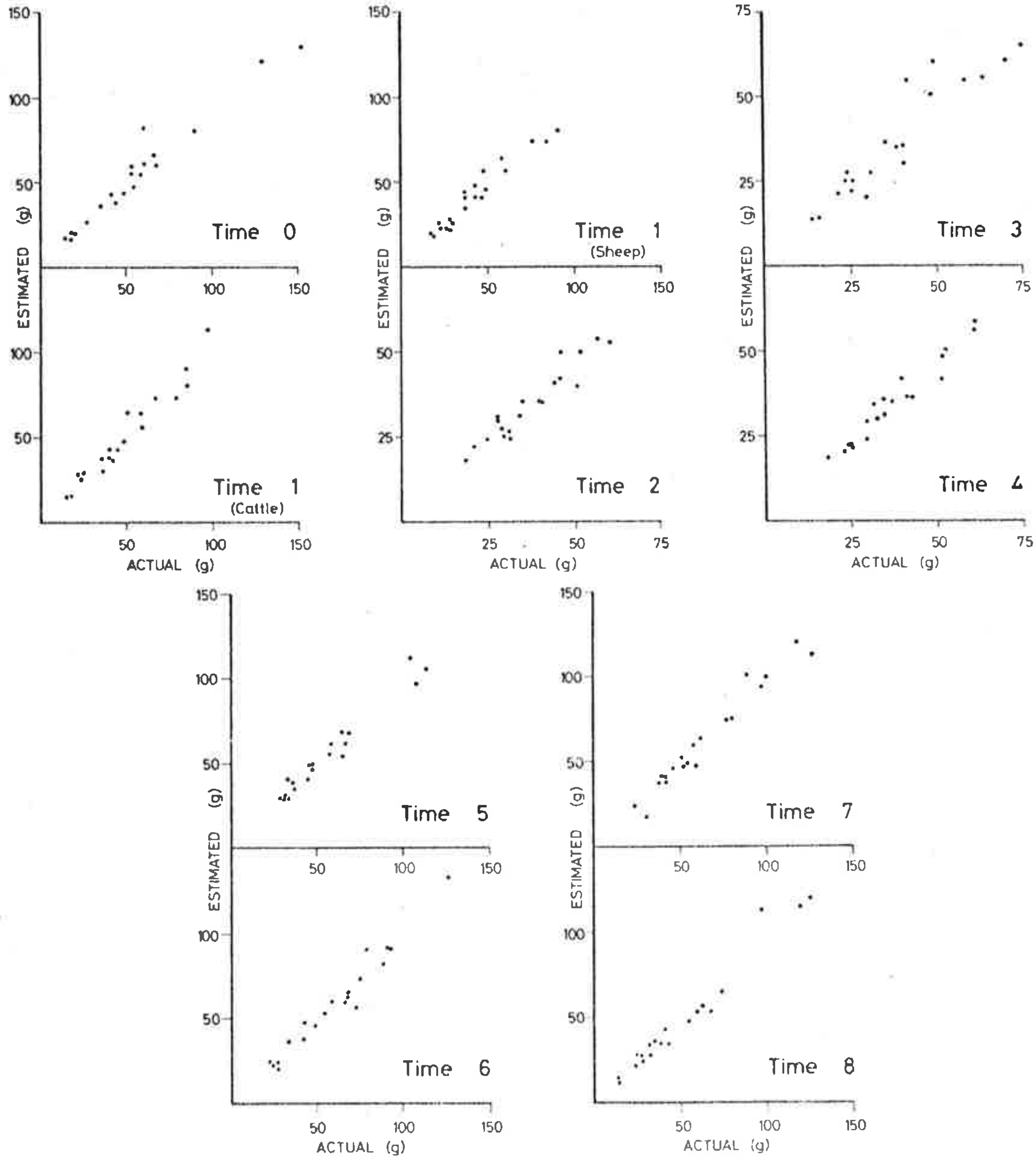


Fig. 3.6

BIOMASS ESTIMATIONS AND ACTUAL WEIGHTS FOR A. CONTORTA

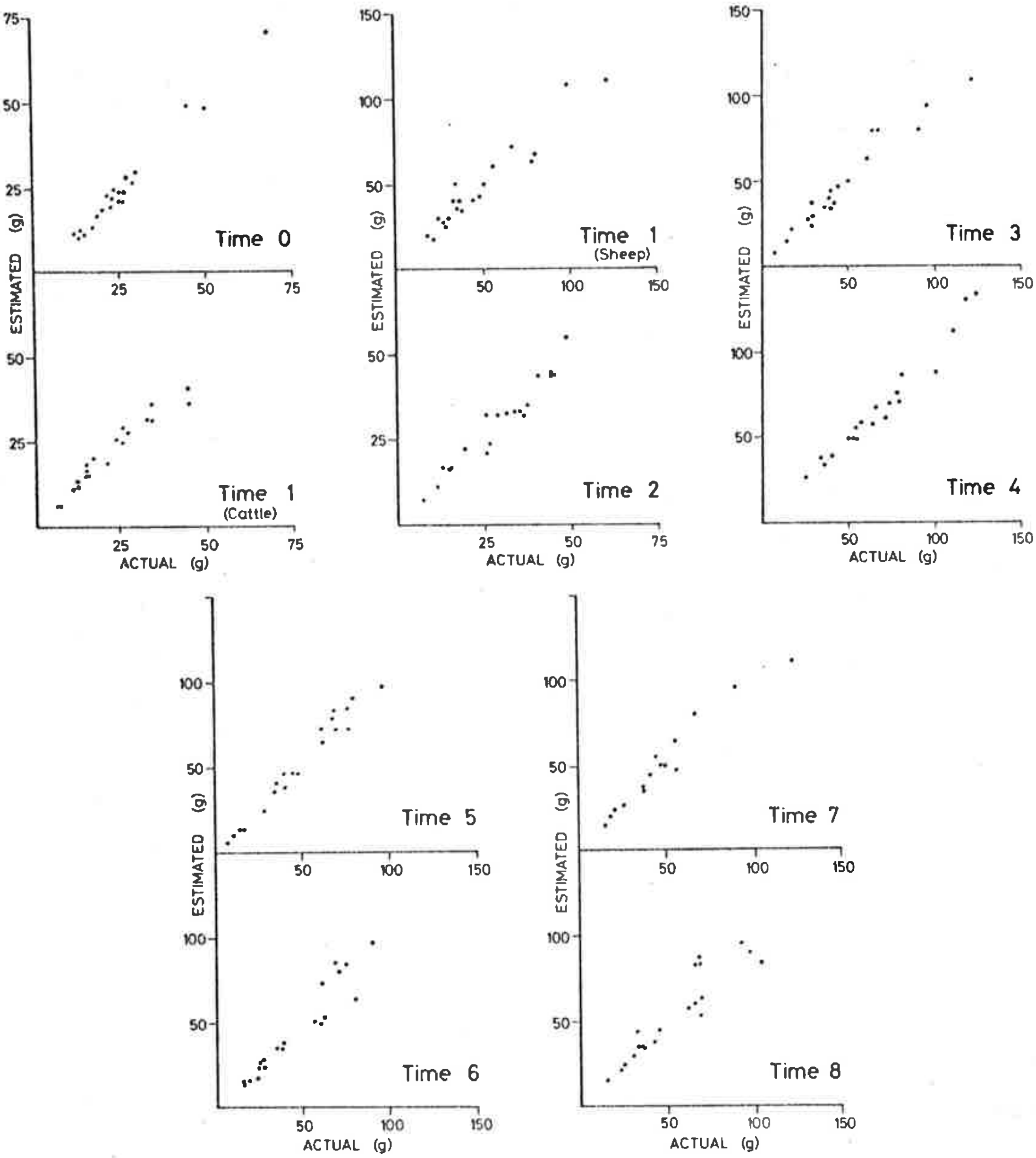


Fig. 3.7

BIOMASS ESTIMATIONS AND ACTUAL WEIGHTS FOR <u>K. ASTROTRICHA</u>

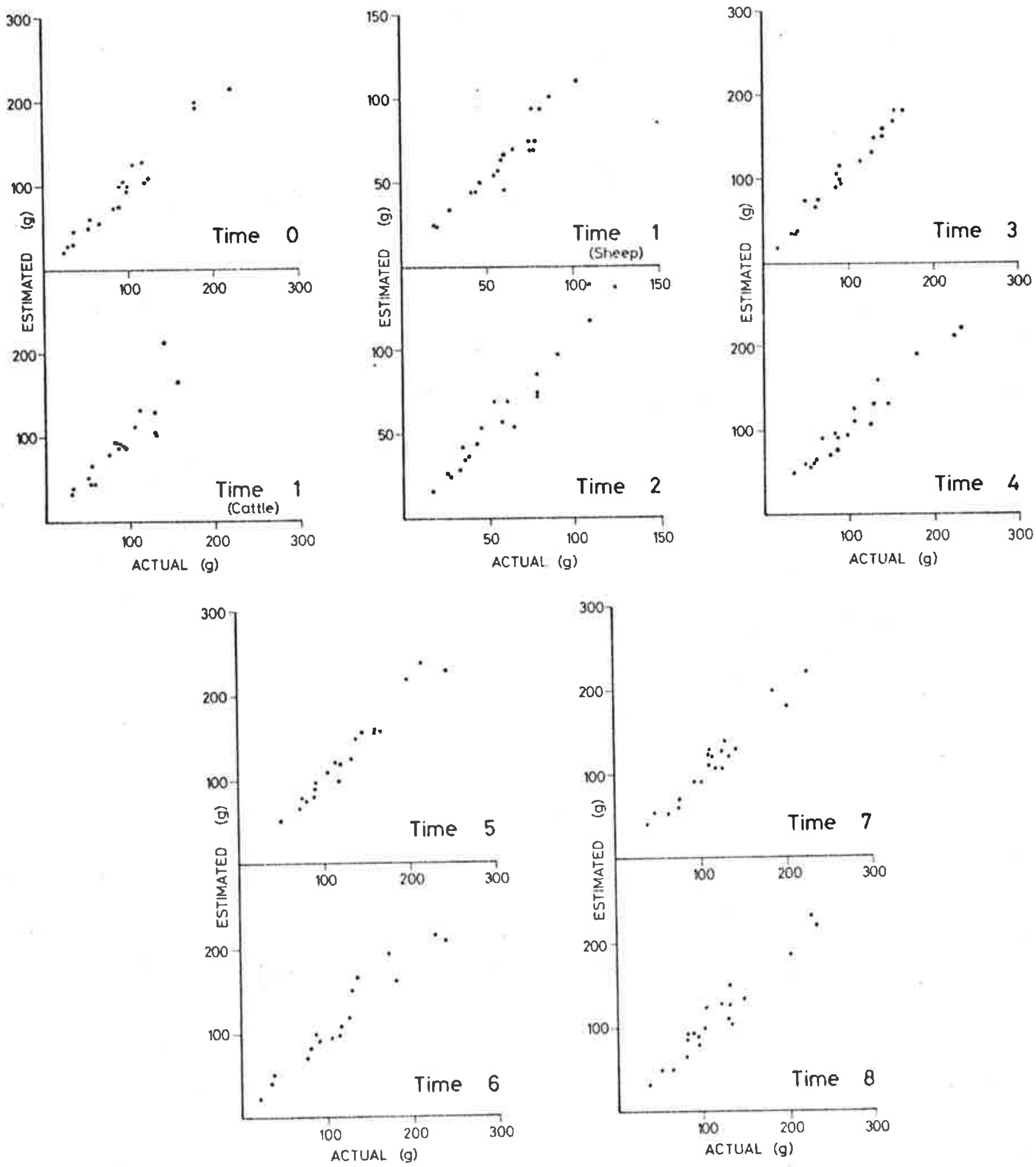


Fig. 3.8

BIOMASS ESTIMATIONS AND ACTUAL WEIGHTS FOR K. PYRAMIDATA

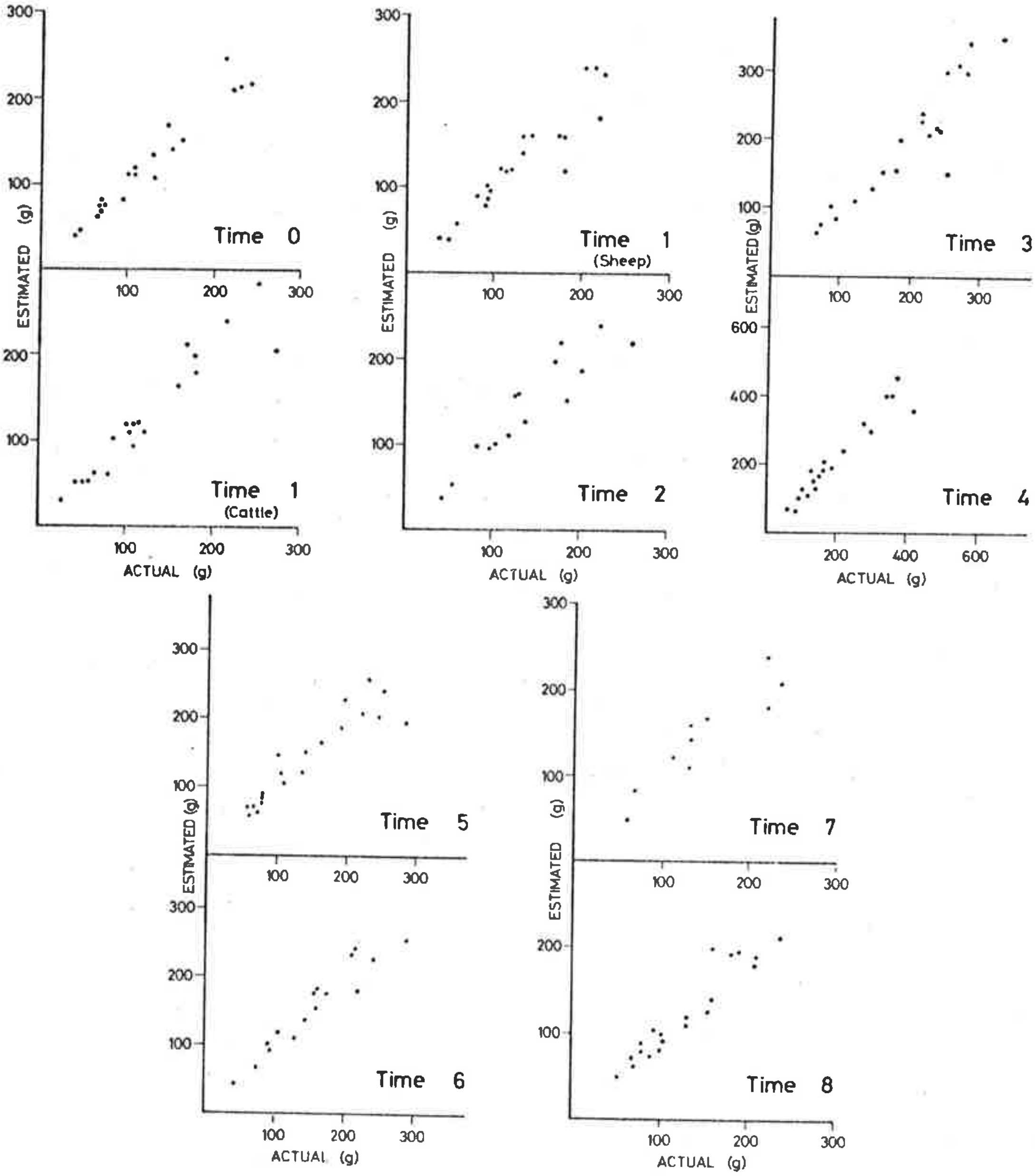


Fig. 3.9

WET AND DRY WEIGHTS OF <u>S. NITIDA</u> HAND HELD SPECIMENS

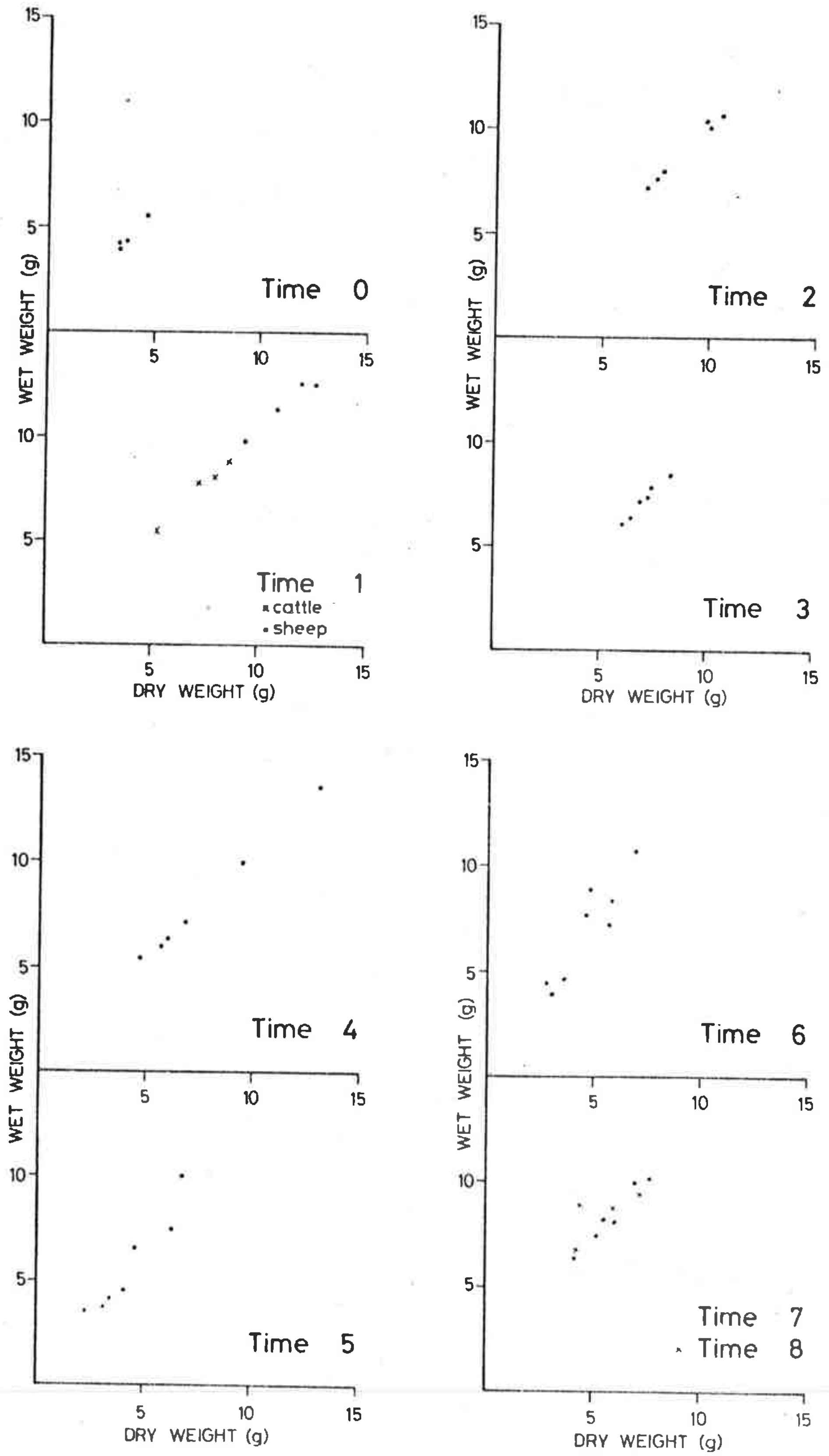


Fig. 3.10

WET AND DRY WEIGHTS OF

ENNEAPOGON SPP HAND HELD SPECIMENS

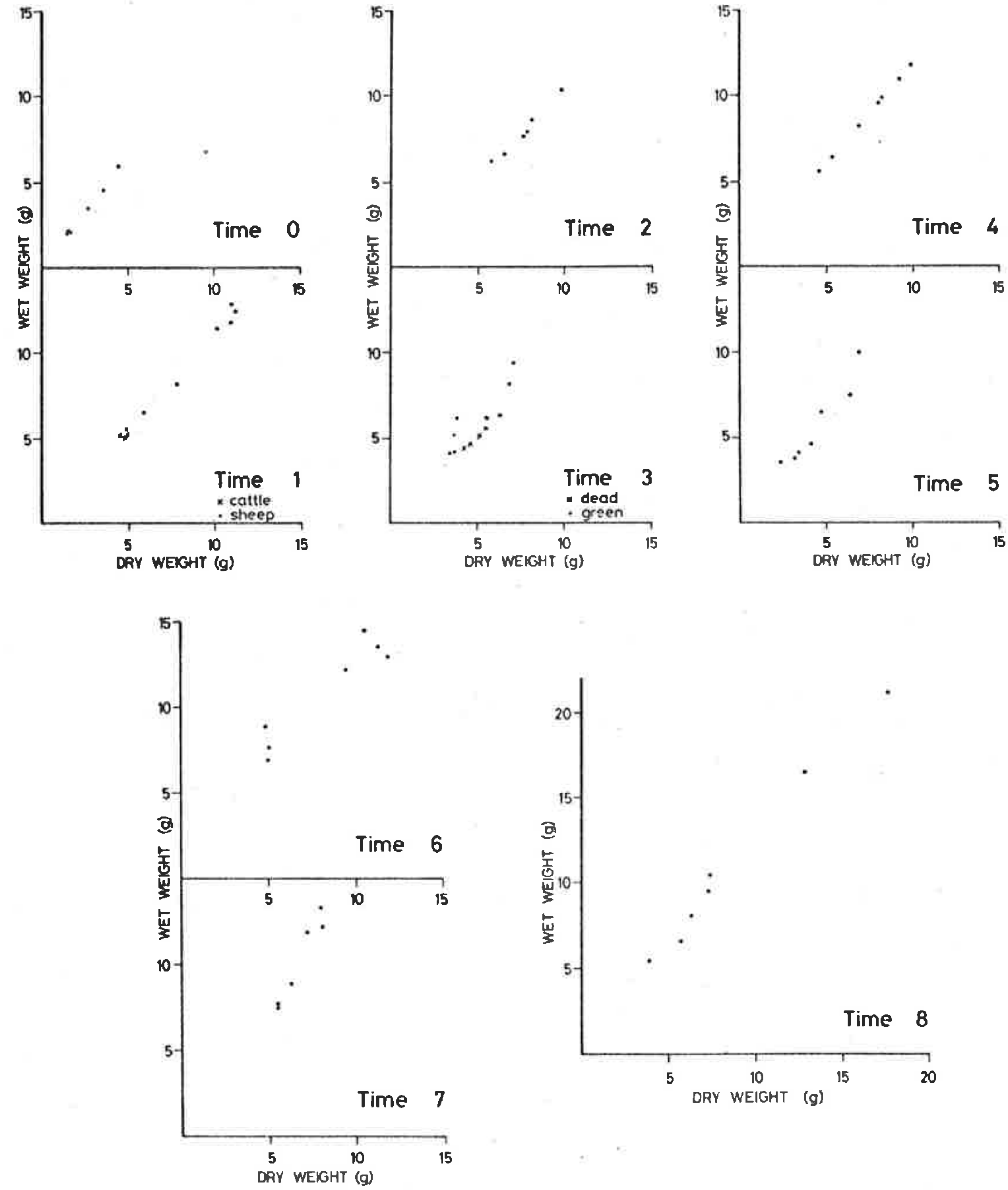


Fig. 3.11

WET AND DRY WEIGHTS OF *A. CONTORTA* HAND HELD SPECIMENS

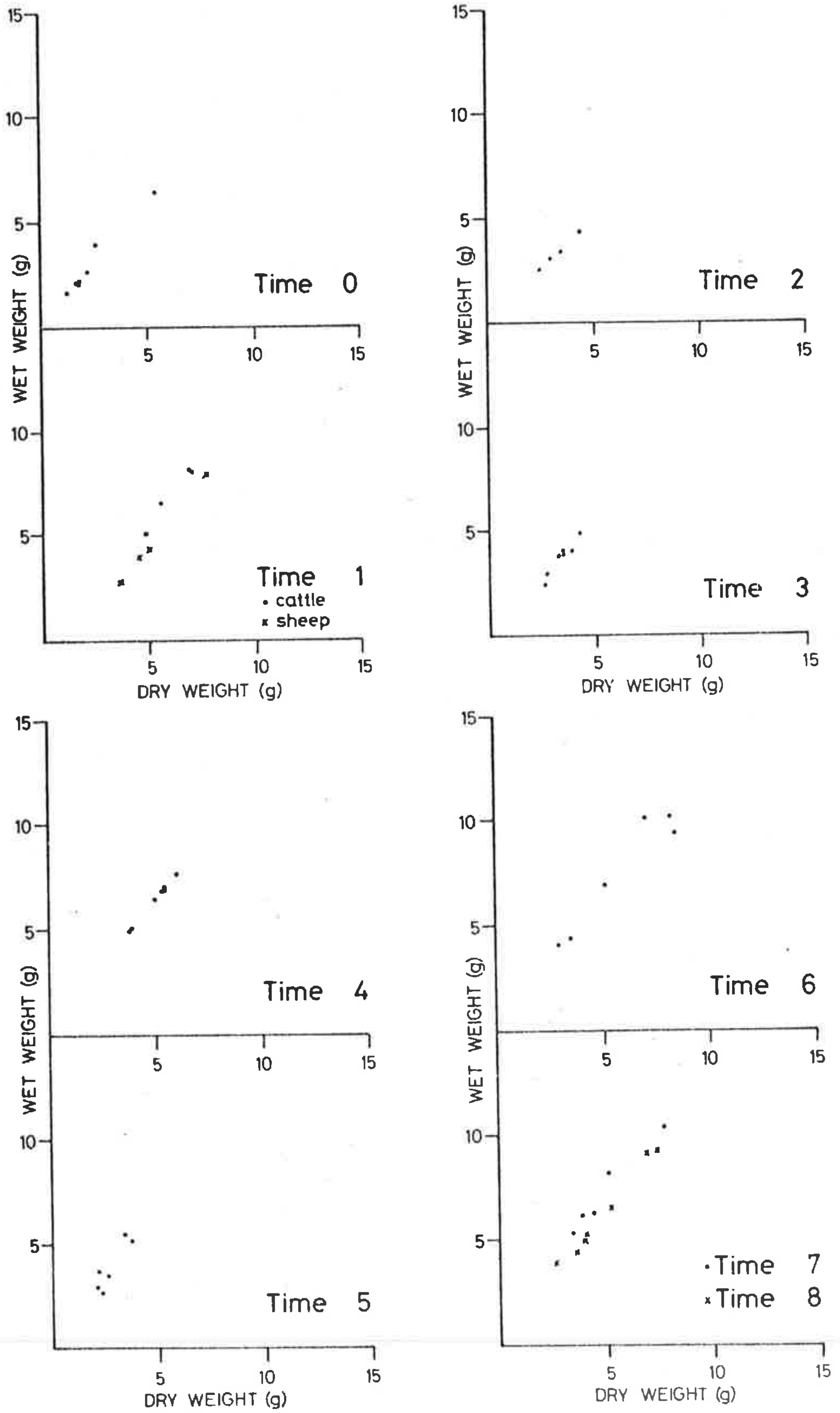


Fig. 3.12

WET AND DRY WEIGHTS OF

K. ASTROTRICHA HAND HELD SPECIMENS

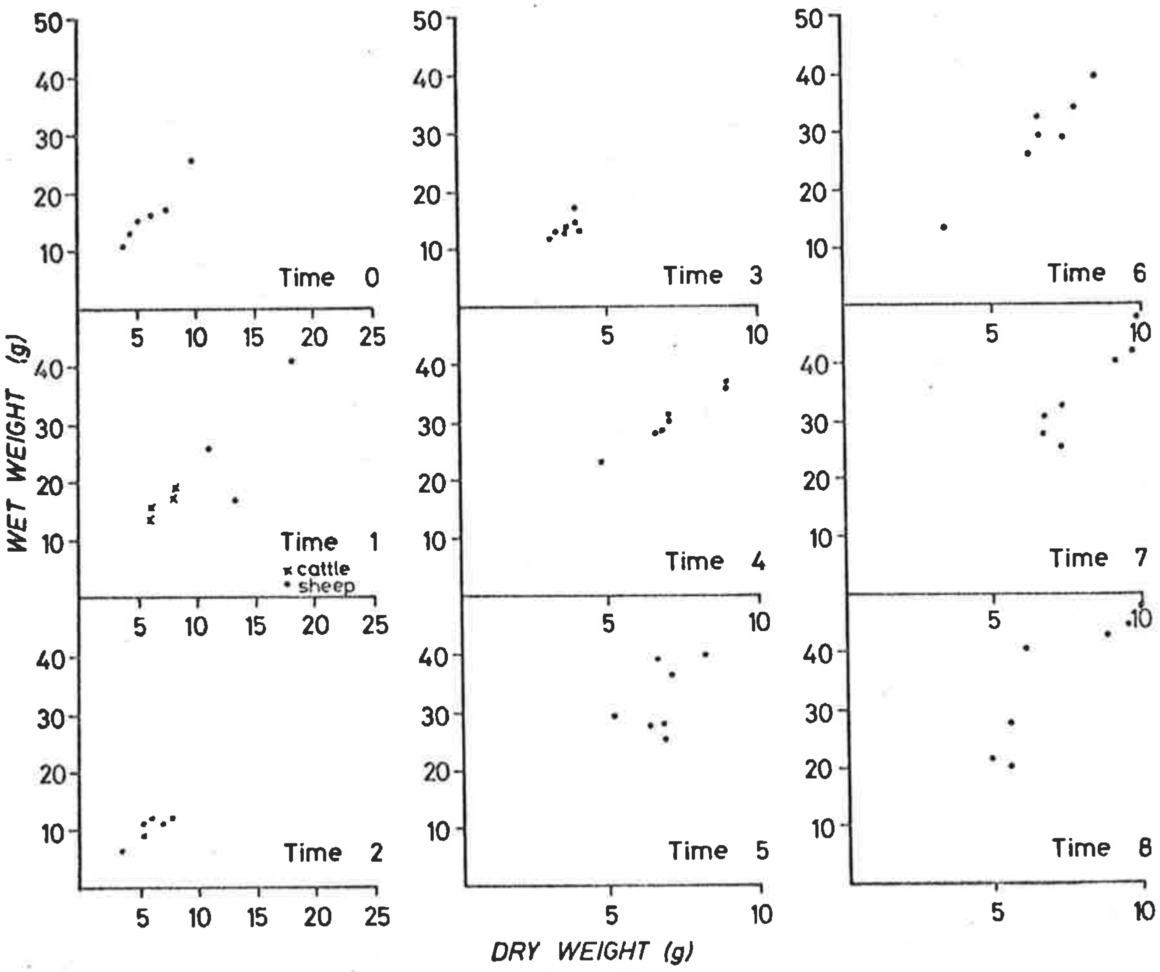
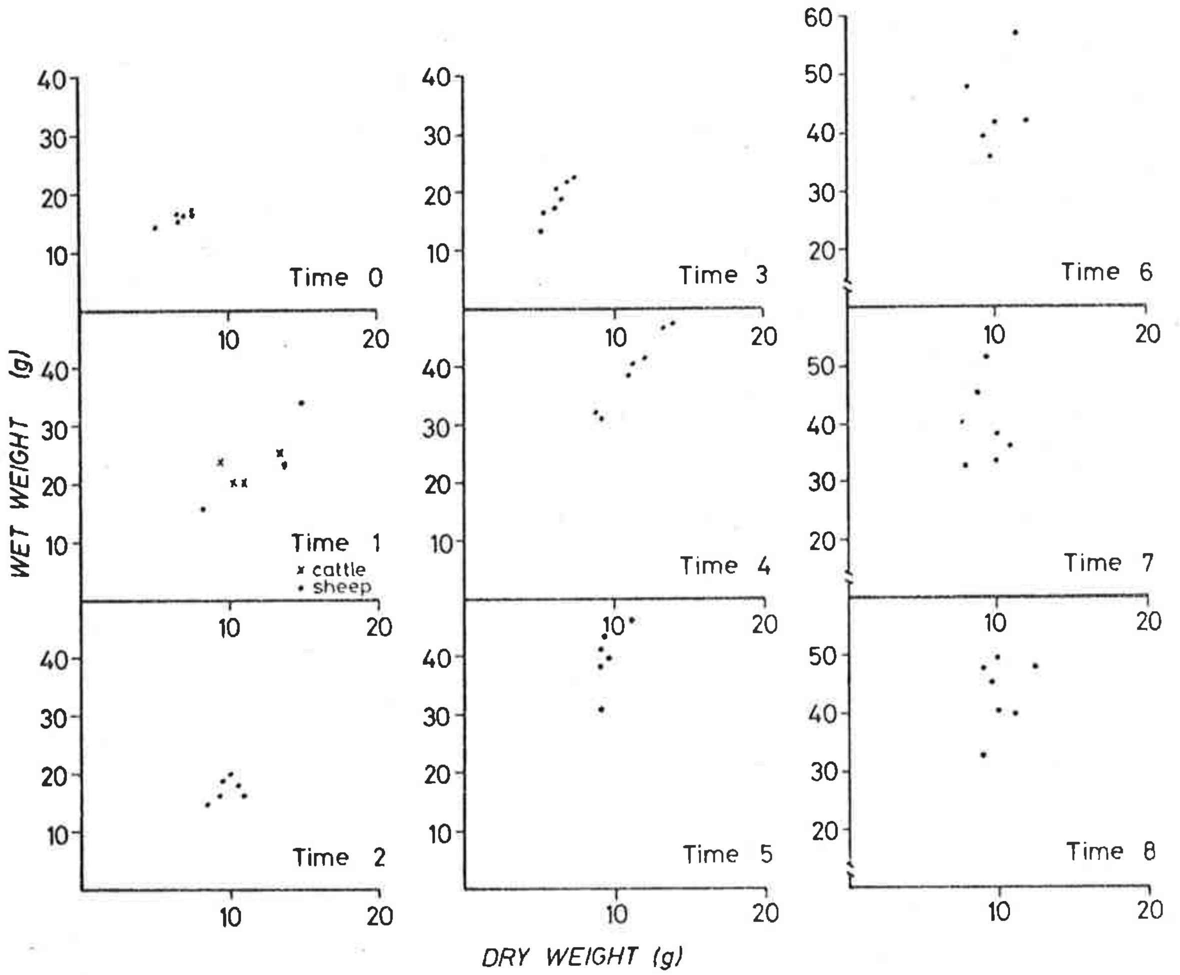


Fig. 3.13

WET AND DRY WEIGHTS OF

<u>K. PYRAMIDATA</u> HAND HELD SPECIMENS



a lightly grazed area being used to estimate plants in a heavily grazed area, with probable differences in form and foliage.

8. After training, ten further specimens of each species, estimated as equivalent in leaf biomass, were collected, and weighed en masse and stored for later oven drying. This reduced relative error in measurement of wet weight due to insensitivity of field balances. In addition, it yielded a more accurate measure of the estimation unit weight, by reducing the error implicit in the individual variation of specimens.

Estimations were of wet weights. The dry weight equivalents were obtained by oven drying the stored samples at 80°C for 48 hours. This requires a linear relationship between wet and dry weights. Figures 3.9 to 3.13 show this to exist for any given time, although the relationship may vary considerably with time.

3-32 *Minor species.*

Density counts of all individuals were made for all other species encountered in quadrats (listing:table 3.3). Most were ephemerals. The two major problems in counting were (a) visual obstruction by large bushes and grasses, and (b) the number of vegetatively similar species; e.g. *Bassia diacantha, B. obliquicuspis, B. patenticuspis, B. sclerolaenoides* and *Malacocera tricorne,* highly similar in appearance, and frequently encountered. Visual obstruction led to spurious rises in apparent abundance of other species as the grasses were grazed down, while the identification

TABLE 3.3

PASTURE SPECIES FOUND IN QUADRATS AT MT VICTOR

POACEAE

Aristida contorta
Dactyloctenium radulans
Enneapogon avenaceus
__________ *cylindricus*
Eragrostis dielsii
__________ *laniflora*
Stipa nitida
Tragus australianus
Triraphis mollis

LILIACEAE

Bulbine semibarbata

CHENOPODIACEAE

Atriplex limbata
________ *spongiosa*
________ *stipitata*
________ *vesicaria*
Bassia biflora
______ *brachyptera*
______ *decurrens*
______ *diacantha*
______ *divaricata*
______ *lanicuspis*
______ *limbata*
______ *obliquicuspis*
______ *patenticuspis*
______ *paradoxa*
Bassia sclerolaenoides
Chenopodium desertorum
Enchylaena tomentosa
Kochia aphylla
______ *astrotricha*
______ *excavata*
______ *georgei*
______ *pyramidata*
______ *sedifolia*
______ *tomentosa*
Malacocera tricorne
Rhagodia spinescens var *deltophylla*
Salsola kali

AMARANTHACEAE

Ptilotus obovatus

FABACEAE

Clianthus formosus

GERANIACEAE

Erodium cygnorum

ZYGOPHYLLACEAE

Tribulus terrestris

SAPINDACEAE

Dodonaea microzyga

EUPHORBIACEAE

Euphorbia drummondii

TABLE 3.3 (Cont.)

MALVACEAE

Abutilon otocarpum	*Sida intricata*
Sida corrugata	____ *petrophila*
____ ________ var *angustifolia*	____ *virgata*

CONVOLVULACEAE	MYOPORACEAE
Convolvulus erubescens	*Eremophila duttonii*

ASTERACEAE

Angianthus pusillus	*Helipterum floribundum*
Brachyscome ciliaris	*?Minuria leptophylla*
Calocephalus dittrichii	

problem, if not adequately solved, would have produced spurious negative correlations between the species confused. For the most difficult species, identification was aided, in the field, by labelled vouchers.

3-4 SAMPLING SYSTEM

To answer even the general question of whether stock-induced differences existed between the paddocks, it was necessary both to define working hypotheses and to select methods of analysis, before commencing sampling. While studies such as this require a broad data base for formulation of specific hypotheses, the sampling system must have a rational basis to return usable information. Much wasted effort and intractable data can result if the approach is to amass data first, then to consider its treatment. The general hypotheses were:

1. Background vegetation pattern and dynamics were the same in both paddocks.
2. There were differences in the effects of sheep and cattle.
3. These effects could be isolated from background noise by the detection of piosphere symmetry.

The search was thus for pasture variables which had a changing relationship with distance from water: the nature of this relationship provided the basis of comparison between the two paddocks.

3-41 *Sampling for cattle/sheep comparisons.*

The analyses mainly considered were regressions of plant parameters on distance from water, requiring at least some form of randomisation to estimate the variances involved. Barker and Lange, for investigations of piosphere pattern, employed regular sampling. In the context of single surveys with mapping as a main aim a regular system is appropriate (Williams, 1971), and such sampling is used in the later chapters of this thesis on this basis. However, such a system cannot provide a statistically acceptable estimate of variance (Grieg-Smith, 1964; Kershaw, 1973).

Restricted rather than full randomisation was used to increase precision, as demonstrated by Pechanec and Stewart (1940) for biomass, Goodall (1952b) for cover and Bordeau (1953) for density and basal area. Further, restricted randomisation provided a more even spread of quadrats for possible secondary mapping than full randomisation.

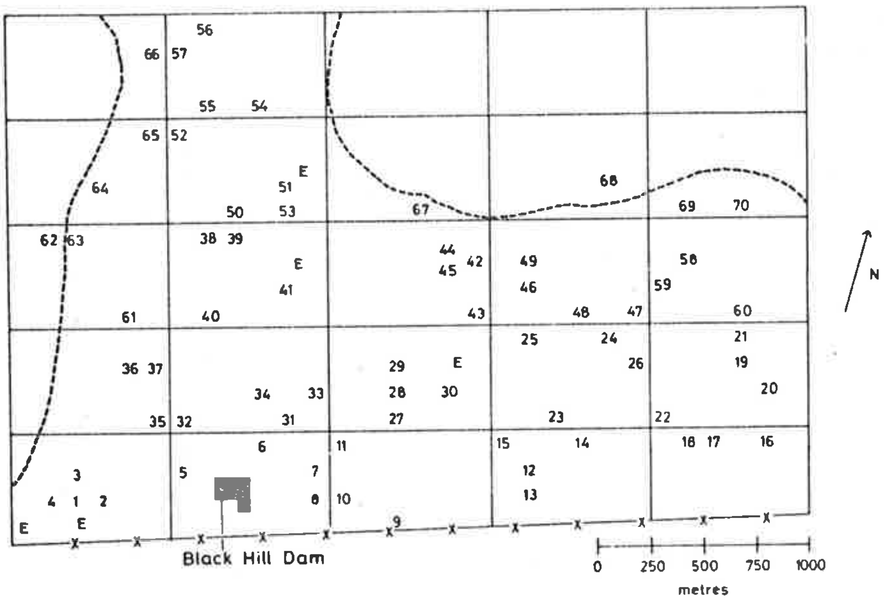
Seventy quadrats were laid in each paddock, as shown in figure 3.14, with a sampling density of $\sim 10/ km^2$. The number was the maximum permitted by time, and was large enough to allow a workable estimate of statistical parameters.

The cattle paddock was laid first, the shape of the sample area being governed by the 3km limit and the heterogeneities mentioned earlier. The sheep paddock sampling area was set up to approximate this shape, in an attempt to avoid any hidden bias (e.g. potential "grazing into the wind" effects). Incomplete sampling blocks around the fringes were allotted quadrats in proportion to their area.

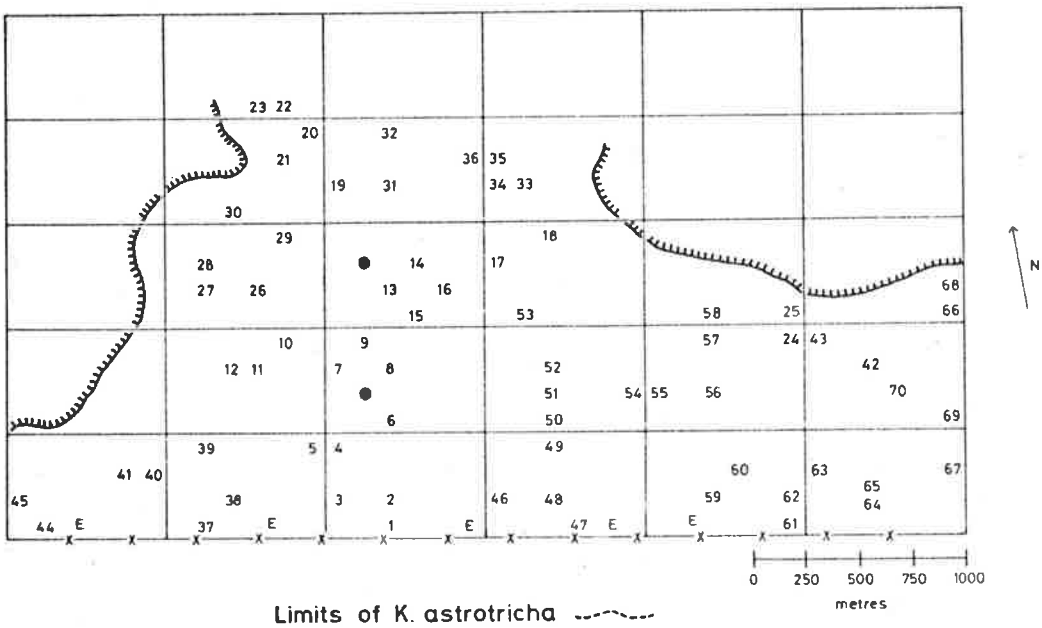
Surveying was by prismatic compass and rangefinder, with waters and the southern fences providing reference points. Due to the problems of estimating bearings of wire fences, a false angle was read in the cattle paddock. During the initial quadrat erection,

Fig. 3.14

(a) CATTLE PADDOCK (Black Hill) QUADRAT LAYOUT



(b) SHEEP PADDOCK (Emu Leg) QUADRAT LAYOUT



Limits of K. astrotricha	-.-.-.-.-
Dense mulga groves	
Quadrat	67
Trough	●
Fence	-x—x-
Exclosure	E

two quadrats were found to be the wrong side of the fence. As the fence had removed a proportionate area of the sampling blocks concerned, they were not relocated in the block but two new quadrats were laid in fringe areas to keep N equal to 70.

Samples were located at the same sites, throughout the study. Goodall (1952b) showed that this removes a large part of the sampling error from the estimate of change. (He presented data for cover changes over a year, obtained from permanent quadrats, in comparison with data from separate quadrats for the beginning and end. Variance of the change was less when estimated from the permanent quadrats). However, successive observations at the same point possibly give rise to correlations of the successive changes, not related to the real situation (Grieg-Smith, 1964). As yet there is no certain evidence that this happens. Such an eventuality could be avoided by a stepwise sampling: measurement at one point at the start and finish of an observation period, with a simultaneous measurement elsewhere for the start of the next period. In the present context, such an approach would have halved the time-restricted sample number, by forcing the duplication of quadrats, and by requiring surveying of new quadrats at each time. Further, the certain advantage of reduction in error outweighed the potential disadvantage of correlated changes, if the same quadrats were read throughout.

3-42 *Sampling for background dynamics.*

Major differences in background dynamics were considered unlikely; the paddocks had similar vegetations and soils, and were sufficiently close to render differing rainfall inputs improbable. Thus only a general check was required; on direction of response to rain and season rather than the absolute magnitude of the responses. Only a small sample was considered necessary.

Within each paddock, five $40x10m^2$ exclosures were erected. The number was limited largely by non-statistical factors, viz. a wire shortage, the expense of completely stock-proof fencing, transport problems, and the time and effort involved in erection. The particular size was selected, because (a) it allowed multiple sampling within the exclosure; (b) it filled a camera frame (see section 3-6); (c) it permitted a sizeable buffer zone around the exclosed quadrats; and (d) massive construction was needed to exclude cattle regardless of dimensions.

Exclosures were restricted to areas adjoining tracks, though sited at least 40m away to avoid immediate track effects. They were located by numbering each 0.1 mile track segment within the sample area and taking five segments at random. Locations are given in figure 3.14.

Two quadrat sets were laid within each exclosure giving N=10 for each paddock. The low number combined with the over sampling probably generated a large sampling error, and any parametric test run between paddocks for exclosure quadrats, or between inside and outside quadrats would be likely to give misleading results. Nonetheless the sample size was considered adequate to give the general check required, fulfilling the purpose of the exclosures.

3-43 *Quadrat size and shape.*

The sizes of quadrats were 10x1m^2 for ephemeral species (ca. 50 species) and 20x2m^2 for large perennial species (8 species). They were laid as shown in figure 3.15. The marker post was lightly seated in the ground, and easily knocked over by stock, though never dislodged entirely. This followed prior experience with stock using quadrat pegs for scratching posts, and consequently biasing results by trampling quadrats excessively.

The long rectangular shape was used for the reasons given in section 5-31. Sizes were set pragmatically, with quadrats as large as was feasible. The larger quadrat followed the work of Barker and Lange (1969,1970), who used 20x1.5m^2 quadrats for density counts in similar circumstances, for the perennial chenopods. This size was tried initially, but increased to 20x2m^2 to lessen edge errors for *K. astrotricha*. A smaller size was considered in the first place for the ephemerals. The large perennials have a much more open distribution of individuals than the ephemerals. Hence if the same sized quadrat were to be used for both, the threshold of observation would be relatively higher for the perennials, because of their wider spacing.

However, scoring time was the deciding factor. Both 20x2m^2 and 20x1m^2 quadrats were attempted for ephemerals. The former took two hours to score completely (in a period of relatively low biomass), the observer was easily lost inside it, and undue trampling occurred. The latter took forty minutes to score, and although the disorientation and trampling problems were largely eliminated, the time was still regarded as too great.

Fig. 3.15

QUADRAT LAYOUT

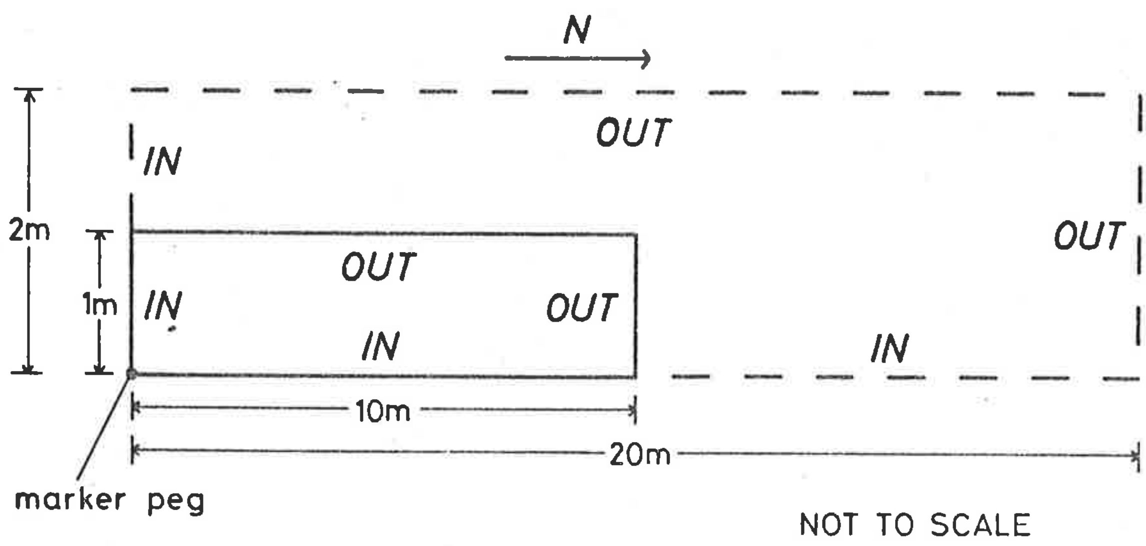
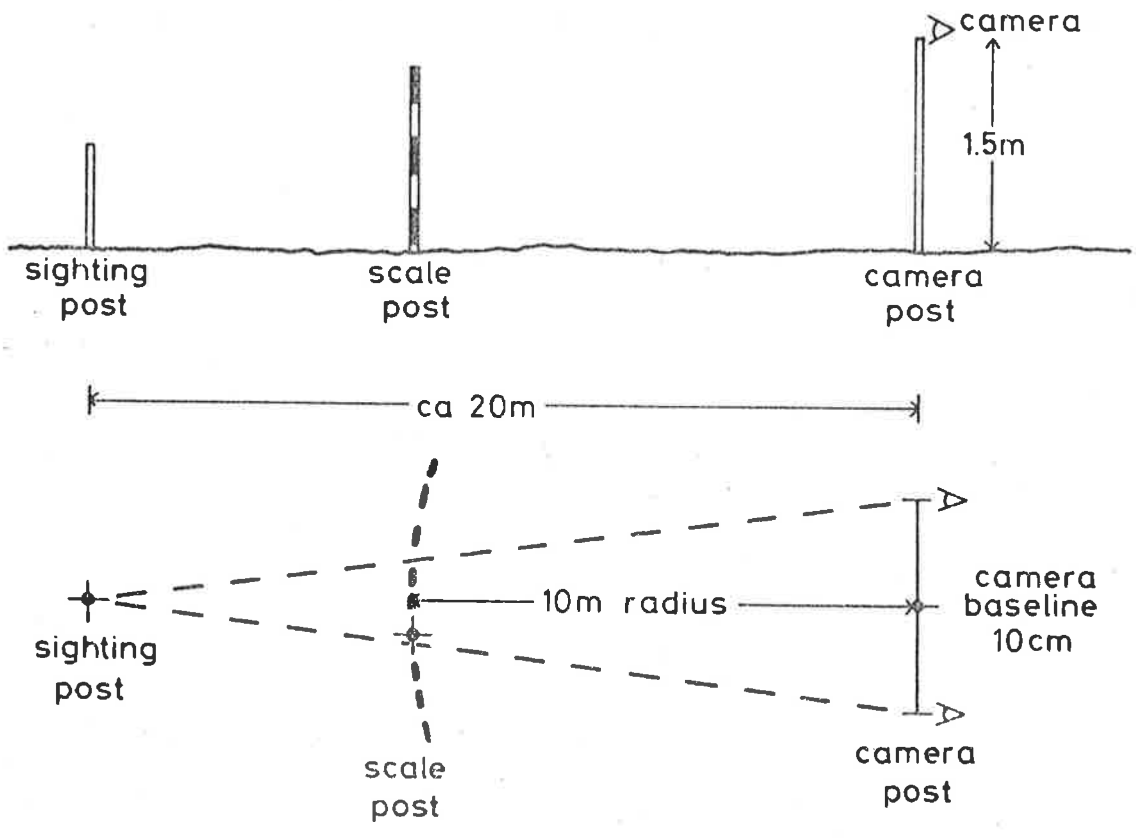


Fig. 3.16

PHOTOGRAPHIC METHOD



Because of the different sizes used, all quantitative data has been expressed in the common units kg/ha and density/ha. Where association analyses are applied, only incidence in the small quadrat is considered.

3-5 ANALYSIS METHODS.

Emphasis was placed on the analysis of quantitative data, using correlation, regression and related techniques. However, a first-order analysis of species incidence was made, using Influence Analysis.

3-51 *Influence analysis.*

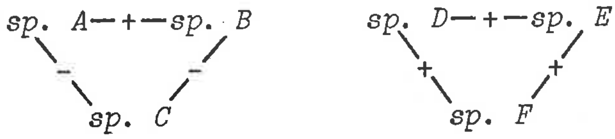
Influence analysis (Lange, 1968) is a method for detection of environmental influences on the basis of species association. Applications are shown by Barker and Lange (1969), Rogers and Lange (1971) and Lange (1971). Collectively, these papers express all the relevant features, and highlight the danger of injudicious use, of the analysis.

Briefly, independent *nodes* of species interaction, consequent on underlying independent influences, are defined by the patterns of association. The reliability of the node is determined by the amount and level of reinforcement within the association matrix. For each node, two of the possible combinations of species incidence are set as the *poles* of interaction. *Influence ratings* (IR's) are assigned to all possible combinations: the poles represent the extremes of the influence range. This procedure is

TABLE 3.4

DETERMINATION OF INFLUENCE RATINGS

(a) Nodes.



Node I *Node II*

(b) Poles of interaction.

Node I	*A*	*B*	*C*	*Node II*	*D*	*E*	*F*
	+	+	−		+	+	+
	−	−	+		−	−	−

(c) Assignment of influence ratings.

Node I

Poles	Species combinations *A*	*B*	*C*	Recoding *A*	*B*	*C*	IR
	+	+	+	+	+	−	2
*	+	+	−	+	+	+	3
	+	−	+	+	−	−	1
	+	−	−	+	−	+	2
	−	+	+	−	+	−	1
	−	+	−	−	+	+	2
*	−	−	+	−	−	−	0
	−	−	−	−	−	+	1

Node II

Poles	Species combinations *D*	*E*	*F*	Recoding *D*	*E*	*F*	IR
*	+	+	+	+	+	+	3
	+	+	−	+	+	−	2
	+	−	+	+	−	+	2
	+	−	−	+	−	−	1
	−	+	+	−	+	+	2
	−	+	−	−	+	−	1
	−	−	+	−	−	+	1
*	−	−	−	−	−	−	0

summarized in table 3.4. Quadrat data is then re-examined, and the various species combinations assigned the respective influence rating. Backplotting the IR's reveals the extent and strength of the influence.

3-52 *Correlation and regression.*

The text used for guidelines in the application of correlation and regression analyses was Sokal and Rohlf (1969, pp 494 et seq.).

Two sets of relations were sought; the degree of plant/plant interaction, and the relationship of plant parameters to stocking pressure, as indexed by distance from water. The first set was dealt with by correlation and the related Principal Components analysis, the second set by linear regression (following the discussion in section 1-72 on linear relations within the piosphere). For regression analyses, the basic assumptions were (a) the distribution of the Y variables--plant parameters--approximated normality for any value of X; and (b) X variables could be treated as measured without error. Regression analyses were applied to the individual major species, but not to the individual minor species. It was felt that the information gained, if the latter were considered in detail, would not justify the time expenditure. Instead, the Principal Components extracted were used as the basis for summarizing piosphere relation of minor species (discussed below).

Simple regressions of biomass and density on distance from water were calculated first. Standing crops were used rather than changes in standing crops, once the changes over a period were found to be highly dependent on the standing crops at the start.

However, simple equations did not allow consideration of the subtleties of the situation, for example, plant competition controlling abundance independent of stocking. Therefore, multiple regressions were attempted, to isolate direct stock effects. The problem of collinearity of X variables then arose. While there is no absolute requirement in the mathematics for complete independence of these variables (Mead, 1971), covariance between them will lead to redundancy and interpretation problems (Yarranton, 1971). The most efficient solution is to replace the variables with a smaller set showing less covariation--a complex modelling situation beyond the scope of this thesis-- or alternatively, to include only one variable from the covarying set in the equation (Austin, 1971).

The general equations used for major species in the present study were of the form

$$B = b_o + b_1 D + b_2 (B_t - B) + b_3 W$$

$$D = b_o + b_1 (B_t - B) + b_2 W$$

where B and D are the biomass and density of the species in question; $B_t - B$ is the biomass of the other species, considered originally as an index of competition; and W is the stocking index, distance from water. The probable collinearity between X variables was considered unavoidable to a great extent, for the following reasons.

1. While both density and biomass of a species are likely to vary with W, the variation is not necessarily of the same order for both parameters. Hence, when dealing with biomass, that part of variance due to the relationship with density, independent of the stocking effects, should be accounted for; even though this may introduce

collinearity of the X variables.

2. Similarly, the abundance of a species may be affected by the presence of other species, independently of stocking effects. Such a component in its variance should also be accounted for.

To reduce collinearity difficulties, the compound variable of average size was used. This was defined for each species as the ratio of biomass to density, B/D, in each quadrat. The equation used was

$$B/D = b_0 + b_1 (B_t - B) + b_2 W.$$

3-53 *Principal Components analysis.*

Principal Components analysis (PCA) is a sound method for summarizing multivariate data, by means of multiple axes ordinations. Recent reviews of the method are available in Orloci (1966), Pielou (1969) and Kershaw (1973). Its normal use in ecology is the detection of underlying environmental influences (as in Grieg-Smith et al, 1967; Austin, 1968; Austin and Grieg-Smith, 1968; Kershaw 1968; and Noy-Meir, 1971). There are two serious limitations:

1. The principal components or axes are mathematical entities which need not have biological significance; and
2. Being linear functions of the original data, the components are unlikely to show simple relationships with non-linear environmental influences. However, the particular influence sought, stocking pressure, may be approximated by a linear model; thus this second limitation need not obtain for the present case).

Analysis was performed on a CDC 6400 computer in the University of Adelaide, using the "Factor" Analysis program, BMDO3M, of the Health Sciences Computing Facility, U.C.L.A. This program performed a principal components solution of a correlation matrix, followed by orthogonal rotation of axes. The initial solution is not unique: rotation of axes does not change the information content (i.e. the configuration of data points), but provides a new solution of different properties, allowing easier interpretation (Kershaw, 1973). Examples of the effective use of rotation in phytosociological studies are given by Ivimey-Cook and Proctor (1967), and Noy-Meir (1971).

Details of procedure were as follows. PCA was performed on density data for individual times and for all species, with distributions assumed approximately normal. The first five components, accounting for the bulk of the total variance, were rotated. Site affinities (or loadings) for each rotated component were calculated next, and regressed on distance from water. This determined which component(s) related to the stocking influence. Species affinities with the stocking component(s) were compared subsequently between paddocks, to seek differences in the species affected under cattle and sheep.

The use of site affinities in regression analyses was valid: the original data block was multivariate-normal in distribution, the components were linear functions of this data, and site affinities were derived from the original data by application of the components. Hence site affinities were also normally distributed, and so, acceptable for use as values of the dependent variable in regression. A similar justification of such method is given by Austin (1968, 1971), and an example of its use by Noy-Meir (1974).

3-6 MINOR STUDY (Sampling by stereo-photopoints)

3-61 *General approach.*

The photopoint system, dealing with the same hypotheses as the major study, was set up (a) to provide an insurance in the event of difficulties with the major study (particularly in measurement of biomass); (b) to give an indication of plant dynamics in areas beyond the sampling limits of the major study; and (c) to provide some information on tall shrub or tree dynamics not covered by the major study. It was designed to be run as swiftly and easily as possible, allowing samples to be taken while passing through the district if necessary. Hence the photopoints were sited near tracks to allow the use of any vehicle in sampling.

3-62 *Photographic methods.*

Stereophotograph pairs were taken at each photopoint using a standard 35mm camera, from a height of 1.5m, with a baseline of 20cm. Photographs were oblique, of the middle-distance type, with most information in the area between 5 and 15m from the camera. The camera field was centred on a set post ca 20m away. A vertical scale was placed at any point within the field along a 10m radius from the camera position (see fig. 3.16). Strict control was kept on the position in the field of the centering post and the horizon, to prevent wandering of the field between trips as much as possible.

In other vegetation studies, vertical photographs have been used rather than obliques. For example Wimbush et al (1967) used tracings from stereopairs taken vertically to estimate changes in cover.

The oblique type was chosen for the following reasons:-

1. It is easier to interpret an oblique than a vertical photograph, in the sense that the oblique gives an immediately identifiable picture;
2. A vertical photograph limits the size of the photosample much more than an oblique taken from the same height;
3. The ephemeral populations in the study area were largely upright in habit, hence changes in biomass were more likely to be correlated with height than cover;
4. As with most arid regions, much of the ground was bare, and this would decrease the information on plant biomass if vertical photos were used;
5. The one set of photographs could be used for both pasture and tree dynamics if necessary; and
6. Similar photographs, used in other studies, have provided tractable data (e.g. Hall et al, 1964; Albertson et al, 1967).

As far as was possible, photographs at a point were taken each time under similar light conditions to minimise variations in interpretation resulting from shadowing. During the study, it was found that overcast conditions produced a more easily read stereo pair than strong light, although individual prints were less clear through lack of contrast.

Black and white film was used throughout rather than colour, because of the cost of the latter. However, it is my opinion that, had cost permitted colour, the information content of photographs would have increased greatly. Species (particularly grasses) can be separated on the basis of their colour coding, and the state of production can be partially estimated from the colour of the plants.

3-63 *Plant populations studied and parameters estimated.*

The type of photograph combined with the use of black and white film limited both the species identifiable and the parameters which could be estimated. Only the major species and tall shrubs or trees were considered for analysis.

Grass species were lumped as one unit (grass standing biomass). *K. astrotricha* and *K. pyramidata* were readily recognisable, and were each scored for standing leaf biomass.

No attempt was made to calibrate the relative biomass on the photographs with absolute biomass (photograph followed by full harvest). This would have been necessary had the major study not yielded tractable data, but the harvesting required was considered too time demanding unless absolutely necessary. The decision whether or not to attempt direct calibration was delayed until February 1973, by which time it was clear that the methods in the major study were workable.

3-64 *Sampling system.*

Photopoints were sited at regular intervals along tracks, though at least 50m away to avoid immediate track effects. Regular rather than random sampling was used to provide an even sampling with the limited number of replicates.

Sampling along tracks was necessarily biased. Tracks are laid to provide access to waters and fences, and usually avoid hills. As a result, the sampling in the cattle paddock was mainly restricted to the *K. astrotricha* areas, with little sampling of the other vegetation types, and sampling in the sheep paddock was largely restricted to the southern fence. These limitations must be considered in comparing paddocks.

Since the sheep paddock had fewer usable tracks, photopoints were placed at shorter intervals (0.3 mi, 0.5km) than in the cattle paddock (0.5 mi, 0.8 km) to give an equivalent replication between paddocks. 23 and 20 photopoints were set up in the cattle and sheep paddocks respectively. In addition, a photopoint

TABLE 3-5

PHOTOPOINT OBSERVATIONS

CATTLE	SHEEP	MAJOR STUDY TRIPS
7/7/72	-	Pilot (Cattle)
4/9/72	4/9/72	1 (Sheep)
1/10/72	5/10/72	1 (Cattle)
28/11/72		2 (Both)
13/2/73		3 "
28/4/73		4 "
24/7/73		5 "
1/11/73		6 "
13/2/74		7 "
31/7/74		8 "

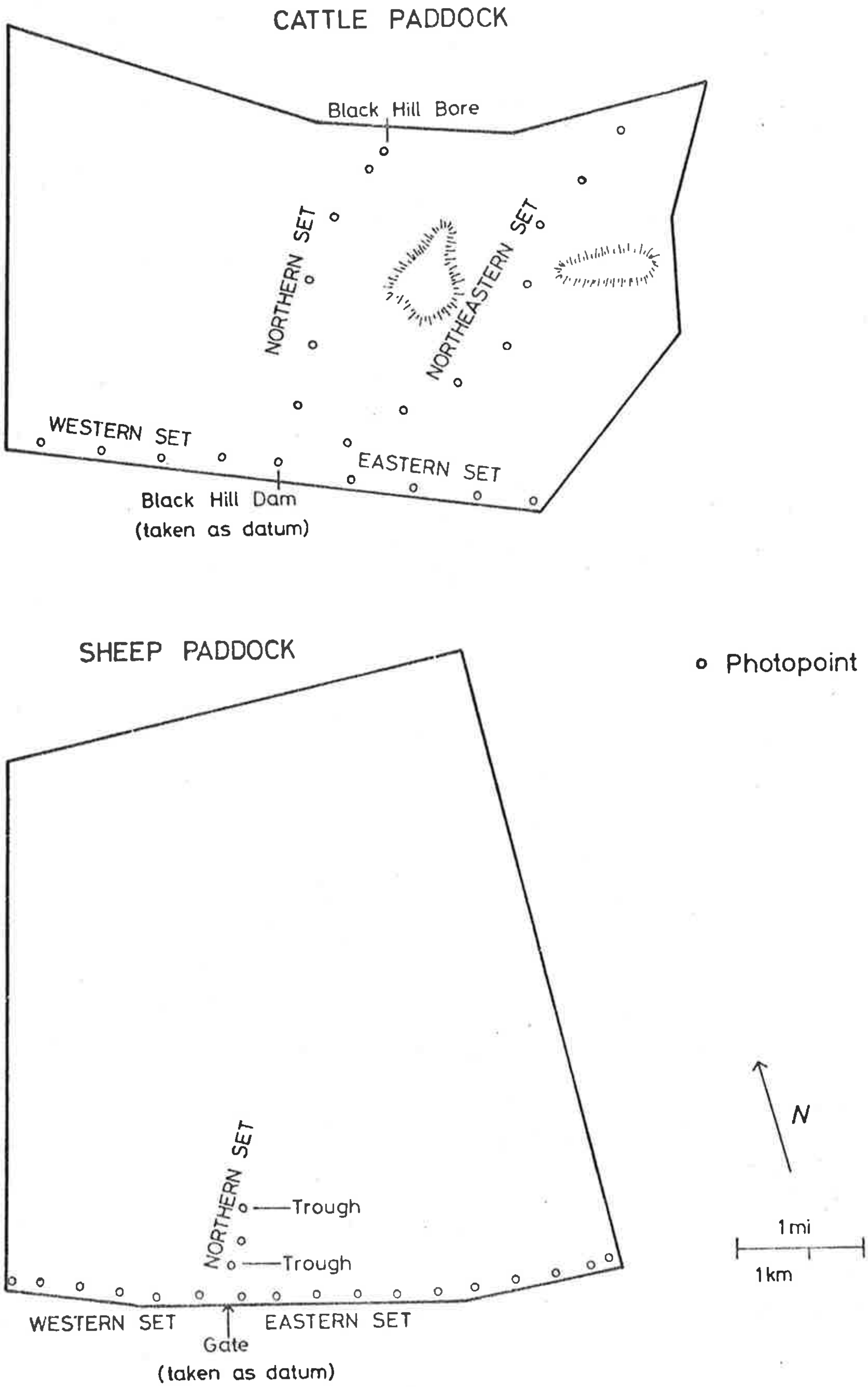
was placed in each enclosure. Table 3.5 gives observation dates for the photopoint system, and figure 3.17 the sample distribution.

3-65 *Analysis method.*

Analysis of photopoint data was kept elementary and semi-quantitative, once the major study methods were found effective. For each observation, every photograph was enlarged to a standard size. In combination with the control on camera field, this permitted the overlay, under a stereo viewer, of photographs taken at different times, but at the same point. The image resulting showed trees, fences, hills and the rest in three dimensions, but pasture plants as overlaid two-dimensional images. This allowed a rapid estimate of the changes in the pasture between times.

Fig. 3.17

PHOTOPOINT LOCATION



Using this technique, the differences between consecutive times were scored, for each point, as obvious increase/decrease, slight increase/decrease, or no apparent change. Appendix 1 provides worked examples of the full time series, for three photopoints from each paddock.

Following the estimation of change, the data scores were inspected for any piosphere pattern. The patterns found were subjectively compared between paddocks.

3-7 RAINFALL MONITORING.

Rainfall was recorded at Mt Victor homestead. Gauges were not placed in the study areas, due to the length of time between observations. Even with a kerosene or oil film, results for the intended periods would be inaccurate due to evaporation, and the error would not be consistent with season. Further, such results could give only the total rain since the previous observation.

For part of the period, rainfall records were obtained from the adjoining Koonamore and Curnamona stations. The rationale was that close correlation in the rains for these stations, relatively widely separated, would imply close correlation in the rains for the two paddocks, with their closer proximity.

3-8 STOCK MONITORING.

3-81 *Stocking levels.*

Fortunately, the station maintained adequate stock records. These were the basis for following stock fluctuations and levels.

Stock were mustered and counted at least twice a year, with the count recorded on the same day. Difficulties arose after February, 1973. At this time, cattle broke the fence between Black Hill and the paddock north, Old Station, creating a semi-open range. There was, however, no evidence that cattle then congregated in one or other paddock after this, but rather there was a constant interchange between paddocks. From this time, entries in stock ledgers combined the two paddocks, and are given likewise in chapter 6.

3-82 *Movements.*

No objective observations of day-to-day movements were made. The cumulative penetration of stock in both paddocks was subjectively estimated by observation of pad pattern and relative dung drop.

CHAPTER 4

COMPARISON OF SHEEP AND CATTLE PIOSPHERES OVER A SHORT TERM: RESULTS

4-1 RAINFALL OVER THE STUDY PERIOD.

Two-, three- and four-month running means for rainfall in 1972 and 1973, at Mt Victor, Koonamore and Curnamona stations are plotted in figure 4.1 . The positions of these stations relative to the sample areas are shown in figure 4.2. There is close correlation in the running means at each station, both in the pattern and the magnitude of rainfall. Since these stations are relatively widely spaced, yet show such correlation, rainfall inputs for the two sampled paddocks, with their closer spacing, can be considered equivalent. Further, rainfall at Mt Victor station can be taken as an accurate indicator of rainfall in the sample areas.

Monthly rainfall at Mt Victor station, for January 1972 to July 1974 inclusive, is given in figure 4.3, with the two-, three- and four-month running means plotted. The major features were:

1. Heavy falls at the start of 1972, with little for the remainder of that year;
2. Heavy falls in the first quarter of 1973, followed by two months of lighter rains;
3. Consistently heavy falls from mid-1973 to the end of observations at the beginning of August 1974.

Throughout the S.A. rangelands, the falls from mid-1973 were the heaviest on record (Bureau of Census and Statistics, 1974). For instance, mean annual rainfall at Mt Victor, 1958-1970,

Fig. 4.1

2-, 3-, AND 4-MONTH RAINFALL RUNNING MEANS FOR STATIONS NEAR STUDY AREA

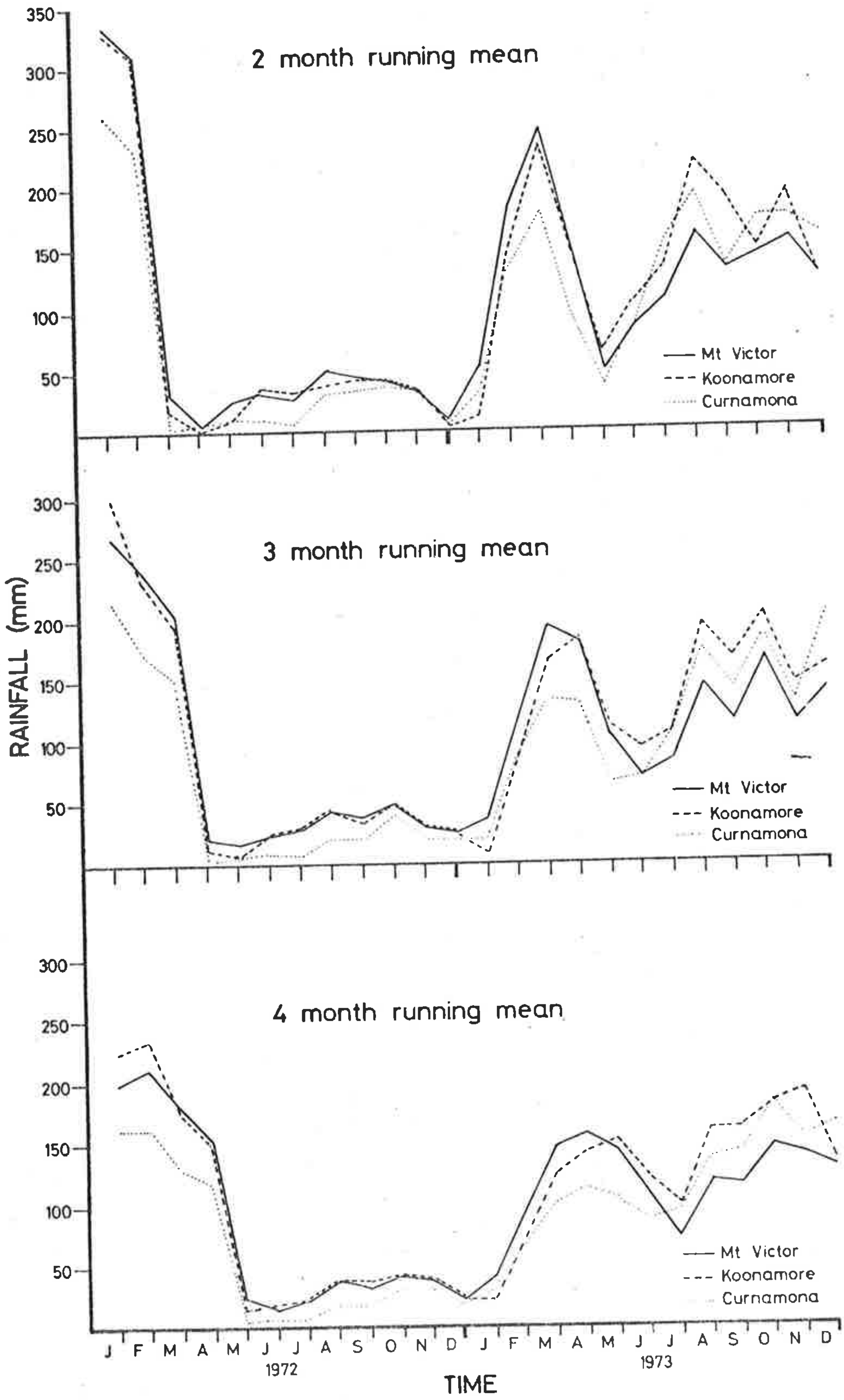


Fig. 4.2

LOCATION OF SAMPLE AREAS IN RELATION TO RAINFALL MONITORING STATIONS

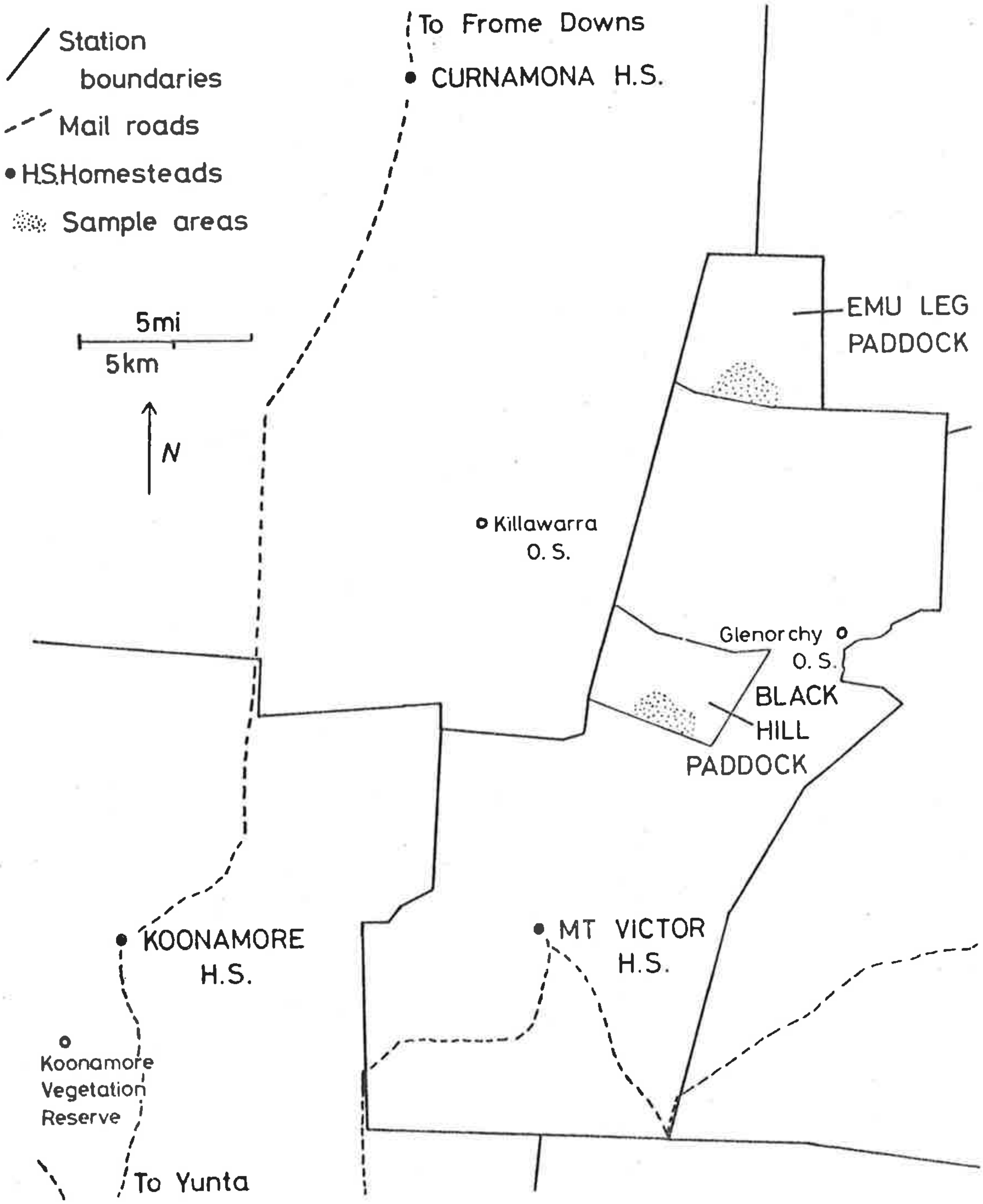
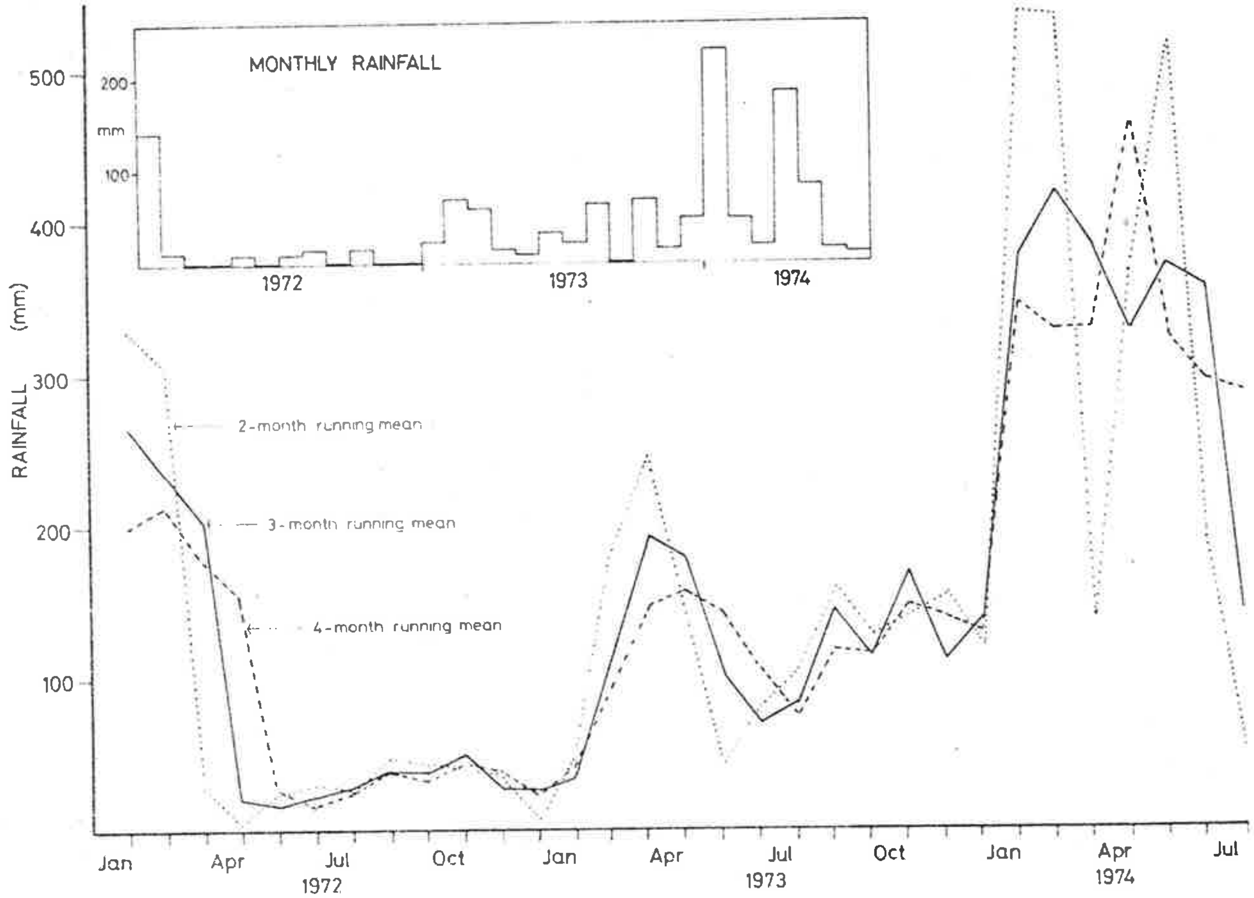


Fig. 4.3

RAINFALL AT MT VICTOR STATION

DURING THE PERIOD OF OBSERVATIONS



was 178mm, with a range from 51mm (1967) to 340mm (1958). Total rainfall for 1973 was 407mm, and for the first seven months of 1974 was 640mm. These atypical rains severely limited the findings of the short-term observation.

4-2 STOCK MONITORING

4-21 *Stocking rates.*

Table 4.1 gives the stocking levels in the sampled paddocks, for both the study period and the preceding months. For cattle, figures from the sampled paddock and its neighbour, Old Station paddock are combined: as already stated, these two paddocks formed a semi-open cattle range from February, 1973, served by five waters.

The main features were:

1. The steady increase in cattle number throughout the study period;
2. The fluctuations in sheep number, culminating in a 25% mortality between February and May 1974, due to fly-strike, and followed by the removal of sheep thereafter;
3. The ratio of sheep to cattle, of the order 5:1, and markedly higher than the ratios given in section 2-22.

The fluctuations and absolute differences in stock numbers imply that the paddocks were not equivalently stocked, in terms of number per unit area or number per water.

TABLE 4.1

STOCK NUMBERS

(a) Cattle: Black Hill and Old Station Paddocks*.
10600ha total area, 5 effective waters.

Period	Total stock	ha/animal	animals/water
Dec 1971- July 1972	300	35	60
July 1972- Sep 1972	350	30	70
Sep 1972- Nov 1972	390	27	78
Nov 1972- Sep 1973	470	23	94
Sep 1973- Aug 1974	500	21	100
Sheep prior to Dec 1971	2400	4.5	480

(b) Sheep: Emu Leg Paddock*.
6000ha total area, 2 effective waters.

Dec 1971- Jun 1972	600	10	300
Jun 1972- Aug 1972	1000	6	500
Aug 1972- Mar 1973	600	10	300
Mar 1973- Aug 1973	400	15	200
Aug 1973- Feb 1974	830	7	415
Feb 1974- May 1974	ca 200 deaths from fly-strike.		
May 1974- Aug 1974	stock removed.		

---

* Figures given are total stock: included in cattle figures are cows and calves, in sheep figures are ewe hoggets and wethers.

4-22 *Stock movements.*

Figures 4.4 and 4.5 show the extent of stock penetration in the paddocks sampled, over the study period. They do not show the seasonal variation in stock movement, and should only be taken as a general indication of the areas usually grazed. The main patterns were:

1. The relative concentration of sheep movement in the southern part of the paddock;
2. The absence of cattle from the hill areas;
3. The number of very long, heavily incised cattle pads, suggesting a significant proportion of "walkers" (Schmidt, 1969; see section 1-64) in the cattle herd;
4. The use of roads by cattle.

The cattle ranged over a much larger proportion of the paddock than did the sheep, though not further from water. Hence absolute statements on the stocking levels of the two paddocks are not possible. Although it was suggested above that the overall stocking rates were not equivalent, with the sheep stocked more lightly than the cattle, the concentration of the sheep into a small part of the paddock may have nullified this difference.

4-3 ABUNDANCES AND DYNAMICS OF MAJOR PASTURE SPECIES

4-31 *In the absence of grazing.*

For both paddocks, figures 4.6, 4.7, and 4.8 display the total biomass of the major pasture species, the individual species' bio-

Fig. 4.4
CATTLE UTILISATION OF BLACK HILL PADDOCK

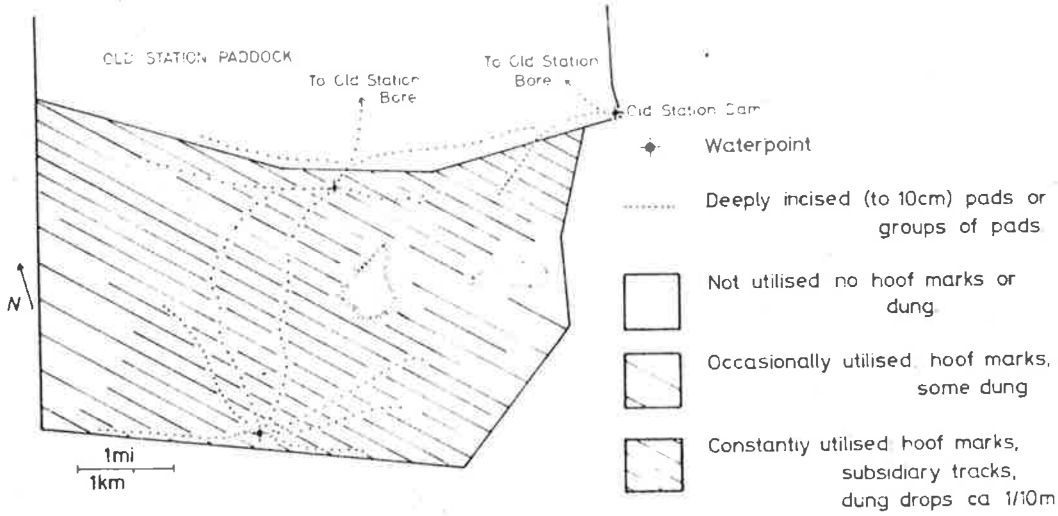
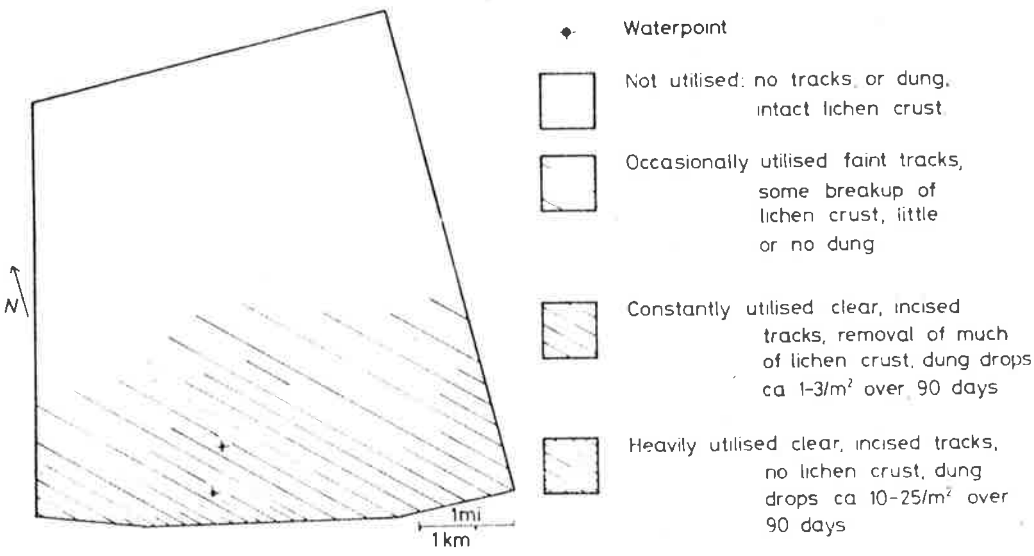


Fig. 4.5
SHEEP UTILIZATION OF EMU LEG PADDOCK



masses, and the individual species' densities in exclosed quadrats.

Total biomass showed close correlation between paddocks for the first half of the study. From time 5, however, a greater standing crop was evident for the sheep paddock exclosures relative to that of the cattle paddock exclosures. Fluctuations in total biomass, for both exclosure sets, correlated most closely with the three-month rainfall means. Although amplitudes differed between exclosure sets, the directions of responses to rainfall were the same in both cases. Periods of major pasture growth were found between times 3 and 4, and between times 5 and 7.

Enneapogon spp. comprised half the standing crop in both exclosure sets. Following the first significant rains, both its density and leaf biomass were greater in sheep paddock exclosures than in cattle paddock exclosures, but the direction of responses to rainfall, for both parameters, were the same for both paddocks.

Aristida contorta and *Stipa nitida* comprised only a small proportion of the total standing crop over most of the study period. The former displayed the same pattern as given for *Enneapogon* spp.. The latter showed very close correlation between paddocks throughout the study: from an initially high standing biomass and density, *Stipa* abundance decreased to near zero, with new growth appearing only after the winter and spring rains between times 5 and 7.

Kochia astrotricha biomass in sheep paddock exclosures was closely correlated with that in cattle paddock exclosures, both for standing crops and seasonal changes. The density of adults remained constant throughout. Seedling density fluctuated with

Fig. 4.6

MEAN BIOMASS (TOTAL) FOR EXCLOSURE QUADRATS

WITH ASSOCIATED STANDARD ERRORS

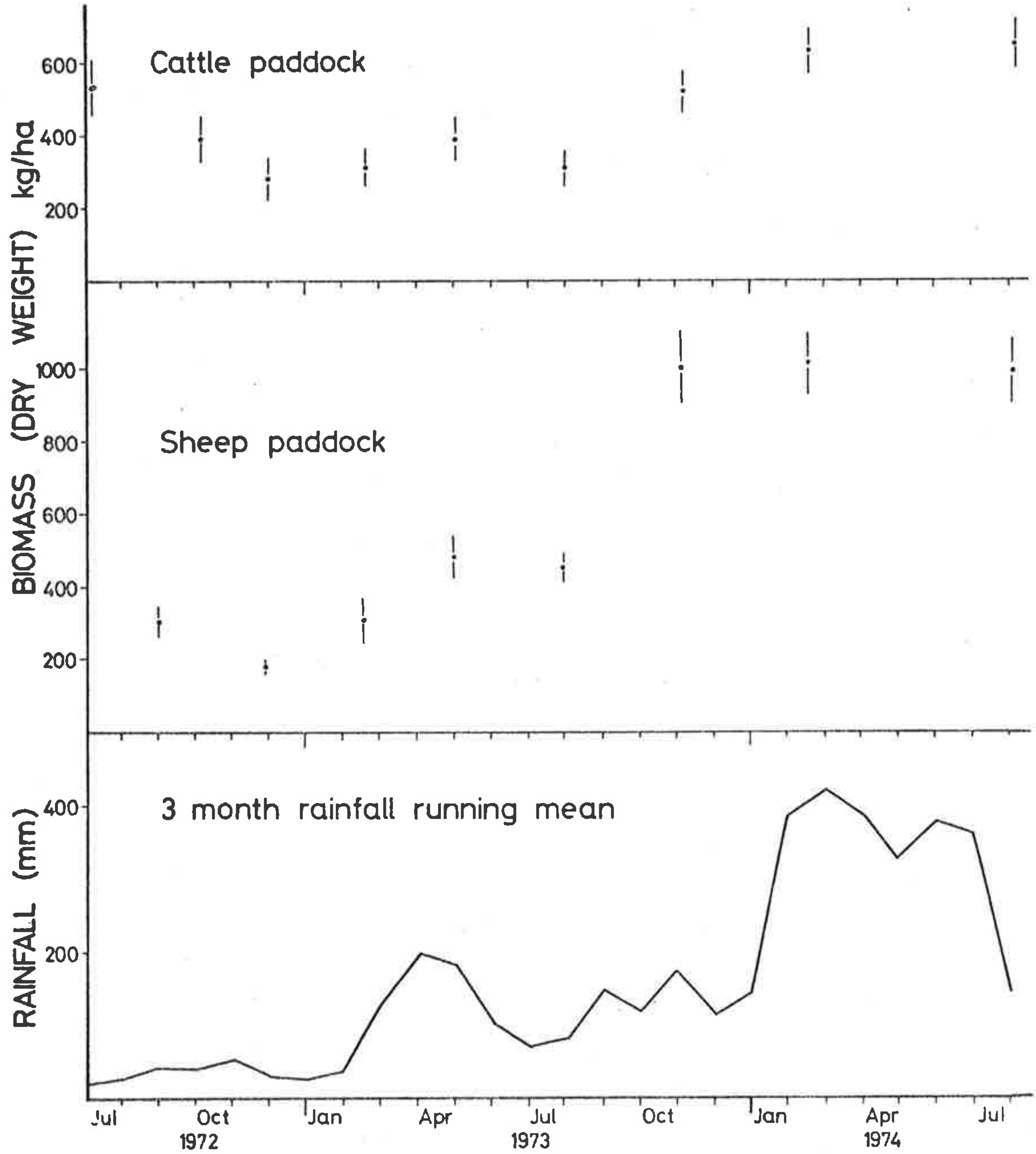
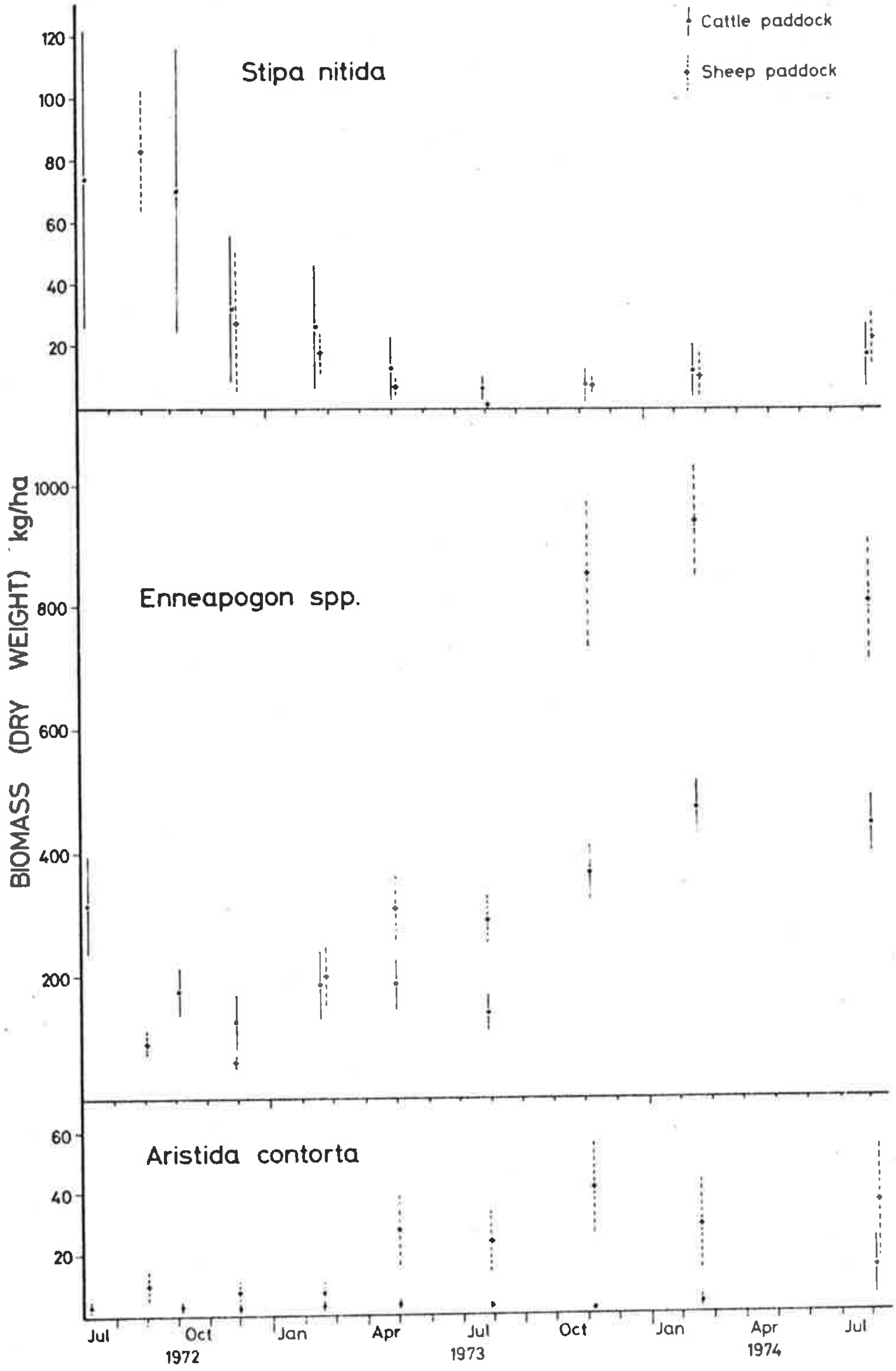


Fig. 4.7

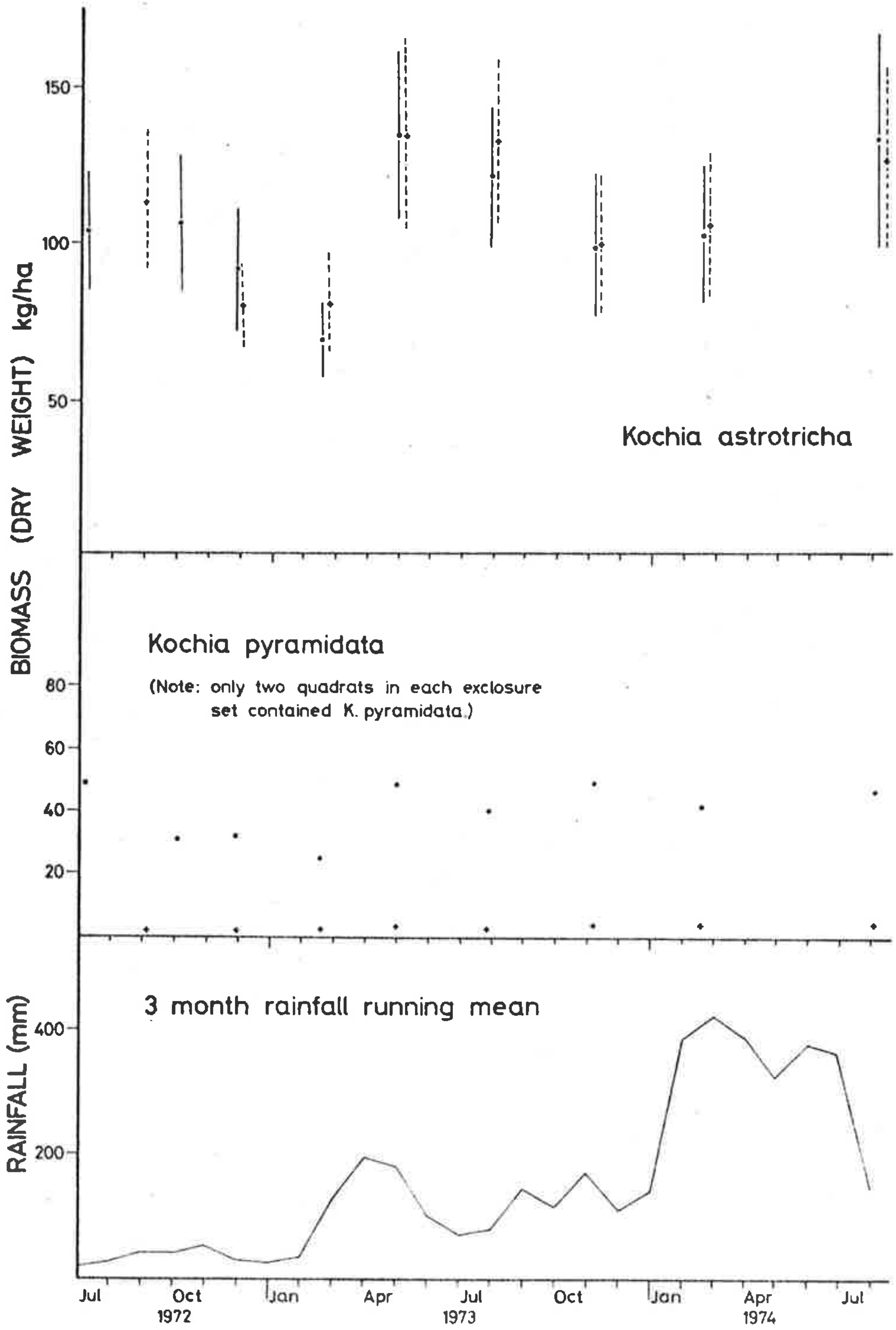
MEAN BIOMASSES OF MAJOR SPECIES FOR EXCLOSURE QUADRATS

WITH ASSOCIATED STANDARD ERRORS



(Cont..

Fig. 4.7 (Cont.)

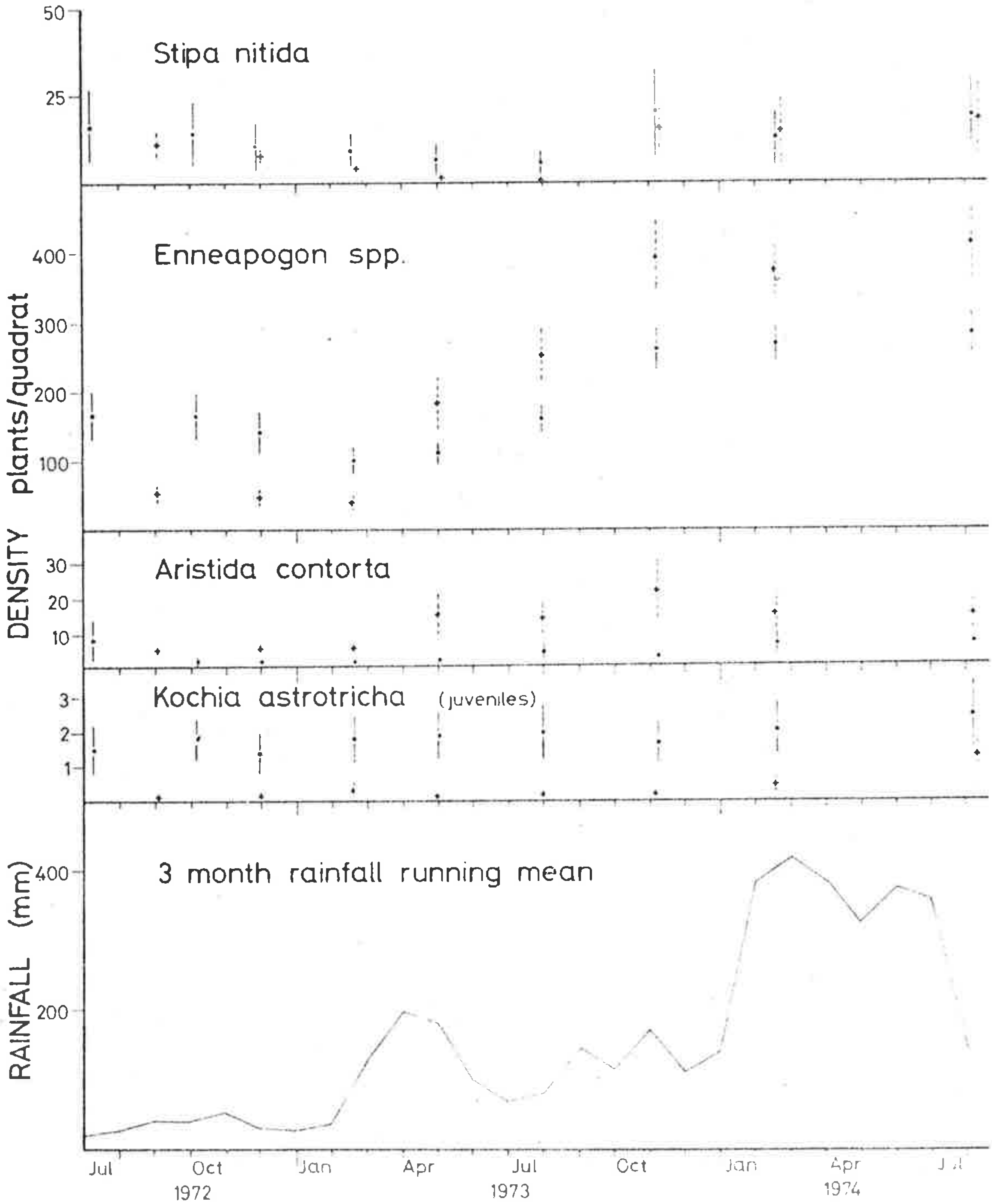


BIOMASS (DRY WEIGHT) kg/ha
150
100
50
Kochia astrotricha
Kochia pyramidata
(Note: only two quadrats in each exclosure set contained K. pyramidata.)
80
60
40
20
RAINFALL (mm)
3 month rainfall running mean
400
200
Jul
Oct
1972
Jan
Apr
Jul
1973
Oct
Jan
Apr
1974
Jul

Fig. 4.8

DENSITIES OF MAJOR SPECIES FOR EXCLOSURE QUADRATS

WITH ASSOCIATED STANDARD ERRORS



Cattle paddock

Sheep paddock

K. astrotricha (adults) and K. pyramidata densities remained constant, with respective means of [illegible] and 0.5 plants/quadrat in the cattle paddock and [illegible] and 0.2 plants/quadrat in the sheep paddock with respective standard errors of ±[illegible], ±0.5, ±[illegible] and ±0.2

no discernible pattern, but counts were consistently higher in the cattle paddock exclosures.

Kochia pyramidata was inadequately sampled on both exclosure sets. From the bushes sampled, its biomass appeared relatively constant throughout the study period.

Thus the direction of responses to rainfall of the major species were the same for both paddocks in the absence of grazing. This was considered to indicate that background dynamics were comparable between paddocks. However, clear differences were evident between paddocks; in the magnitude of these responses, and in the relative standing crops. Although these differences may have resulted in part from the limited sampling, they were taken as representative. The implications were:

1. Stocking effects would be less evident in the sheep paddock than in the cattle paddock: the higher standing crops in the former would mean a relatively smaller proportion of the total pasture removed by stock than in the cattle paddock, and therefore a masking of the sheep effects by background variation;
2. Direct comparisons between paddocks (e.g. analyses of variances) to determine stock impact would mislead, since the absolute amounts of the various species differed in the absence of grazing.

The search for piosphere pattern thus remained the only feasible method of detecting stock effects with certainty, and the general comparison of sheep and cattle piospheres the only sound basis for comparison between paddocks.

4-32 *Grazed compared with ungrazed.*

For both paddocks, figures 4.9, 4.10 and 4.11 respectively display the total biomass of major pasture species, the individual species' biomasses and the individual species' densities in open quadrats. From the previous section, no comment on relative stocking effects can be made from direct comparison between paddocks. However, within paddocks, differences were observed between grazed and exclosed quadrats potentially due to stocking.

In both sheep and cattle paddocks, *Enneapogon* density and biomass did not increase significantly in open quadrats until time 4. In exclosures, biomass had noticeably increased by time 3, although density had not. This implied that the increase at time 3 was due to regrowth from old butts. By comparison with the sheep paddock, variations in *Enneapogon* density, on open quadrats, was not as great in the cattle paddock, and, in particular, it was not reduced to the same extent in the period of no growth (from time 0 to time 3). This implied that the cattle were leaving more butts than the sheep. Therefore, if the first response of *Enneapogon* to rain is a regrowth from the remaining butts, cattle stocking will allow more immediate regrowth than sheep stocking, because of the greater proportion of butts remaining.

A less obvious difference between responses of open and exclosed quadrats in the sheep paddock was shown by *K. astrotricha* biomass. In exclosures, biomass was not significantly different between times 2 and 3, but in open quadrats, it showed a significant decrease between these times. In the cattle paddock, however,

Fig. 4.9

MEAN BIOMASS (TOTAL) FOR OPEN QUADRATS

WITH ASSOCIATED STANDARD ERRORS

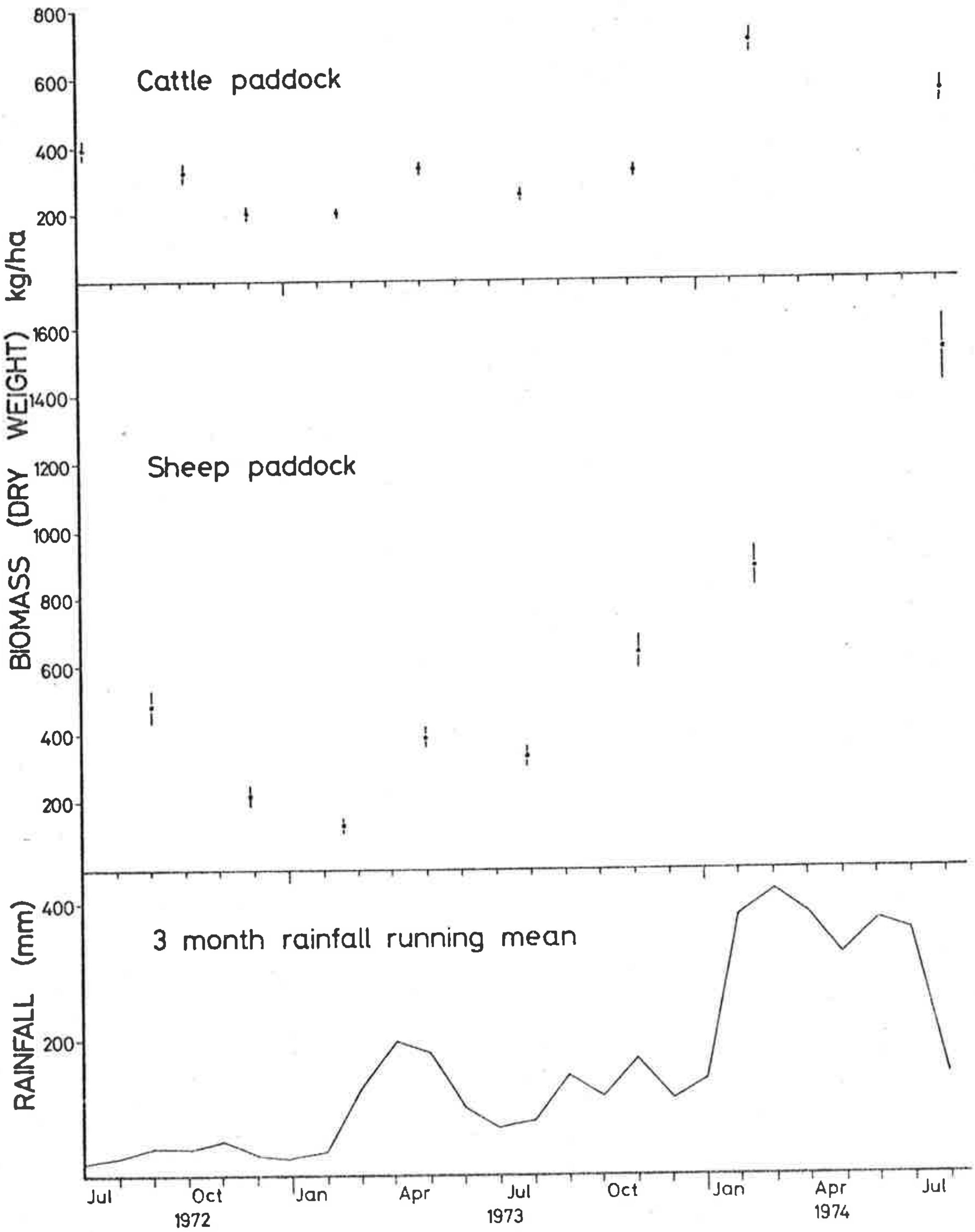
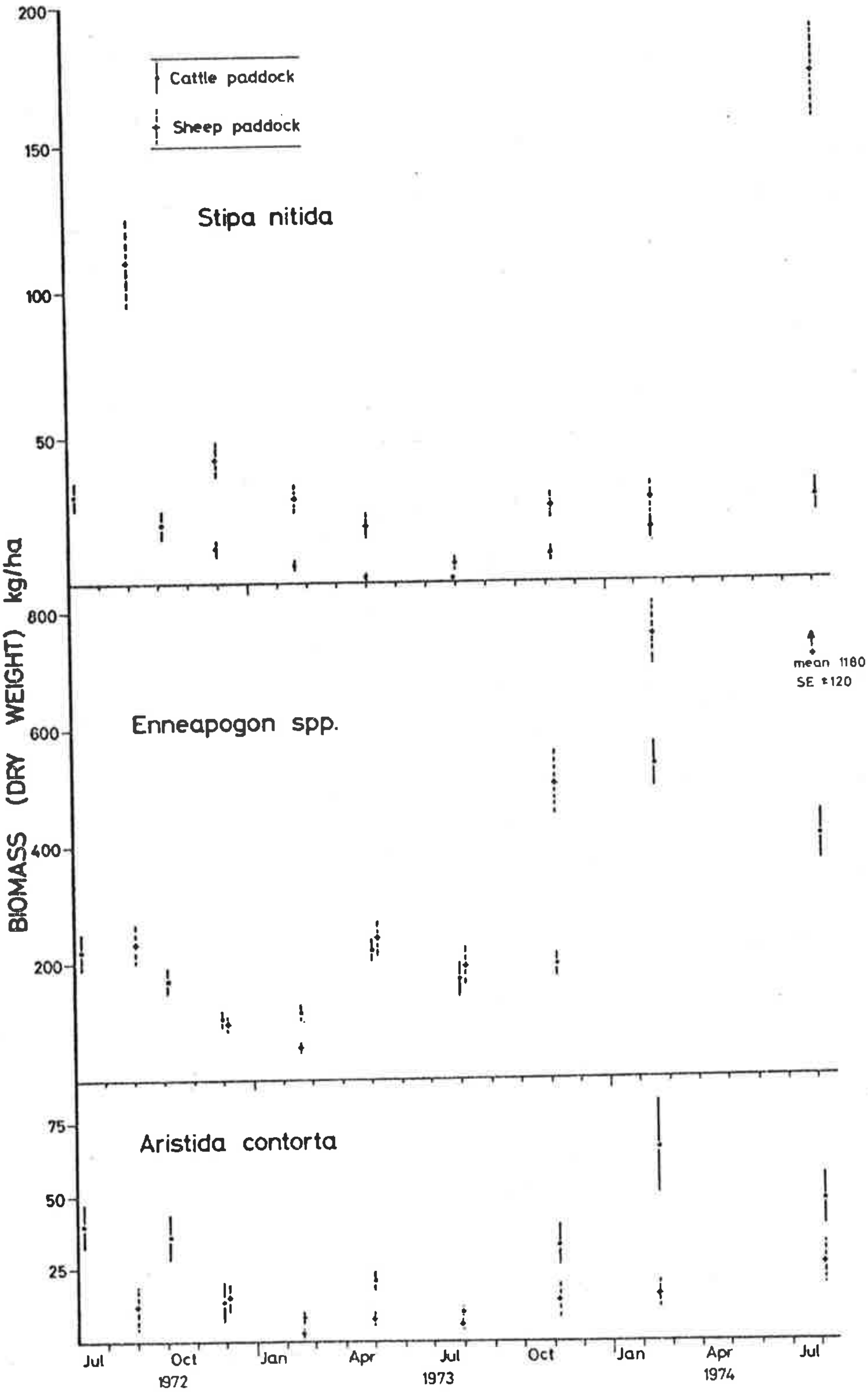


Fig. 4.10

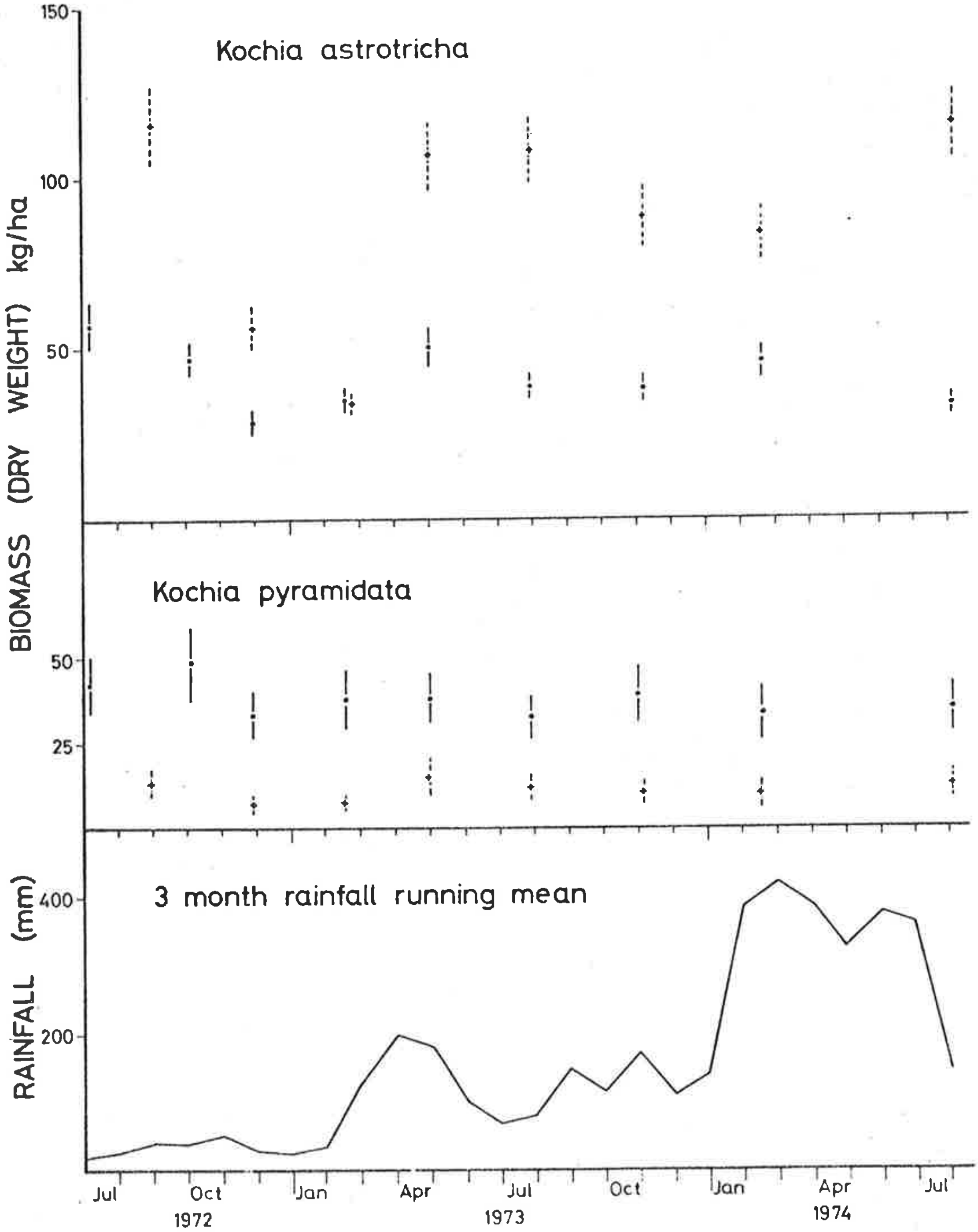
MEAN BIOMASSES OF MAJOR SPECIES FOR OPEN QUADRATS

WITH ASSOCIATED STANDARD ERRORS



(Cont..

Fig. 4.10 (Cont.)

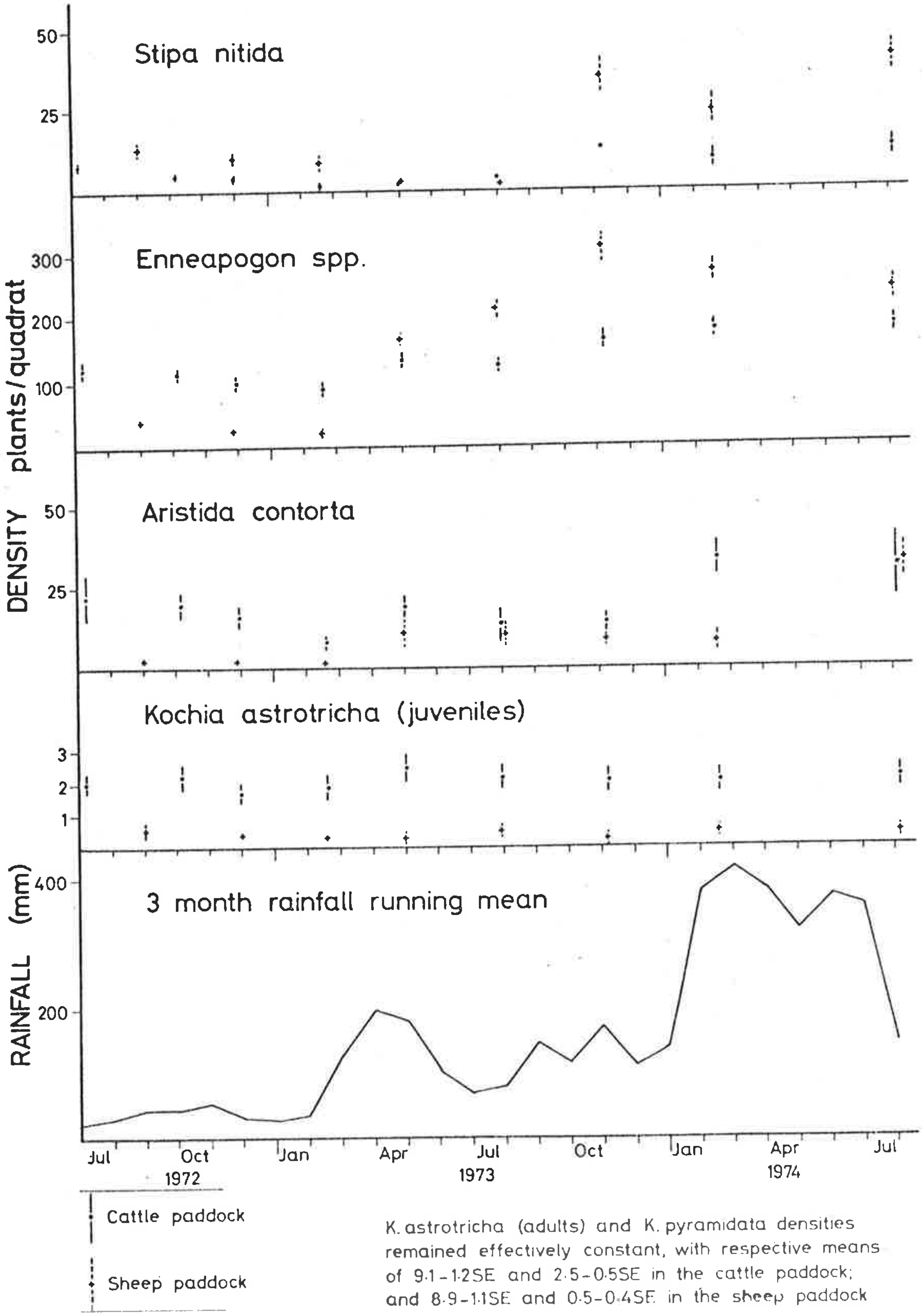


Kochia astrotricha
Kochia pyramidata
3 month rainfall running mean
BIOMASS (DRY WEIGHT) kg/ha
RAINFALL (mm)
150
100
50
50
25
400
200
Jul
Oct
Jan
Apr
Jul
Oct
Jan
Apr
Jul
1972
1973
1974

Fig. 4.11

DENSITIES OF MAJOR SPECIES FOR OPEN QUADRATS

WITH ASSOCIATED STANDARD ERRORS



K. astrotricha (adults) and K. pyramidata densities remained effectively constant, with respective means of 9.1-1.2SE and 2.5-0.5SE in the cattle paddock; and 8.9-1.1SE and 0.5-0.4SE in the sheep paddock both open and exclosed quadrats showed no significant difference in *K. astrotricha* biomass between these times. This suggests that the sheep, but not the cattle, were consuming or otherwise removing the *K. astrotricha* during this period.

4-33 *The effect of the 1973-1974 rains.*

The first major pasture growth during the observation resulted from late summer rains which, while heavy, were by no means unusual (c.f. summer rains in previous years--table 3.1). Because the arid rangeland soils are typically low in plant nutrients, and in particular nitrogen and phosphorous (Charley and Cowling, 1968), such a growth burst would be expected to lock up a significant proportion of the available nutrients, and so limit the magnitude of future increases; at least until considerable pasture breakdown had occurred (see Beadle and Tchan, 1955). Nonetheless, the pasture growth following the exceptional rains from mid-1973 was very much greater than the early 1973 growth: correlation between pasture biomass and rainfall was of the same order in the later periods as in the first period, and not less as would be expected if the initial growth burst had removed a significant proportion of the available nutrients. This implies that the nutrients may not be as limiting as is normally assumed.

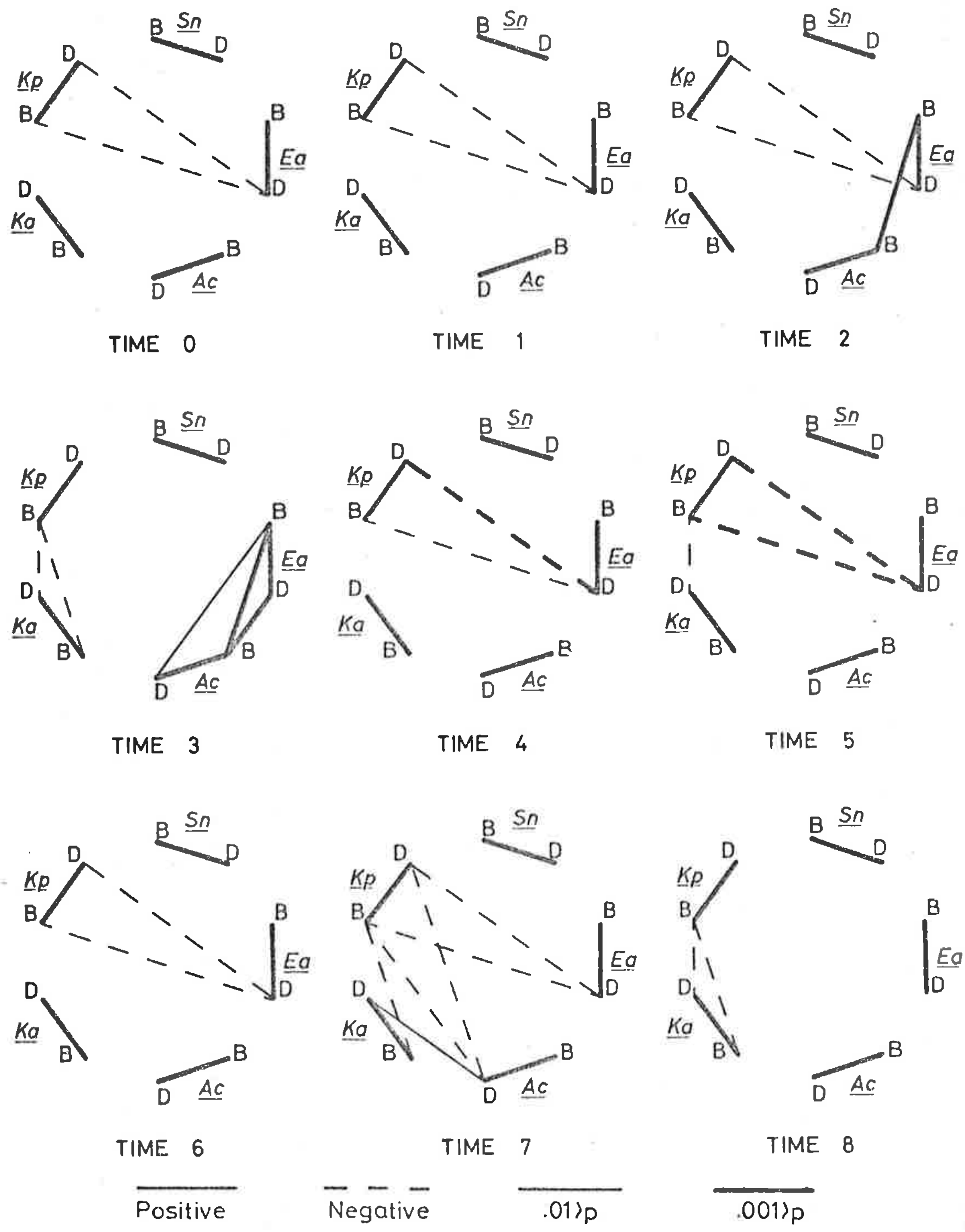
4-34 *Correlations within and between species.*

Figures 4.12 and 4.13 display the significant correlations between species and between biomass and density parameters, for the cattle and sheep paddocks respectively. In both areas, biomass (b) and density (d) were consistently highly correlated within species, as should be expected. However, correlations between species varied greatly with time. It would be unwise to infer a great deal from these correlations. Analyses were performed primarily to show the possible covariation between species, underlining the difficulties of coping with covariation in regression equations. It can be seen that, were equations for each time modelled to allow for all the demonstrated covariation, each equation would be structured differently, and so the comparability of results from equations at different times would necessarily be reduced. In this study, comparability was paramount.

Nonetheless, the correlations between *Stipa* and *Enneapogon* in the sheep paddock require some comment, because of the change of sign with time in their relationships. Other correlations recurring with time maintain the same sign. The *Stipa/Enneapogon* relationships indicated that two distinct processes were in operation. Possibly the positive correlation which developed in the no-growth period was a grazing effect. After a long period without growth, grasses would be grazed or trampled out over much of the range. The survival of individuals of a particular species in parts of the range would indicate that they had escaped grazing to some extent. Hence other species might be expected in the same area, for the same reason. A positive correlation so formed should disappear following growth, since the species would reappear elsewhere on the range, not only on areas which had

Fig. 4.12

INTERCORRELATIONS BETWEEN PASTURE SPECIES (BIOMASS and DENSITY) IN THE CATTLE PADDOCK



Sn = Stipa nitida   Ea = Enneapogon spp.   etc.

B = Biomass   D = Density

Fig. 4.13

INTERCORRELATIONS BETWEEN PASTURE SPECIES (BIOMASS and DENSITY) IN THE SHEEP PADDOCK

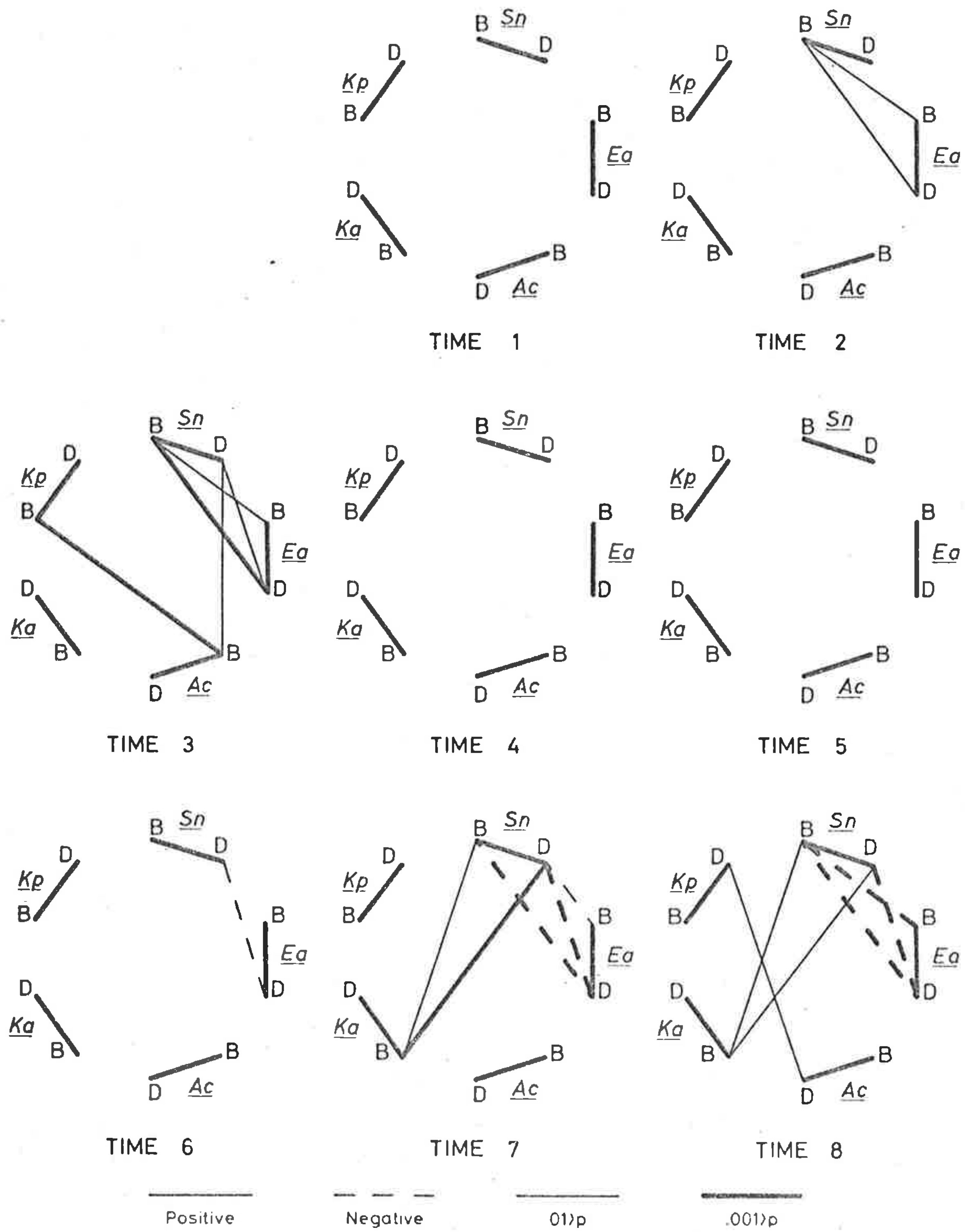


Fig. 4.14

INTERCORRELATIONS BETWEEN PASTURE SPECIES (AVERAGE SIZE) IN THE CATTLE PADDOCK

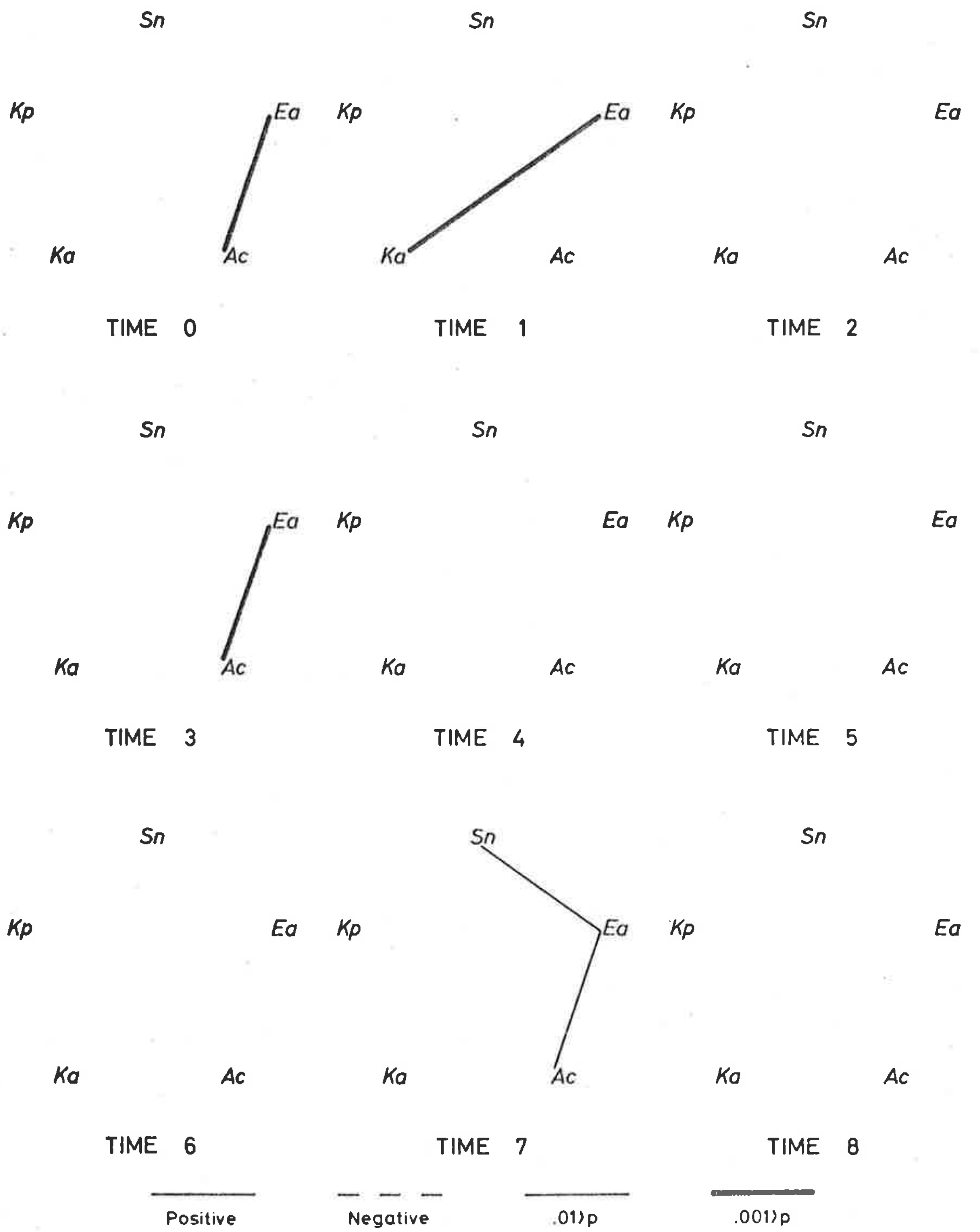
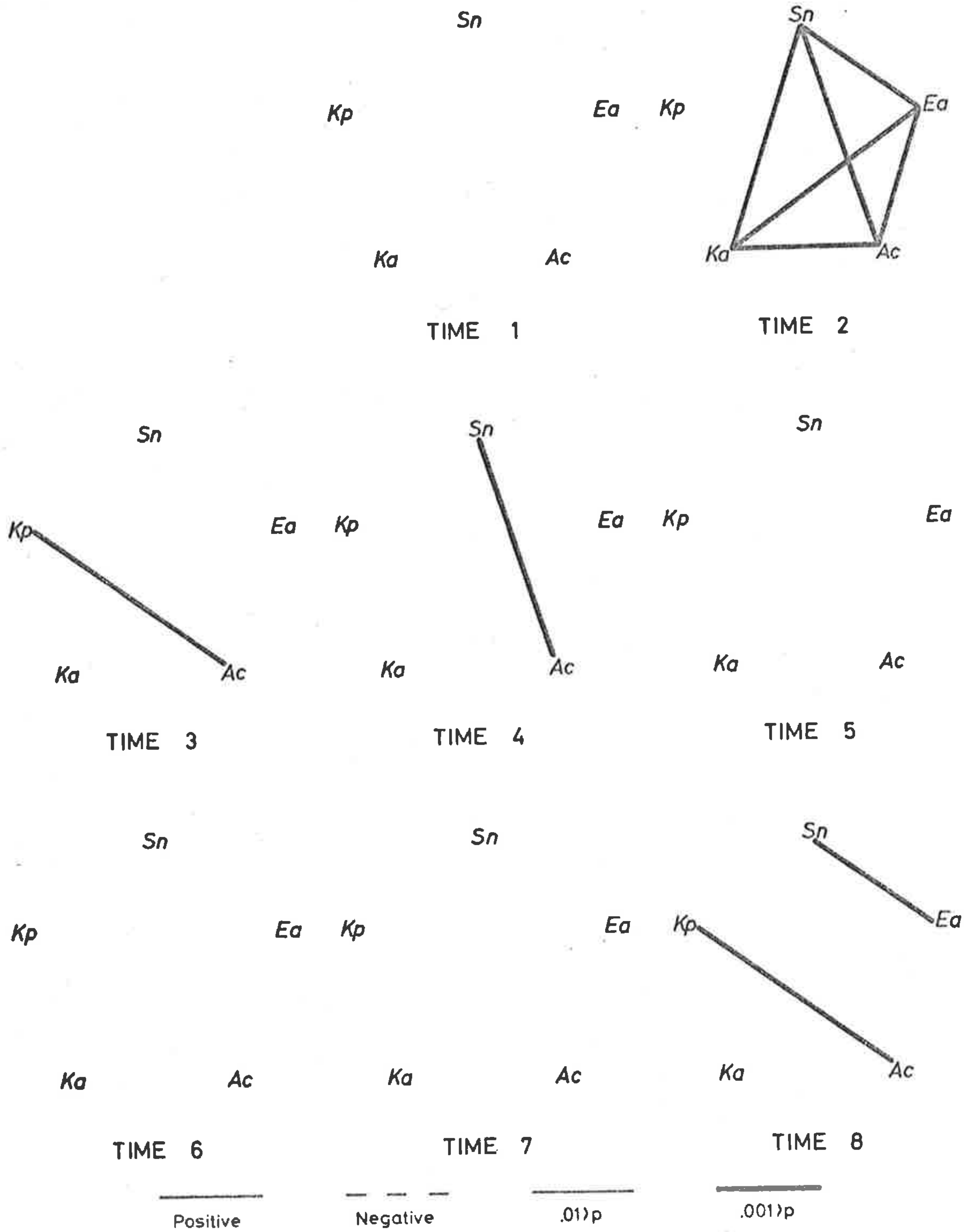


Fig. 4.15

INTERCORRELATIONS BETWEEN PASTURE SPECIES (AVERAGE SIZE) IN THE SHEEP PADDOCK



escaped grazing. The positive correlation between *Stipa* and *Enneapogon* did in fact disappear following growth. The negative correlation between the two species, developing from time 6 onward, could be ascribed to competition between them: *Aristida* germinated following summer rains (figure 4.11) and was already abundant when the *Stipa* germinated following winter and spring rains. Hence *Stipa* would only establish in areas where *Aristida* was low in abundance, and so give rise to the negative association.

Figures 4.14 and 4.15 display the significant correlations in average size (biomass/density, B/D) between species, for the cattle and sheep paddocks respectively. The most striking feature was the lack of congruence with the correlations observed between species for biomass and density. For instance, there was positive correlation between *Stipa* and *Enneapogon* average size, but negative correlation between the species' biomasses at time 8. Thus the compound variable detected relationships not shown by its constituent variables. Its separate use in regression equations can therefore be justified on this basis, in addition to the original justification of reducing collinearity in the equations.

4-4 REGRESSION ANALYSES: MAJOR SPECIES

4-41 *Introduction.*

Only linear regressions of plant parameters on distance from water were attempted for data from individual species, following the argument of section 1-72. However, certain plots of total biomass against distance from water suggested that curvilinear functions might provide a better fit than a linear regression, and curve-fitting was accordingly attempted for this data.

As stated in the previous chapter, the sheep piosphere was complicated by the presence of two waters in close proximity. There was strong correlation (r = 0.853) between distances of quadrats from the south water and distances from the north water, and one or other distance parameter had to be excluded from equations to avoid redundancy (see section 3-52). The distance to the north water was the term excluded: the north water was subject to frequent stoppages due to pipeline breaks, and was completely shut down in October, 1973; whereas the south water remained in service continuously up to the removal of the sheep in 1974.

Area-dependent units were standardized, to avoid undue confusion in interpretation, of results. Biomass is given as kg/ha and density as individuals/ha, as estimated from quadrats. The threshold of detection for biomass varied with the size of hand-held estimation units, but was of the order 5kg/ha. The threshold for density, of one individual per quadrat, was equivalent to 1000 individuals/ha for species counted in small quadrats, and to 250 individuals/ha for species counted in large quadrats.

Results of regression analyses are presented as follows. The regression coeffecients and equation efficiencies are presented in tables, segregated for individual species and parameters. The tables are extensive, and results show intricate variation with the time of observation. Hence, for each species and each of its parameters, summaries of significant relationships are given in the text, without immediate discussion, in order to highlight pertinent aspects. For each species, a discussion on its relationships follows the summaries, before the results for other species are discussed. A general discussion on the regression analyses is presented in section 4-49: this discussion considers all species and all relationships.

In the tables, only equations displaying either a significant relationships or an R^2 value greater than 0.200 are given. A significant relationship is defined by the presence of a partial regression coefficient significantly different from zero at the .01 level, as determined by a t-test.

4-42 *Linear and non-linear regressions of total biomass on distance.*

Several plots of total biomass against distance from water, using cattle paddock data, showed the pattern displayed in figure 4.16. To test whether the assumption of linearity in the piosphere was in fact justified in such cases, the following equations were fitted to cattle paddock data from all observation times.

$$B_t = b_0 + b_1 W$$

$$\ln B_t = b_0 + b_1 W$$

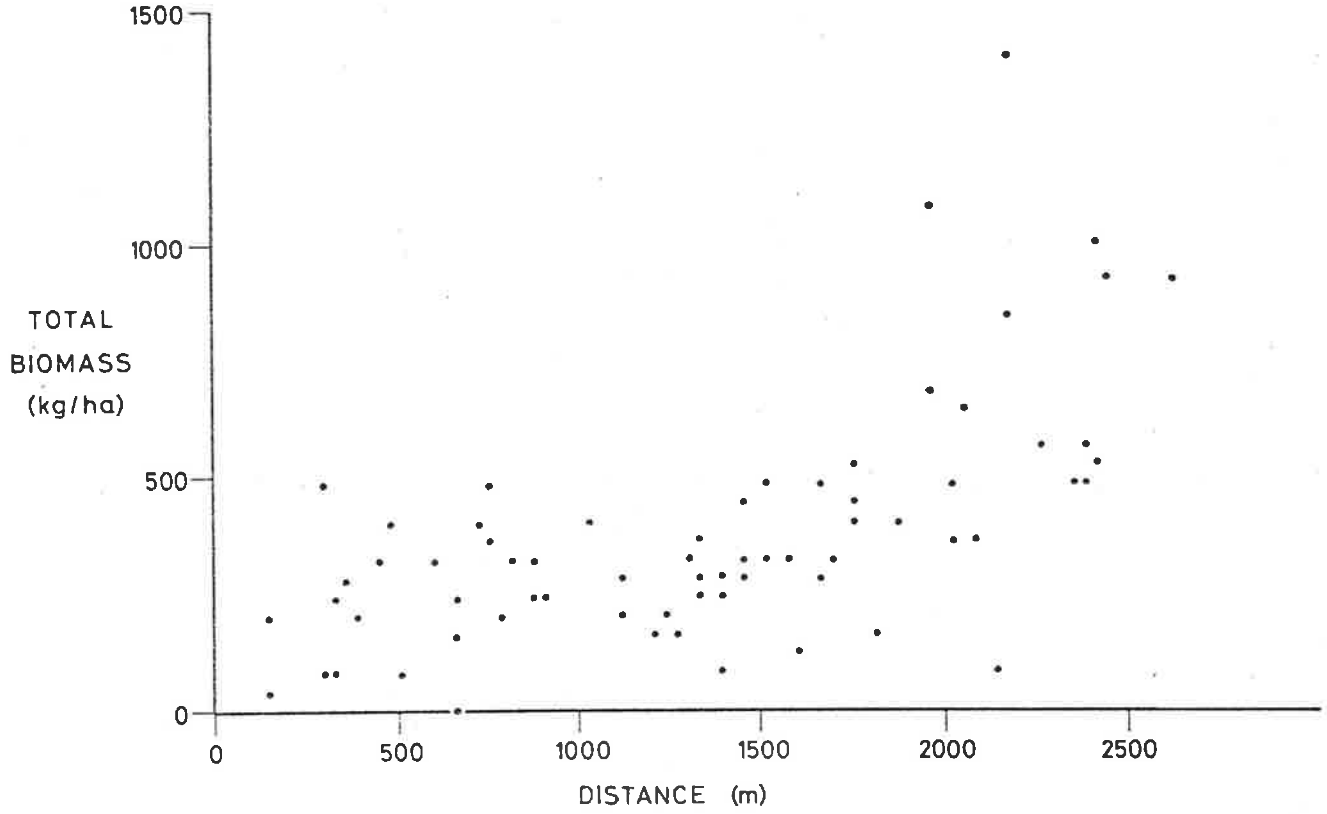
$$B_t = b_o + b_1 W^2$$

$$B_t = b_0 + b_1 W + b_2 W^2$$

The latter three equations were proposed, not from a theoretical base, but simply as transformations or curves which potentially presented better approximations to the data curve than the simple linear equation. The results for the various equations are given

Fig. 4.16

TOTAL BIOMASS WITH DISTANCE
CATTLE PADDOCK, TIME ZERO



in table 4.2 . The following points were evident.

1. The square and quadratic equations did provide a better fit than the simple linear equation, but the differences in efficiencies were small.

2. All equations were grossly inefficient in accounting for the variance of B_t at times 4,6 and 7: these times coincided with or followed periods of pasture growth.

3. b_1 for the first and third equations decreased, from time 0 (pilot trip) to time 3 inclusive.

From the first point, there was no reason to abandon the search for linear relationships between plant abundances and the index of stocking pressure, distance from water. Clearly, considerably more complicated equations would be required to provide a fit significantly more efficient than that of the simple linear equation. The inadequate theoretical basis cannot justify the use of such equations.

From the second point, periods of major growth apparently obscured the stocking impress, as indexed by W. Two possible reasons are offered to account for this. Firstly, stock may not have been watering regularly on the dams at this time, but on casual surface waters elsewhere in the paddock; hence the short-term piosphere patterns would become confused. Secondly, the biomass removed by stock may have been negligible by comparison with the pasture growth, and the background variation would thus obscure the stocking impress.

The third point suggested that stock ranged further as pasture

TABLE 4.2

LINEAR AND NONLINEAR REGRESSIONS
FOR TOTAL BIOMASS, CATTLE PADDOCK.

The equations:
1. $B_t = b_0 + b_1W$
2. $B_t = b_0 + b_1W^2$
3. $B_t = b_0 + b_1W + b_2W^2$
4. $\ln B_t = b_0 + b_1W$
5. $B_t = b_0 + b_1/W$

(a) R^2 values.

Time	Equation 1	2	3	4	5
0	0.380	0.440	0.457	0.353	0.148
1	0.308	0.322	0.322	0.315	0.167
2	0.302	0.309	0.310	0.266	0.170
3	0.233	0.240	0.240	0.161	0.144
4	0.039	0.036	0.040	0.043	0.017
5	0.212	0.223	0.223	0.202	0.100
6	0.061	0.052	0.064	0.053	0.040
7	0.077	0.070	0.078	0.117	0.063
8	0.354	0.413	0.430	0.289	0.135

(b) Regression coefficients with associated standard errors, equations 1,2 and 3.

Time	Equation 1. b_0	b_1 *SE*	Equation 2. b_0	b_1 *SE*	Equation 3. b_0	b_1 *SE*	b_2 *SE*
0	78.2	0.230 ±0.0357	186.	8.95E-05 ±1.22E-05	299.	-0.204 ±0.145	1.61E-04 ±5.23E-05
1	80.8	0.179 ±0.0324	173.	6.59E-05 ±1.16E-05	161.	0.213 ±0.140	5.84E-05 ±5.04E-05
2	45.3	0.111 ±0.0206	103.	4.07E-05 ±7.38E-06	85.0	0.0332 ±0.0887	2.97E-05 ±3.20E-05
3	87.2	0.0850 ±0.0187	131.	3.12E-05 ±6.73E-06	121.	0.0190 ±0.0809	2.45E-05 ±2.92E-05
4	293.	0.0523 ±0.0314	293.	1.80E-05 ±1.13E-05	254.	0.0703 ±0.136	-6.68E-06 ±4.91E-05
5	68.8	0.135 ±0.0315	138.	4.95E-05 ±1.13E-05	134.	0.0070 ±0.136	4.75E-05 ±4.90E-05
6	235.	0.0601 ±0.0286	271.	1.99E-05 ±1.04E-05	206.	0.119 ±0.124	-2.17E-05 ±4.47E-05
7	494.	0.152 ±0.0641	580.	5.22E-05 ±2.31E-05	465.	0.208 +0.276	-2.08E-05 ±9.97E-05
8	152.	0.295 ±0.0483	290.	1.15E-04 ±1.66E-05	445.	-0.280 ±0.197	2.13E-04 ±7.11E-05

decreased. Were this not so, the intercept (b_0) would be expected to decrease and the slope (b_1) to remain constant as the pasture was grazed down within the range of the animals: but the situation was the reverse of this.

The equations were also fitted to data from the sheep paddock, using distance from south water as W in the first instance. No significant relationships were detected, and R^2 values were below .100 in every case. Equations were then calculated using distance from the north water as W, with the same result. These findings were interpreted as indicative of a weaker, and so undetectable, sheep impress by comparison with the cattle impress.

4-43 *Regression analyses for Stipa nitida.*

No regressions were calculated on *Stipa* data for time 5, both paddocks. Incidence then was less than 20%, and the number of zero scores were likely to introduce complications if analyses were attempted (see section 3-52).

(a) Density relationships; table 4-3

$$D_{Sn} = b_0 + b_1 (B_t - B_{Sn}) + b_2W \ *$$

In the sheep paddock, significant partial regressions (S.P.R.'s) of D on (B_t -B) were found at times 3,7 and 8. The S.P.R. was positive at time 3, negative at other times. There were no S.P.R's of D on W. In the cattle paddock, no significant

* All equations as discussed in section 3-52

TABLE 4.3

REGRESSION COEFFICIENTS

STIPA NITIDA DENSITY RELATIONSHIPS

Paddock	Time	b_0	$b_1(B_t-B)$ *(t)*	b_2W *(t)*	R^2
Sheep	3	2034	28.1	1.26	.138
			*3.12***	*0.95*	
Sheep	7	54500	-28.6	-4.79	.096
			*2.67***	*0.65*	
Sheep	8	51700	-16.2	7.86	.156
			*3.45****	*1.30*	

TABLE 4.5

REGRESSION COEFFICIENTS

STIPA NITIDA AVERAGE SIZE RELATIONSHIPS

Paddock	Time	b_0	$b_1(B_t-B)$ *(t)*	b_2W *(t)*	R^2
Cattle	0	2.81E-06	-6.40E-06	1.61E-06	.165
			*3.63****	*2.37*	
Sheep	1	3.65E-03	8.92E-06	9.85E-07	.184
			*3.88****	*0.91*	
Sheep	3	1.79E-03	1.09E-05	-9.41E-08	.153
			*3.48****	*0.20*	
Sheep	8	4.25E-03	-1.06E-06	7.99E-07	.104
			*2.57***	*1.51*	

TABLE 4.4

REGRESSION COEFFICIENTS

STIPA NITIDA BIOMASS RELATIONSHIPS

Paddock	Time	b_0	b_1D	$b_2(B_t-B)$	b_3W	R^2
Cattle	0	46.4	2.38E-03	-4.37E-02	1.93E-02	.576
			*8.28****	*2.46*	*2.88***	
Cattle	1	-1.44	4.38E-03	-3.86E-03	2.96E-03	.735
			*13.01****	*0.29*	*0.70*	
Cattle	2	-3.81	3.26E-03	6.75E-03	1.81E-03	.817
			*16.86****	*0.62*	*0.83*	
Cattle	3	0.216	3.25E-03	7.41E-03	-6.99E-04	.522
			*8.37****	*0.57*	*0.31*	
Cattle	4	0.161	4.21E-03	9.98E-04	-1.75E-04	.593
			*9.88****	*0.36*	*0.24*	
Cattle	6	3.88	5.49E-04	-5.12E-04	-1.05E-03	.827
			*17.17****	*0.07*	*0.61*	
Cattle	7	-1.98	1.52E-03	6.90E-03	9.59E-04	.692
			*11.92****	*0.83*	*0.21*	
Cattle	8	-1.01	1.67E-03	-1.33E-02	8.35E-03	.754
			*13.50****	*1.20*	*1.51*	
Sheep	1	-16.9	7.34E-03	7.52E-02	6.82E-03	.782
			*14.08****	*3.32****	*0.63*	
Sheep	2	3.66	3.83E-03	2.12E-02	-1.14E-03	.692
			*11.64****	*1.43*	*0.22*	
Sheep	3	-3.90	3.71E-03	5.75E-02	1.95E-03	.698
			*10.58****	*2.08*	*0.51*	
Sheep	4	-0.702	8.25E-03	1.45E-02	-1.12E-03	.747
			*13.31****	*1.82*	*0.39*	
Sheep	6	-1.83	8.54E-04	6.99E-03	-6.36E-04	.804
			*16.23****	*1.30*	*0.22*	
Sheep	7	3.55	1.00E-03	-8.43E-04	1.29E-03	.799
			*15.45****	*0.14*	*0.33*	
Sheep	8	62.9	4.48E-03	-4.05E-02	3.75E-03	.683
			*10.05****	*2.17*	*0.17*	

relationships were found.

(b) Biomass relationships; table 4-4

$$B_{Sn} = b_0 + b_1 D_{Sn} + b_2 (B_t - B_{Sn}) + b_3 W$$

B on D was significant in all cases. Only one S.P.R. of B on $(B_t - B)$ was found, in the sheep paddock at time 1. B on W was significant (positive) in the cattle paddock, time 1.

(c) Average size relationships; table 4-5

$$B/D_{Sn} = b_0 + b_1 (B_t - B_{Sn}) + b_2 W$$

For cattle paddock data, a positive S.P.R. of B/D on $(B_t - B)$ was found at time 0. For sheep paddock data, positive S.P.R.'s for the same relationship were found at times 1 and 3, and a negative S.P.R. at time 8. No other significant coefficients were found.

(d) Discussion.

Only in the cattle paddock did a plant parameter show a significant relationship with W, and this was an isolated instance. Clearer demonstration of piosphere symmetry is required before any inferences can be drawn concerning the relative effects of sheep and cattle. Therefore it is concluded that neither cattle nor sheep have affected the abundance of *Stipa nitida* to any detectable extent.

The effect of the presence of other species on *Stipa* appeared more directly associated with density or average size than with biomass, although the times at which relationships were detected varied with the particular plant parameter. The argument of section 4-34 may be invoked to account for the sign changes with time, observed for relationships within the sheep paddock, but founders in the case of the cattle paddock, where the relation between B and (B_t - B) was negative at a time of pasture scarcity.

4-44 *Regression analyses for Enneapogon spp..*

(a) Density relationships; table 4-6

$$D_{Ea} = b_0 + b_1 (B_t - B_{Ea}) + b_2 W$$

S.P.R's of D on (B_t -B) were found for both paddocks as follows: in the cattle paddock for times 0, and 4 to 8 inclusive (all positive), and in the sheep paddock for times 1 and 3 (positive), and times 7 and 8 (negative). D on W was significant (positive) in the cattle paddock, for data from times 0,1,2 and 8; but was non-significant at all times in the sheep paddock.

(b) Biomass relationships; table 4-7

$$B_{Ea} = b_0 + b_1 D_{Ea} + b_2 (B_t - B_{Ea}) + b_3 W$$

B on D was significant in all cases. B on (B_t - B) was significant only for sheep paddock data from time 2. B on W was significant (positive) for cattle paddock data from times 0 to 3 inclusive, time 5 and time 8. For sheep paddock data, B on W was significant (negative) at times 2 and 6.

TABLE 4.6

REGRESSION COEFFICENTS

ENNEAPOGON SPP. DENSITY RELATIONSHIPS

Paddock	Time	b_0	$b_1(B_t-B)$ *(t)*	b_2W *(t)*	R^2
Cattle	o	106000	-365 *2.87***	57.6 *3.25***	.202
Cattle	1	94600	-251 *2.43*	43.2 *2.64***	.157
Cattle	2	59200	-342 *2.41*	52.5 *3.83****	.241
Cattle	4	185000	-60.4 *4.31****	12.9 *0.90*	.235
Cattle	5	156000	-673 *4.38****	17.2 *1.35*	.252
Cattle	6	202000	-672 *3.77****	30.8 *1.49*	.205
Cattle	7	162000	-259 *2.76***	42.8 *2.05*	.165
Cattle	8	187000	-589 *3.72****	59.7 *2.71***	.256
Sheep	1	25700	469 *2.70***	-3.11 *0.71*	.100
Sheep	3	11000	111 *3.38***	-2.83 *0.94*	.147
Sheep	7	395000	-743 *3.49****	-19.2 *0.68*	.163
Sheep	8	385000	-421 *6.68****	1.33 *0.06*	.401

TABLE 4.7

REGRESSION COEFFICIENTS

ENNEAPOGON SPP. BIOMASS RELATIONSHIPS

Paddock	Time	b_0	b_1D *(t)*	$b_2(B_t-B)$ *(t)*	b_3W *(t)*	R^2
Cattle	0	-131	1.64E-03 *11.25****	-0.151 *0.94*	0.132 *5.81****	.792
Cattle	1	-150	1.43E-03 *9.97****	-0.0167 *0.13*	0.114 *5.68****	.740
Cattle	2	-99.3	1.11E-03 *12.39****	0.211 *1.95*	0.0565 *5.08****	.811
Cattle	3	-35.4	6.22E-04 *6.88****	5.94E-04 *0.00*	0.0693 *5.60****	.607
Cattle	4	-16.8	1.00E-03 *4.37****	0.347 *1.17*	0.048 *1.80*	.279
Cattle	5	-107	9.28E-04 *3.27****	0.0494 *0.12*	0.122 *4.08****	.364
Cattle	6	50.9	7.39E-04 *5.15****	-0.234 *1.01*	0.393 *1.60*	.410
Cattle	7	33.9	1.86E-03 *6.80****	0.286 *1.29*	0.0916 *1.90*	.479
Cattle	8	-114	1.64E-03 *9.07****	-0.300 *1.16*	0.194 *5.64****	.750
Sheep	1	1.19	8.39E-03 *10.02****	0.184 *1.47*	-0.0771 *2.51*	.665
Sheep	2	-13.2	3.81E-03 *6.67****	0.0735 *8.02****	-0.0420 *2.60***	.664
Sheep	3	-4.52	3.93E-03 *11.46****	0.0765 *0.77*	-6.45E-03 *0.76*	.709
Sheep	4	-4.58	1.59E-03 *8.34****	0.279 *1.39*	-0.0452 *1.73*	.545
Sheep	5	25.3	9.65E-04 *7.89****	0.0910 *0.44*	-0.0367 *1.58*	.504
Sheep	6	191	1.69E-03 *10.95****	-0.229 *0.63*	-0.135 *3.08***	.695
Sheep	7	285	2.24E-03 *10.87****	-0.0371 *0.10*	-0.104 *2.17*	.695
Sheep	8	109	3.57E-03 *5.88****	-0.331 *0.82*	0.264 *2.38*	.521

TABLE 4.8

REGRESSION COEFFICIENTS

ENNEAPOGON SPP. AVERAGE SIZE RELATIONSHIPS

Paddock	Time	b_0	$b_1(B_t-B)$	b_2W	R^2
Cattle	0	6.13E-04	4.82E-07 *0.54*	7.82E-07 *6.24****	.377
Cattle	2	8.14E-07	2.15E-06 *1.62*	6.00E-07 *4.69****	.264
Cattle	3	-1.42E-02	1.73E-06 *0.59*	1.08E-06 *3.66****	.169
Cattle	5	-2.92E-04	6.20E-06 *1.62*	9.58E-07 *3.02***	.139
Cattle	7	-2.21E-03	3.85E-06 *2.87***	4.61E-07 *1.54*	.127
Cattle	8	-8.64E-04	8.61E-07 *0.68*	9.10E-07 *5.15****	.284
Sheep	1	5.21E-03	1.28E-05 *4.13****	-2.11E-06 *2.08*	.253
Sheep	3	2.24E-03	1.27E-05 *2.77***	-7.60E-07 *1.80*	.122
Sheep	7	2.86E-03	7.90E-06 *3.63****	-5.25E-07 *1.81*	.188

(c) Average size relationships; table 4-8

$$B/D_{Ea} = b_0 + b_1 (B_t - B_{Ea}) + b_2 W$$

B/D on (B_t - B) was significant, for cattle paddock data from time 7, and for sheep paddock data from times 1,3 and 7. B/D was significant (positive) for cattle paddock data from times 0,2,3,5 and 8; but no significant relationship was observed for the sheep paddock.

(d) Discussion.

In both paddocks, a number of significant relationships between plant parameters and distance from water were detected. From the rationale in section 3-4, these are considered stocking effects. In the cattle paddock, such relationships were displayed by all three plant parameters. They became obscured during or immediately after periods of pasture growth. In all cases, regression coefficients were positive. There was variation between parameters in the clarity with which they displayed the piosphere symmetry: relationships with distance to water were found most frequently when using biomass as the dependent variable. Probability values were much lower for the S.P.R's of biomass and average size on distance to water than for the S.P.R's of density on distance to water. This implied that the former two parameters, since they showed the stocking impress with more certainty, were more immediately affected by the cattle than density.

In the sheep paddocks, piosphere relations were detected only by biomass, and the S.P.R's were negative. Decreasing abundance of *Enneapogon* with increasing distance from water (and so, with decreasing stocking pressure) is surprising, since the two species involved are reported to decrease with increasing stocking pressure (Beadle, 1948). However, piosphere relationships were not detected as commonly as in the cattle case, but were not necessarily obscured by pasture growth (e.g. B on W at time 6).

The conclusions in regard to stocking effects were thus:

1. Both cattle and sheep imposed piosphere symmetry on the distribution of *Enneapogon* spp..
2. The sheep impress was the reverse of the cattle impress: abundance increased with distance from water under cattle, but decreased with distance under sheep.
3. The cattle impress was the more consistent, but became undetectable during or immediately following periods of major pasture growth.
4. The sheep impress was detected only intermittently, but was detectable in one period of pasture growth.
5. The clarity with which piosphere symmetry was shown varied with the particular plant parameter used.
6. The parameters which demonstrated the symmetry most clearly differed under sheep- and cattle-stocking.

The variable "biomass other species", or (B_t - B), was originally intended as an index of plant competition (section 3-52). This appears to be a misconception. The sign changes observed for this term in regressions using sheep paddock data suggest at least two processes in operation, but the argument of section 4-34 cannot account for the cattle case, where all relationships involving this variable were found positive. The latter case suggests that competition played no detectable part in influencing the abundance of *Enneapogon* spp. in the cattle paddock. S.P.R's on biomass of other species were most evident when density was the dependent variable, for both sets of data. Whether or not other species' biomass was an index of competition, it is surprising that its effect was most clearly displayed by density, the least quantifiable parameter used.

4-45 *Regression analyses for Aristida contorta.*

(a) Density relationships; table 4.9

$$D_{Ac} = b_0 + b_1 (B_t - B_{Ac}) + b_2 W$$

No S.P.R's of D on (B_t - B) were detected. D on W was significant for cattle paddock data from times 0,1,7 and 8, and for sheep paddock data from times 2,3 and 8. B on W was positive in each case.

(b) Biomass relationships; table 4.10

$$B_{Ac} = b_0 + b_1 D_{Ac} + b_2 (B_t - B_{Ac}) + b_3 W$$

B on D was significant in all cases. No S.P.R's of B on (B_t - B) were detected. B on W was significant (positive) only for cattle paddock data from times 4 and 5.

TABLE 4.9

REGRESSION COEFFICIENTS

ARISTIDA CONTORTA DENSITY RELATIONSHIPS

Paddock	Time	b_0	$b_1(B_t-B)$ *(t)*	b_2W *(t)*	R^2
Cattle	0	1040	-28.7 *1.34*	23.4 *3.14***	.1304
Cattle	1	-656	-23.5 *1.10*	19.9 *3.19***	.1344
Cattle	7	18800	-35.2 *2.15*	28.4 *3.44****	.1653
Cattle	8	19700	-44.1 *2.19*	25.6 *2.58***	.0989
Sheep	2	-3180	1.74 *0.38*	3.61 *2.65***	.0950
Sheep	3	-1800	-0.32 *0.07*	2.30 *2.79***	.1043
Sheep	8	-6782	13.9 *1.16*	64.4 *4.57****	.2728

TABLE 4.10

REGRESSION COEFFICIENTS

ARISTIDA CONTORTA BIOMASS RELATIONSHIPS

Paddock	Time	b_0	b_1D *(t)*	$b_2(B_t-B)$ *(t)*	b_3W *(t)*	R^2
Cattle	0	-12.4	1.73E-03 *21.76******	4.62E-03 *0.32*	9.45E-03 *1.82*	.898
Cattle	1	-14.2	1.70E-03 *13.41******	1.76E-02 *0.75*	9.32E-03 *1.28*	.774
Cattle	2	-10.2	1.05E-03 *14.07******	3.48E-02 *1.88*	4.15E-03 *1.20*	.793
Cattle	3	-4.31	9.13E-04 *15.98******	1.48E-02 *1.69*	3.11E-03 *2.00*	.837
Cattle	4	-7.70	7.93E-04 *12.63******	6.56E-03 *0.64*	9.64E-03 *3.58******	.751
Cattle	5	-3.60	4.84E-04 *13.74******	-9.33E-04 *0.18*	4.50E-03 *3.00****	.774
Cattle	6	-8.34	1.85E-03 *14.58******	-1.71E-02 *0.86*	8.45E-03 *1.72*	.793
Cattle	7	55.4	1.91E-03 *6.03******	7.09E-02 *1.61*	-5.17E-02 *2.23*	.352
Cattle	8	15.4	1.37E-03 *11.75******	5.83E-03 *0.29*	-1.05E-02 *1.05*	.688
Sheep	1	-2.81	6.15E-03 *23.86******	6.49E-03 *1.25*	9.56E-04 *0.32*	.907
Sheep	2	-2.34	3.97E-03 *5.41******	2.05E-01 *2.50*	-7.63E-03 *0.89*	.568
Sheep	3	-4.37	1.52E-03 *7.61******	2.97E-02 *2.30*	1.73E-03 *1.05*	.497
Sheep	4	-0.446	4.71E-04 *8.17******	6.21E-03 *0.97*	4.81E-04 *0.20*	.528
Sheep	5	3.79	4.21E-04 *9.99******	-8.09E-04 *0.15*	-1.21E-03 *0.71*	.620
Sheep	6	8.00	1.20E-03 *10.54******	-2.23E-03 *0.30*	-2.67E-03 *0.55*	.642
Sheep	7	-1.58	1.62E-03 *24.25******	8.04E-04 *0.25*	2.56E-03 *1.55*	.904
Sheep	8	28.3	2.22E-04 *22.89******	-1.45E-02 *1.41*	9.24E-03 *0.91*	.797

TABLE 4.11

REGRESSION COEFFICIENTS

ARISTIDA CONTORTA AVERAGE SIZE RELATIONSHIPS

Paddock	Time	b_0	$b_1(B_t-B)$ *(t)*	b_2W *(t)*	R^2
Cattle	0	1.23E-05	1.36E-07 *0.24*	7.01E-07 *3.58****	.226
Cattle	1	-1.61E-04	-1.28E-06 *1.36*	1.14E-06 *4.17****	.211
Cattle	2	-2.64E-04	5.19E-07 *0.74*	4.47E-07 *3.54****	.239
Cattle	3	-3.63E-04	1.35E-06 *1.22*	5.81E-07 *3.14***	.213
Cattle	4	-2.21E-04	7.54E-07 *1.26*	5.21E-07 *3.36***	.176
Cattle	5	-2.29E-05	-2.81E-07 *0.94*	3.23E-07 *3.72****	.177
Cattle	6	-7.44E-04	-2.61E-06 *1.79*	9.53E-07 *2.72***	.123
Sheep	1	-1.23E-03	3.51E-06 *2.90***	8.14E-07 *1.23*	.119
Sheep	3	-1.44E-03	1.23E-05 *4.81****	5.63E-07 *1.27*	.273

(c) Average size relationships; table 4.11

$$B/D_{Ac} = b_0 + b_1 (B_t - B_{Ac}) + b_2W$$

B/D on $(B_t - B)$ was significant (positive) for sheep paddock data from times 1 and 3. B/D was significant (positive) for cattle paddock data from times 0 to 6 inclusive, but no such relationship was evident for sheep paddock data. In the cattle case, the equation was less efficient when fitted to data from periods of pasture growth (times 4 and 6) than when fitted to data from no-growth periods (times 0 to 3, and time 5).

(d) Discussion.

In both paddocks, significant relationships between plant parameters and distance from water were observed. From the rationale in section 3-4 these are considered stocking effects. In the cattle paddock, the piosphere symmetry was detected by all three plant parameters, but most frequently by the average size variable, suggesting that this parameter was the most immediately affected by cattle (c.f. *Enneapogon*). The relationships were positive in each case. Unlike the *Enneapogon* analyses, symmetry was detected in growth periods as well as no-growth periods, but the pattern was partially obscured, as evidenced by the lower efficiency of the equation when fitted to data from growth periods. In the sheep paddock, piosphere symmetry was detected only with density as the dependent variable, and only in no-growth periods. The relationships were positive, as for the cattle case.

The conclusions with regard to stocking effects were thus:

1. Both cattle and sheep imposed piosphere symmetry on the

distribution of *Aristida contorta*.

2. The general impress was the same in both cases: abundance increased with distance from water.
3. The cattle impress was the more consistent, but became at least partially obscured in periods of major pasture growth.
4. The sheep impress was detectable only in no-growth periods.
5. The clarity with which the piosphere symmetry was shown varied with the particular plant parameter used.
6. The parameters which demonstrated the symmetry most clearly differed under sheep- and cattle-stocking.

4-46 *Regression analyses for Kochia astrotricha adults.*

(a) Density relationships;

In both the sheep and cattle paddocks, the density of *K. astrotricha* remained constant throughout the study (figure 4.11). Therefore *K. astrotricha* density could not be regarded as an independent variable in the same sense as, for example, density. Further, any piosphere pattern found in density distributions would necessarily have had its origins prior to the study, and in the cattle paddock, prior to the introduction of cattle. The equation

$$D_{Ka} = b_0 + b_1W$$

was fitted, to detect any prior impress. The regression was non-significant for data from both paddocks, with R^2 near zero.

(b) Biomass relationships; table 4.12

$$B_{Ka} = b_0 + b_1 D_{Ka} + b_2 (B_t - B_{Ka}) + b_3 W$$

Positive S.P.R's of B on D were observed throughout. A positive S.P.R. of B on $(B_t - B)$ was detected for sheep paddock data from time 2. No other significant relationships were found.

(c) Average size relationships; table 4.12a

$$B/D_{Ka} = b_0 + b_1 (B_t - B_{Ka}) + b_2 W$$

B/D on $(B_t - B)$ was found significant (positive) only for cattle paddock data from time 5. S.P.R's of B/D on W were found only for sheep paddock data, from times 2,3 and 7. The regression coefficients were positive.

(d) Discussion.

From the density data, it can be concluded that no long term stock impress on *K. astrotricha* was present in either paddock.

Significant relationships between plant parameters and distance from water were only found for data from the sheep paddock. From the rationale of section 3-4, these relation-ships are considered a stocking effect, specific to sheep. Piosphere symmetry was only detected with average size as the dependent variable, hence this was the parameter most immediately affected by the sheep. Symmetry was observed in both growth and no-growth periods, but the equation was more efficient when fitted to data from the latter. Thus, as before, pasture growth obscured the stocking relationships.

TABLE 4.12

REGRESSION COEFFICIENTS

K. ASTROTRICHA (ADULTS) BIOMASS RELATIONSHIPS

Paddock	Time	b_0	b_1D *(t)*	$b_2(B_t-B)$ *(t)*	b_3W *(t)*	R^2
Cattle	0	16.5	2.08E-02 *13.05****	6.75E-04 *0.04*	-5.19E-03 *0.79*	.725
Cattle	1	20.4	1.69E-02 *13.74****	-8.93E-03 *0.61*	-7.09E-03 *1.47*	.750
Cattle	2	11.9	1.13E-02 *14.96****	5.03E-03 *0.35*	-6.93E-03 *2.34*	.776
Cattle	3	5.27	1.31E-02 *16.87****	-4.68E-03 *0.29*	2.09E-04 *0.07*	.814
Cattle	4	19.6	2.01E-02 *15.12****	-1.86E-02 *1.16*	-6.83E-03 *1.59*	.791
Cattle	5	9.48	1.43E-02 *15.06****	-1.92E-03 *0.16*	-1.60E-03 *0.46*	.775
Cattle	6	13.0	1.27E-02 *11.90****	-9.92E-03 *0.69*	-3.70E-04 *0.11*	.694
Cattle	7	13.3	1.44E-02 *8.93****	-4.04E-03 *0.41*	2.03E-03 *0.38*	.546
Cattle	8	1.55	1.09E-02 *11.30****	-1.71E-02 *1.52*	9.47E-03 *2.48*	.683
Sheep	1	0.278	4.94E-02 *9.92****	3.53E-02 *1.83*	-7.65E-03 *0.76*	.617
Sheep	2	-9.66	1.89E-02 *5.94****	1.30E-01 *6.70****	6.46E-04 *0.10*	.511
Sheep	3	-11.7	1.44E-02 *8.50****	4.01E-02 *2.00*	8.51E-03 *2.50*	.536
Sheep	4	-5.17	4.39E-02 *9.51****	4.94E-02 *1.84*	-1.27E-03 *0.14*	.583
Sheep	5	-6.97	4.37E-02 *10.71****	3.38E-02 *1.15*	7.10E-03 *0.86*	.634
Sheep	6	15.2	3.45E-02 *7.82****	-2.07E-02 *1.44*	5.49E-03 *0.60*	.507
Sheep	7	2.28	3.34E-02 *8.94****	-2.60E-03 *0.23*	6.25E-03 *0.83*	.563
Sheep	8	17.3	4.14E-02 *8.43****	-6.93E-03 *0.82*	1.08E-02 *1.09*	.536

TABLE 4.12a

REGRESSION COEFFICIENTS

K. ASTROTRICHA AVERAGE SIZE RELATIONSHIPS

Paddock	Time	b_0	$b_1(B_t-B)$ *(t)*	b_2W *(t)*	R^2
Cattle	5	1.00E-02	4.85E-05 *4.89******	-3.26E-06 *1.12*	.276
Sheep	2	1.13E-02	-4.44E-06 *0.35*	1.17E-05 *2.85****	.114
Sheep	3	4.63E-03	9.08E-06 *0.56*	9.51E-06 *3.57******	.165
Sheep	7	2.25E-02	-4.66E-07 *0.06*	1.40E-05 *2.63****	.100

TABLE 4.13

REGRESSION COEFFICIENTS

K. ASTROTRICHA: REGRESSION OF JUVENILE ON

ADULT DENSITIES, CATTLE PADDOCK

Time	b_0	b_1D_{Ka} *(t)*	R^2	Time	b_0	b_1D_{Ka} *(t)*	R^2
0	.63	.146 *4.05******	.195	5	.58	.181 *4.25******	.210
1	.44	.199 *5.38******	.298	6	.51	.177 *4.12******	.200
2	.26	.158 *5.40******	.300	7	.54	.180 *4.41******	.222
3	.55	.150 *3.82******	.177	8	.61	.175 *3.95******	.187
4	.87	.180 *4.66******	.242				

The conclusions with regard to stocking effects were thus:

1. Only sheep imposed piosphere symmetry on the distribution of *K. astrotricha*.
2. Abundance of this species increased with distance from water.
3. The impress was intermittent, but was detectable in both growth and no-growth periods.
4. The impress was only evidenced by the average size of bushes.

S.P.R's of plant parameters on biomass of other species were observed twice, and were positive in both cases. Thus, as for *Aristida*, it appears that the presence of other species had little effect on the biomass or average size of *K. astrotricha*.

4-47 *Regression analyses for Kochia astrotricha juveniles.*

Before investigating piosphere relationships, the degree of dependence of juvenile on adult *K. astrotricha* densities was sought, through the equation

$$D_{Kaj} = b_0 + b_1 D_{Ka}.$$

In the cattle paddock, the regression was significant (positive) at all times (table 4.13). In the sheep paddock, no significant relationship was observed. However, the latter situation may have arisen from the low occurrence of juveniles in the sheep paddock (see fig. 4.11). Inclusion of B_t, as an index of abundance of potential competitors, and of W as independent variables did not increase R^2 values significantly: nor were any new relationships observed.

Thus, in the cattle paddock, juvenile density was dependent only on the density of adults, showed no evidence of competition with other species, or, for that matter, with adults of its own species, and was not affected by stocking to any detectable extent. In the sheep paddock, none of the above factors appeared to affect juvenile densities. The overall differences in densities between paddocks, shown in figure 4.11, may still have been a differential stocking effect, but without demonstration of piosphere symmetry there are no grounds for stating this with certainty. Therefore it must be concluded that neither sheep- nor cattle-stocking have affected the distribution and abundance of *K. astrotricha* juveniles.

4-48 *Regression analyses for Kochia pyramidata.*

In both the sheep and cattle paddocks, the density of *K. pyramidata* remained constant throughout. Strictures thus applied for *K. astrotricha* (q.v. section 4-46). D_{Kp} on W was non-significant for data from both paddocks, with R^2 value near zero in the sheep case, and 0.07 in the cattle case. Hence it was concluded that no significant long-term stock impress existed.

The standard biomass equation was fitted to the data, but the only significant relationships detected were between biomass and density (table 4.14). No significant relationships were found for average size. Hence it was concluded that;

1. Neither sheep nor cattle affected the abundance of *K. pyramidata* to a significant extent; and

TABLE 4.14

REGRESSION COEFFICIENTS

K. PYRAMIDATA BIOMASS RELATIONSHIPS

Paddock	Time	b_0	b_1D *(t)*	$b_2(B_t-B)$ *(t)*	b_3W *(t)*	R^2
Cattle	0	6.01	5.22E-02 *9.45****	-4.25E-02 *1.60*	1.34E-02 *1.32*	.632
Cattle	1	12.9	5.85E-02 *7.00****	-5.96E-02 *1.29*	1.36E-02 *0.89*	.481
Cattle	2	10.7	3.97E-02 *8.59****	-5.19E-02 *1.27*	5.97E-03 *0.70*	.573
Cattle	3	1.97	5.27E-02 *9.33****	-6.74E-02 *1.17*	1.24E-02 *1.25*	.613
Cattle	4	5.88	5.21E-02 *12.43****	1.30E-02 *0.52*	-8.58E-04 *0.12*	.716
Cattle	5	6.49	4.19E-02 *11.03****	-2.83E-02 *1.33*	6.14E-03 *0.95*	.681
Cattle	6	21.8	5.35E-02 *12.35****	-5.34E-02 *2.07*	1.10E-03 *0.16*	.750
Cattle	7	14.0	4.89E-02 *12.65****	-1.83E-02 *1.71*	2.91E-03 *0.48*	.743
Cattle	8	10.6	4.56E-02 *10.06****	-2.42E-02 *1.49*	8.30E-03 *1.01*	.657
Sheep	1	2.73	0.154 *25.77****	-2.15E-03 *0.72*	-1.85E-03 *1.13*	.909
Sheep	2	-1.53	0.105 *23.47****	9.55E-04 *0.29*	4.53E-04 *0.37*	.892
Sheep	3	-1.63	0.102 *18.85****	7.59E-03 *0.89*	1.31E-04 *0.09*	.844
Sheep	4	-1.23	0.197 *19.65****	3.89E-03 *0.51*	-9.32E-04 *0.34*	.853
Sheep	5	1.68	0.152 *20.63****	-2.57E-03 *0.36*	1.02E-03 *0.87*	.866
Sheep	6	4.55	0.140 *19.69****	-5.87E-03 *1.78*	-1.63E-03 *0.81*	.853
Sheep	7	5.79	0.143 *16.04****	-3.83E-03 *1.03*	-2.97E-03 *1.19*	.794
Sheep	8	7.76	0.570 *17.14****	-4.20E-03 *1.93*	-1.63E-03 *0.64*	.815

2. The abundance was not dependent on the other species present.

4-49 *General discussion on regression analyses.*

With the exception of biomass equations with a density term, the regression equations were inefficient in accounting for the variation of the plant parameters. This was only to be expected: the regressions were intended for the detection of piosphere patterns superimposed on the intrinsic vegetation patterns, and were not proposed as models of the total system. Therefore, such underlying influences as soil moisture, nutrient levels, insect grazing and the rest, which largely determine plant abundance, were excluded from consideration. Much of the variance of the dependent variables was not accounted for, because such factors were excluded. Equations with biomass as the dependent variable and density as an independent variable were accordingly more efficient, since density provided, in effect, an index of the background variables influencing species abundances.

The efficiency of all equations was least during or immediately after periods of pasture growth. This was considered to be due either to confusion of the short term piosphere pattern resulting from the animals' lesser dependence on the waters at such times or to the obscuring of stock effects by the increase in forage. For instance, with an overall stocking rate of 1 sheep per 5ha, the forage consumed over 100 days would be equivalent to a 40kg/ha (assuming the sheep to take 2kg (d.w.)/day -- Weston and Hogan, 1973). If the pasture at the beginning of the 100-day period had a total biomass of 100kg/ha and no growth occurred, the grazing effect would be readily evident; as it was for the first few observations. However, an increase in pasture levels of 300kg/ha (as observed in the sheep paddock between times 3 and 4) must tend to obscure the loss to stock. The proportionate increase in background noise (i.e. the variation in the effects of other environmental influences) over such a period would necessarily lessen the efficiency of equations designed to isolate the stocking influence.

In general, equations were more efficient when applied to data from the cattle paddock than when applied to data from the sheep paddock. This might be taken as indicative of an impact heavier for cattle- than for sheep-stocking, with the cattle piosphere patterns being the more easily detected in consequence. This in turn could be related to the greater dependence of cattle on the waters provided (see section 1-62). However, in the present case, the heavier impact of cattle may also have been due to (a) a heavier overall stocking rate in the cattle paddock than in the sheep paddock (section 4-2); (b) a concentration of cattle grazing in the sampled vegetation type (fig. 4.4) as opposed to a more even spread of sheep grazing; and (c) the two waters of the sheep paddock confusing and weakening the piosphere pattern centred on either one. Thus the clarity of patterns under cattle-stocking relative to that under sheep-stocking may have arisen from the special circumstances of the study; hence the differences in clarity cannot be considered representative of the general case.

The relationship between abundance of a particular species and the abundance of other species was obscure. As already stated, the term can not be considered simply as an index of competition as was intended: significant regressions, where detected, were always positive in the cattle paddock case, and both positive and negative in the sheep paddock case, rather than consistently negative as would be expected were the term a competition index. Without independent evidence, there is no point in speculating on the nature of the influences which the term was detecting. Nonetheless, the term necessarily remained in the equations: presence of other species did influence the abundance of the individual species, and this influence, whatever the cause, had to be taken into account to isolate the stocking effects.

The main objective of the regression analyses was the detection of piosphere symmetry, with variations in this symmetry allowing objective comparison of the impacts of sheep and cattle. Neither herbivore imposed discernible pattern on the distributions of *Stipa nitida* and *Kochia pyramidata*. This may have been due to the low incidences of these species for much of the period of study. Sheep-induced pattern in *Stipa* has been well documented by others (e.g. Osborn et al, 1931). The major differences between the patterns imposed by sheep and those imposed by cattle were:

1. The inverse distribution of *Enneapogon* spp. abundance in the sheep case relative to the cattle case: and
2. The piosphere pattern for *K. astrotricha*, observed in the sheep case but not in the cattle case.

Both cattle and sheep imposed similar symmetries on the distribution of *Aristida contorta*, but the parameters which most consistently and clearly displayed the symmetry differed between the two cases.

Both the differences and similarities in sheep- and cattle-imposed patterns are explained in part by the dietary preferences of the two animals: the cattle have consumed only grasses, while the sheep have consumed both grass and shrub, as would be expected from the outline of preferences in section 1-63. This explanation is not entirely satisfactory, however. *Enneapogon avenaceus* (scored as part of *Enneapogon* spp.) is known to be preferred by both cattle (Chippendale, 1968; Low,1973) and sheep (Leigh and Mulham, 1965; Beadle, 1948). If grazing by sheep and cattle was the cause of the piosphere pattern, then an increase in abundance with decreasing stocking pressure should have been found under both herbivores. *Enneapogon* abundance increased with distance (i.e. with decreasing grazing pressure) in the cattle paddock, but decreased with increasing distance in the sheep paddock. Grazing as a direct influence cannot explain the latter relationship. Further, other mechanisms proposed, such as trampling or nutrient transfer, would be expected to apply equally in the cattle paddock.

The detection of piosphere pattern in the distribution of *K. astrotricha* average size is also inadequately explained by citing preferential grazing selection as the cause of the pattern. *K. astrotricha,* although more palatable to sheep than most other perennial chenopods (Jessup, 1951; Beadle, 1948), nonetheless cannot be considered more highly preferred than the grasses studied (as indicated by Jessup, 1951; also see section 1-63 on sheep-grazing trials involving other *Kochia* species). Sheep-induced patterns in no-growth periods (e.g. times 2,3) may be explained by the removal of the more preferred species by sheep, followed by more intense grazing of the shrub; but by the same token, such patterns in *K. astrotricha* size are not expected when the preferred species are abundant, as at time 7. Nor can the patterns at such times be considered as a residue of the patterns imposed in the no-growth periods: the latter patterns were completely obscured by the first pasture growth.

Aristida contorta, showing similar piosphere pattern under both animals, provides a useful basis for comparing the mechanics of cattle and sheep grazing. In the cattle case, piosphere pattern was detected most commonly by the average size parameter, but in the sheep case by the density parameter. This illustrated the closer grazing of sheep (discussed in section 2-3): the whole plant was taken at a time, hence there was no reduction in quadrat biomass or average size independent of the reduction in density. On the other hand, the cattle took only part of the plant: there was reduction in biomass and size independent of the reduction in density.

It was hoped that short-term patterns would indicate the potential future trends in the pasture, by showing the beginnings of divergences between sheep and cattle paddocks. For instance, were the patterns more consistent, a long-term decrease in *Enneapogon* populations with cattle-grazing, and an increase with sheep-grazing might be predicted. However, in no case were the patterns evident throughout. In the cattle case, any piosphere symmetry was obscured during pasture growth, and in the sheep case, patterns were very intermittent. Thus all the patterns observed were considered ephemeral, dependent only on season, and so could not be used as the basis for predicting longer-term outcomes of stocking.

In summary, the conclusions from the foregoing analyses were:

1. Neither sheep nor cattle affected *Stipa nitida* and *Kochia pyramidata* to a discernible extent.
2. Both sheep and cattle imposed similar piosphere symmetries on the distribution of *Aristida contorta:* but the parameters which displayed the patterns most clearly differed between paddocks, as a result of grazing habits differing between sheep and cattle.
3. Sheep and cattle imposed markedly different piosphere symmetries on the distributions of *Enneapogon* spp. and *Kochia astrotricha*.
4. The hypothesis, that preferential grazing selection is the cause of stock-related pattern, accounted for only part of the foregoing results.
5. All the observed patterns were ephemeral, generally becoming obscured with pasture growth.
6. There was no evidence of the initiation of long term divergences between paddocks as a result of the differential stocking.

4-5 ABUNDANCE OF MINOR SPECIES

The densities of minor species for each observation time are plotted in Appendix 1, with data from open quadrats, both paddocks. Table 4.15, compiled from these plots, demonstrates the preponderance of the species which grow following late spring and summer rains. The plots also demonstrate the ephemeral nature of many species,

TABLE 4.15

SEASONAL RESPONSES OF PASTURE SPECIES AT MT VICTOR

(a) Density increase following summer rain.

Aristida contorta	*Bassia patenticuspis*	*Salsola kali*
Atriplex limbata	*Dactyloctenium radulans*	*Sida corrugata*
Atriplex spongiosa	*Convolvulus erubescens*	*Clianthus formosus*
Bassia biflora	*Erodium cygnorum*	*Tragus australianus*
Bassia lanicuspis	*Kochia excavata*	*Tribulus terrestris*
Bassia limbata	*Triraphis mollis*	

(b) Density increase following both late spring and summer rains.

Enneapogon spp.	*Euphorbia drummondii*	*Sida virgata*
Bassia diacantha	*Sida intricata*	

(c) Density increase following spring rain.

Stipa nitida	*Bassia paradoxa*	*Helipterum floribundum*
Atriplex stipitata	*Kochia georgei*	*Angianthus pusillus*
Bassia decurrens	*Minuria leptophylla*	*Calocephalus dittrichii*
Bassia obliquicuspis		

(d) Density increase following winter rains.

Bassia divaricata	*Eragrostis dielsii*	*Brachyscome ciliaris*

The remainder of the species listed in Table 3.3 showed no discernible density response to rains.

often considered perennial; particularly *Bassia* species, considered by Black (1943) to be biennial or short-lived perennials.

In most cases, fluctuations in density showed the same pattern between paddocks, although overall densities often differed between paddocks. However, certain species showed a continuous decline in one or other paddock, notwithstanding the abundant and continuous rains during the latter half of observations. In the cattle case, the species were the ephemerals *Atriplex limbata*, and *Eragrostis dielsii*. In the sheep case, they were the ephemerals *Bassia diacantha* and *Bassia obliquicuspis*.

The differences between paddocks of these species' trends were considered potentially indicative of divergence between paddocks, resulting from the differential stocking. Simple linear regressions of the species' densities on distance from water were calculated, but were found non-significant in all cases. Inclusion of total biomass of major pasture species as an independent variable also resulted in non-significant regressions.

Any stock-induced pattern present may have been obscured by the low incidence of the species (frequency of occurrence less than 20%), but, nonetheless, evidence of short-term piosphere symmetry was necessary to allow certain statement regarding long term divergence. Since no piosphere symmetry was evident, the differential trends between paddocks for these species were not considered to be a direct result of the particular stocking regimes.

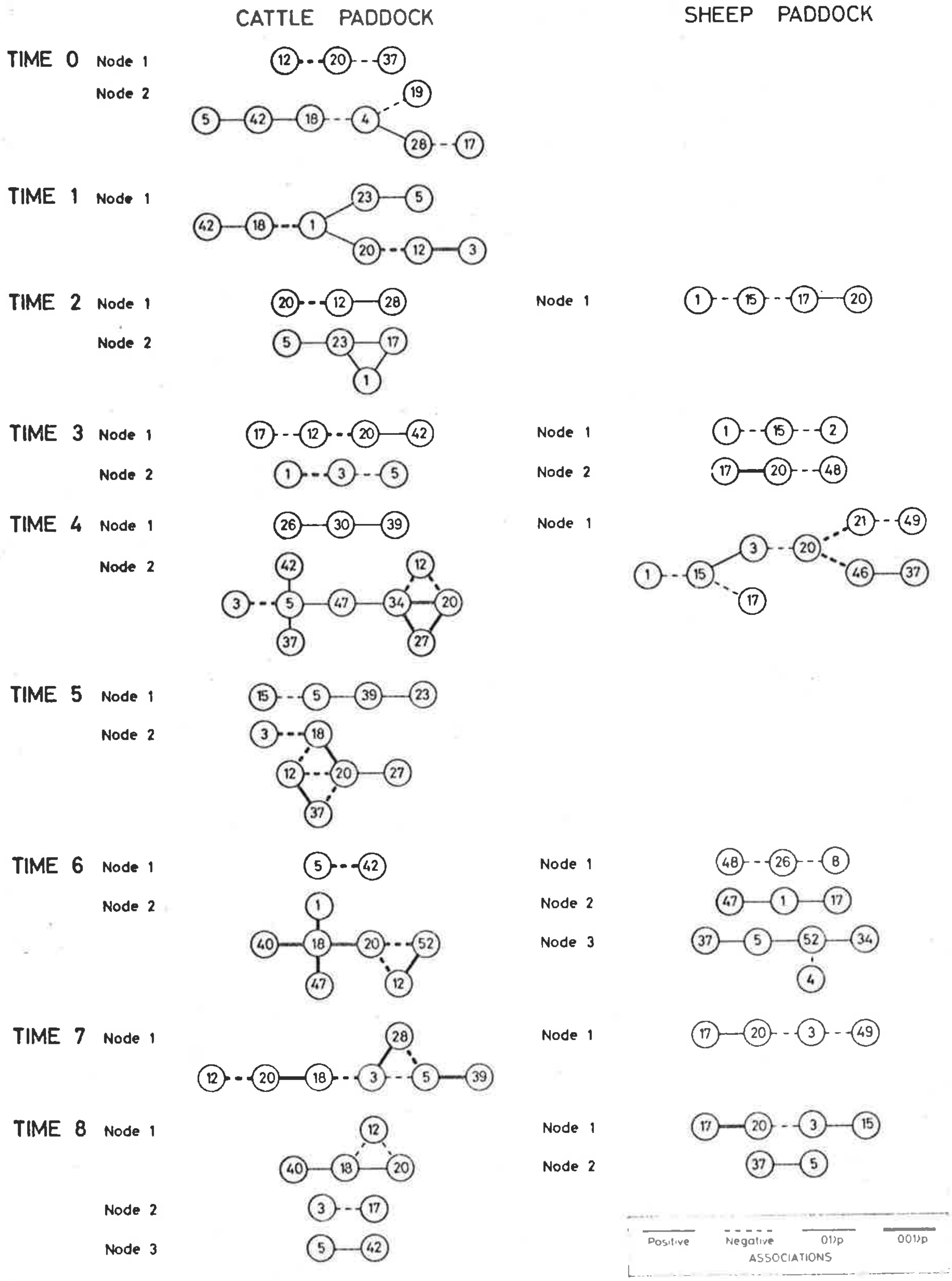
Even were the divergences real, and not a chance effect, they were not such as to imply a major change in the character of the two pastures: the species involved comprised only a small proportion of the total flora, and contributed little to the total standing crop.

4-6 INFLUENCE ANALYSES

Figures 4.17 and 4.18 show associations at the .01 level for the cattle and sheep paddocks respectively, and for all times. The nodes of interaction did not show the reinforcement (cross-correlation) usually requisite for an Influence Analysis, and varied so greatly with time that individual analyses may not have been comparable in any case. The lack of reinforcement could be ascribed to the small sample size (N=70) but the changes in associations must have resulted from changes in relative abundances. Influence Analysis nonetheless should be able to detect a particular influence regardless of the particular species present, and used in the analysis, at any one time. For example, Barker and Lange (1970) reported stocking influences, determined by back-plots from nodes composed of largely ephemeral species (e.g. *Bassia* species). Lange (1971) stated that Influence Analysis would be viable in monitoring changes in the stocking influences with time. The implication is that the influences would still be detected, no matter which species were observable at each time. However, if the nodes of figure 4.18 were used in Influence Analyses, despite the lack of reinforcement, various influences would be confused; at time 2, species 1,15,17 and 20 form a single node, but at time 3, species 1 and 15 form part of one node, and species 17 and 20 part of a separate node.

Fig. 4.17 & Fig. 4.18
SPECIES ASSOCIATIONS IN THE CATTLE AND SHEEP PADDOCKS

(Species numbered as given in Appendix 1)



The first case suggests one influence in operation but the second suggests two in operation.

In the present study, Influence Analysis was intended only as a first order approach. Investigations using this method were abandoned after the above complications became evident.

4-7 PRINCIPAL COMPONENTS ANALYSES

4-71 *Results*

Few principal components appeared related to stocking pressure. For cattle paddock data, the regressions of site affinities for the five varimax components on distance from water were significant only for components R3 at time 1, R5 at time 2, R3 at time 3, R2 at time 6 and R2 at time 8. For sheep paddock data, the regressions were significant only for components R1 at time 1, R3 at time 2, R5 at time 3, and R5 at time 5. The efficiency of the regression was low in all cases. The equations are given in table 4.16. Since these components displayed piosphere symmetry in their expression, they were considered functions of the stocking influence. Species affinities for each of these components are given in table 4.17. The other components may have related to various environmental influences, or to vagaries of the data, but, since they showed no relationship with stocking pressure, were not further investigated.

For the stocking components, interpretation proceeded as outlined in section 3-53, with the species affinities being used to

TABLE 4.16

REGRESSIONS OF SITE AFFINITIES ON DISTANCE FROM WATER

(a) Cattle paddock

Time	Varimax component	b_0	b_1W	Significance	R^2
1	R3	.823	-6.12E-04	.001 *p*	.171
2	R5	-.943	7.88E-04	.001 *p*	.224
3	R3	.719	-5.35E-04	.01 *p* .001	.130
6	R2	-.693	5.16E-04	.01 *p* .001	.121
8	R2	-.678	5.04E-04	.01 *p* .001	.116

(b) Sheep paddock

Time	Varimax component	b_0	b_1W	Significance	R^2
1	R1	-.523	4.20E-04	.01 *p* .001	.094
2	R3	.512	-4.10E-04	.01 *p* .001	.090
3	R5	.655	-5.23E-04	.001 *p*	.147
4	R5	.543	-4.36E-04	.01 *p* .001	.101

TABLE 4.17

SPECIES AFFINITIES (x100) FOR STOCKING COMPONENTS

Species.		CATTLE PADDOCK					SHEEP PADDOCK			
	Time▾	1	2	3	6	8	1	2	3	4
	Compt▾	R3	R5	R3	R2	R2	R1	R3	R5	R5
1	*Stipa nitida*	00	-11	42	-76	-04	54	23	-04	18
2	*Enneapogon spp.*	-48	39	-69	19	32	07	-21	23	64
3	*Aristida contorta*	-48	04	-71	14	27	21	07	-14	-03
4	*Kochia astrotricha*	-30	-06	03	10	09	-05	11	00	27
5	*Kochia pyramidata*	79	-07	32	08	-31	66	06	01	15
7	*Atriplex limbata*	00	*	*	*	*	*	*	*	*
8	*Atriplex spongiosa*	*	*	*	*	*	*	*	*	-64
12	*Bassia decurrens*	-07	-30	15	-27	07	*	*	*	*
13	*Bassia diacantha*	-23	04	03	-11	04	-81	52	30	10
14	*Bassia divaricata*	17	-20	-15	18	14	*	*	*	*
15	*Bassia lanicuspis*	-15	05	*	11	15	-07	03	-62	-66
17	*Bassia obliquicuspis*	61	09	02	-15	01	15	-88	10	07
18	*Bassia patenticuspis*	44	*	*	-27	15	*	*	*	*
19	*Bassia paradoxa*	09	*	*	08	18	*	*	*	*
20	*Bassia sclerolaenoides*	35	-14	21	-78	02	13	-38	-39	-08
21	*Dactyloctenium radulans*	*	*	*	*	*	*	*	*	17
22	*Convolvulus erubescens*	*	*	*	-02	*	*	*	*	*
23	*Dodonaea microzyga*	25	14	39	-12	*	*	*	*	*
25	*Eragrostis dielsii*	11	*	*	*	*	*	*	*	*
26	*Erodium cygnorum*	*	*	*	*	*	*	*	*	03
27	*Euphorbia drummondii*	*	*	*	-25	*	*	*	*	39
28	*Brachyscome ciliaris*	14	02	-49	24	-03	*	*	*	*
30	*Kochia excavata*	-06	52	04	15	38	-15	-01	75	10
34	*Minuria leptophylla*	*	*	*	-26	-59	*	*	*	*
37	*Triraphis mollis*	03	*	*	24	-80	*	*	*	21
39	*Salsola kali*	*	*	*	05	*	*	*	*	16
40	*Sida corrugata*	*	*	*	-16	30	*	*	*	*
41	*Sida intricata*	12	*	*	05	03	*	*	*	*
46	*Tragus australianus*	*	*	*	*	*	*	*	*	09
47	*Tribulus terrestris*	*	*	*	-33	*	*	*	*	08
48/c	Cattle dung	07	-79	-19	02	*	-	-	-	-
48/s	Sheep dung	-	-	-	-	-	20	47	04	-47
49	Kangaroo dung	*	*	*	-79	*	*	*	*	11
Eigenvalue.		1.85	1.16	1.38	2.27	2.13	1.65	1.30	1.10	1.32
Proportion of total variance.		.082	.078	.100	.079	.110	.150	.110	.100	.067

* *Species' frequency of occurrence below 10% at this time; not included in analysis.*

TABLE 4.18

SPECIES WITH DENSITIES INCREASING (+) OR DECREASING (-) WITH INCREASING DISTANCE FROM WATER

Species	*Cattle paddock* Time					*Sheep paddock* Time			
	1	2	3	6	8	1	2	3	4
Stipa nitida	.	.	-	-	-	+	.	.	.
Enneapogon spp.	+	+	+	.	+	.	.	.	-
Aristida contorta	+	.	+	.	.	.	.	.	.
Atriplex spongiosa	.	.	.	.	.	.	.	.	+
Bassia diacantha	.	.	.	.	.	-	-	.	.
Bassia lanicuspis	.	.	.	.	.	.	.	+	+
Bassia obliquicuspis	-	.	.	.	.	.	+	.	.
Bassia patenticuspis	-	.	.	.	-	.	.	.	.
Bassia sclerolaenoides	-	.	.	-	.	.	+	+	.
Brachyscome ciliaris	.	.	-	.	.	.	.	.	.
Euphorbia drummondii	.	.	.	.	.	.	.	.	-
Kochia excavata	.	+	.	.	+	.	.	-	.
Minuria leptophylla	.	.	.	.	-	.	.	.	.
Triraphis mollis	.	.	.	.	-	.	.	.	.

infer the variations in species densities with distance from water. The results are summarized in table 4.18.

4-72 *Discussion.*

Evidence of stocking influence was intermittent, as for the regression analyses of section 4-4. Stocking relationships were largely obscured in the second half of the period of study. Although inferences were therefore limited, as in the regression analyses, the following points were apparent.

1. Where any species showed strong affinity with the stocking influence at more than one time, the relationship was consistent within paddocks (e.g. *Stipa nitida* and *Bassia patenticuspis*, always decreasing in density with increasing distance from water in the cattle paddock).
2. Where major species were involved, relationships with the stocking influence as inferred from P.C.A's were coincident with the relationships detected by regression analyses in section 4-4 (e.g. *Enneapogon* spp. in the cattle paddock, inferred from the P.C.A's to increase in density with distance from water, and found to increase with distance in regression analyses).
3. A relationship between *Stipa* density and distance from water was found in P.C.A's, but was not discernible in the previous regression analyses.

The first point implied a consistently recurring pattern, albeit short-term in nature. The second point largely confirmed that the particular components had been correctly interpreted as representing the stocking influence. The third underlined the advantages of considering the vegetation as a whole, rather than dealing with individual species: relationships between species' abundances and stocking pressure, not evident when species were considered in isolation, became evident when analysis dealt with all species simultaneously.

Species' densities showed markedly different distributions between sheep and cattle piospheres. Either piosphere pattern in a species' distribution was detected in only one paddock, or, if detected in both, the relationship with distance from water showed opposite signs in the two paddocks. Hence, for the species showing stocking influence in the P.C.A's, cattle and sheep had markedly different effects.

In the cattle case, preferential grazing selection of grass species, with reduction of density near water and a consequent increase in density of less favoured species, accounts for most of the patterns observed. The grasses *Enneapogon* and *Aristida* increased with decreasing grazing pressure, while the less favoured forbs *Bassia* spp. decreased with decreasing grazing pressure. (However, the grass *Stipa* would not be expected to behave in the same manner as these forbs).

In the sheep case, preferential grazing of certain species cannot account for the observed patterns. As before, the piosphere pattern in *Enneapogon* is the reverse of the pattern expected if preferential selection is the main cause of stock-related pattern. Further, the chenopod forbs *Bassia diacantha,* *B. sclerolaenoides* and the small shrub *Kochia excavata* are considered to be more or less equally palatable to sheep (e.g. Jessup, 1951); the differences in their piosphere patterns are thus difficult to account for in terms of differences in grazing selection.

Very few of the 55 pasture species scored in quadrats showed any detectable response to grazing pressure. Further, patterns were only detected for the most commonly occurring species, notwithstanding the high degree of selectivity of stock (see the grazing trials reported in section 1-63, where much of the stock intake was of minor components of the pasture). This further suggests that some factor other than dietary selection was the immediate cause of piosphere patterns.

As with the regression analyses, patterns became obscured in growth periods. Prediction of long-term divergence between paddocks was not possible because of this: the patterns had to be considered ephemeral. Nonetheless, patterns which recurred in the course of the study, because of their consistency, are predicted to recur elsewhere.

In summary, the main conclusions were:

1. Sheep and cattle imposed piosphere symmetry on few of the species encountered in the course of observations.
2. Sheep and cattle impresses differed markedly.
3. The hypothesis, that preferential selection of species is the main cause of stock-related vegetation pattern, was unable to account for much of the observed pattern.
4. Piosphere s mmetry was detected intermittently, becoming obscured during or after periods of pasture growth.

5. The observed patterns were ephemeral, giving no sound basis for prediction of divergences in the vegetations under the two grazing regimes.

4-8 ANALYSES OF PHOTOPOINT DATA (MINOR STUDY)

4-81 *The effects of cattle and sheep grazing on plant habits.*

Plates 5, 6, 7 and 8, taken at times 1 and 3 in the cattle and sheep paddocks respectively, show clearly the differences in the effect of grazing on grass species. The cattle, over this period, acted as "lawn-mowers": the visible grass standing crop was evenly reduced without much change in density. Sheep on the other hand removed smaller individuals completely, while leaving entire the ranker forage (particularly *Stipa nitida* individuals). The same pattern can also be seen in the photopoint sets of appendix 1.

These observations correspond with the inferences drawn from regression analyses. In section 4-4 it was considered that sheep-grazing most closely affected the density of grasses, but that cattle-grazing removed a proportion of the biomass without causing a commensurate reduction in density. The photographs support this.

4-82 *Browsing by cattle.*

Section 1-63 has stated that browse is unimportant in cattle diets, but may constitute a significant part of sheep diets. Trees in both paddocks displayed a well marked browse line maintained by stock, but leaf growth below this browse line, within the reach of

PLATE 5.

Photopoint 2, cattle paddock, 0.5mi north of Black Hill Dam. 4/9/72

PLATE 6.

Photopoint 2, cattle paddock, 0.5mi north of Black Hill Dam.

Note the even reduction of grasses by comparison with the standing crop in plate 5. 13/2/73

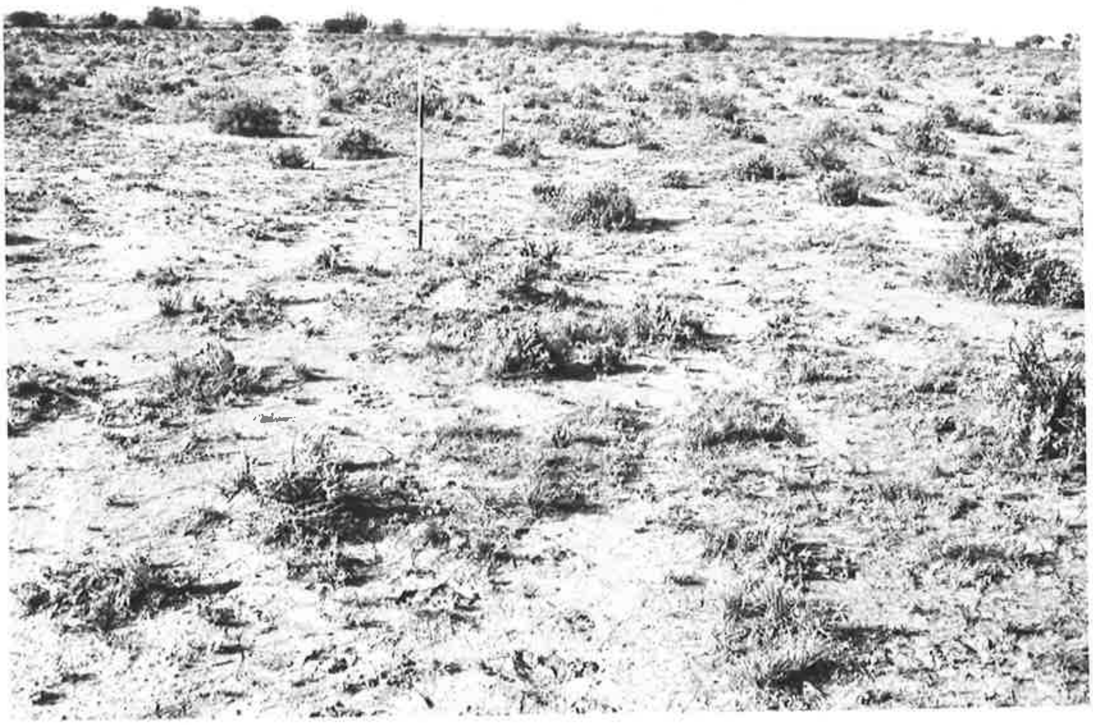
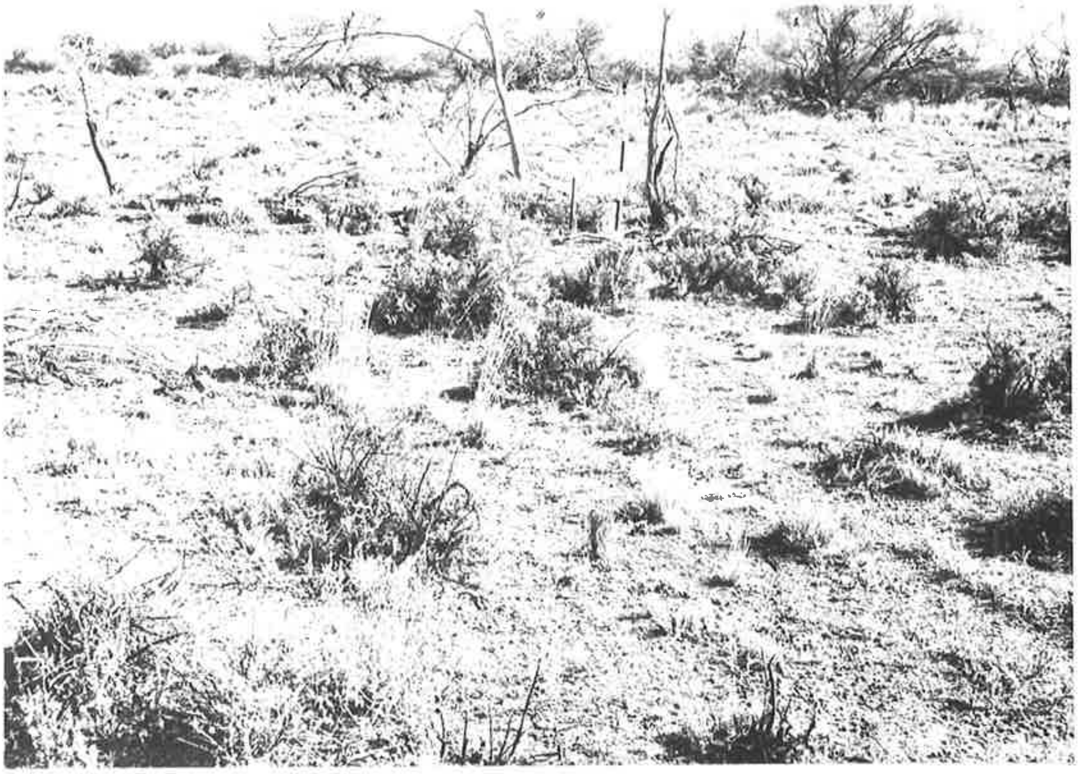


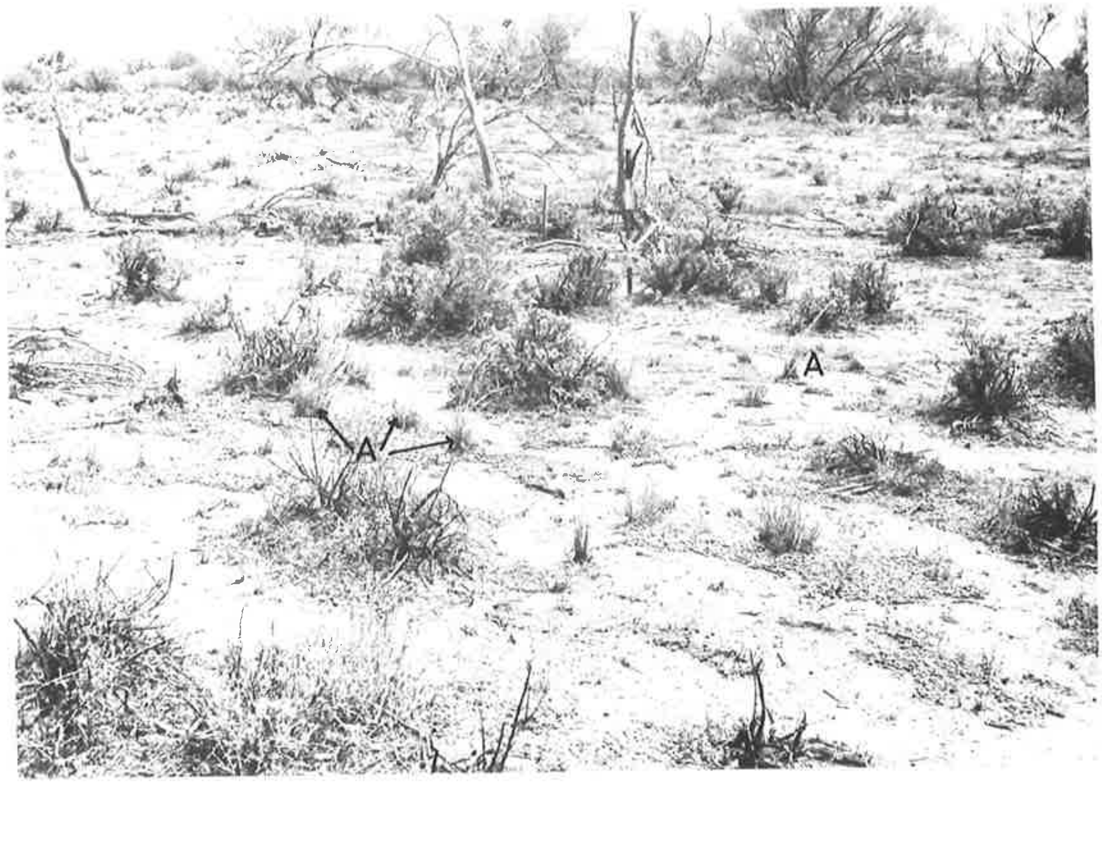
PLATE 7.

Photopoint 6, sheep paddock, 0.6mi west of gate. 4/9/72

PLATE 8.

Photopoint 6, sheep paddock, o.6mi west of gate. Note that large individuals of *Stipa nitida* (A) are still standing, despite the marked reduction in amount and number of grasses by comparison with plate 7. 13/2/73




A
A

stock, was very limited (see the exclosure photopoint, sheep paddock, in appendix 1). Hence the tree forage was considered to be of little significance in both cases, by comparison with the ground pasture.

However, an interesting facet of cattle grazing, not observed in the sheep paddock, was the almost total destruction by browsing of several individuals of *Eremophila duttonii*, a shrub species growing to a maximum height of 3m. Photopoint 4, cattle paddock, included one of these shrubs in the foreground of the camera field (see appendix 1). This individual was almost totally destroyed by cattle in the period of observations, with foliage removed even during times of pasture abundance. Broken branches, but no leaves, were found around the plant at each observation, hence the cattle were browsing, and not trampling the bush. In view of the dietary preferences of cattle, this was unusual. Further, *Eremophila* species in general, and *E. duttonii* and *E. sturtii* in particular, contain in the leaves large quantities of turpenes, which render them highly unpalatable to any ungulate. (*E. sturtii* is commonly named "turpentine bush", because of the obvious odour of the turpenes). Grazing of such species by cattle was thus unexpected, but was observed both in the sample area, elsewhere in the paddock, and in other cattle paddocks throughout the study period. Some saplings (to 30cm tall) of both species were found in quadrats, and these were carefully observed. There was no evidence of grazing. Hence there are no grounds for assuming that the grazing of adults of these species by cattle will affect the maintenance of the population.

4-83 *Shrub and grass dynamics.*

Figures 4.19 to 4.22 inclusive were compiled from the photographs, using the method of section 3-65. In exclosures in both paddocks, very little decrease in standing biomass of shrub or grass was evident between times from the start of observations to time 3, although an overall decrease could be seen. In grazed photopoints of the sheep paddock, a decline in grass biomass was evident by time 2, and a decline in shrub biomass by time 3. The time lag between observation of clear decrease in grass biomass and observation of clear decrease in shrub biomass was interpreted as showing increased grazing of the shrub *K. astrotricha* by sheep, consequent to the major reduction of more preferred grass species. In the cattle paddock, decreases in grass biomass were evident from the start of observations to time 3, but decreases in shrub biomass were largely undetectable between times, despite an overall decrease. This was interpreted as demonstrating the exclusive grazing of grasses by cattle.

The pasture growth between times 3 and 4 was clearly evident for all photopoints. Between times 4 and 5, exclosures showed no visible decrease in either grass or shrub biomass. In the paddocks, however, some slight decreases were noted, mostly for grass biomass. Between times 5 and 6, both decreases and increases were noted for exclosures, but most photographs showed little difference. In paddocks, the pattern was confused.

Between times 6 and 7, major growth of both grass and shrub was evident, in exclosures and in paddocks. At time 7, however, the grass largely obscured the shrubs--a rare phenomenon which was

Fig. 4.19

RELATIVE CHANGES IN APPARENT BIOMASS OF *K. ASTROTRICHA* IN THE CATTLE PADDOCK

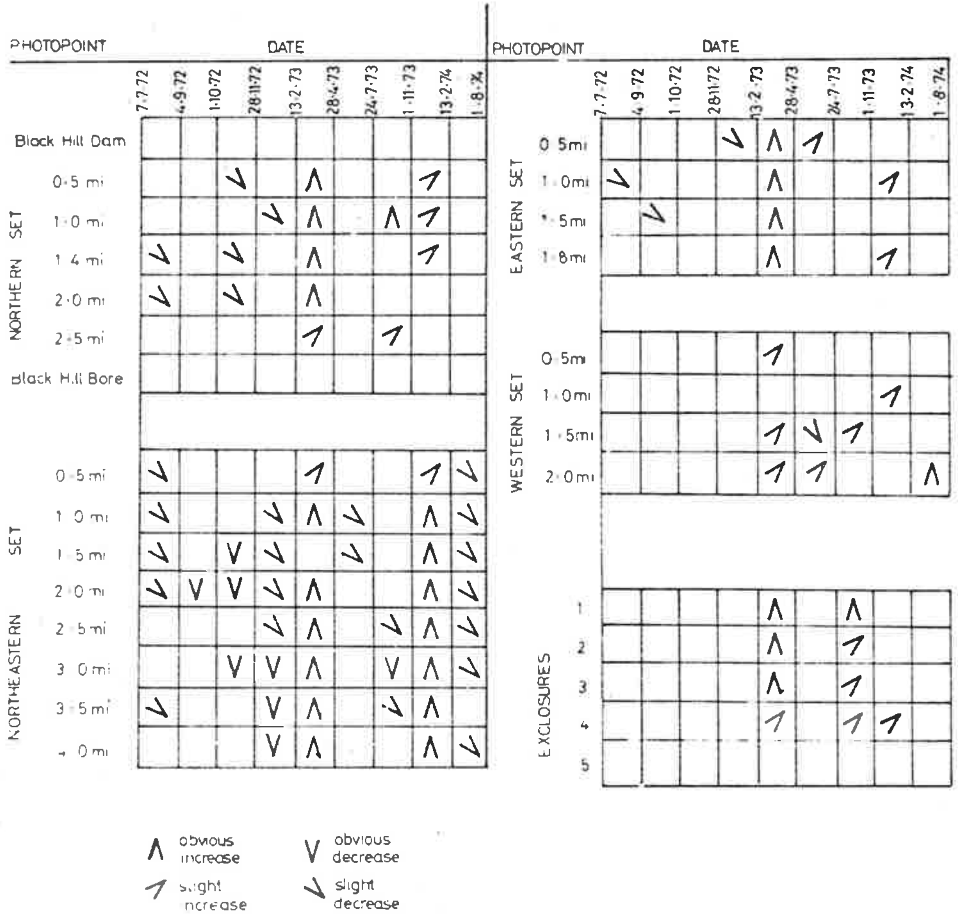


Fig. 4.20

RELATIVE CHANGES IN APPARENT BIOMASS OF *K. ASTROTRICHA* IN THE SHEEP PADDOCK

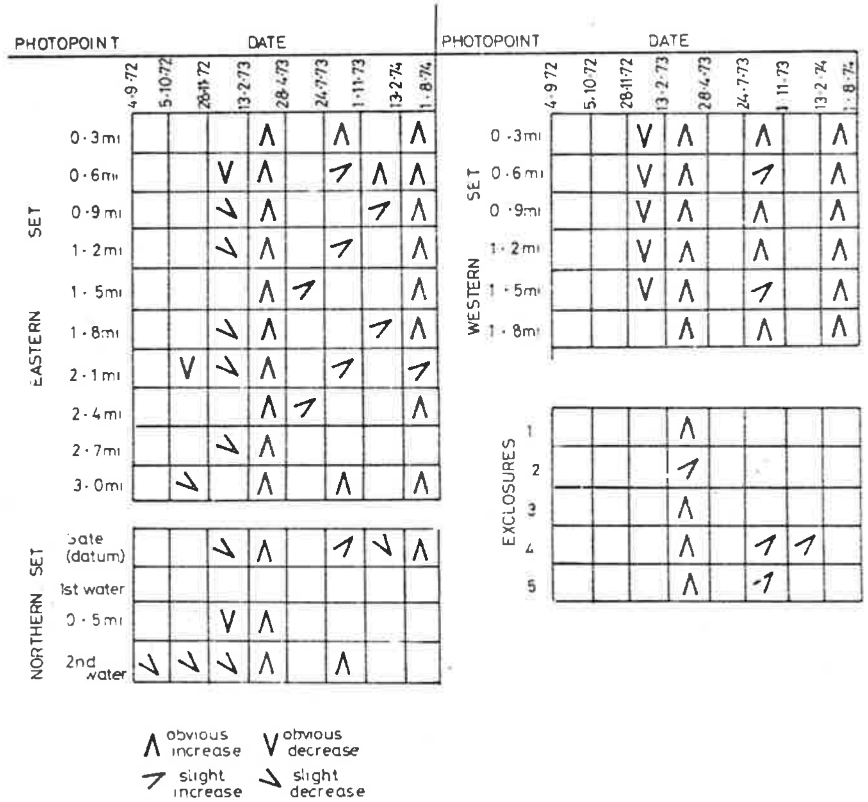


Fig. 4.21

RELATIVE CHANGES IN APPARENT BIOMASS OF GRASSES IN THE CATTLE PADDOCK

PHOTOPOINT		7.7.72–4.9.72	4.9.72–1.10.72	1.10.72–28.11.72	28.11.72–13.2.73	13.2.73–28.4.73	28.4.73–24.7.73	24.7.73–1.11.73	1.11.73–13.2.74	13.2.74–1.8.74
NORTHERN SET	Black Hill Dam (Datum point)	V		↘		↗		Λ	↗	
	0·5mi	V			↘	Λ			Λ	
	1·0mi	↘			V	Λ			Λ	↘
	1·4mi	V		V	V	Λ	↘		Λ	
	2·0mi	↘	↘	V	↘	Λ		↘	Λ	
	2·5mi	↘		V	V	Λ		V	Λ	
	Black Hill Bore			↘		↗		Λ	Λ	V
NORTHEASTERN SET	0·5mi	↘				Λ			Λ	↘
	1·0mi	↘			↘	Λ	↘		Λ	↘
	1·5mi	↘		V	↘	Λ	↘		Λ	↘
	2·0mi	↘	V	V	↘	Λ			Λ	↘
	2·5mi				↘	Λ		V	Λ	↘
	3·0mi			V	V	Λ		V	Λ	
	3·5mi	↘			V	Λ		↘	Λ	
	4·0mi				V	Λ			Λ	↘

PHOTOPOINT		7.7.72–4.9.72	4.9.72–1.10.72	1.10.72–28.11.72	28.11.72–13.2.73	13.2.73–28.4.73	28.4.73–24.7.73	24.7.73–1.11.73	1.11.73–13.2.74	13.2.74–1.8.74
EASTERN SET	0·5mi				↘	Λ	↗			
	1·0mi	↘				Λ			↗	
	1·5mi		↘			Λ				
	1·8mi					Λ			↗	
WESTERN SET	0·5mi	V	V	↘	V	Λ	↘	Λ	Λ	↘
	1·0mi		↘		V	Λ	↘	↗	Λ	↘
	1·5mi	↘		↘	V	Λ	↘	↗	Λ	↘
	2·0mi	↘			V	Λ		↘	Λ	↘
EXCLOSURES	1					Λ		↘	Λ	
	2					Λ		↘	Λ	
	3			↘		Λ		V	Λ	
	4			↘	V	Λ		Λ	Λ	
	5					Λ			Λ	

Λ obvious increase V obvious decrease
↗ slight increase ↘ slight decrease

Fig 4.22

RELATIVE CHANGES IN APPARENT BIOMASS OF GRASSES IN THE SHEEP PADDOCK

PHOTOPOINT		4.9.72–5.10.72	5.10.72–28.11.72	28.11.72–13.2.73	13.2.73–28.4.73	28.4.73–24.7.73	24.7.73–1.11.73	1.11.73–13.2.74	13.2.74–1.8.74
EASTERN SET	0·3mi		V	↘	Λ			Λ	
	0·6mi			V	Λ	↘	↗	Λ	Λ
	0·9mi		↘	↘	Λ	↘		Λ	Λ
	1·2mi		V	V	Λ		↗	Λ	Λ
	1·5mi		↘	↘	Λ	↘	↗	Λ	Λ
	1·8mi	↘	V	↘	Λ		↗	Λ	Λ
	2·1mi		↘	V	Λ		Λ	Λ	Λ
	2·4mi				Λ			Λ	Λ
	2·7mi		V		Λ		Λ	Λ	
	3·0mi				↗		↗		↗
NORTHERN SET	Gate (datum)				Λ			Λ	Λ
	1st water	↘		V	Λ		V	Λ	
	0·5mi		V	V	Λ			Λ	↗
	2nd water		↘	↘	Λ	↗	Λ	Λ	↗

PHOTOPOINT		4.9.72–5.10.72	5.10.72–28.11.72	28.11.72–13.2.73	13.2.73–28.4.73	28.4.73–24.7.73	24.7.73–1.11.73	1.11.73–13.2.74	13.2.74–1.8.74
WESTERN SET	0·3mi		V	↘	Λ		↘	Λ	Λ
	0·6mi		↘	V	Λ		V	Λ	Λ
	0·9mi		V		Λ	V	Λ	Λ	Λ
	1·2mi	↗	↘	↘	Λ	V	Λ	Λ	Λ
	1·5mi		V	↘	Λ		Λ	Λ	Λ
	1·8mi	V			Λ			Λ	Λ
EXCLOSURES	1				Λ				
	2				↗				
	3				Λ		↗	↗	
	4				Λ		↗		
	5				Λ				

Λ obvious increase V obvious decrease
↗ slight increase ↘ slight deacease

not anticipated. Observations of shrub biomass were therefore difficult, and the changes stated to occur must be viewed with caution.

In the cattle paddock, exclosures showed little change in grass or shrub biomass in the long interval between times 7 and 8. However, open photopoints showed a general decrease in grass biomass, though not in shrub biomass. As before, this was considered the result of cattle grazing the grass rather than the shrubs. The sheep paddock presented a markedly different pattern. Changes over this period in exclosures were the same as observed in the cattle paddock exclosures. However, the grasses in open photopoints, almost without exception, showed a marked increase in biomass. Sheep had been removed from the paddock three months prior to the taking of final photographs, hence much of the increase was due to grass production in the absence of domestic grazing. Inspection of the sheep paddock photographs in appendix 1 will show that the grass standing crops of open photopoints were not visibly different from the standing crops of exclosures. Hence it appears that the exclosures had nearly reached peak biomass by time 7, but the paddock could not attain this peak under the pressure of stocking. This suggests a maximum limit on biomass, in contrast to the statement in section 4-33 (q.v.) that increases in biomass did not appear limited by the biomass attained during previous growth.

4-84 *Piosphere patterns.*

There was little evidence of piosphere pattern in the distribution of change in pasture, as determined from the photographs. Both the regression and Principal Components analyses indicated that the piosphere pattern only accounted for a small part of the variance of biomass, hence such a result was not entirely unexpected. Nonetheless, a pattern was detected in the no-growth period between times 0 and 3, for grass biomass in the cattle paddock. Photopoints within 2mi of water, along the northeast track, showed some decrease in grass biomass between times, from time 0 to time 3. Photopoints beyond 2mi showed no apparent change except between times 2 and 3. This was interpreted as showing that (a) a gradient of grazing pressure existed between times 0 and 2, extending to 2mi from water; beyond which grazing was not evident, and (b) between times 2 and 3, this gradient extended to the limits of sampling, as a result of cattle foraging further in a period of severely diminished pasture. This provides independent evidence that the changes in the piosphere pattern of total biomass discussed in section 4-42 (q.v.) were indicative of progressively more distant grazing by the cattle, and were not chance events.

4-9 DISCUSSION AND CONCLUSIONS

4-91 *The relative importance of stocking and other influences.*

Few species encountered in the course of observations displayed stocking effects. These effects were only observed intermittently, and when detected, accounted for only a small proportion of the total variation in the respective species' abundances. Therefore it is concluded that the stocking influence during the study was minor by comparison with other environmental influences.

The above is not necessarily true for the general case. The heavy rains during the study resulted in abundant pasture growth. Considering the stocking rate, it is not surprising that stocking effects became obscured in such periods: the amount of pasture removed by stock would be negligible by comparison with the overall increase, hence any piosphere pattern still extant would be largely hidden by background noise. However, in a drought, the stocking influence would probably be the major factor controlling the distributions of pasture species. This was partly evidenced by data from the first three trips. The regression analyses were most efficient when applied to this data, hence the stocking influence was at its peak at these times.

All the piosphere patterns observed during the study were ephemeral, though usually recurring. This did not necessarily result from the search for patterns evolving in the short-term. The emphasis was placed on short-term pattern detection, to avoid ascribing prior sheep impress to the effects of cattle introduction. New patterns were expected to arise under cattle, and it was anticipated that the patterns would be maintained. That they were ephemeral in nature has an important bearing on the use of piosphere pattern in monitoring stocking effects (discussed below).

4-92 *Linear relationships within the piosphere.*

Linear relationships between plant parameters and distance from water were sought, following the evidence of such relationships reported by Lange (1969) and Rogers and Lange (1971). Linear relationships were found to exist within the sampling limits, under both sheep and cattle stocking. Even where the plotted data suggested non-linear relationships, as in the distribution of total biomass in the cattle paddock, linear functions nonetheless fitted the data with efficiencies equivalent to those of non-linear functions suggested by the data curve.

Linearity of relationships, although observed, is difficult to rationalise. Plant abundances proportional to distance from water implies that stocking pressure is inversely proportional to distance from water. In terms of grazing behaviour, this implies that stock graze out from water at an even rate. (To expand: the standing crop of pasture, P, is assumed inversely proportional to the grazing pressure, G. Grazing pressure is defined as proportional to the time available for grazing, over the area available, T/A. Stock grazing out from water at an even rate have available at each unit of time an area $\pi(r+i)^2 - \pi r^2$, where i is the distance increment. Expansion of this gives $A = \pi i^2 + 2\pi ri$, or A proportional to r since π and i are constant. thus G is inversely proportional to r, and P proportional to r .) However, the available evidence regarding patterns in grazing behaviour indicates that the cumulative effect is not likely to be structured in this manner. A trampling rather than a grazing effect might therefore be proposed as the cause of the linearity, since stock have to return to the water constantly regardless of grazing patterns; but even so, patterns of movement tend to be stratified in such a way as to render such cumulative pattern improbable. For example, Schmidt's (1969) walkers and non-walkers would not be expected to impose linear patterns in the vegetation through trampling, because of the heterogenous movement pattern.

Nonetheless, this study has shown linear relationships to exist in the cattle and sheep piospheres, thereby providing independent confirmation of Lange's (1969) observations. It remains to be determined whether these relationships represent the true situation, or, instead, approximations to more subtle functions of stocking pressure.

4-93 *Possible causes of stock-induced vegetation pattern.*

As shown by the regression and Principal Components analyses, the species which decreased in abundance with increasing stocking pressure were grasses under cattle, and grasses, shrubs and forbs under sheep. These results could be expected, from the preferences of the two herbivores, as already discussed at length. However, such interpretation is complicated by the species observed to increase in abundance with stocking pressure: particularly in the sheep case, many of these increases cannot be explained by reduced competition following the grazing down of preferred species.

Other potential determinants of stock-related vegetation pattern are disturbance and nutrient transfer (section 1-8).

However, these factors were considered to be of the same order in the two paddocks. If they were the determinants, any differences in pattern between paddocks should have been differences in magnitude, rather than the reverse situations which were found (e.g. for *Enneapogon* spp.).

Thus, neither preferential selection, resulting in a decrease in preferred species and an attendant increase in less preferred species, nor trampling, nor nutrient transfer can individually account for the vegetation patterns observed. In the first case, differences between paddocks would be expected; but the differences actually found did not necessarily relate to the animals' preferences for the species concerned. In the latter two cases, some differences might be expected between paddocks, because of the potential differences in stocking levels, but the reversed signs between paddocks for piosphere pattern could not be explained by the action of these factors.

4-94 *On monitoring stock-induced changes.*

Many, if not most, of the Australian research reports on stock-induced vegetation trend, in the rangelands, have been based on surveys made at a single time, with patterns in space being used as the base for inference of trends in time. Prime examples are the studies of Beadle (1948), Jessup (1951) and Newman and Condon (1969), in which long-term grazing succession was inferred by comparison of site surveys, without long-term observation. Such philosophy is used extensively in the remainder of this thesis.

Barker and Lange (1969) and Lange (1971) discussed the need to monitor trends by repeated observation, in such a way that pasture degradation could be detected, and corrective action taken, before permanent damage ensued. The monitoring agent proposed was observation of piosphere patterns at each time, using Influence Analysis which, of course, deals simultaneously with a number of species. The rationale was that incipient degradation could be detected by changes in the extent of piosphere patterns, before reaching the stage of damage to the perennial species' populations.

The results of this chapter must cast doubt on the validity of such approaches, and indeed on the remainder of the research reported in this thesis, which is based on similar approaches. The piosphere patterns, and also the pattern of plant associations, were found to be ephemeral in nature: piosphere pattern was only evident at certain times, and species intercorrelations changed markedly in the course of observations. Hence the inference of long-term trend which might be drawn from observation of patterns in space at a single time will be very greatly dependent on the conditions at the time of observation, and may not indicate the true long-term trends at all.

The ephemeral nature of the patterns may be ascribed in part to the ephemeral species showing piosphere symmetry in their distributions, but many of these species are the very species considered to be advance indicators of pasture degradation. For example, the various *Bassia* species are generally reported to increase with grazing pressure, and to demonstrate degradation, by Ratcliffe (1936), Crocker and Skewes (1941), Beadle (1948), Jessup (1951), Moore (1935b), Carrodus et al (1964) and Barker and Lange (1970). *Stipa nitida* is reported to decrease under stocking (Osborn et al, 1931), as is *Enneapogon* (Beadle, 1948). The results described in this chapter show that such species cannot be regarded as reliable indicators of the level of stocking pressure; the stock-induced patterns appear intermittently, and so detection of the stocking influence is highly dependent on the time of survey. Thus great difficulty can be anticipated in the interpretation of changes in pattern with the view to monitoring pasture trends.

The problems in detecting incipient pasture degradation thus remain unsolved. Once the degradation becomes apparent in the populations of the long-lived perennial pasture plants, near-permanent damage has already occurred (see section 1.5). However, the shorter-lived species which might be expected to show the early progress of degradation, before the damage is serious, must be considered unreliable indicators because of the intermittent manner in which they display stocking effects.

4-95 *The short-term impact of cattle introduction.*

The prime purpose of the study was the determination of the effects of cattle introduction on the vegetation of former sheep pasture, in relation to the effects of continued sheep stocking. The individual stocking effects have been discussed in detail in the course of analyses, and the detailed conclusions can be summarized as follows.

1. The stocking effects of the two herbivores, particularly as evidenced by the existence of piosphere symmetries, differed with regard to the species concerned, the rection of the relationships, and the plant parameters most immediately affected by stocking.
2. Stocking effects were most easily detected in the distribution of common species, which, however, comprised only a small percentage of the total flora.
3. All stocking effects observed, for both herbivores, were ephemeral in nature; becoming obscured or disappearing entirely following re-growth of pastures.

The third conclusion is perhaps the most significant: it implies that the short-term patterns cannot be construed as indicative of long-term divergence between vegetations stocked with sheep and vegetations stocked with cattle. If this were not so, the short-term effects would imply considerable divergence in pasture composition, because of the manifest differences between the herbivores' effects on the most common species. The effect of the rains of 1973-74 must be considered once more. As already stated, the stocking effects must be, and are, most pronounced during drought. The nature of the rains, and the consequent frequency of pasture growth, would lead to the delay of any long-term divergence by minimising the effect of stock. This underlines the difficulty of mounting any investigation in the arid rangelands: the weather in the short-term cannot be predicted with certainty, and the predictive value of the results will be highly influenced by the weather patterns prevailing during observations. This was accepted at the outset of the study, but the rainfall was expected to be either absent, or intermittent, in keeping with past history. In either case, results of greater predictive value than those actually gained were anticipated. The heavy and continuous rains of 1973-74 were without parallel in a century of recordings, and the predictive value of data gained in such an atypical period was necessarily low.

Nonetheless, on the basis of the data gained from the short-term comparison of sheep and cattle stocking, the final conclusions, on the effect of cattle introduction to former sheep pasture, must be as follows:

1. The introduction of cattle to former sheep pastures results in the formation of short-term vegetation patterns, significantly different from those imposed under sheep-stocking.
2. There is no evidence that the differences in impact will result in long-term divergence between pastures switched to cattle and pastures still under sheep.

CHAPTER 5

LONG TERM CHANGE IN VEGETATION GRAZED BY CATTLE

5-1 INTRODUCTION

This chapter describes two surveys, which were undertaken to determine the long-term trend in vegetation grazed by cattle. One survey compared differences in species abundances between virgin and cattle-grazed areas, and the other made the comparison between cattle- and sheep-grazed areas. The effects on abundances of such factors as soil variation were minimised by careful selection of sample areas. Differences in abundance were considered to be evidence of long-term pasture divergence between stocking regimes. The surveys were not repeated. The basic assumptions, for inferring long-term change, were;

1. The status of that part of the plant community, observable at a particular time, would reflect the status of the whole community.
2. The status of the community under various grazing regimes could be directly inferred by comparisons of plant abundances between regimes; provided that differences resulting from disparities in landform, soil type, original vegetation or short-term weather effect were first eliminated.

A careful matching of site landscapes minimised the effect of landform, soil type and original vegetation on differences in plant abundance between sample areas. Any residual disparities in these features were taken into consideration, before stocking effects were inferred. Differences in weather sample areas were minimised, by selection of areas as close to each other as possible, and by simultaneous sampling.

Sampling areas were small (550ha), but the sampling was objective, with high internal replication (ca 110 quadrats/sample area). Species abundances between sample areas were compared by subjective appraisal of mapped data. Only those differences immediately obvious were considered further.

The choice of sites was limited, by (a) the few stations, within the dog fence, which had carried significant cattle herds for at least ten years, (b) the very few which had restricted cattle to set areas, and (c) the requirement for matched landscapes. Sites for the virgin/cattle comparison were selected on Pernatty station, and sites for the cattle/sheep comparison on Roxby Downs station (locations: fig. 1.1); in the sand/clay systems mentioned in chapter 2.

5-2 METHODS

5-21 *Selection of sample areas.*

In selecting areas with matched landscapes, soils and landforms could be directly compared, but the original vegetation had to be inferred. Tree distributions were used as the indicators of the original vegetation. Mature trees respond much more slowly to the impact of domestic grazing than do shorter-lived pasture species. The exact lifespans of tree species are not known, but they are over a century for such species as *Callitris collumelaris* (Lange, 1965) and *Acacia aneura* (Preece, 1971a,b). Hence, although understoreys may have been completely modified by stocking since settlement, the tree stratum still provides an index of the original vegetation. There are some limitations, however. Although mature trees are little affected by stock, seedlings and small saplings may be completely eliminated--see Hall et al (1964). Further, reduction of tree populations by previous logging may lead to incorrect inferences. The initial match was by ground reconnaissance, aided by aerial photographs. The validity of the match was checked in detail, in the course of the survey.

5-22 *Parameters used in sampling.*

Density counts (discussed in section 3-3) were attempted for all pasture plants encountered, dead or alive; although density was unsatisfactory for certain species, individuals of which could not be clearly defined. For instance, *Myriocephalus stuartii* was present in the virgin/cattle survey, but as dried and fallen sticks and seedheads: in this case, incidence only was recorded. *Eragrostis australasica*, also present, grew from underground rhizomes: in this instance, frequency was estimated, from ten $2x1.5m^2$ quadrats at each sample point. Frequency has severe statistical limitations in situations such as the present one, where adequate replication is not possible (Grieg-Smith, 1964). However, as Goodall (1970) suggests that it is a valid measure, if considered in its own right rather than as an index of other measures, frequency was employed in this investigation.

5-23 *Sampling system.*

20 x $1.5m^2$ quadrats were used throughout. Such quadrats were used successfully for density counts in similar situations by Barker and Lange (1970). The merits of the shape have already been discussed (section 3-3). The edge effects noted in that section were not apparent in this case. The same in/out rules were used.

In each survey, 112 quadrats were laid in a rectangular grid, dimensions 1800 x $3200m^2$ (2000 x 3500 yd^2). Dams were the datum points, set on or near a short side of the grid. As with the short-term study of the previous chapters, this area of greatest traffic was expected to show changes wrought by stock most clearly. Regular radial sampling, as used by Barker and Lange (1969), Rogers and Lange (1971), and random sampling were considered, but rejected on the following grounds.

1. With mapping as a main aim, an orthogonal grid was the most efficient system, since it gave a consistent scale over the whole area (Williams, 1971).
2. Radial sampling centred on waters would have oversampled clay flats in which waters were sited, relative to sand areas of equal concern.
3. Only overt differences in abundance and pattern were sought, and statistical treatments requiring estimates of precision were not contemplated.

The sampling grid was staggered; as the dune ridges had a more or less regular pattern, it was necessary to avoid bias which might result from a regular, repetitive soil pattern. The grids are shown in figure 5.1.

5-24 *Data presentation and analysis.*

Density data was displayed in map form. Comparisons were drawn on the basis of obvious differences in occurrences and/or abundances between sample areas. The maps are presented in appendix 2. As an adjunct to the density maps, associations based on species incidence were calculated, and are presented as constellation diagrams.

5-25 *Criteria for inferring long-term change.*

The virgin/cattle survey, on Pernatty station, was run in drought, but the cattle/sheep comparison, on Roxby Downs station, was made in a period of growth, following rains in late summer and autumn, 1973 (table 5.1). The method of inference differed accordingly between surveys. In the first case, a difference in abundance of a perennial species between sample areas was considered evidence for a long term change. However, lower abundances of an ephemeral species in the grazed area may have resulted from short-term grazing since last growth, or from a long-term decrease in the population under grazing. No inference was drawn, since the two possibilities could not be distinguished within the context of the survey. On the other hand, greater abundance of an ephemeral in the grazed area, irrespective of short-term grazing effects, was considered to indicate a long-term increase in the population

Fig. 5.1
SAMPLING GRIDS FOR VIRGIN/CATTLE AND CATTLE/SHEEP SURVEYS

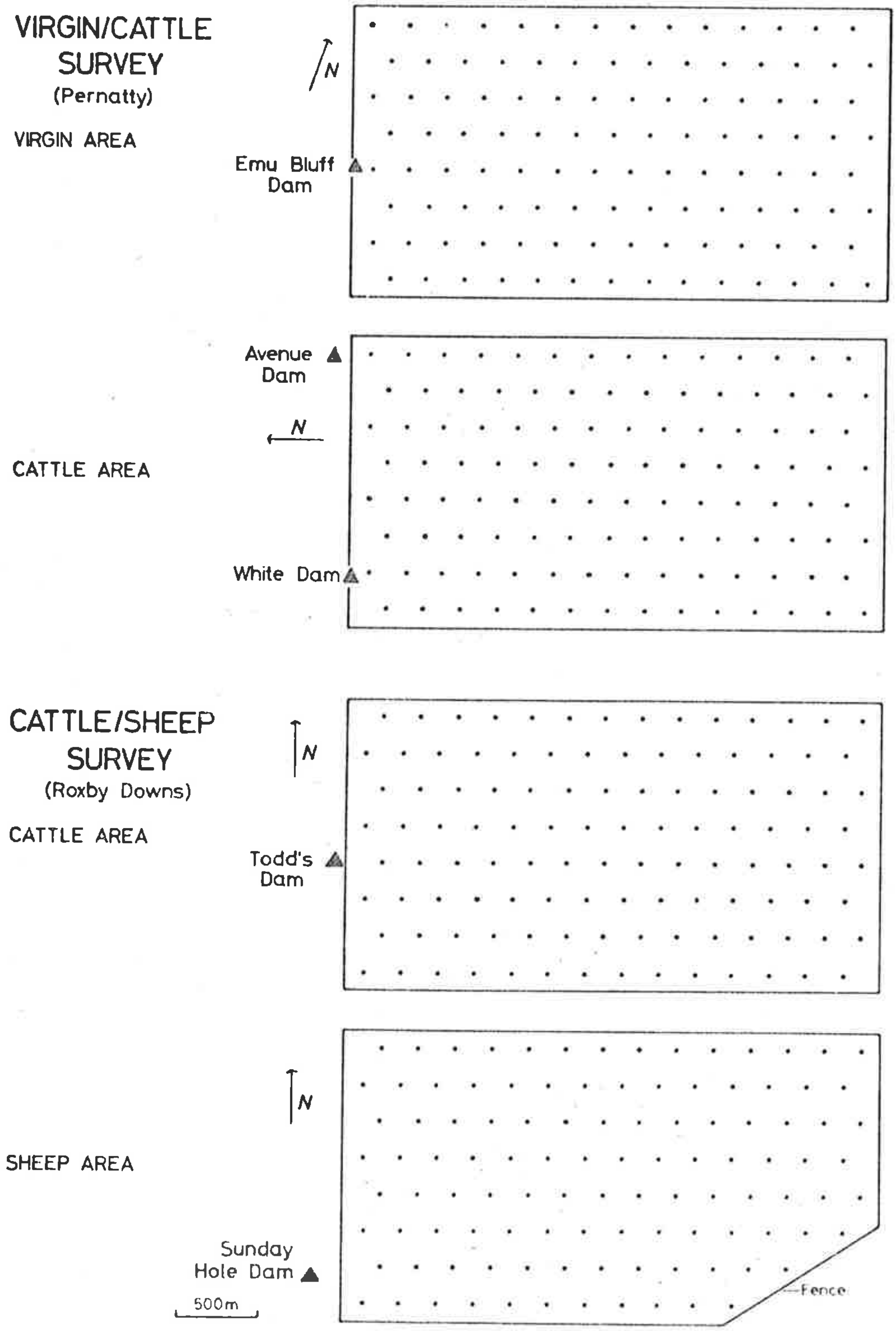


TABLE 5.1

RAINFALL IN THE PERNATTY-ROXBY DOWNS DISTRICT

(a) Rainfall in mm at Pernatty and Roxby Downs for the six months preceding surveys.

	Pernatty		Roxby Downs
1971 Nov	41	1972 Nov	4
Dec	8	Dec	0
1972 Jan	73	1973 Jan	12
Feb	6	Feb	97
Mar	0	Mar	8
Apr	0	Apr	16

(b) Rainfall in the three months preceding the for areas in the vicinity of the Roxby Downs survey

	Roxby Downs	Pernatty	Andamooka	Woomera
1973 Feb	97	121	99	121
Mar	8	12	11	13
Apr	16	18	41	8

Data courtesy of Bureau of Meteorology, Adelaide under grazing.

The cattle/sheep comparison had a simpler basis. Without the benchmark of a virgin site, species abundances were expressed only in terms of relative differences between sheep and cattle areas. All differences were treated as long-term rather than short-term in origin, since the survey was made in a growth period. Chapter 4 provides adequate evidence that short-term grazing effects are obscured in such times. Major differences between matched pastures hence may be considered long-term, provided that both pastures have received equivalent rain. The rains immediately preceding the cattle/sheep survey were widespread and consistent (table 5.1), the station manager reported that both areas had received equivalent amounts, and there were no obvious differences in the stage of growth between areas (plates *9, 10*).

5-3 RESULTS: VIRGIN/CATTLE COMPARISON.

5-31 *Stocking history of sample areas.*

The sample areas, in cattle-grazed and in virgin pasture, were located as shown in figure 5.2. The original Pernatty homestead was established in 1866, near the grazed area sampled. Log fences were built shortly after, containing both the flood flat of Pernatty Creek and the surrounding sandhills. Sheep were the main domestic stock, but a small cattle herd (ca 20 head) was maintained. Severe pasture degradation occurred, particularly in the first two decades of this century. Erosion was aggravated by periodic flooding. Dykes were built across the creek flats in 1926, to lessen flood

PLATE 9.

Near Todd's Dam, Roxby Downs Station. New growth of ephemeral species forming a sparse ground cover. Trees are *Acacia aneura* (foreground) and *Callitris columellaris* (extreme left). 11/5/73

PLATE 10.

Near Sunday Hole Dam, Roxby Downs Station. New growth of ephemeral species, largely grasses, forming a sparse ground cover. Trees are *Heterodendrum oleaefolium*. 11/5/73

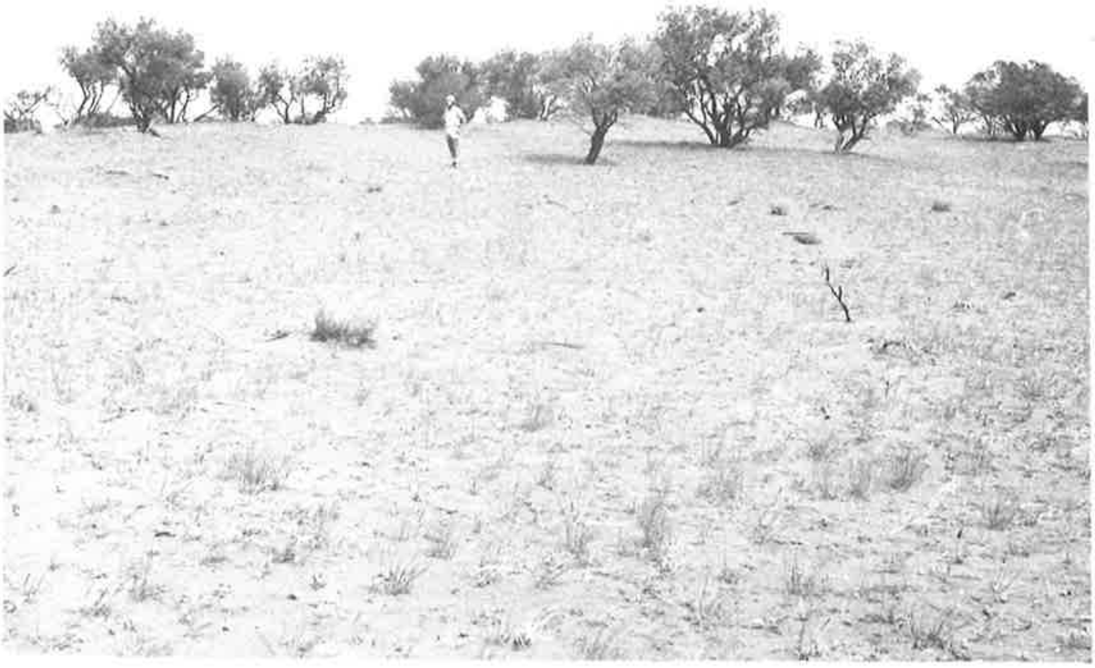
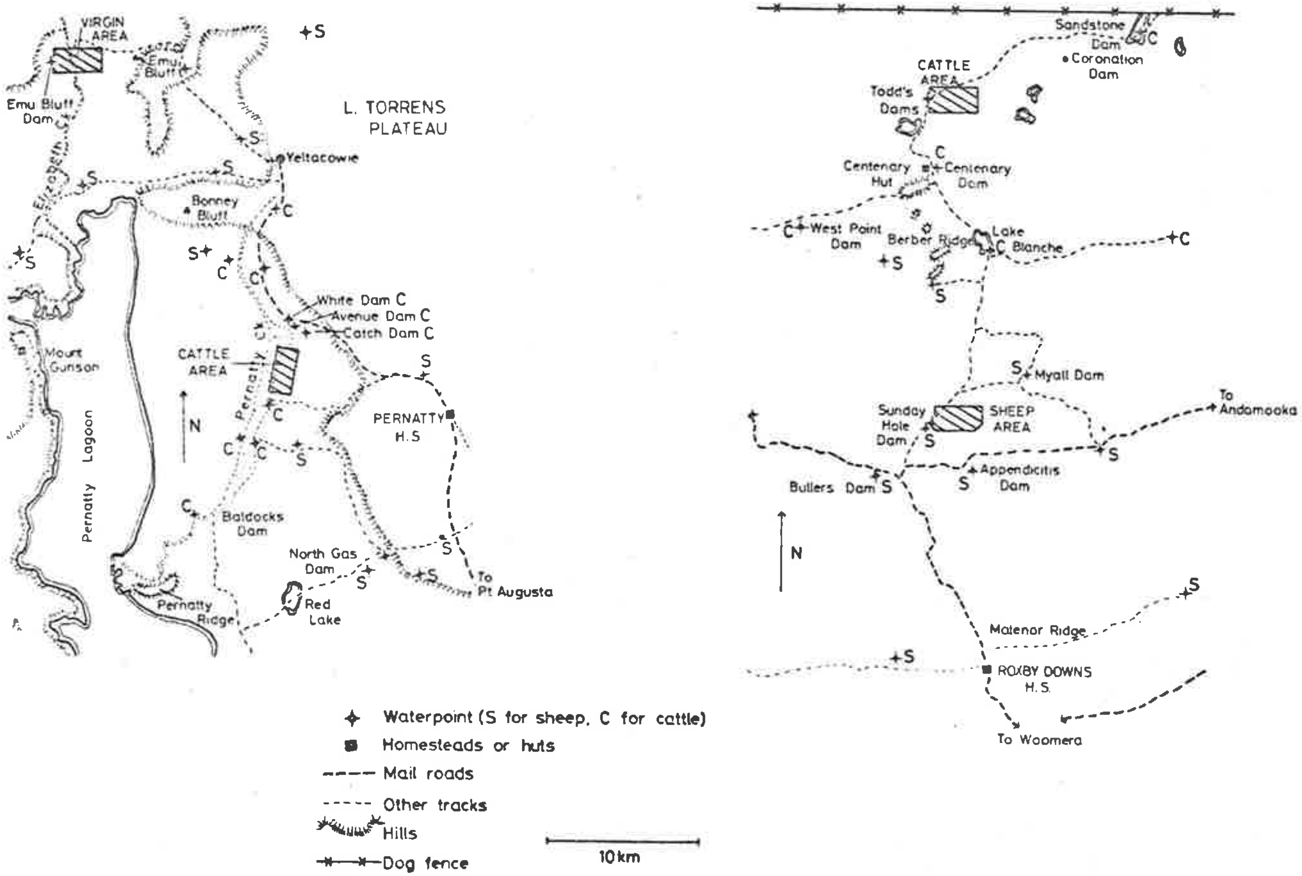


Fig. 5.2

LOCATION OF SURVEYS ON PERNATTY AND ROXBY DOWNS STATIONS

(a) PERNATTY (VIRGIN/CATTLE) SURVEY

(b) ROXBY DOWNS (CATTLE/SHEEP) SURVEY



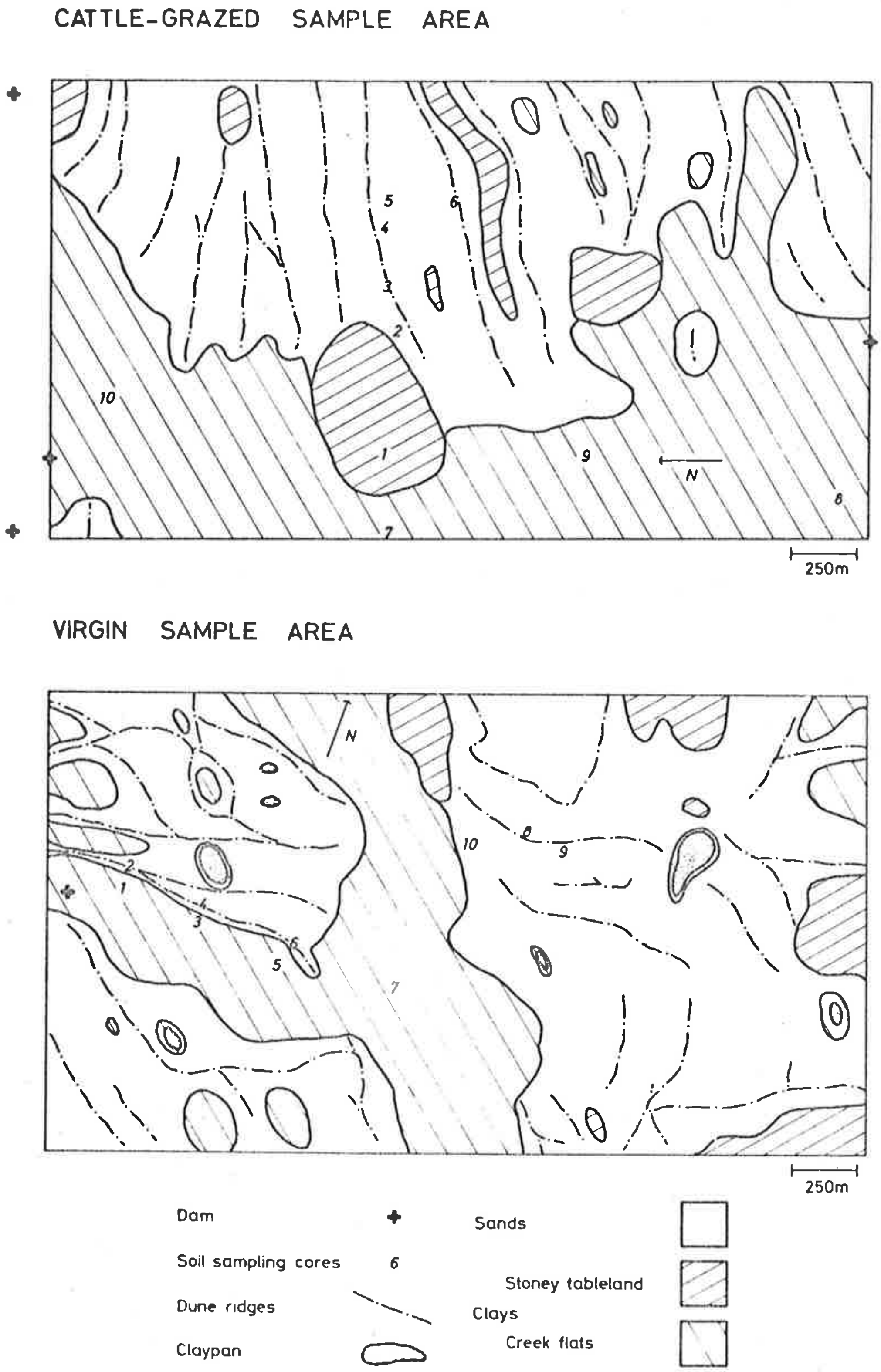
damage, and have been maintained since. These halted the water erosion, and the pasture of the flats regenerated to some extent. The cattle herd was increased gradually, from 50 head in 1930 to 200 head by 1950. Herd size has since fluctuated between 200 and 500 head, with the mode at 300 head. By 1950, the Pernatty Creek and the surrounding dunes had been turned over entirely to cattle, as a semi-open range. The range's limits were, in 1972, Yeltacowie outstation and Baldock's dam. Cattle tended to move from water to water, with camps in sandhills up to 2000m from the creek: maximum penetration into the sandhills was ca 3000m. While sheep were responsible for the initial impact and resultant change in vegetation, cattle were expected to have imposed patterns of their own during the twenty years of continuous and exclusive grazing.

The Elizabeth Creek area was also leased in the 1860's, but shortage of water prevented its utilisation. The near-virgin part sampled may have been grazed, by sheep, for a short period in the late 19th century, but there remains no evidence of damage. Emu Bluff dam, used as the sampling grid datum point, was sunk in 1958; but has only held water intermittently. From 1960 to 1972, stock (probably cattle, but no certain record) were run from it, for short periods totalling seven months at the most. Prior to 1958, the area was ungrazed in living memory. The soil lichen crust was intact, and shrubs and trees bore no evidence of browsing.

5-32 *Description of matched landscapes.*

Figure 5.3 shows the soil distributions for both virgin and cattle-grazed areas. None of the mapping units are completely

Fig. 5.3
SOIL LANDSCAPES
IN THE VIRGIN/CATTLE SURVEY



homogenous: main units contained small pockets of other types. The principal profile forms (P.P.F's; Northcote, 1971) for the mapping units, as observed from auger cores, were;

1. Ucl.22 for sands--coarse red sands with some accumulation of organic matter in the surface 10cm, but no other pedologic organisation; not coherent;
2. Drl.33 for clays--duplex soils, with a loam overlaying heavy clay, A horizon with a surface crust, a sporadically bleached A_2 horizon, increasing alkalinity down the profile, calcareous in the B horizon, with gypsum inclusions appearing;
3. Drl.13 for stoney tableland soils--as for Drl.33 excepting the absence of an A_2 horizon and gypsum inclusions, but with surface pebbles and stones in the profile.

This concurs with the mapping in the Atlas of Australian Soils (1960). While the P.P.F's were the same for both surveys, there existed detailed differences. The A horizon in the cattle sample was much deeper than in the virgin sample, possibly due to silt deposition behind dykes. Both horizons in the cattle sample contained a lower proportion of soluble salts than was found in the virgin sample. Differences are summarized in table 5.2.
No such differences were found between areas for stoney tableland soils or sands.

Both sample areas embraced equivalent topographies, viz., areas of stabilised sand ridges, as marked on figure 5.3, extensive clay flats containing major drainage channels, and some rises of stoney tableland associated with the neighbouring Lake Torrens and Arcoona plateaux.

TABLE 5.2

SALT CONTENT AND HORIZON DEPTH OF CLAY FLAT SOILS.

From five cores in each sample area, ranked in order.

% soluble salts (1:5 soil:water)				Depth of A horizon in cm.	
A hor.		B hor.			
virgin	cattle	virgin	cattle	virgin	cattle
3.0	1.7	4.5	2.0	10	100
1.4	0.02	3.5	0.8	10	60
o.7	0.02	3.0	0.4	7	40
0.2	0.02	2.5	0.25	5	25
0.05	0.02	1.1	0.25	5	25

Figure 5.4 shows the tree distribution in each survey. As with the soils, there was little difference between the two sample areas for trees of the sands and stoney tablelands. The clay flats in the cattle area bore more trees, in particular *Eucalyptus camaldulensis*, probably as a result of the lower salinity by comparison with the clay flats in the virgin survey.

The match in landscape was thus not complete. Nonetheless, it was adequate for comparison between pastures of the sand and stoney tableland soils, but comparisons between pastures of the clay flats had to allow for soil differences.

Quadrats laid on the soil types, for virgin and cattle-grazed areas respectively, 67 and 73 on sands, 37 and 48 on clays, and 8 and 11 on stoney tableland soils.

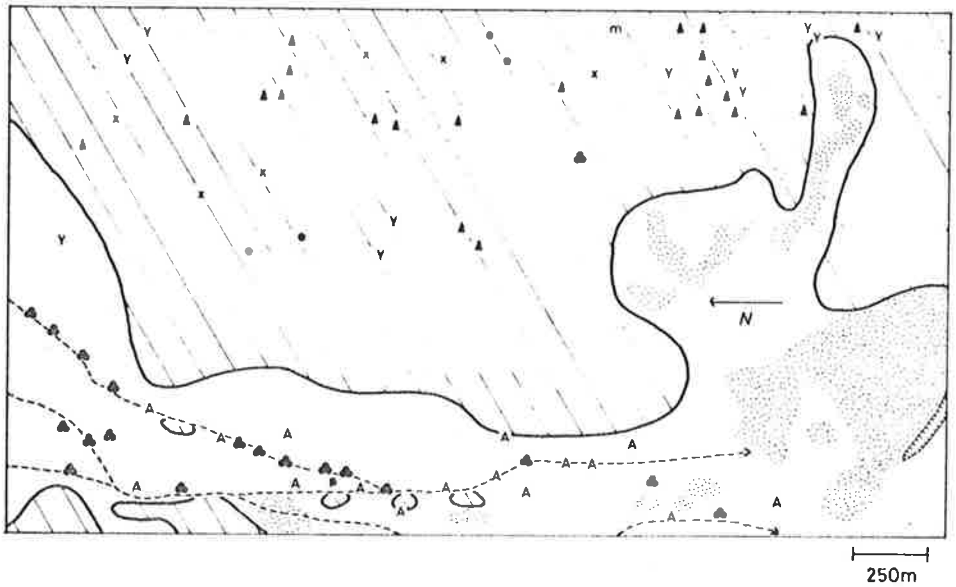
5-33 *Abundance of pasture species.*

The distributions of 39 species other than trees or tall shrubs were mapped. Table 5.3 summarizes the comparisons of abundance between surveys.* Abundances were compared for the particular soil types; since most species were restricted to one or other type, overall comparisons between sample areas would have been biased by the differences in proportion of quadrats on the types. Ten species were found with no overt differences in abundance between sample areas, 14 were less abundant in the cattle area (including one completely

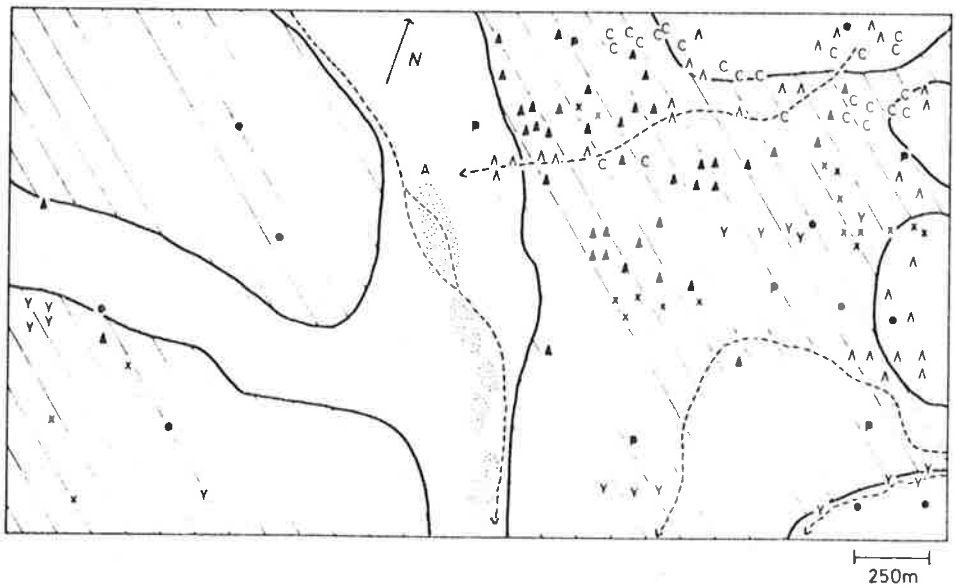
*Maps are presented in appendix 2.

Fig. 5.4
TREE DISTRIBUTIONS IN THE VIRGIN/CATTLE SURVEY

CATTLE-GRAZED SAMPLE AREA



VIRGIN SAMPLE AREA



Acacia aneura	Y	Heterodendrum oleifolium	●	Dyke	
Acacia linophylla	x	Callitris columellaris	▲	Drainage line	
Acacia sowdenii	Λ	Pittosporum		Swamp	
Casuarina cristata	C	Myoporum platycarpum	m	Acacia ligulata-Dodonea viscosa	
Acacia victoriae	A	Euc camaldulensis			

TABLE 5.3

VIRGIN/CATTLE COMPARISON: SPECIES ABUNDANCES IN THE GRAZED AREA RELATIVE TO ABUNDANCES IN THE VIRGIN AREA.

Species	Perennial or Ephemeral	Main soil type	Abundance * in grazed area
Atriplex spongiosa	E	Clays	+
Bassia brachyptera	E	Clays	+
---- *diacantha*	E	Clays	+
---- *divaricata*	E	Clays	+
---- *paradoxa*	E	Clays	+
Enneapogon avenaceus	E	Ubiquitous	+
Eragrostis australasica	P	Clays	+
---- *dielsii*	E	Clays	+
Plagiosetum refractum	E	Sands	+
of *Sisymbrium* sp.	E	Sands	+
Tragus australianus	E	Clays	+
Xanthium spinosum	E	Clays	+
Aristida contorta	E	Sands	-
Atriplex limbata	E	Clays and sands	-
---- *vesicaria*	P	Clays	-
Crotalaria dissitiflora	P	Sands	-
Kochia astrotricha	P	Clays	-
---- *georgei*	P	Clays	-
Myriocephalus stuartii	E	Sands	-
Nitraria schoberi	P	Clays	-
Portulaca oleracea	E	Clays and sands	-
Sida virgata	P	Sands	-
Salsola kali	E	Clays and sands	-
Pachycornia tenuis	P	Clays	-
Abutilon otocarpum	E	Sands	(+)
Aizoon quadrifidum	P	Clays	(-)
Physllanthus fuernrohrii	P	Clays	(-)
Bassia obliquicuspis	E	Stoney t/land clays	0
Brachyscome ciliaris	E	Ybiquitous	0
Citrullus lanatus	E	Sands	0
Euphorbium drummondii	E	Sands	0
Kochia pyramidata	P	Clays	0
---- *tomentosa*	P	Clays	0
Carpobrotus equilaterale	P	Clays	0
Panicum effusum	E	Ubiquitous	0
Triraphis mollis	E	Sands	0
Zygochloa paradoxa	P	Sands	0

* Abundance ratings: + more abundant in grazed relative to virgin.
- less abundant in grazed relative to virgin.
( ) difference is marginal.
0 no difference between areas.

absent), and 13 species were more abundant in the cattle area (including two not present in the virgin area). Two species showed an apparent shift in preferred soil type between sample areas.

Of the species less abundant in the grazed area, five were ephemerals, for which no inferences of long-term decrease could be drawn. The remainder were perennials, two of which showed only marginal differences, and so were not considered. Of the rest, *K. georgei* was completely absent from the cattle-grazed area; *Nitraria schoberi, Atriplex vesicaria* and *Crotalaria dissitiflora* were rare by comparison with the virgin area; *Pachycornia tenuis* was absent from the sands of the cattle area; and both *Kochia astrotricha* and *Sida virgata* had incidences similar between areas, but lower densities in the cattle area. *N. schoberi* is a character plant of saline loams or clays (Specht, 1972), and its lower abundance was ascribed to the lower salinity of such soils in the cattle area. Such an argument did not apply to the other clay-soil species. *K. astrotricha, K. georgei* and *A. vesicaria* tolerate a range of salinities greater than that found in the survey (Jessup, 1951), and are usually low in abundance in *Nitraria*-dominated vegetations in any case (Specht, 1972, App.V). Nor was the swamp present in the cattle area extensive enough to account for their lower abundances. *C. dissitiflora* and *S. virgata* grew on sands, with no edaphic differences between sample areas. *P. tenuis* is usually found on saline loams and clays (Jessup, 1951), and its occurrence on sands in the virgin area was unusual. However, its absence from sands in the cattle area, when present in the other, also was not a result of edaphic differences but rather of stocking. Thus, the lesser abundances of *A. vesicaria, C. dissitiflora, K. georgei, K. astrotricha, P. tenuis* and *S. virgata* in the grazed area, by comparison with the virgin area, were also considered indicative of a long-term decrease in their populations, resulting from stocking.

Of the thirteen species with a greater abundance in the cattle area, only *Eragrostis australasica* was perennial. A character plant of swamps (Specht, 1972), its abundance was probably due to ephemeral swamps formed by the dyke within the sample area. The ephemerals *Atriplex spongiosa* and *Tragus australianus* were positively correlated with it. These three species, and *Abutilon otocarpum,* only marginally more abundant, were not considered further. *Bassia paradoxa* and the alien invader *Xanthium spinosum* were widespread in the cattle-grazed area, but completely absent from the virgin area; *Bassia brachyptera, B. diacantha, B. divaricata, Enneapogon avenaceus,* and *Eragrostis dielsii* showed greater abundances in the cattle area. These species were more abundant, not only on clay flats where the cause may have been the soil differences, but also on clay pockets isolated from the flats, and on sands. *Plagiosetum refractum* and of *Sisymbrium* sp., restricted to sands, were more frequent and more abundant in the cattle area, despite the similarity of the sands between sample areas. Thus, the greater abundances of *Bassia brachyptera, B. diacantha, B. divaricata, B. paradoxa, Enneapogon avenaceus, Eragrostis dielsii, Plagiosetum refractum,* of *Sisymbrium* sp., and *Xanthium spinosum* in the grazed area, by comparison with the virgin area, were considered indicative of long-term decreases in the species' populations, resulting from stocking.

Atriplex inflata and *Babbagia acroptera* showed apparent differences between sample areas in soil habitat. In the virgin area, the former was found on all soils, with maximum densities on sands; and the latter, while growing mainly on clay soils, was also found on sands. In the cattle area, *A. inflata* was less frequent and far less abundant on sands by comparison with clay soils, and *B. acroptera* was not found on sands at all. Possible explanations are that (a) these species were more abundant on clays than on sands in the cattle area, by comparison with the virgin area, because of the less saline and more loamy soils; and (b) their absence from the sands was a result of short-term grazing. Further investigation was not made. No inferences were drawn regarding the long term effect of stock on these species.

5-34 *Association of pasture species.*

An association analysis for each treatment divided the species into two main groups, positively associated within groups, and negatively associated between groups. The groups corresponded to sand habitat and clay soil habitat respectively (fig. 5.5). Main groups in the cattle pasture were not as clearly defined as those in the virgin pasture: this may have been due to both grazing and soil differences.

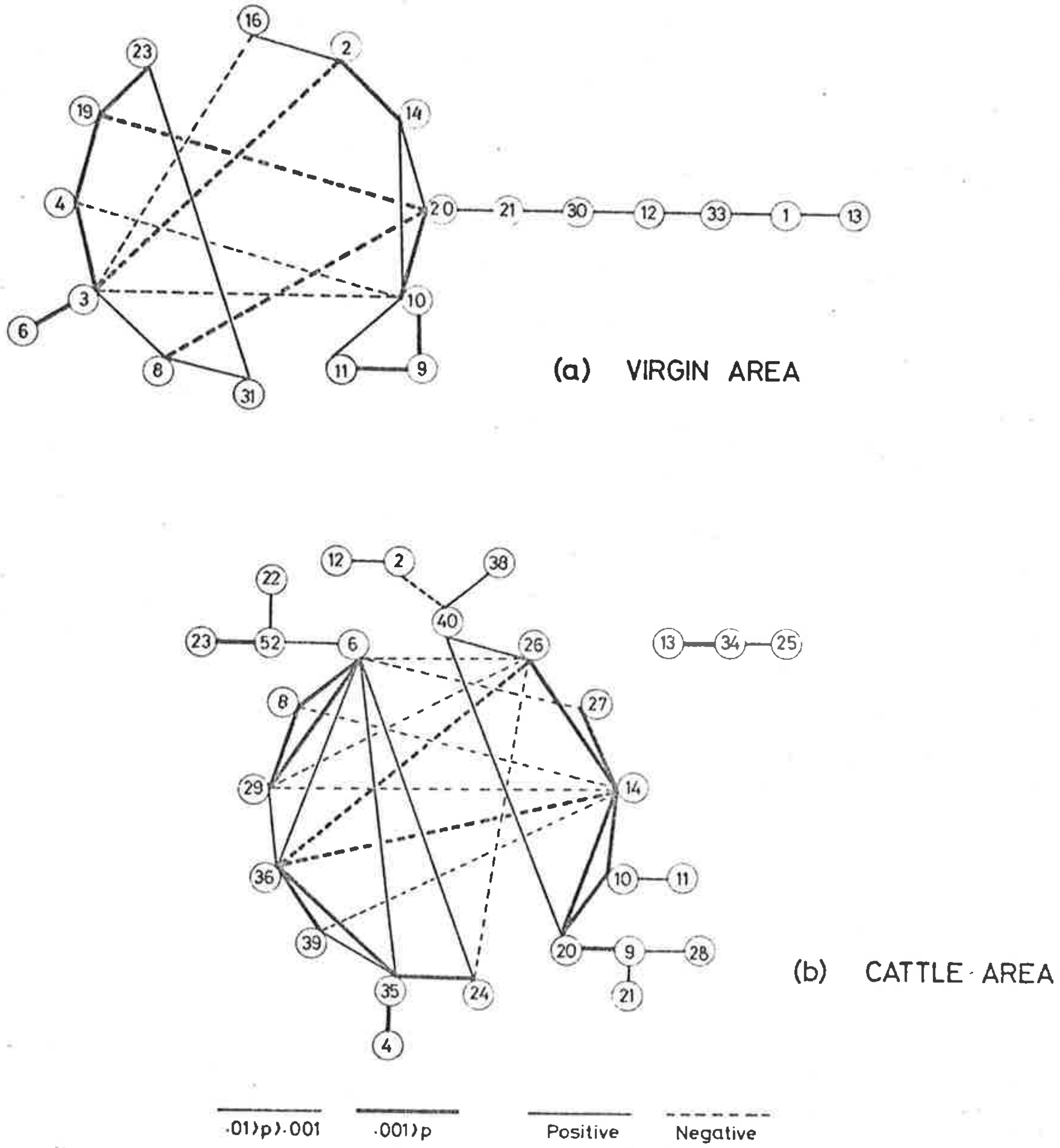
FIGURE 5.5

PLANT ASSOCIATIONS IN THE VIRGIN/CATTLE SURVEY

KEY

1. *Atriplex limbata*
2. *A. inflata*
3. *A. vesicaria*
4. *Pachycornia tenuis*
6. *Bassia decurrens*
8. *Babbagia acroptera*
9. *Euphorbia drummondii*
10. *Sida petrophila*
11. *Phyallanthus fuernrohrii*
12. *Brachyscome ciliaris*
13. *Aizoon quadrifidum*
14. *Salsola kali*
16. *Myriocephalus stuartii*
19. *Eragrostis dielsii*
20. *Aristida contorta*
21. *Triraphis mollis*
22. *Tragus australianus*
23. *Dactyloctenium radulans*
24. *Atriplex spongiosa*
25. *Kochia tomentosa*
26. *Palgiosetum refractum*
27. *cf Sisymbrium*
28. *Dodonaea viscosa*
29. *Bassia brachyptera*
30. *Enchylaena tomentosa*
31. *Portulaca oleracea*
33. *Panicum effusum*
34 *Bassia diacantha*
35. *B. paradoxa*
36. *B. divaricata*
38. *Enneapogon avenaceus*
39. *Eragrostis australasica*
40. *Solanum* sp.
52. *Tragus australianus* + *Dactyloctenium radulans**

* Confused identification in certain quadrats.



ASSOCIATIONS

5-4 DISCUSSION: VIRGIN/CATTLE COMPARISON

The decrease of the perennials *A. vesicaria, C. dissitiflora, K. astrotricha, K. georgei* and *P. tenuis* was a likely result of the heavy sheep stocking and subsequent erosion prior to the introduction of cattle, as discussed in chapter 1. Nonetheless, the period under cattle was considered adequate for significant regeneration of at least some of these populations. (For example, regeneration of *Atriplex* species on the Koonamore Vegetation Reserve was well advanced after an equivalent period, despite severe intervening drought--Hall et al, (1964). Seed sources for the latter three species were found within the sample area, and sources for the former two were present upstream, along Pernatty Creek. The periodic flooding of this watercourse must have brought seeds into the sample area at several intervals after the introduction of cattle. At the least, the cattle have maintained the original sheep impress on these perennials by suppressing regeneration, if not reducing the surviving populations further.

For the ephemeral species encountered in the Pernatty survey, several generations would have elapsed since 1950. Chapter 4 indicated that short-term stocking effects on such species are largely obscured in growth periods. A series of ephemeral growth periods in the absence of grazing must obscure, if not obliterate, the longer-term stocking effects. Populations of the grass *Stipa nitida,* on the Koonamore Vegetation Reserve, showed marked differences in abundance between populations within the ungrazed Reserve and neighbouring grazed paddocks, although the Reserve had only been in existence for six years (Osborn et al, 1931--the authors considered *Stipa* to be perennial, but the fluctuations in its populations, reported in chapter 4, show it to be ephemeral). Similarly, a series of ephemeral growth periods, following a change in grazing regime, must obscure the effects of the earlier, and show most clearly the effects of the later regime. Hence, the inferred increases in ephemeral populations were regarded as due only to cattle.

The general trends imposed under cattle grazing, as indicated by the results of the comparison, are:

1. The regeneration of some perennial pasture species is suppressed;
2. Increases in abundance, due solely to cattle grazing, are found only for ephemerals.

This is the same pattern reported to develop under sheep grazing (section 1-52). The *particular* species involved are reported as reacting in the same manner to sheep grazing: *A. vesicaria, K. astrotricha* and *K. georgei* are reported as decreasers (Ratcliffe, 1936; Crocker and Skewes, 1941; Beadle, 1948; Jessup, 1951; Carrodus et al, 1965), and *Bassia* (all the above species), *Babbagia acroptera,* and the invader *X. spinosum* are reported as increasers under sheep stocking (above references; and Leigh and Mulham, 1965). The only conflict between the present inferred trends under cattle and the reported trends under sheep is the increase of *Enneapogon avenaceus,* a species decreasing under sheep (Beadle, 1948). The increase also conflicts with other reports on the effect of cattle. Chapter 4 indicates that the species decreases with increasing cattle stocking; and Low (1973) has shown its importance in cattle diet in the Alice Springs area. Hence, under prolonged cattle grazing, the species could be expected to decrease rather than to increase.

Preferential grazing selection of plant species is often considered the major cause of stock-induced vegetation pattern (section 1-8), resulting in a decline of preferred species, and an increase of less preferred species due to lowered competition. Cattle preferences show some similarities in general, but marked differences in detail, by comparison with sheep preferences (section 1-63). Hence, there should arise marked differences in the effects of the two herbivores. In the present case, the inferred long-term effects of cattle are closely similar to the reported long-term effects of sheep. If the animals' preferences are the main causes of pattern, this is a most unlikely result.

Alternative determinants are disturbance and nutrient transport. The latter plays a minor role, because of the low stocking rates: excepting perhaps in the immediate vicinity of the water (section 1-8), the "sacrifice zone". Mechanical disturbance of soils and plants is proposed here, as the major cause of long-term vegetation pattern and change related to stocking. If this is correct, most of the pattern should be independent of dietary preferences of the particular herbivore. This can explain the close similarity between the observed cattle effects and the reported sheep effects, despite the animals' different diets.

The special situation at Roxby Downs was selected to test this hypothesis in part. The comparison was drawn between cattle- and sheep-grazed areas, with equivalent stocking (in the manager's estimation). The predicted result was no difference in vegetation between areas, attributable to differential dietary selection of sheep and cattle.

5-5 RESULTS: CATTLE/SHEEP COMPARISON

5-51 *Stocking history of sample areas.*

The sample areas, in cattle-grazed and in sheep-grazed pastures, were located as shown in figure 5.2. The northernmost part of the present Roxby Downs station, including the cattle-grazed sample area, was stocked from 1870 to ca 1930 under a separate lease. Sheep were run initially, with a gradual transition to cattle. By 1945, the northernmost paddocks were grazed solely by cattle. Degradation of pastures followed settlement, and continued at least until 1961. At this time, the lease came under the present management, and pasture regeneration was attempted (B.G. Lay, pers. comm.,* has informed me that the perennial pastures in 1971 were still in worse condition than in 1949). From 1945 to 1973, cattle numbers varied between 100 and 700 head, with above 200 head in most years. The highest continuous level was 500 head, between 1945 and 1951. From 1966 to 1973, numbers had increased to 600 head. As on Pernatty, cattle were run on

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* M.Sc. Thesis, Botany Dept., University of Adelaide (1972). Lay repeated Jessup's (1951) assessment of pasture condition on this station.

semi-open range, with no maintenance of the original subdivisional sheep fencing. However, there was less movement between waters, probably because of the wider spacing. The manager reported that herds tended to graze from a particular water. The datum point for the cattle-grazed sample areas was Todd's dam, sunk in 1945. The piosphere centred on this dam was induced solely by cattle, with no prior sheep impress, as the nearest waters before 1945 were too distant for sheep to graze the area.

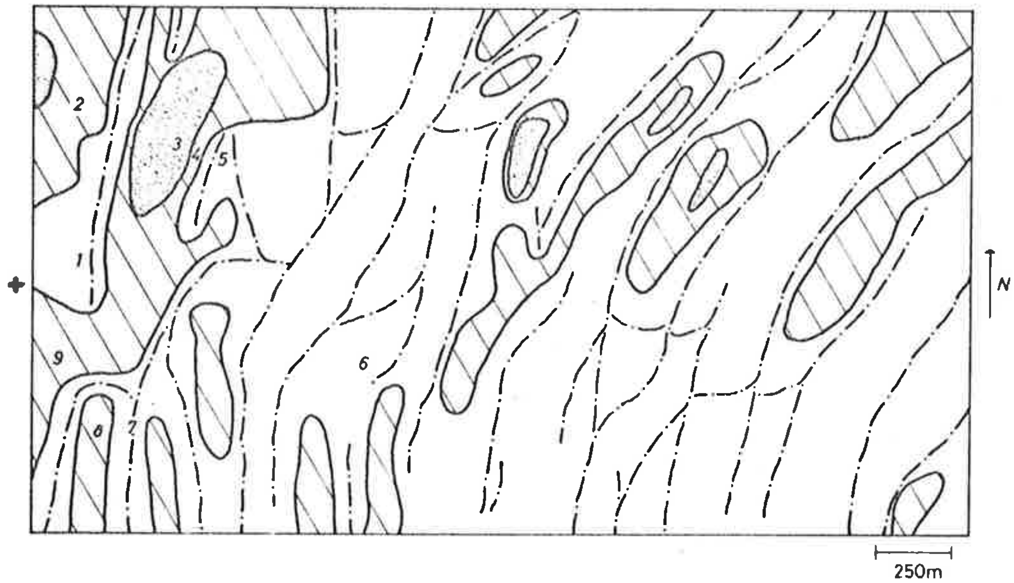
The southerly part of the station, including the sheep-grazed sample area, was grazed by sheep only, from 1870. Pasture degradation occurred, as in the northernmost parts. From 1946 to 1973, sheep numbers varied between 9,000 and 25,000 head, with the mode at 15,000. Highest continuous levels were 23-24,000 head between 1953 and 1957. Numbers had declined from 22,000 in 1969 to 11,000 in 1973, to permit major expansion of the cattle herd. The datum point for the sheep-grazed sample area was Sunday Hole dam, sunk 1920 as a small catch, enlarged in 1945 and 1961. Stock numbers on this dam prior to 1961 were not known, but the present management has run 600 head, with little variation, since 1961, and considered this equivalent to their cattle-stocking rates.

5-52 *Description of matched landscapes.*

Figure 5.6 shows the soil distributions for both sample areas. Mapping units are more homogenous than in the virgin/cattle comparison. The P.P.F's for the mapping units, as observed from

Fig. 5.6
SOIL LANDSCAPES IN THE CATTLE/SHEEP SURVEY

CATTLE-GRAZED SAMPLE AREA



SHEEP-GRAZED SAMPLE AREA

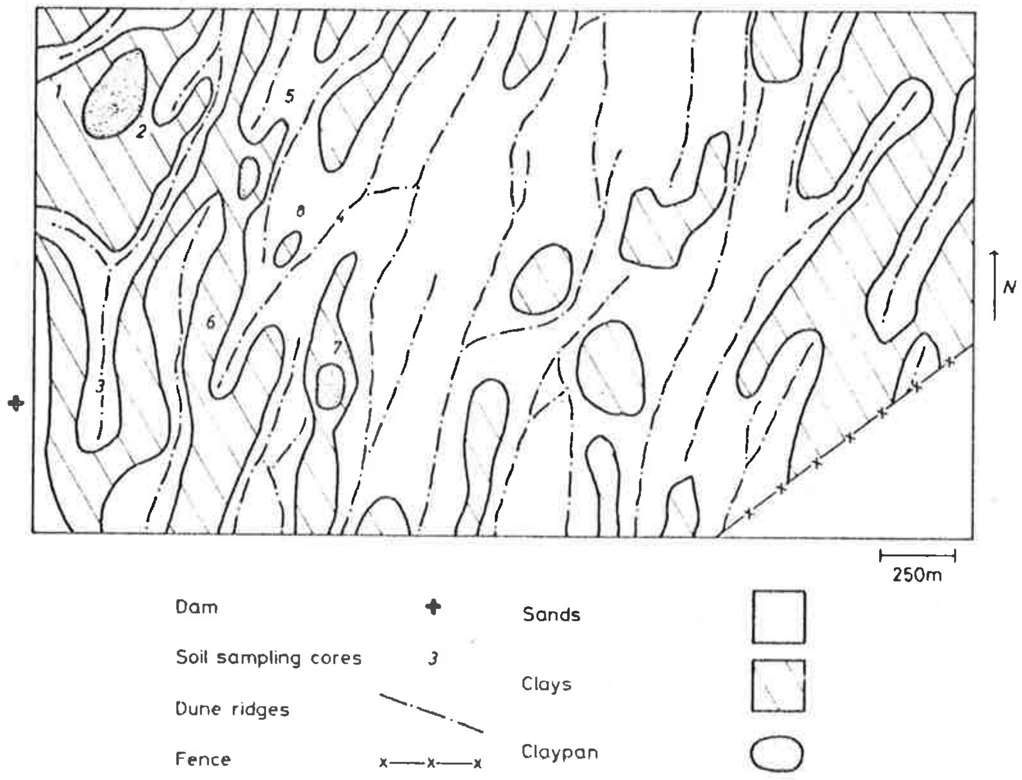
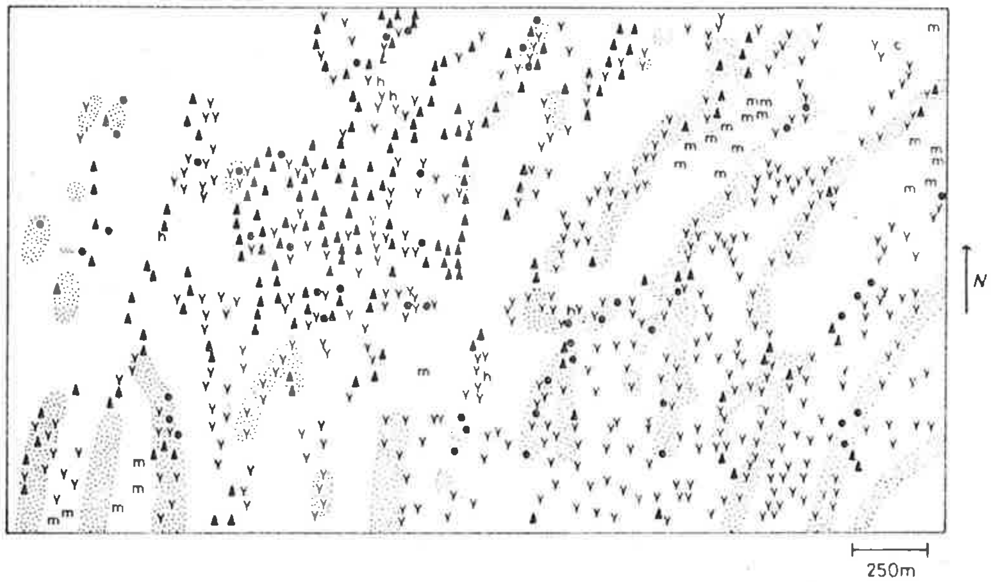
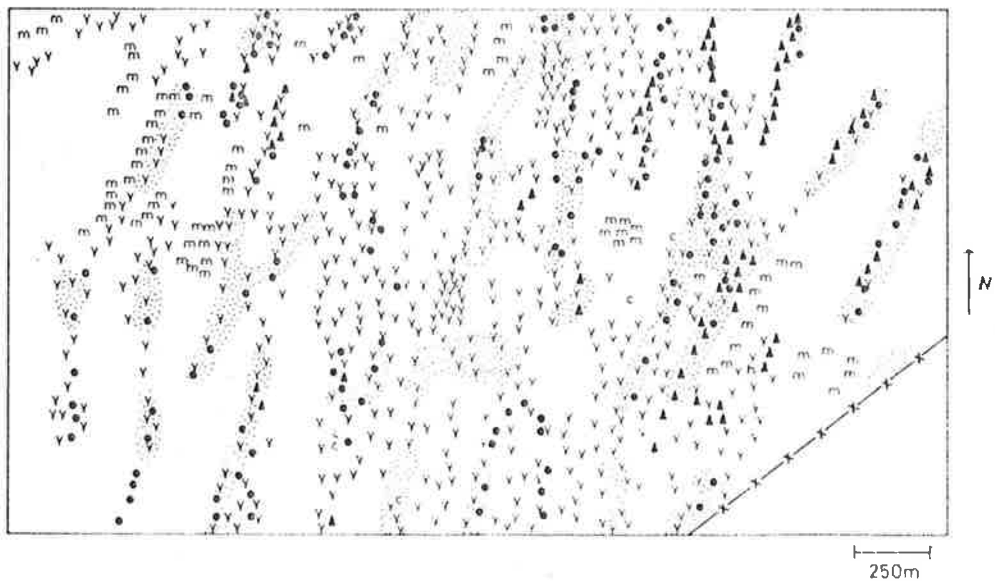


Fig. 5.7
TREE DISTRIBUTIONS IN THE CATTLE/SHEEP SURVEY

CATTLE-GRAZED SAMPLE AREA



SHEEP-GRAZED SAMPLE AREA



Heterodendrum oleifolium	●	Cassia nemophila	c
Callitris columellaris	▲	Hakea leucoptera	h
Mulga	Y	Acacia ligulata-Dodonea viscosa	
Acacia sowdenii	m	Fence	x——x——x

auger cores, were:

1. Ucl.22 for sands (described in section 5-32);
2. Gn3.12 for clay soils--gradational soils with a sandy loam A_1 horizon, no A_2 horizon; a red clay B horizon, calcareous with a smooth-ped fabric.

The P.P.F's were the same for both areas, and no differences in other parameters were found (table 5.4 c.f. table 5.2).

TABLE 5.4

SALT CONTENT AND HORIZON DEPTH OF CLAY SOILS
From four cores in each sample area, ranked in order

% soluble salts (1:5 soil:water)				Depth of A horizon in cm.	
A hor.		B hor.			
cattle	sheep	cattle	sheep	cattle	sheep
.1	1.0	.5	1.0	40	45
.1	.06	.4	1.0	40	40
.05	.03	.4	.1	35	20
.04	.02	.2	.1	30	20

Both areas had similar topographies. The dominating land-forms were low sandridges, as before, interspersed with clay subsoiled flats. No major drainage channels were present, but instead there were small, ill-defined channels draining into claypans within the sandridges.

Figure 5.7 shows the tree distributions for each area. *Acacia aneura* and *A. linophylla* were mapped as one unit, "mulga". While these most common species could be distinguished on the ground, they were indistinguishable from aerial photographs. Hence their distribution could not be interpolated between the ground transects with confidence. There were slight differences in tree distributions, with *Callitris collumelaris* (native cypress) more continuous in the cattle area than in the sheep area, and mulga *vice versa;* but differences were not so great as to cast doubt on the comparability of the two vegetations.

The match was more complete than in the previous comparison. On the basis of the soils, topographies and tree distributions, the vegetations of both sand and clay soils were regarded as comparable between sample areas. The number of quadrats laid on the two soil types were, for the cattle and sheep surveys respectively, 79 and 72 on sands, with 33 and 35 on clay soils.

5-53 *Abundance of pasture species.*

The distributions of 43 species other than trees or tall shrubs were mapped. Table 5.5 summarizes the comparisons of abundances between surveys. Abundances were compared as described in section 5-33. 26 species showed either marginal or no differences in abundance between sample areas, 11 species were more abundant in the cattle-grazed area, and 6 species less abundant in the cattle area. Only two of the species showing differences were perennial. Following the rationale of section 5-25, these differences were ascribed to long-term changes in the populations caused by stock, with different outcomes for sheep and cattle stocking.

TABLE 5.5

CATTLE/SHEEP COMPARISON: SPECIES ABUNDANCES IN THE CATTLE AREA RELATIVE TO ABUNDANCES IN THE SHEEP AREA.

Species	Perennial or Ephemeral	Main soil type	Abundance * in cattle area
Aizoon quadrifidum	P	Clays	+
Atriplex inflata	E	Sands	+
Crotalaria dissitiflora	P	Sands	+
Erodium cygnorum	E	Ubiquitous	+
Portulaca oleracea	E	Clays	+
Salsola kali	E	Sands	+
Sida virgata	E	Sands	+
Tribulus terrestris	E	Sands	+
Tripogon loliiformis	E	Sands	+
Zygophyllum aurantiacum	E	Clays	+
Atriplex spongiosa	E	Clays	-
Aristida contorta	E	Ubiquitous	-
Citrullus lanatus	E	Sands	-
Enneapogon avenaceus	E	Ubiquitous	-
Eragrostis dielsii	E	Clays	-
Ptilotus polystacheus	E	Sands	-
Abutilon otocarpum	E	Sands	(-)
Atriplex limbata	E	Ubiquitous	0
---- *vesicaria*	P	Clays	0
Babbagia acroptera	E?	Clays	0
Bassia brachyptera	E	Clays	0
---- *decurrens*	E	Clays	0
---- *diacantha*	E	Ubiquitous	(+)
---- *divaricata*	E	Clays	(+)
Bassia intricata	E	Clays	0
---- *obliquicuspis*	E	Clays	0
---- *paradoxa*	E	Clays	0
---- *patenticuspis*	E	Clays	(-)
---- *sclerolaenoides*	E	Clays	0
Brachysome ciliaris	E	Clays	0
Clianthus formosus	E	Sands	0
Dactyloctenium radulans	E	Clays	(+)
Eragrostis eriopoda	E	Sands	0
Euphorbium drummondii	E	Ubiquitous	0
Kochia astrotricha	P	Clays	[illegible]
---- *eriochlada*	P	? (rare)	[illegible]
Phyallanthus fuernrohrii	P	Clays	[illegible]
Plagiosetum refractum	E	Sands	(-)
Ptilotus obovatus	P	? (rare)	[illegible]
Sida corrugata	E	Sands	(-)
of *Sisymbrium* sp.	E	Sands	[illegible]
Tragus australianus	E	Sands	[illegible]

* Abundance ratings:
+ more abundant under cattle-grazing relative to under sheep-grazing.
- less abundant under cattle-grazing relative to under sheep-grazing.
( ) difference is marginal.
0 no difference between areas.

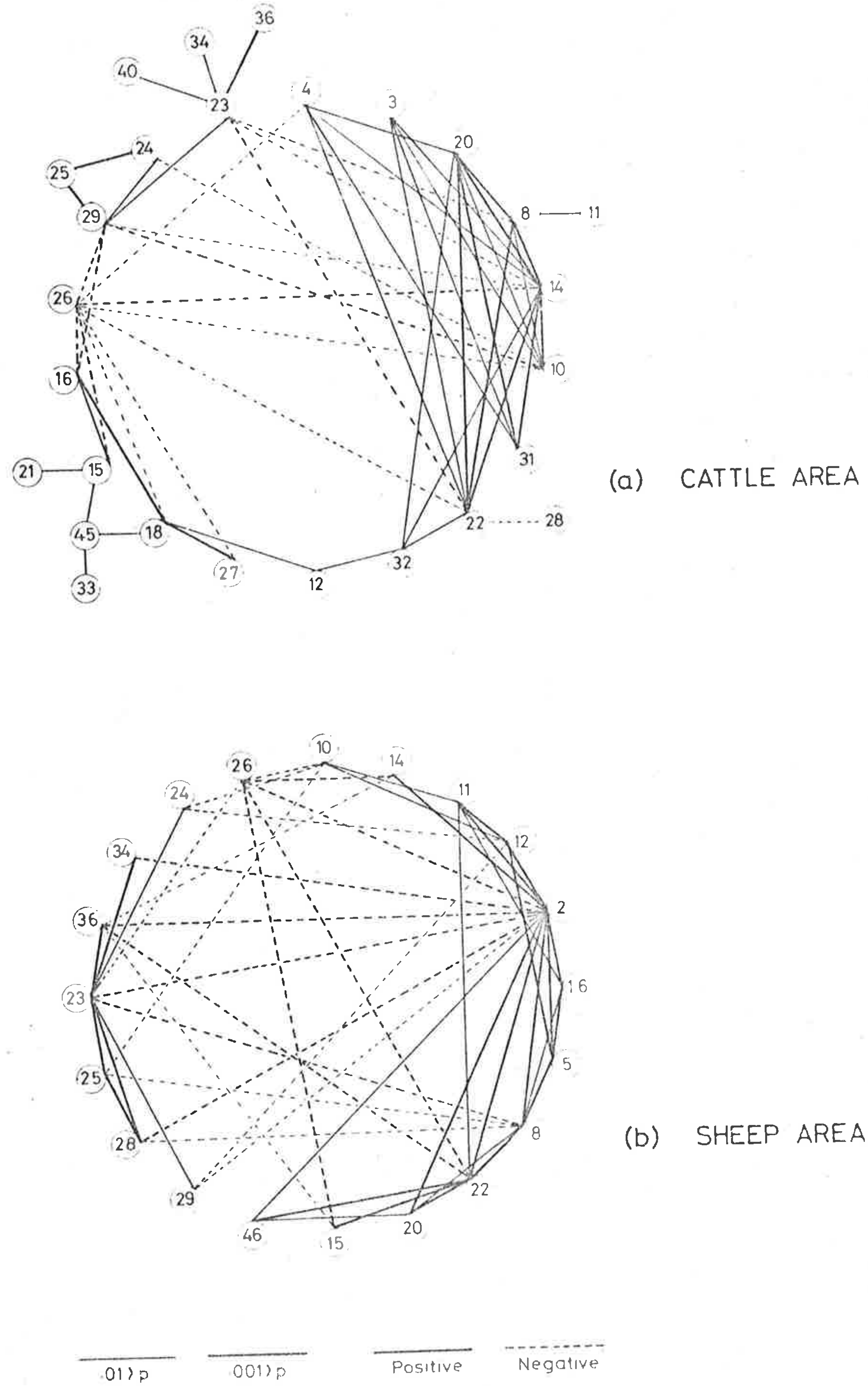
FIGURE 5.8

PLANT ASSOCIATIONS IN THE CATTLE/SHEEP SURVEY

KEY

2. *Atriplex spongiosa*
3. *A. vesicaria*
4. *Pachycornia tenuis*
5. *Kochia astrotricha*
8. *Bassia intricata*
10. *B. divaricata*
11. *B. brachyptera*
12. *B. paradoxa*
14. *B. decurrens*
15. *B. diacantha*
16. *B. patenticuspis*
18. *Zygophyllum aurantiacum*
20. *Dactyloctenium radulans*
21. *Enneapogon avenaceus*
22. *Eragrostis dielsii*
23. *Aristida contorta*
24. *Triraphis mollis*
25. *Tragus australianus*
26. *Plagiosetum refractum*
27. *Enneapogon cylindricus*
28. *Abutilon otocarpum*
29. *Sida virgata*
31. *Aizoon quadrifidum*
32. *Portulaca oleracea*
33. *Salsola kali*
34. *Euphorbia drummondii*
36. *Erodium cygnorum*
40. *Goodenia cycloptera**
45. *Babbagia acroptera*
46. *Clianthus formosus*

*Identification doubtful.



ASSOCIATIONS

5-54 *Association of pasture species.*

An association analysis for each treatment divided the species, as before, into two groups, one corresponding to sand, the other to clay soil habitats (fig. 5.8). A point of note is the pattern of associations for *Plagiosetum refractum.* As will be shown in the next chapter, this species is a coloniser of disturbed or unstable soils. It was negatively associated with both the main groups, suggesting that the species of these groups are decreasers where there is undue disturbance.

5-6 DISCUSSION: CATTLE/SHEEP COMPARISON.

Some information exists in the literature concerning the relative importance to sheep and cattle of *Aristida contorta, Atriplex spongiosa* and *Enneapogon avenaceus* (all less in the cattle area), *Erodium cygnorum, Salsola kali* and *Tripogon loliiformis* (both more in the cattle area). *Enneapogon* has already been discussed. *A. contorta,* although regarded by pastoralists as poor fodder, has been shown by Low (1973) to contribute significantly to cattle diets in the Alice Springs area. Jessup (1951) regarded it as unpalatable to sheep. Chapter 4 showed this species to be affected in the same way by both sheep and cattle over a short term. On the basis of the two papers cited, differential grazing selection might be invoked as the cause of the differences between surveys, but this conflicts with the results of chapter 4. Of the other species, all but

A. spongiosa are regarded as highly preferred by both sheep and cattle (*Erodium* and *Salsola*, Leigh and Mulham, 1965, for sheep, Chippendale, 1968, for cattle; *Tripogon*, Leigh and Mulham, 1965, for sheep, Low, 1973, for cattle). While there are no relative studies, these herbs and grasses should be of more importance to cattle (section 1-63), and hence should be less abundant under cattle than under sheep if dietary selection is the main cause of pattern. *A. spongiosa*, an increaser under sheep (e.g. Crocker and Skewes, 1941), is not known to be grazed by cattle.

Little information exists concerning the other species which showed differences between the sheep-grazed and cattle-grazed sample areas, and so the following is largely speculation. The review in section 1-63 has shown that, on the whole, cattle diets contain a greater proportion of herbs and grasses than do sheep diets: the latter animals eat more forbs and shrubs. Hence, if dietary selection determines the effects of stock on rangeland vegetation, a higher abundance of forbs and shrubs, and a lower abundance of herbs and grasses, would be expected under cattle grazing, relative to sheep grazing; in the absence of differences in background environment. Other than species already discussed, two herbs (*Citrullus lanatus* and *Ptilotus polystacheus*) were less abundant, but four herbs (*Atriplex inflata*, *Portulaca oleracea*, *Tribulus terrestris* and *Zygophyllum aurantiacum*) were more abundant under cattle, Two shrubs and one forb (*Aizoon quadrifidum*, *Crotalaria dissitiflora* and *Sida virgata*) were more abundant under cattle.

There is good agreement between the results of the virgin/cattle and cattle/sheep comparisons, as outlined in table 5.6.

TABLE 5.6

SPECIES SHOWING CHANGE UNDER CATTLE- AND SHEEP-STOCKING

Species	Inferred change under cattle (Pernatty)	Reported change under sheep	Relative abundance under cattle (Roxby Downs)
Atriplex vesicaria	D	$D_{1,2,3}$	0
Crotalaria dissitiflora	D	D_{1}	+
Kochia astrotricha	D	$D_{1,2,3}$	0
Bassia brachyptera	I	$I_{1,2,3}$	0
---- *diacantha*	I	$I_{1,2,3}$	0
---- *divaricata*	I	$I_{1,2}$	0
---- *paradoxa*	I	$I_{1,2,3,4}$	0
Enneapogon avenaceus	I	D_{2}	−
Eragrostis dielsii	?	I_{1}	0
Plagiosetum refractum	I	$I?_{5}$	0
Sida virgata	D	?	+
of *Sisymbrium* sp.	I	I_{1}	0

References:
1 Jessup (1951)
2 Beadle (1948)
3 Crocker and Skewes (1941)
4 Barker and Lange (1970)
5 Murray (193)

The table lists increasing and decreasing species under cattle, as inferred from the first comparison, the species' reported behaviour under sheep, and their relative abundances in the second comparison. It can be seen that, in general, the same species increase or decrease in abundance under both sheep and cattle stocking; only 3 of the 12 indicator species showed differences in abundance between cattle- and sheep-stocking. These observations strongly suggest that the conclusions of section 5-4 are correct.

The foregoing results indicate that only a small part of the differences between the vegetations, under the two grazing regimes, can be adequately explained by differential dietary selection. Because of this, it cannot be said that there is firm evidence for mechanical disturbance as the cause of stock-related vegetation change, even though the reaction of the majority of plant species would suggest this. The results may therefore be construed as showing both processes in operation, but to varying degrees.

Interpreting the cause of observed stock-induced change, by indirect observation and reference to the literature, has proved inadequate. In hindsight, a broader approach was required. As well as resultant pattern in plant populations, the research should have dealt with the detail of stock action--grazing behaviour and disturbance. A full study of grazing behaviour was beyond the scope of the research, but the relationship between disturbance and plant distributions was investigated, and is reported in the following chapter.

5-7 SUMMARY AND CONCLUSIONS

The virgin/cattle comparison indicated long-term trends in pasture under cattle, similar in outline to trends, reported in the literature, in pasture under sheep: cattle-stocking on Pernatty station has been accompanied by a decline in abundance of perennial species and an increase in abundance of ephemeral species. The cause of such trend is unlikely to be the preferential selection of certain species by cattle: cattle do not consume shrubs to a great extent (section 1-63) and, while no specific information exists, are unlikely to graze chenopod shrubs in particular, because of these species' salt content (section 1-62).

The particular species found to decrease and increase under cattle stocking on Pernatty are reported, almost without exception, to react in the same manner under sheep-stocking. Preferential grazing selection by cattle cannot be the cause of the changes, since, although there are some general similarities, there are major differences in detail between the preferences of sheep and cattle (section 1-63). Dietary selection is said to cause change in grazed vegetation, by removal of the more preferred species, with a resultant increase in less preferred species due to the lowered competition (e.g. Leigh and Noble, 1969). If this is so, then cattle and sheep should remove different species, because of their differing preferences, and the species benefitting from the lowered competition should not be the same in both cases.

Mechanical disturbance, unlike dietary preference, is common to both animals. Soil disturbance, for instance, will have a certain effect on a plant community, largely independent of the disturbing agent. For example, breakup of a lichen crust will result in a lower nitrogen input (see Rogers et al, 1966); erosion of a disturbed soil will remove much of the plant nutrients (Charley and Cowling, 1968). In both cases, the changed nutrient status will favour the establishment or increase of species better adapted to low nutrient levels, and the decrease of species less well adapted.

Mechanical disturbance, independent of the particular herbivore, is therefore proposed as the main determinant of stock-related vegetation change, to account for the similarity of trends in vegetation, stocked with cattle on Pernatty, to trends in vegetation stocked with sheep elsewhere. The partial test by the comparison of equivalently stocked sheep and cattle pastures, on Roxby Downs, yielded no conclusive evidence for or against the hypothesis. In this latter comparison, the cattle and sheep pastures displayed some differences which could result from cattle and sheep grazing differing species. On the other hand, such differences were found for very few species: most showed no detectable differences in abundances between grazing regimes, as would be expected for equivalently stocked paddocks, with a more or less equivalent level of disturbance, were the hypothesis correct. Nonetheless, although the results of the virgin/cattle comparison on Pernatty can only be explained by proposing disturbance as the cause of stock-related vegetation change, the validity of the hypothesis remains uncertain, and more detailed testing is required.

CHAPTER 6

RELATIONSHIPS BETWEEN SPECIES ABUNDANCES AND SOIL DISTURBANCE

6-1 INTRODUCTION

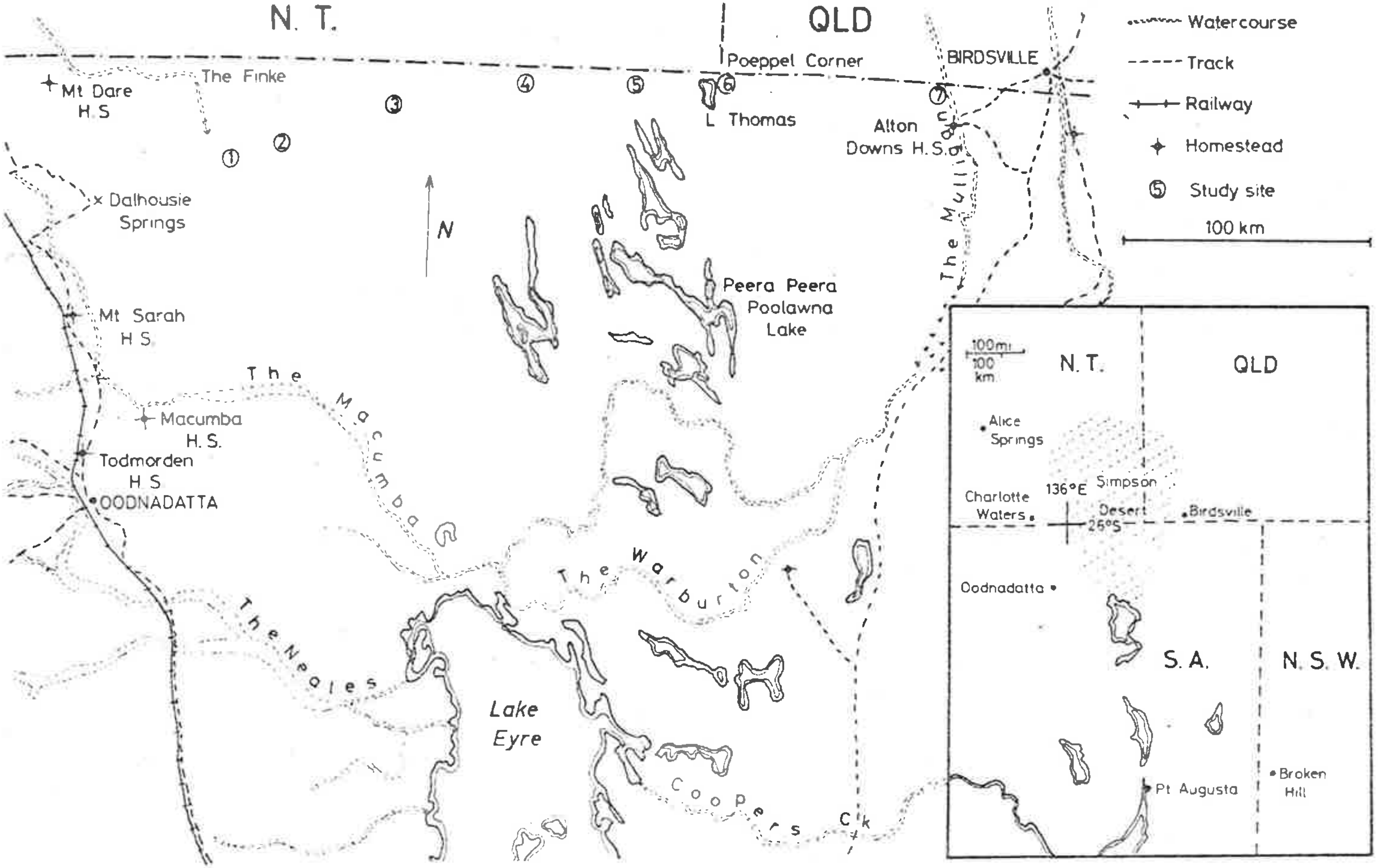
In the previous chapter, mechanical disturbance of soils and plants by stock was proposed as the main determinant of long-term trend in grazed pastures. The investigations reported in this chapter provide a partial test of this hypothesis. The effects of variations in soil stability on species abundances were observed in a virgin situation. From these observations, the effects of soil disturbances were readily inferred. In the light of this information, the data of the previous studies were re-examined, to determine the extent to which an increase in soil disturbance, resulting from stocking, might account for the observed changes in species abundances.

A significant number of the species encountered on the Pernatty and Roxby Downs studies occur also in the Simpson Desert (location: fig. 6.1). Except on the margins, this sandridge desert has never been grazed by domestic stock. The soils have local variations in stability: these variations, correlated with topography, follow a regular pattern, are marked and clearly defined, and are well documented. Hence patterns in local abundances of species can be simply related to the stability of the soil habitats, without the complication of stocking effects; and the outcome of soil disturbance is readily inferred.

Although neither the Desert's landforms nor the structure of its vegetations are directly comparable with those of the study

Fig. 6.1

LOCATION OF SIMPSON DESERT STUDY SITES



sites already discussed, the surface soils, and particularly the sands, are closely similar. Therefore, a species found to occur on unstable surface soils in the Desert should indicate unstable surface soils if found in the other study areas. Further, an increase in such a species' abundance with stocking can be most simply explained as the result of soil disturbance.

Data were gathered during a rapid traverse of the southern Simpson Desert in July, 1972 (see fig. 6.1). The Desert was crossed in drought, hence only 35 species were sufficiently abundant for inclusion in analyses. Table 6.1 lists these species, and gives their occurrences in the other study areas.

6-2 DESCRIPTION OF THE DESERT

6-21 *Climate*

The Simpson Desert includes the most arid parts of the continent (Gentilli, 1972). Most of the available climatic data has been recorded on the margins of the Desert. The rainfall is very low and variable: the mean annual rainfalls at Oodnadatta (S.A.) and Cordillo Downs (S.A.), over a 48-year period, were 147mm and 116mm respectively, with annual falls ranging from 25mm to 340mm (Crocker, 1946); and at Birdsville (Qld), the mean annual rainfall over a 10-year period was 116mm, with a range from 50mm to 330mm (Boyland, 1970). Rainfall has a pronounced seasonality, with most falls in summer (Crocker, 1946). Solar radiation levels are high (fig. 1.8), and the mean annual temperatures on the margins exceed 20^{0}C (Crocker, 1946).

TABLE 6.1

OCCURRENCE OF SPECIES
IN SIMPSON DESERT AND OTHER STUDY AREAS

(a) Species in Belt Transect analyses-

	Species	Desert	Pernatty	Roxby
1	*Triodia basedowii*			
2	*Goodenia cycloptera*			+
3	*Aristida contorta*		+	+
4	*Abutilon otocarpum*		+	+
5	*Phyallanthus fuernrohrii*		+	+
6	*Enneapogon avenaceus*		+	+
7	*Leschenaultia divaricata*			
8	*Euphorbium wheeleri*			
9	*Babbagia acroptera*		+	+
10	*Bassia paradoxa*		+	+
11	______ *diacantha*		+	+
12	*Eremophila longifolia*		+	+
13	*Atriplex limbata*		+	+
14	*Plagiosetum refractum*		+	+
15	*Zygochloa paradoxa*		+	+
16	*?Rutidosis helichrysoides?*			
17	*Ptilotus latifolius*			
18	*Myriocephalus stuartii*		+	
19	*Eragrostis dielsii*		+	+
20	*Enneapogon cylindricus*			+
21	*Ptilotus polystacheus*			+
22	*Tribulus histrix*			

(b) Additional species in density studies

Species	Desert	Pernatty	Roxby
Acacia cambagei			
______ *dictyophleba*			
______ *murrayana*			
Crotalaria cunninghamii			
______ *dissitiflora*		+	+
Dicrastylis doranii			
Dodonaea viscosa		+	+
Eragrostis eriopoda			
Eragrostis laniflora			+
Frankenia sp.			
Portulaca oleracea		+	+
Rhagodia spinescens		+	+
Salsola kali		+	+
Sida virgata		+	+
Tragus australianus		+	+
Trichodesma zeylanicum		+	+

6-22 *Physiography and soils.*

The principal feature of the Desert is its sandridge system. The sandridges are parallel, trending northwest-southeast, and apparently windformed (Madigan, 1936). They vary between 8m and 30m in height, with a separation of 130m-550m between ridges, and may exceed 300km in length (Madigan, 1936). They are usually unstable at the crests, but the lower slopes and interdune flats are stabilised by sparse vegetation (Crocker, 1946; Boyland, 1970). The eastern slopes of ridges (slipslopes) are steeper, and often less stable, than the western slopes (backslopes).

The soil of the ridge crests and slopes is a fine, red quartz sand (type Ucl.22 or Ucl.23). The crests have slightly larger grains than the slopes, but there are no other soil differences between crests and slopes, apart from soil stability (Crocker, 1946). The interdune flats are either red clayey sands (Litchfield, 1962) or, in restricted areas, clay soils with an overlying sandy loam (Crocker, 1946).

6-23 *Vegetation.*

The vegetation of the Desert is primarily a hummock grassland (Specht, 1972-- see discussion, section 1- 51 , on the main vegetation divisions of S.A.). A checklist of the known flora is given in Symon (1969). The vegetation was first described by Crocker (1946), as a *Triodia basedowii-Spinifex paradoxus** "edaphic complex", comprising five well-defined associations. Those of importance here are the ubiquitous *Spinifex paradoxus*

* Now *Zygochloa paradoxa*

association of the mobile crests, the *Triodia basedowii* association of the stable lower slopes and sandy interdune corridors, and the *Acacia cambagei* association of clay interdune corridors in the eastern Desert. The last is a low open woodland. Similar associations were defined by Boyland (1970). Wiedemann (1972), unlike the previous authors, applied objective techniques to the description of the vegetation. He found that, although particular soil habitats could be clearly defined, the vegetation varied continuously: the definition of distinct plant associations was not realistic. Analyses in this chapter support this view.

Correlations between species abundances and topography are obvious from these reports, but all authors agree that the correlation is indirect: species distributions are primarily determined by the stability of the substrata. Soil features themselves are directly correlated with topography, hence topography provides a convenient index of soil conditions. Nonetheless, although topography *per se* may play some part in controlling species distributions, it is a minor factor by comparison with soil features (Crocker, 1946; Boyland, 1970; Wiedemann, 1972).

6-24 *Domestic grazing in the Desert.*

On the margins of the Desert, cattle are run where underground water is accessible, or where streams exist. Within the Desert, very deep bores are required to tap the Great Artesian Basin. The expense of such bores, and the difficulties of access, are the major reasons for the absence of stock within the Desert, rather than any intrinsic feature of the pastures. Where deep bores have been sunk within the Desert, cattle are run. An example is Purni Bore (fig. 6.1), which was sunk in 1961 by a petroleum exploration team in the western Desert: it has since been stocked with cattle.

6-3 COMPARABILITY OF THE DESERT AND OTHER STUDY AREAS

From the foregoing descriptions, the physiography and vegetation of the Desert differs greatly from the study areas on Pernatty and Roxby Downs stations; particularly in the size and relative instability of the Desert dunes, and the preponderance of hummock grasslands in the Desert by comparison with the tall shrublands or low woodlands of the other areas. Nonetheless, the sand soils are directly comparable, and many species are common to both areas. Therefore this study concentrates on the distributions of those species in common, occurring on sands.

The Desert provides an excellent situation for observing in isolation the effect of soil stability on the species' populations, with results directly applicable to the sand areas of Pernatty and Roxby Downs stations. On the Desert dunes, there are no significant soil differences other than in soil stability; differences in stability are clearly discernible; and changes in stability can be simply indexed by changes in topography.

6-4 METHODS

6-41 *For observation of species incidences across dune profiles.*

At each camp on the traverse, except site 6, a straight belt transect was run across the ridges, including at least one complete topographical cycle. Contiguous 4m long by 2m wide quadrats were laid, and incidence of all species recorded. Influence Analysis (section 3-51) was applied, using those species with frequency of occurrence greater than 10%. Only associations at or below the .01 probability level were considered. Influence Ratings (IR's) were backplotted on a topographic profile. From this backplot, the effects of soil stability on the incidence of the species involved were readily inferred.

6-42 *For observation of species densities across dune profiles.*

At site 6, large and well defined dunes, with mobile crests and variety of interdune areas, were selected for determination of relationships between species abundances and soil parameters. Both sand and clay soils were present. The profile was divided into four topographic divisions: dune crests (unstable sand), slipslope (semi-stable sand), backslope (stable sand) and flat. The soil of the flat was a texture-contrast type, sandy loam over a clay subsoil: this flat supported a low open woodland of *Acacia cambagei*, unlike the hummock grassland of the sand areas. The topographic profile is given in figure 6.2 and shows the relative extent of each division.

Three parallel transects, at 400m intervals, were run along this profile. A total of sixty-six 20x1m^2 quadrats were laid, with each quadrat set at right angles to the transect. Slipslopes and crests were sampled more densely, relative to their area, than the other divisions: this allowed sufficient replication for comparison with other divisions. Quadrats were regularly spaced along transects within divisions.

All investigations at site 6 were carried out jointly with Dr. Susan Barker. *

6-5 RESULTS

6-51 *Influence Analyses on species incidences.*

For belt transect data, the nodes of association are given in figure 6.3 and the Influence Analysis backplots in figure 6.4. In backplots, quadrat scores (IR's) are regularly spaced for clarity: since the quadrats followed the ground contours, the accompanying profiles are slightly distorted.

Twenty-two species were included in the analyses, but not all were encountered at each site. However, the number of combinations found were sufficient to determine the pattern of associations which would arise were all species encountered in one survey. On this basis, the species list was divided into two main groups, species 1-13, and species 14-22. Within groups, species' associations were positive, between groups negative. For consistency of presentation, the high IR's, derived for any node, were awarded to quadrats containing species of the second group. For instance, if species 1,14 and 15 formed a node, with species 1 negatively associated with the other two, the maximum IR of 3 was awarded to

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Fig. 6.2

PROFILE OF TRANSECTS AT SITE 6

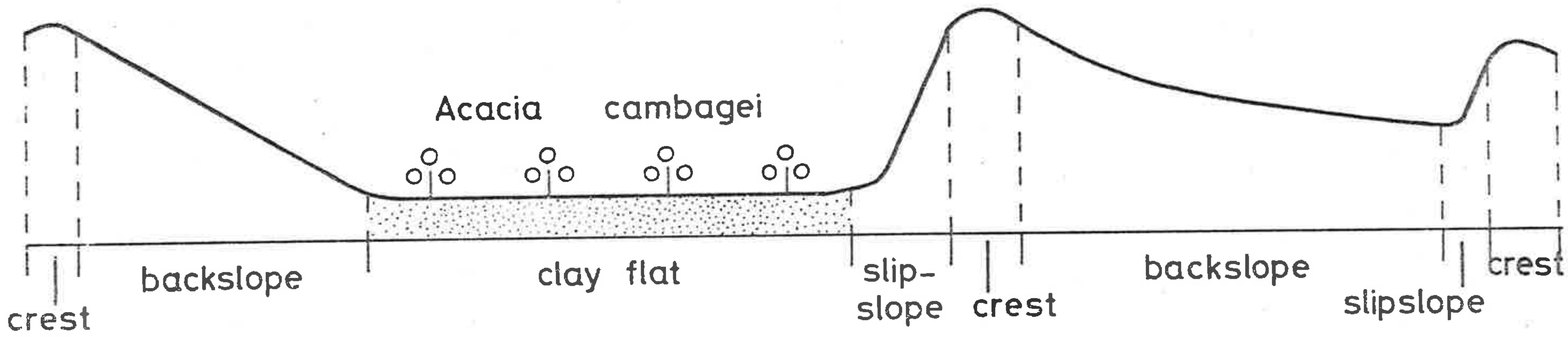
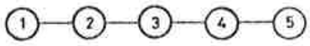


Fig. 6.3
NODAL STRUCTURE
FOR SPECIES AS NUMBERED IN TABLE 6.1

SITE 1
(Purni Bore, grazed)



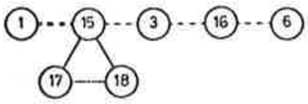
Node 1

IR	1	2	3	4	5
5	+	+	+	+	+
0	−	−	−	−	−

SITE 2
(Virgin)

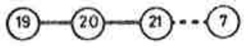
Node 1

IR	5	14
2	−	+
0	+	−



Node 2

IR	1	3	6	15	16	17	18
7	−	−	−	+	+	+	+
0	+	+	+	−	−	−	−



Node 3

IR	7	19	20	21
4	−	+	+	+
0	+	−	−	−

SITE 3
(Virgin)

Node 1

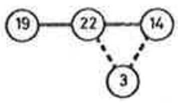
IR	9	10	11	14	15	22
6	−	−	−	+	+	+
0	+	+	+	−	−	−

SITE 4
(Virgin)

Node 1

IR	5	6	14	21	22
5	−	−	+	−	+
0	+	+	−	+	−

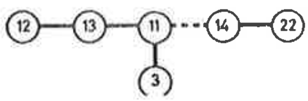
SITE 5
(Virgin)



Node 1

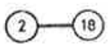
IR	3	14	19	22
4	−	+	+	+
0	+	−	−	−

SITE 7
(Virgin)



Node 1

IR	3	11	12	13	14	22
6	−	−	−	−	+	+
0	+	+	+	+	−	−



Node 2

IR	2	18
2	+	+
0	−	−

ASSOCIATIONS

Positive —— Negative - - - - -

01) p —— 001) p ━━

Fig. 6.4

INFLUENCE RATINGS FOR BELT TRANSECTS

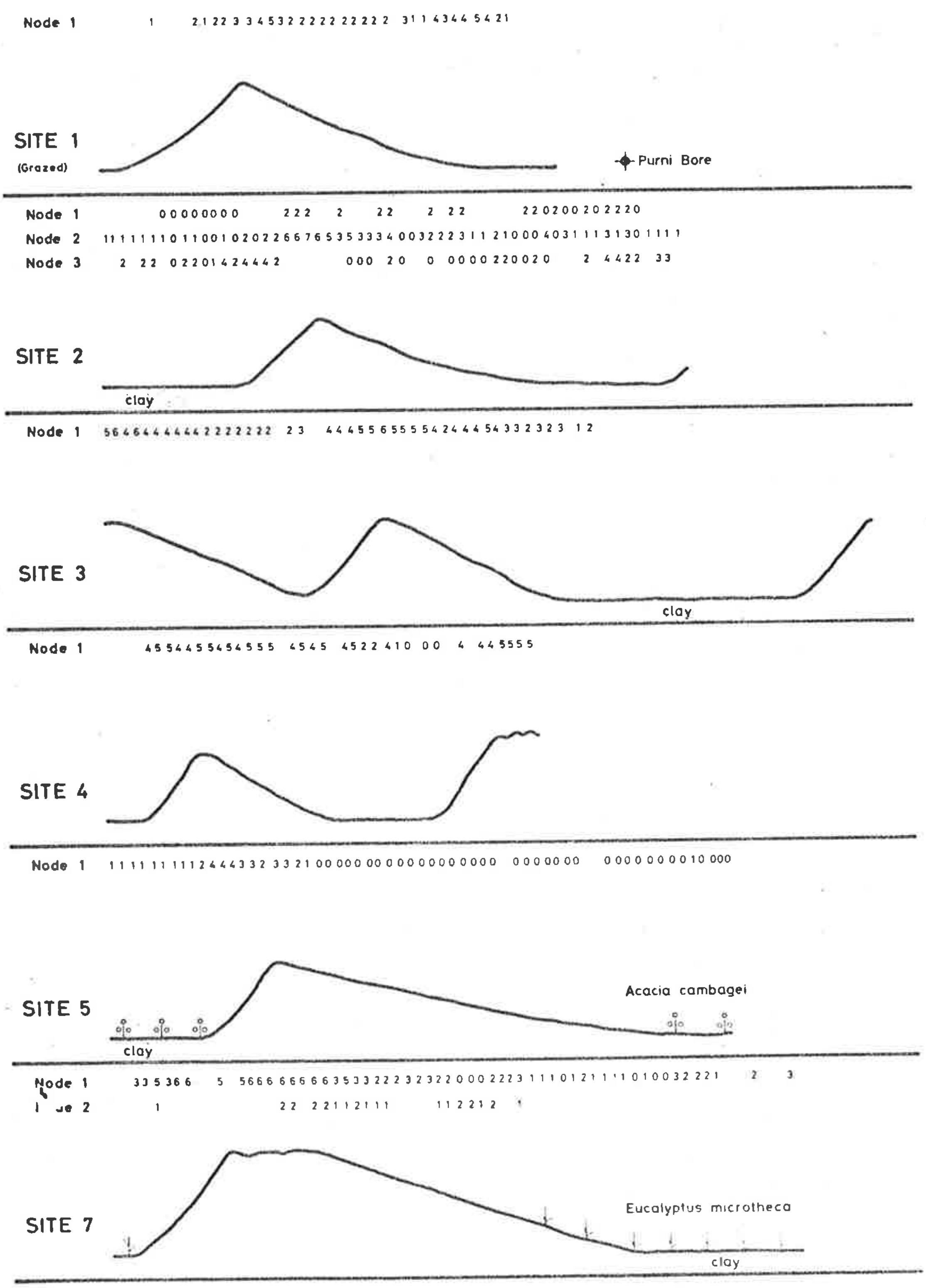
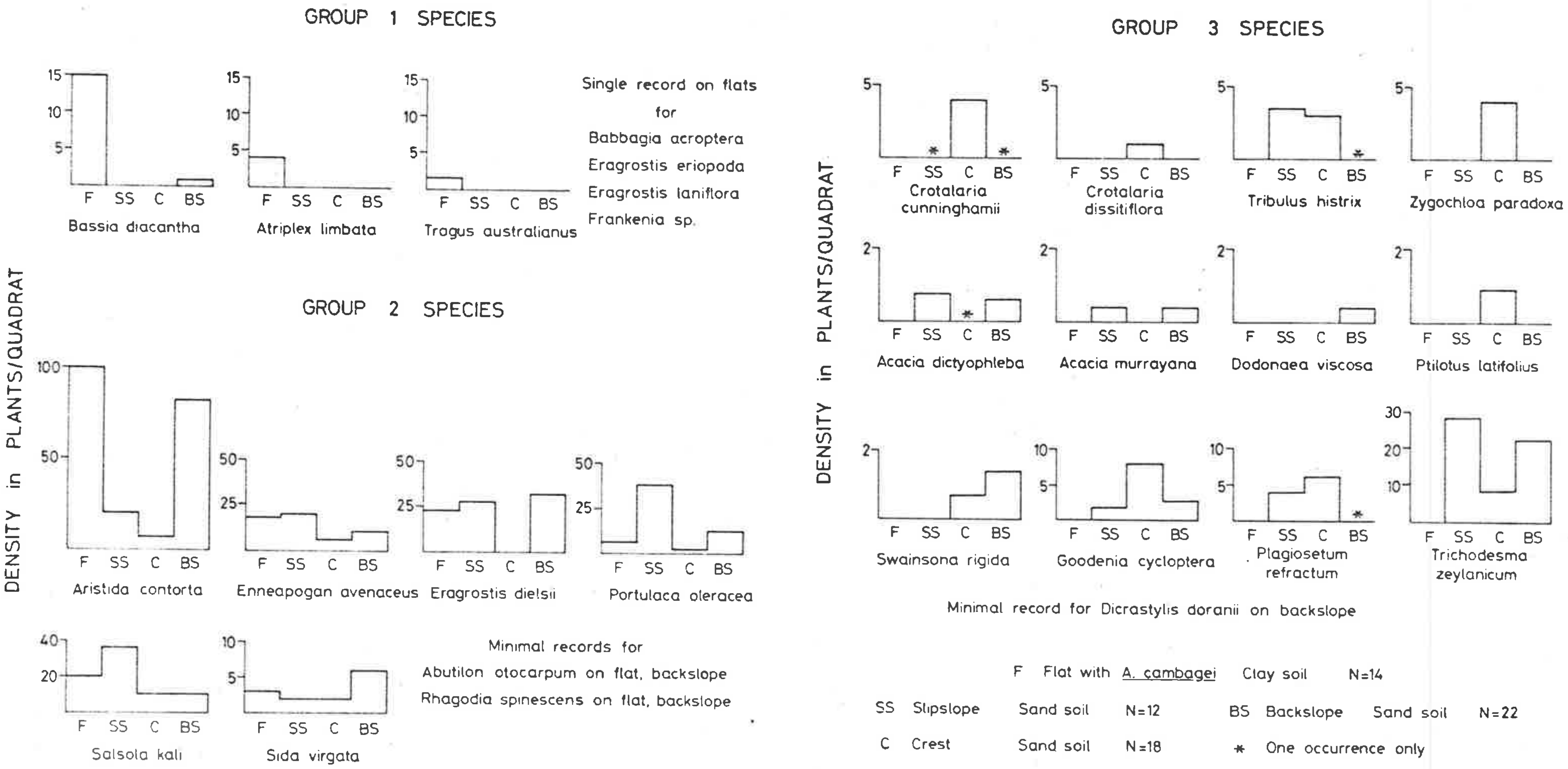


Fig. 6.5

SPECIES ABUNDANCES ON ZONES AT SITE 6



quadrats with species 14 and 15 present, but species 1 absent. Similarly, if species 1,2 and 14 formed a node, with species 14 negatively associated with the other two, the maximum IR was awarded to quadrats with species 14 present, and the other two absent.

At virgin sites (sites 2 to 7), the high IR's were most consistently found on and around dune crests, the mobile sand area. Therefore, incidences of species of the second group were greatest in such areas, and incidences of the first group least in such areas. IR's varied elsewhere along the profiles, with values displaying the influence of sand or clay substrates. The variation was continuous, as would be expected from the studies of Wiedemann (1972), and not disjunct as would be expected from the other authors' descriptions. At site 1 (Purni bore, stocked with cattle), high ratings were found on both mobile crests and the margin between dune and flat.

6-52 *Density distributions along topographic profiles.*

Figure 6.5 displays the average density, on each topographical division, for the species encountered at site 6. These species formed three main groups: those restricted to the clay flat, those restricted to sands, and those present throughout. On the sands, the only species restricted to a particular division were *Zygochloa paradoxa*, *Crotalaria dissitiflora*, and *Ptilotus latifolius*, on the crests; and the uncommon *Acacia murrayana* and *Dicrastylis doranii*, on slipslopes and backslopes respectively. Nonetheless, the abundance of other species varied considerably from division to division, and so with variations in soil stability. In particular, on the mobile crests, *Aristida contorta, Abutilon otocarpum* and *Enneapogon avenaceus* showed lowest abundances, or were completely absent, and *Plagiosetum refractum* reached its greatest abundance. This pattern corresponds with that shown by belt transects. There were only two disparities between the results at site 6 and the inferences from the belt transects. The latter indicated *Goodenia cycloptera* to be a stable-soil species, and *Eragrostis dielsii* an unstable-soil species, the reverse of the actual findings at site 6.

6-6 DISCUSSION

6-61 *The effect of soil disturbance.*

For virgin sites, both approaches demonstrated that the species found on sands could be grouped according to the stability of their soil habitats. Thus, if sands are disturbed, a decrease in the stable-sand species and an increase in the unstable-sand species should occur at the site of disturbance. Examples of this were found in the Desert. The area around Purni bore (site 1) was stocked with cattle:figure 6.4 shows the position of the bore relative to the belt transect. Cattle at this bore were observed to move mainly along the interdune corridors, only crossing dunes by means of the track used for the vehicle traverse. This track was 500m distant from the transect. The backplot of site 1

IR's showed the highest ratings to be not only on mobile crests, but also on the margin of the flat, where cattle in their movements had disturbed the sand. A further example is disturbance caused by roadmaking. The unimproved earth track used for the vehicle traverse was built in 1961 by the exploration team mentioned earlier, and has since been used by tourist parties. The removal of vegetation in the path of the track, and in particular the perennial hummock-grass *Triodia*, resulted in wind erosion, as would be expected from the studies of Marshall (1973). Although relatively infrequent, the tourist excursions have largely prevented regeneration. Although the resultant deflation was most obvious where the track cut through crests, it was also found on previously stable sand flats. Such areas were being colonised by plants normally restricted to crests, particularly *Plagiosetum refractum*.

Table 6.2 lists the species corresponding to stable and unstable sand habitats, which on the above basis, could be expected to decrease or increase following soil disturbance.

6-62 *Comparison with results from Pernatty and Roxby Downs surveys.*

Table 6.3 gives the species, considered on the foregoing evidence to change in abundance with disturbance; the changes in their populations under stocking inferred from the virgin/cattle comparison (Pernatty); and their relative abundances in the cattle/sheep comparison (Roxby Downs).

If mechanical disturbance by stock is the cause of

TABLE 6.2

SPECIES EXPECTED TO INCREASE OR DECREASE FOLLOWING SAND DISTURBANCE

Increasers	Decreasers	Evidence from
Plagiosetum refractum	*Abutilon otocarpum*	
Zygochloa paradoxa	*Aristida contorta*	Belt transect and density data
	Enneapogon avenaceus	
	Portulaca oleracea	
Myriocephalus stuartii	*Phyallanthus fuernrohrii*	Belt transect data only
Ptilotus polystacheus		
Crotalaria dissitiflora	*Salsola kali*	Density data only
	Sida virgata	

TABLE 6.3

SPECIES' REACTION TO DISTURBANCE IN THE DESERT AND TO STOCKING ELSEWHERE

Species	Change following disturbance (Simpson)	Inferred change under cattle (Pernatty)	Abundance under cattle rel. to sheep (Roxby Downs)
Crotalaria dissitiflora	I	0	+
Myriocephalus stuartii	I	*	*
Plagiosetum refractum	I	I	0
Ptilotus polystacheus	I	*	-
Zygochloa paradoxa	I	0	**
Abutilon otocarpum	D	*	0
Aristida contorta	D	*	-
Enneapogon avenaceus	D	I	-
Portulaca oleracea	D	*	+
Phyallanthus fuernrohrii	D	(D)	0
Salsola kali	D	*	+
Sida virgata	D	D	+

D decrease in abundance

I increase

* Ephemeral, no inferences drawn

** absent

\+ more abundant) cattle/sheep comparison

\- less abundant)

0 no change, or no difference.

stock-related vegetation change, the species considered to decrease or increase with disturbance in the Desert would be expected to show similar change under stocking; and such change could be inferred from the results of the virgin/cattle survey. Many of the species named are ephemeral, and no inference was drawn concerning them (see previous chapter). For the rest, *Plagiosetum refractum* and *Sida virgata*, respectively increasing and decreasing species with disturbance in the Desert, showed similar changes with stocking. *Phyallanthus fuernrohrii*, a decreaser with disturbance in the Desert, showed only a marginal decrease with stocking. However, *Crotalaria dissitiflora* and *Enneapogon avenaceus* showed changes with stocking, the reverse of those expected if increased disturbance due to stock was the cause of the changes in their abundances. *Zygochloa paradoxa*, an increaser with disturbance in the Desert, showed no apparent change with stocking.

In the cattle/sheep comparison, three outcomes could be expected were disturbance the main cause of change. If the cattle and sheep disturbed the sands to the same extent, no difference between paddocks would be expected in the abundances of the species of table 6.3, since the species would react in the same manner in both paddocks. If cattle-stocking resulted in more disturbance, than sheep-stocking, species increasing with disturbances would be relatively more abundant, and those decreasing with disturbance would be relatively less abundant in the cattle paddock by comparison with the sheep paddock. If sheep-stocking caused the more disturbance, the reverse situation would be expected. Table 6.3 displays no such consistency.

6-63 *Conclusions.*

Once more, there is no conclusive evidence for or against the disturbance hypothesis. Certain species, the reactions of which to soil disturbance in a virgin situation have been noted, have reacted to stocking as would be expected were the hypothesis correct: other species have not. Further, the results of the cattle/sheep survey have not shown the consistent pattern expected from the hypothesis. Nonetheless, the hypothesis cannot be dismissed with certainty. There still remains the problem of the close similarity between the trends observed under cattle and the trends reported under sheep, inexplicable in terms of dietary selection, and most simply accounted for by the disturbance hypothesis. Disturbance as a potential major cause of stock-related vegetation change is worthy of more detailed investigation than was possible in the course of research for this thesis, and of more emphasis in other research than has been given to date.

CHAPTER 7

SOME EFFECTS OF CATTLE ON PERENNIAL CHENOPODS

7-1 INTRODUCTION

Two minor studies, investigating the long-term effect of cattle on perennial chenopods, are described in this chapter. The first dealt with changes in populations of *Atriplex vesicaria* and *Kochia astrotricha* in 45 years; and the second concerned possible regeneration of *Atriplex* and *Kochia* species under cattle.

7-2 POPULATION CHANGE IN *A. VESICARIA* AND *K. ASTROTRICHA*

7-21 *Methods*

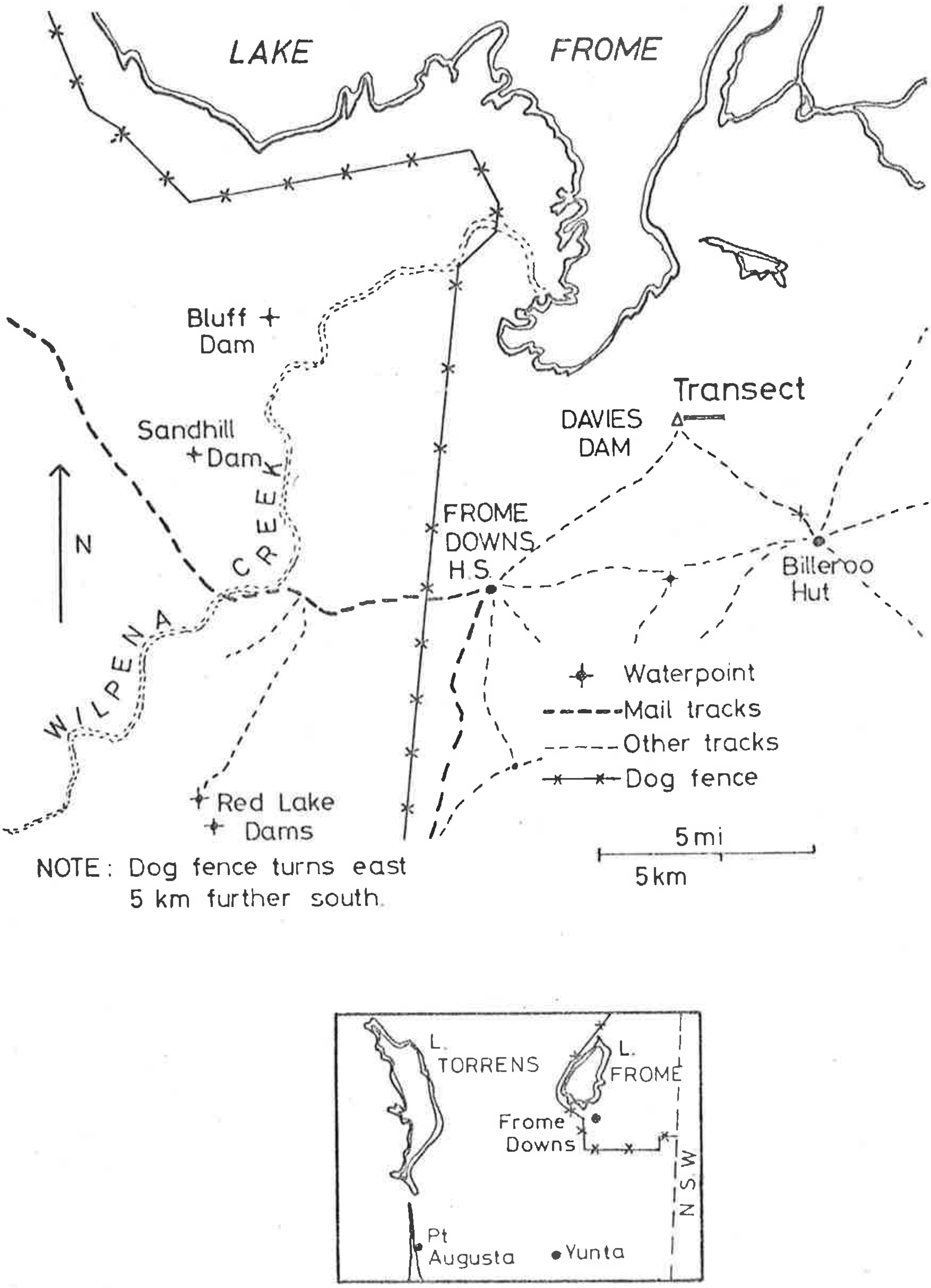
Osborn et al (1932) used belt transects, radiating from water points, to estimate the density of *A vesicaria:* these provided the basis for their pioneering paper on sheep grazing effects. The original data sheets are stored in the Botany Department, University of Adelaide. Apart from the Koonamore Vegetation Reserve records, they represent the only early research, in arid South Australia, capable of direct repetition.

Of the many run, three transects were laid in virgin pasture on Frome Downs station (locality: fig. 1.1), in 1929; immediately prior to stock introduction. They were mentioned, but not analysed, in the 1932 paper. Two were run from a newly sunk dam, which could not be relocated due to lack of station records. The longest transect, of over 2000m, was run from Davies (Davis's) dam, sunk at the same time. This transect was relocated and repeated (fig. 7.1).

In 1929, the transect was laid on a strict compass bearing,

Fig. 7.1

LOCATION OF DAVIES DAM TRANSECT



aided by sighting posts, with distance measured in long paces (1.5m). Every bush actually crossed by the observer was scored; for species (listed as *Atriplex* or *Kochia*, i.e. *A. vesicaria* and *K. astrotricha*), height, diameter, vigour as indexed by the state of the foliage, presence or not of a basal soil mound, and juvenile or adult. Criteria for determining juveniles have not been preserved. The transect could be regarded as a strip of quadrats, size one long pace by one shoulder width.

The transect was repeated in March 1974, from the original starting point, but allowing for magnetic variation over the intervening period (2^{o}E). Distance was estimated by rangefinder and sighting posts rather than paces. While the relocated transect could not be expected to coincide exactly with the original, nonetheless it was considered adequately close to permit direct comparison of results.

7-22 *Stocking history of study area.*

Although no complete records exist, sheep may have been run from Davies dam for the initial ten to fifteen years. Cattle were certainly run from it after 1946, when the State dog fence was consolidated along the southern boundary, and the last sheep flocks were removed. However, cattle have always been the main enterprise on Frome Downs, and so the possibility of the transect being grazed only by cattle remains.

Past and present stocking levels on the dam could not be determined, due to both absence of records, and the open range system. There were approximately 100 head on the dam at the time of survey, and the manager considered this a usual level.

7-23 *Results.*

The 1929 transect was run in drought, but the 1974 transect in an exceptional growth period (see chapter 4). Thus foliation as a measure of vigour was not comparable between times. The large number of defoliated bushes reported in 1929 were not necessarily dead (Osborn et al , 1932).

Table 7.1 summarizes the findings. The clearest change is the almost total elimination of *A. vesicaria* and the decrease in density of *K. astrotricha.* Figure 7.2 emphasises this. *K. aphylla* was not mentioned at all in the original data, nor in the accompanying notes. As the notes were comprehensive, the species must then have been a very minor component of the vegetation.

The reduction in size of *K. astrotricha* is also clear. Figure 7.3 shows the relative frequency distribution of diameters, for both times. These suggest a possible change in age structure, but this is rejected on the grounds that (a) the proportion of dead plants remains the same, and (b) in 1974, many of the smaller canopies were growing from extensive and old rootstocks, indicating a pruning down by stock.

TABLE 7.1

DAVIES DAM TRANSECT RESULTS

(a) Number of bushes in transect.

	1929	1974
Total bushes	1245	119
A. vesicaria	946	4
K. astrotricha	299	80
K. pyramidata	*	9
K. aphylla	*	26
Total *Kochia*	299	115
K. astrotricha (juvenile)	6	5

*The only category on 1929 data sheets was *K. astrotricha*

(b) Mean height and diameter of foliated bushes with associated standard errors.

	1929	1974
K. astrotricha		
Height (cm)	37.5 ± 11.6	26.4 ± 12.2
Diameter (cm)	45.6 ± 16.7	30.6 ± 18.5

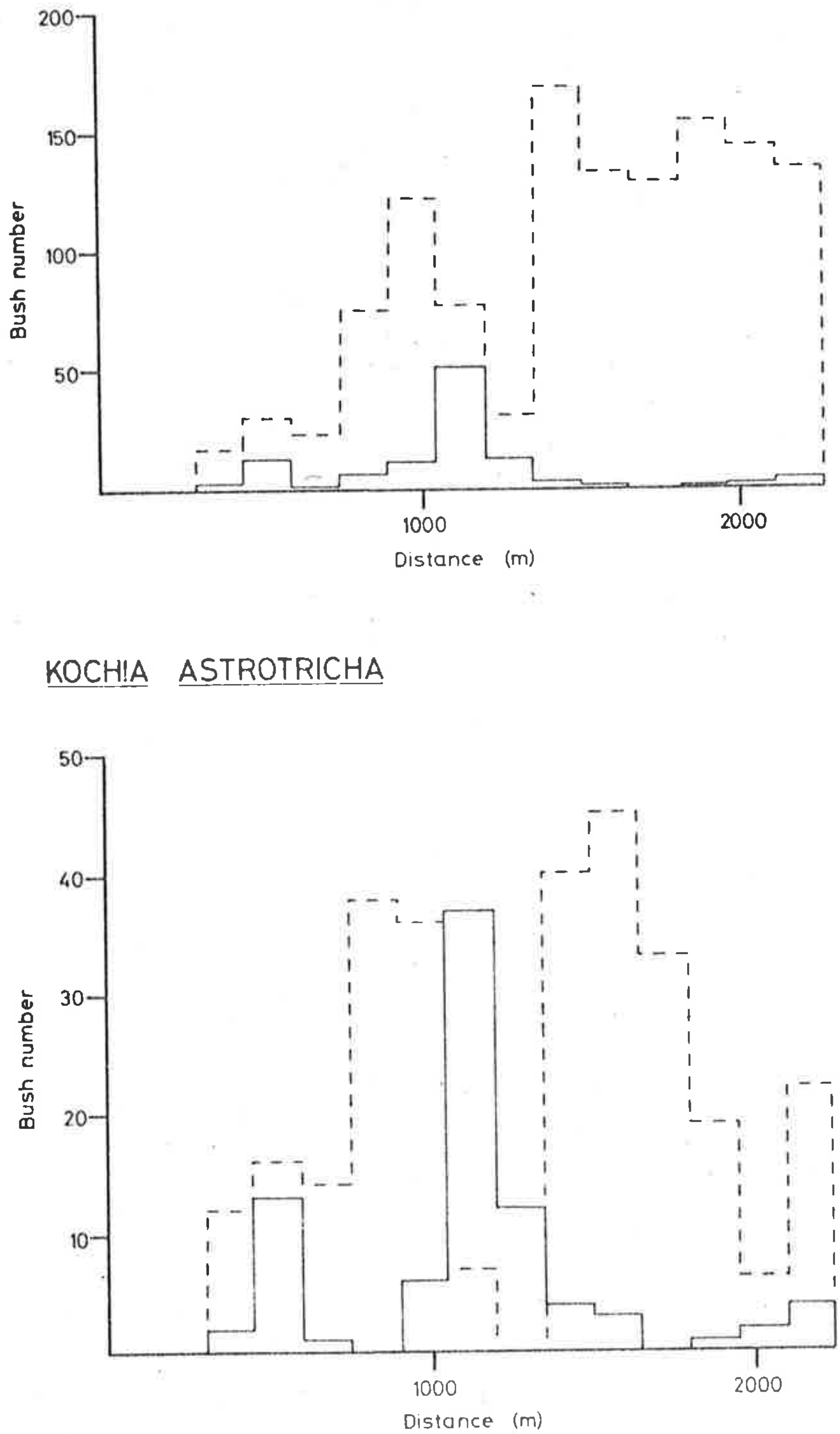
(c) Dead and defoliated bushes.

	1929	1974
K. astrotricha		
Dead	26	9
% total	9	11
Defoliated	135	5
% total	45	6

Fig. 7.2

BUSH DISTRIBUTION ALONG THE DAVIES DAM TRANSECT

TOTAL BUSH



KOCHIA ASTROTRICHA

1929 TBP - - - -

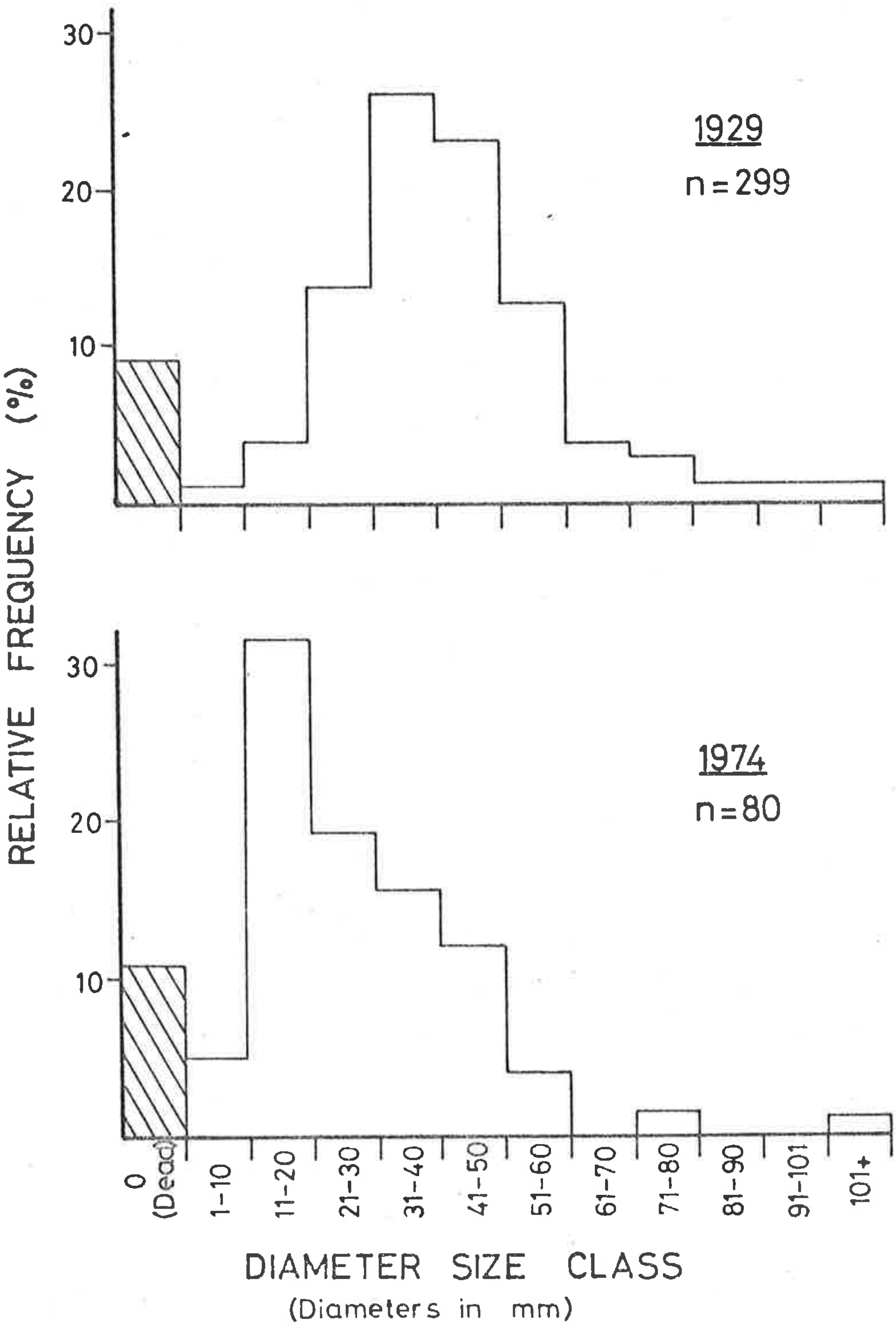
1974 TJF ———

Fig. 7.3

LARGEST DIAMETER OF

K. ASTROTRICHA BUSHES

on Davies Dam transect



7.24 *Discussion.*

There are two possible conclusions, dependent on the past history.

1. If cattle only have been run, then they have brought about the major destruction of shrub populations as described under sheep (chapters 1, 5).
2. If sheep were run first, and were the original cause of destruction, then the cattle have maintained this impress for thirty years.

In either case, the impact of cattle on these species cannot differ markedly from that of sheep.

7-3 A CROSS-FENCE COMPARISON OF BUSH DENSITY: CATTLE VS UNGRAZED

Cattle were introduced on Wabricoola station (locality: Fig 1.1) in 1958. The small paddock shown in figure 7.4 was stocked continuously with cattle from this time, the cattle being restricted by strengthened fences (a rare example--see section 2-32). Prior overstocking with sheep eliminated the original *Atriplex* pasture and resulted in an ephemeral grassland. No record exists of the sheep numbers. Cattle number varied from 20 to 60 head (heifers) with the mode at 30 head. As the paddock was only 500ha ($2mi^2$) in area, this represented a heavier stocking per unit area than situations reported in the rest of the thesis, but a lighter stocking in terms of number per water.

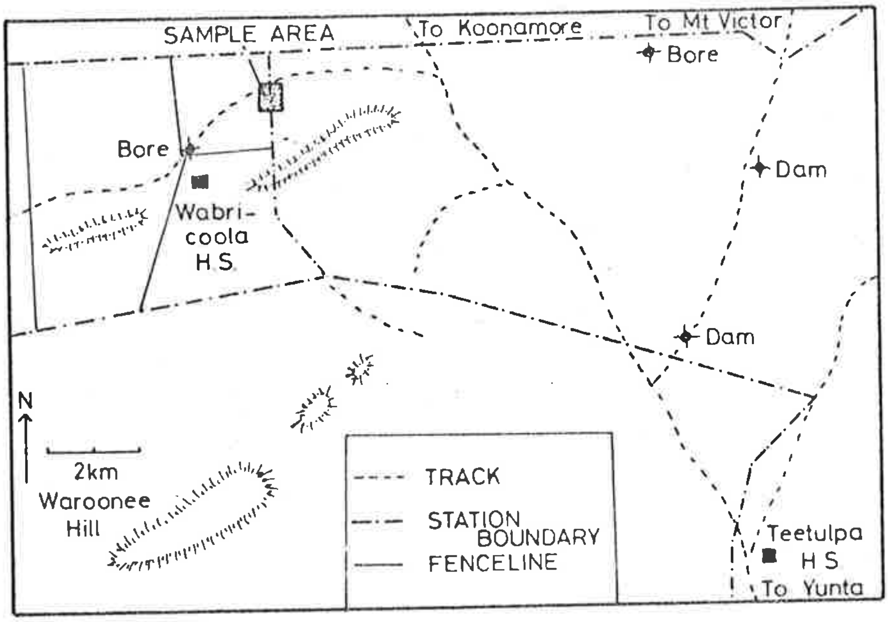
The paddock adjoining the western fence was part of another station, and sheep were run in it. However, sheep rarely penetrated so far, due partly to the distance from the nearest water (8km), and partly to a barrier of low hills. The vegetation showed little sign of grazing: the soil surface was undisturbed, the perennial chenopods were tall and spindly, and tree canopies extended to the ground. (The latter two features indicated the absence of browsing).

A rectangular staggered grid, dimensions $1000 \times 800m^2$, was sited over this fence. 80 quadrats were laid, dimensions $1.5 \times 20m^2$. Density of adults and juveniles were scored, for *Atriplex stipitata, A. vesicaria,* and *K. georgei,* the major chenopods present. Juveniles were defined as single stemmed individuals under 10cm in height. Figures 7.5, 7.6, 7.7 give the distributions of adults for these species, and figure 7.8 the distribution of *A. stipitata* juveniles, the most commonly found.

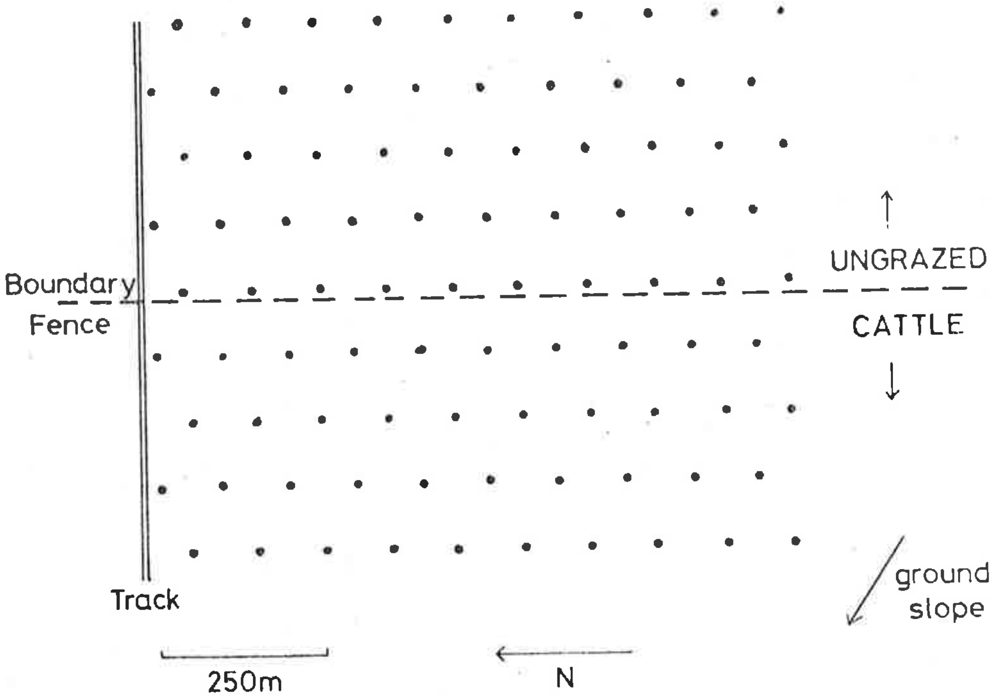
From these distributions, there appeared no significant re-establishment of populations across the fence, despite the seed source on the ungrazed side, the slope of the ground which would aid water transport of seeds, the reported unpalatability of *A. stipitata* (e.g. Barker and Lange, 1970) and the reported regenerative ability of the same species (Hall et al, 1964). Further, the survey was made in May 1974, after a year of above average rainfall (chapter 4). At least some seedlings could be expected to appear in the grazed paddock at such a time, if regeneration was in progress.

Fig. 7.4

LOCATION OF CROSS-FENCE COMPARISON AT WABRICOOLA



Sample grid



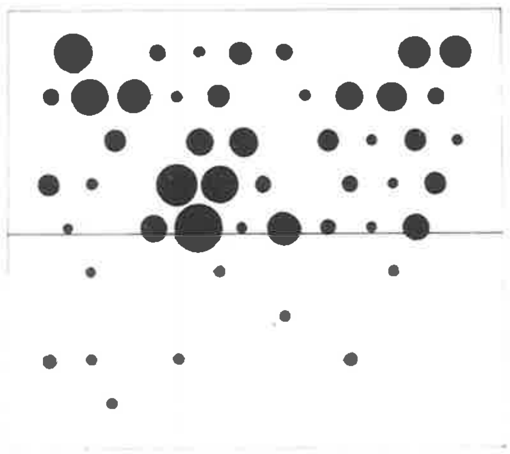


Fig. 7.5

A. STIPITATA (ADULT)

Density

1 plant/quadrat

3 plants/quadrat

5 " "

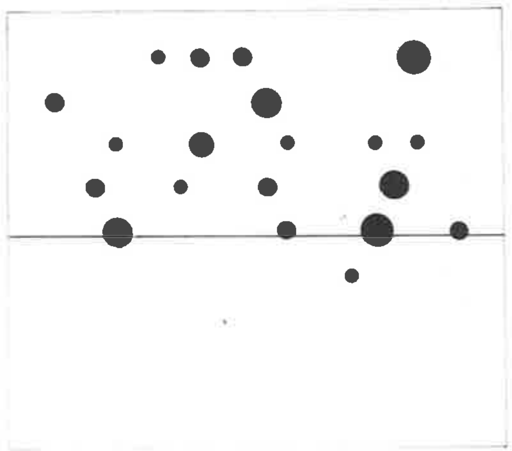


Fig. 7.7

K. GEORGEI

Density

1 plant/quadrat

3 plants/quadrat

5 " "

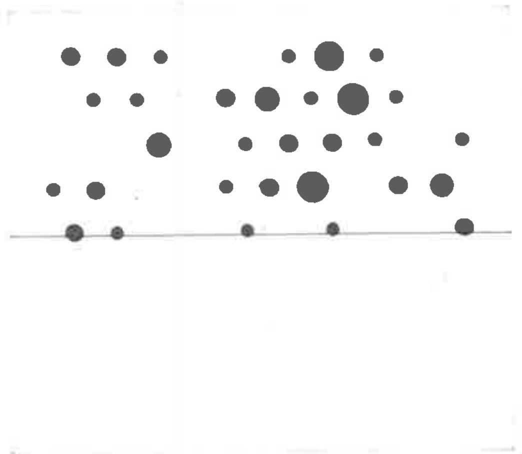


Fig. 7.6

A. VESICARIA

Density

1 plant/quadrat

3 plants/quadrat

5 " "

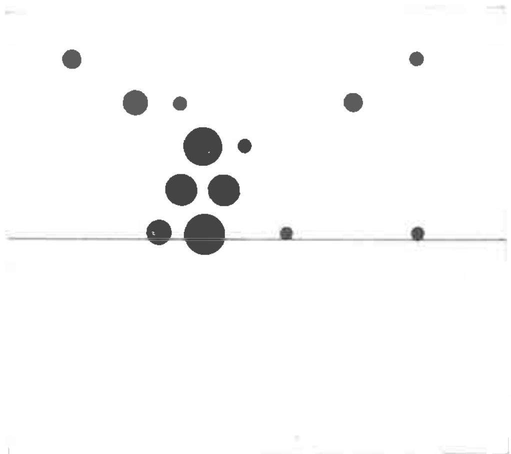


Fig. 7.8

A. STIPITATA

(JUVENILES)

Density

1 plant/quadrat

3 plants/quadrat

5 " "

Hence, cattle appear to have maintained, for fifteen years, the sheep impress on these species.

7-4 CONCLUSIONS.

The above studies were neither extensive nor detailed. However, they dealt with species which, by all accounts, would rank very low on a scale of cattle preference (see section 1-63). Yet cattle were found to induce changes in their populations, comparable with those reported for sheep, or to maintain prior sheep effects.

The results thus provide independent support for the contention of the preceding two chapters, that the long term effect of cattle is not significantly different from that of sheep. Further, they would not be expected if preferential selection of fodder species were the cause of long term change.

CHAPTER 8

GENERAL DISCUSSION

8-1 INTRODUCTION.

The object of this thesis was to outline the immediate impact and the probable long-term effect, on arid pastures, of the introduction of cattle onto former sheeplands; and to determine, if possible, the mechanisms involved. This was attempted by the observation of a small number of representative situations. Detailed discussions and conclusions have been given in the course of reports, and are summarized as follows:

1. The immediate impact of cattle is the formation of new patterns in the vegetation. These patterns are only observed intermittently, but are recurrent.
2. The long-term outcome of cattle introduction is closely similar to the long-term outcome of sheep grazing. Either the former sheep impress is maintained, or the cattle, if introduced to formerly ungrazed pastures, bring about changes in the vegetation as reported to occur under sheep stocking.
3. The cause of the stock-related patterns and changes in vegetation remains uncertain, but it appears that grazing *per se* is a minor factor except in the short-term.

Before discussing the wider implications, both ecological and pastoral, two serious conflicts in the findings must be resolved. These are (a) the validity of methods used in the inference of long-term change, in view of the demonstrated short-term variation; and (b) the disparity between the short-term effect and long-term outcome of cattle introduction.

8-2 THE VALIDITY OF INFERENCES REGARDING LONG-TERM PASTURE CHANGE.

The inferences of long-term pasture change due to stocking, as given in chapter 5 and the latter part of chapter 7, were based on data collected at a single point in time. To recapitulate: the densities of pasture species were compared between sites with differential stocking histories. A difference between sites in density of a species was interpreted as showing a long-term change in the status of the species' population, with allowance being made for the effect of background environmental influences and grazing in the short-term. In chapter 4, short-term effects were shown to fluctuate so greatly as to cast severe doubt on the validity of inferences of change in time drawn from patterns in space: the particular inferences would depend to a great extent on the conditions pertaining at the time of data collection. Thus the accuracy of the inferences drawn in chapters 5 and 7 depend to a great extent on whether adequate allowance was made for the short-term stocking effects.

As regards the long-lived perennials, particularly the salt- and blue-bushes, any significant difference in density relating to differences between stocking treatments will have long-term consequences. The species are slow to regenerate, and until they do, there remains the potential for permanent damage through erosion. Therefore a lower density of perennials in one stocking treatment relative to another must be considered evidence for divergences between the two, if not long-term in origin, then at least long-term in consequences. There is thus little doubt as to the validity of the inferences concerning the perennial species.

As regards ephemerals, the short-term effects were effectively minimised, but this was due to fortunate (though not fortuitous) circumstances. These were the availability of (a) a virgin pasture as a basis for the first comparison (virgin/cattle, Pernatty station); and (b) a growth period in which to draw the second comparison (cattle/sheep, Roxby Downs station). Virgin areas, suitable for comparison with grazed pastures, are understandably rare, after a century of settlement; and comparison between grazing treatments cannot always rely on convenient growth periods. In the first comparison, short-term stocking effects were minimised by disregarding any ephemeral species with a lower abundance in the grazed area, and only considering those with higher abundances in the grazed area, despite probably short-term reduction in densities from the previous growth period. In the second comparison, the growth period meant that short-term stocking effects were obscured or absent--as shown in chapter 4--and any residual differences between treatments must therefore have reflected on a long-term divergence.

The inference of long-term change can thus be considered valid, because of the special circumstances. Nonetheless, since such circumstances are not always available, the general warning in section 4-94, on the interpretation of changes in time from patterns in space, still applies.

8-3 DISPARITY BETWEEN SHORT-TERM AND LONG-TERM OUTCOMES.

Although the immediate impact of cattle is the formation of patterns in vegetation differing from those imposed by sheep, the long-term outcomes are closely similar. Such a disparity is not easily resolved, since the long-term outcome cannot be completely independent of short-term effects. Two possible explanations are offered.

1. The eventual outcome of stocking is not the result of cumulative short-term changes in the vegetation; but is rather the result of occasional catastrophic changes, occurring over a short period, but with long-term consequences.
2. The eventual outcome of stocking is the cumulative result of short-term changes which, though predominantly ephemeral in nature, nonetheless have a residual effect; but the seasonal variation over a short observation period is such as to obscure the direction of the drift in pasture condition.

The two are not necessarily mutually exclusive.

Few of the reports on grazing succession in the southern Australian rangelands give a time scale : on the whole, changes have been largely inferred, as in this thesis, from comparison of different stocking regimes, rather than by direct observation of succession over a long period. Hence there is little evidence as to which of the above processes is in operation. Indirect evidence does exist for the first. The history of grazing on the Australian rangelands is punctuated by periodic catastrophes (section 1-3). Pasture degradation following settlement was not a gradual process. In particular, many of the perennial pastures were destroyed over a short period; during the 1890's in western New South Wales, (Anon, 1901), 1930-1935 in South Australia (Ratcliffe, 1936), to quote only two instances. The result of this damage--erosion, loss of drought fodder reserves, changes in nutrient status--have been detailed in chapter 1. Thus, although occurring over a very short period, this destruction had consequences still evident, and not related to subsequent, non-catastrophic short-term grazing effects. Noble (1975) has also pointed out that trend in pastures is not necessarily a gradual process. Perry (1970) considered that, following the earlier catastrophes, the rangeland pastures are at present in a relatively stable state, although individual outcomes have been determined by the severity of the past crashes. Williams (1968) reached similar conclusions in studies on vegetation changes in the semi-arid Riverina.

Either possibility can account for the disparity reported in this thesis. In the first case, the short-term observations were made during a period of exceptional pasture growth. Stocking effects, because of the light overall stocking, were necessarily minimal, and catastrophic changes could not be expected to occur under such conditions. In the second case, the observation period was too short, and the pasture fluctuations too great, to allow detection of incipient long-term changes resulting from the cattle introduction.

8-4 PIOSPHERE PATTERN

The vegetation patterns of the sheep and cattle piospheres were investigated, primarily to isolate stocking effects from the influences of background environmental variables. However, the findings have implications extending beyond the immediate problems under consideration.

Barker and Lange (1969, 1970) and Rogers and Lange (1971) were primarily concerned with the demonstration and general delineation of piosphere pattern in vegetations stocked with sheep. For this purpose, they used radial sampling grids, designed to amplify any existing radial pattern, and mapping as the main form of data presentation. These methods were adequate to display the general form of piosphere pattern, viz., the existence of continuous gradients in vegetation and the radial nature of the patterns. Only minor attempts were made to determine, in more detail, the form of plant/distance relationships.

The present study has demonstrated two significant points. The first is that an unbiased sampling system will detect piosphere pattern as readily as the above sampling. The second is that the plant/distance relationships can be approximated by linear functions. The search for linear relationships was proposed on the basis of Lange's (1969) observations, of linear relationships between sheep dung drops and distance from water, and on evidence in Rogers and Lange (1971) that lichen frequency also shows a linear relationship. The existence of linear gradients in the pasture have now been amply demonstrated. Nonetheless, further investigations into these relationships are required. All recent studies, and the present one, have dealt with the piosphere pattern well within the normal range of stock. The results cannot be rationally extrapolated to the limits of the piosphere: changes in plant parameters with distance must approach zero towards the limits. Further, linear relationships are not easily accounted for from reports of stock behaviour. These reports indicate that the distribution of grazing pressure is not such as to give rise to linear pattern in vegetation. Thus the detail of the variation remains unknown, although the vegetation studies have demonstrated the existence of the patterns and have shown how these can be approximated. Until the detail has been determined, the direct relationship between the patterns and the actions of the grazing animal cannot be considered in depth.

The present study has demonstrated the existence of piosphere pattern caused by cattle. This was expected, but had not been previously documented in the Australian rangelands. The cattle piospher shows the same basic outline as the sheep piosphere; continuous gradients in the vegetation and radial pattern centred on the waterpoint. The differences between the sheep and cattle piospheres are differences in detail--the particular species affected--rather than differences in principle.

8-5 THE CAUSE OF STOCK-INDUCED VEGETATION CHANGE

Three potential factors in vegetation change resulting from stocking were discussed in chapter 1, viz., the grazing of preferred species, trampling or general disturbance in the course of grazing, and nutrient transfer over the pasture correlated with stock movement. The last factor was not considered to play a major overall role in causation of change, because of the low animal:area ratio, and the resultant minimal transfer (see section 1-8). The first two have been discussed at length throughout the thesis.

In summary, the preferential selection hypothesis is that changes in vegetation result from the grazing down of preferred species, and the consequent increase in less preferred species due to the lessened plant competition. Hence patterns and trends observed should reflect the dietary preferences of the particular herbivore involved. The observations reported in chapter 4 lent some support to this. The findings indicated that the cattle were consuming mainly grass, whereas the sheep were consuming some grass, but also forbs and shrubs. This corresponds with the general differences in preference- between sheep and cattle, as reviewed in section 1-63. Nonetheless, the hypothesis was not convincingly validated. In particular, there was evidence of short-term stock-induced pattern in the distribution of *Enneapogon* spp., the reverse of the pattern expected from reports of sheep preference. Further, *Kochia astrotricha* showed short-term stocking impress under sheep at a time when more highly preferred species were abundant. The review outlined the high degree of selectivity displayed by grazing stock, and sheep in particular. For example, Leigh and Mulham (1966a) reported that species comprising only a small proportion of the total pasture were major contributors to the diet. However, of the 55 species dealt with in the chapter 4 studies, only those most commonly occurring showed the influence of stocking. If dietary selection were the cause of pattern, less common species should also have demonstrated the stocking influence. Although the present findings may arguably have arisen from the particular statistical methods employed, Barker and Lange (1969) also found that the piosphere patterns were only displayed by a few of the more common species, despite their use of sampling systems and analyses designed to amplify any existing pattern.

The outcome of long-term cattle stocking, reported in the first part of chapter 5, was completely inexplicable in terms of dietary preferences. The same species were found to increase or decrease under cattle-stocking as under sheep-stocking. The results of chapter 7 are also inexplicable in such terms; the cattle had suppressed the regeneration of perennial chenopods, and thus maintained the original sheep impress, despite the low preference for shrubs in general, and probably for chenopods in particular (section 1-63, see also chapter 2).

Mechanical disturbance was therefore proposed as the prime causal factor, since the disturbance of soils and plants by stock would necessarily have an effect independent of the dietary preferences. Soil disturbance was the feature considered in depth. The comparison of equivalently stocked sheep and cattle pastures, with a more or less equivalent level of disturbance, indicated little differences between the long-term outcome of the two stocking regimes, as was expected from the hypothesis. However, the findings did not completely rule out the possibility of divergences due to differences in grazing preferences. Relationships between plant distributions and soil stability were examined in more detail (chapter 6), and the data from the preceding chapter re-examined, but again the changes under stocking did not coincide precisely with changes predicted to follow soil disturbances. Hence, although the results indicate that the preferential selection hypothesis is unsatisfactory, the validity of the disturbance hypothesis remains equivocal.

Nonetheless, the findings on the whole concur with Heady's (1964) statement, that

> "vegetation changes seem to be correlated more with the intensity of range stocking and use than with preference, notwithstanding a widespread belief that changes are due in large measure to selection".

8-6 PASTORAL IMPLICATIONS

The investigations of this thesis dealt with representative situations. The particular stations concerned had stocking histories common to most in the South Australian arid sheeplands, and were stocked at a median level for their particular districts. The pastures examined were typical of those most likely to be switched to cattle, both in their structure and composition. The outline of results therefore can be considered indicative of the likely effect of cattle introduction elsewhere, although the detail will vary in accordance with the particular circumstances.

The investigation did not consider the question of optimum rates. Rather, the outcome under the usual rates set by the range managers was sought, whether or not these represented the optimum.

It must be realised that stocking levels are set on the basis of experience, and will continue to be until a sufficient store of unequivocal information is available. Ecological research, however, has only touched the surface of the problem (Perry, 1969). The manager's assessment will thus determine the outcomes for much of the foreseeable future. In this exploratory study, therefore, only the consequences of the most usual assessments have been considered.

As regards the resultant condition of the pasture, the findings imply that neither advantages nor disadvantages will accrue in the long term from the replacement of sheep-stocking by cattle-stocking; the end result will be the same as would occur under continued sheep-stocking. This is of particular importance for those pastures with a residual perennial chenopod component. Under the present median stocking levels, the regeneration of these species will remain suppressed under either sheep-stocking or cattle-stocking. Hence, without a change in the stocking levels, or in set stocking policies, a gradual attrition of the remaining populations is probable. This allows no complacency as regards the future of the arid sheeplands. Although the present stocking levels are now much lower than in the first five decades of utilisation (Heathcote, 1969), and the possibilities of catastrophic destruction are accordingly lessened, nonetheless the attrition of perennial pastures implies a continuing degradation, as the pastures become increasingly ephemeral in composition and the cover against erosion is removed. This need not be always so. Barker (1971) stated that stations with very light set-stocking did not show any change in overall perennial cover, although the dominant species were apparently slowly being replaced with other perennials (the particular instance was *Kochia sedifolia,* slowly decreasing, and *K. pyramidata,* slowly increasing). Certain of the stations discussed in this thesis have largely succeeded in regenerating the perennial pastures, by a combination of spelling and mechanical treatments. These are, however, unusual situations. On the whole, the findings point to a gradual attrition of the vegetation resources, which, because of the long life span of the species involved, may not be evident except over a very long period.

There appears to be a short-term benefit of the switch to cattle, but this is equivocal. It depends largely on the mechanics of cattle-grazing and the pattern of seasons. In chapter 4, the first regrowth of major fodder grasses was reported to be from old butts. Evidence was presented indicating that the cattle tended to leave more butts than did sheep; in the cattle case, a component of biomass showed changes relating to stocking without commensurate changes in density, but in the sheep case there was no change in biomass independent of the change in density. Hence the regrowth of grasses may be faster initially under cattle-stocking than under sheep-stocking, since there is not the time lag in production required for germination and growth to an edible size in the cattle case. However, this is a doubtful benefit; there is probably better potential for production in a new rather than a senescent individual. Further, such a benefit would only apply for seasons such as 1971-1974, where periods without rain are too short for the death and breakdown of butts remaining from the last growth, as would occur in drought.

8-7 CONCLUSIONS

Such considerations aside, the formal conclusions of this investigation are as follows:-

1. The immediate impact of cattle on former sheeplands is the formation of new pattern in the vegetation. This pattern shows piosphere symmetry, similar in its basic characteristics to symmetry in the sheep piosphere. The detail is, on the whole, different to the detail under sheep; in the species affected, the parameters affected, and the direction of relationships.
2. The long-term outcome of cattle introduction is closely similar to the outcome of continued sheep-stocking. Perennial species decrease in abundance, their regeneration is suppressed, and ephemerals increase in abundance. The particular species involved are reported to behave in the same manner under sheep-stocking.
3. The cause of stock-related vegetation pattern and change remains uncertain. Preferential grazing selection of plant species can account for some of the short-term patterns observed, but not for the long-term changes. Disturbance, independent of the particular herbivore, can account for much of the long-term changes, but some changes

and patterns still remain unaccountable. Nonetheless, whatever factors are involved, they appear largely independent of the particular herbivore.

Concerning the nature of the piosphere, two further conclusions can be added.

4. The piosphere concept, originally derived from observations of sheep-stocking effects, can be validly extended to the cattle case.

5. In both sheep and cattle cases, piosphere effects can only be observed in the distributions of a small proportion of pasture species.

Implicit in the first two conclusions is the degradation of the pastures in the South Australian arid sheeplands. The degradation which can occur under sheep has been well reported. The introduction of cattle thus has the same potential. It is therefore vital to determine the basic factors, apparently common to both herbivores, which bring this about.

The piosphere concept provides an excellent basis for the study of stock/plant interactions. Nonetheless, it is evident that only its broadest outlines are at present known. Two points that would bear close investigation are (a) the nature of the distribution of gradients within the vegetation, and (b) autecological studies of the species which consistently show piosphere pattern. Studies dealing with the former point are necessary to determine the true nature of the distribution of stocking pressure within the piosphere. Without this knowledge, examination of the potential causes of pattern must remain difficult. Studies dealing with the latter point should consider, in close detail, changes in soil structure and nutrient status, as it appears that these features may be of greater importance than grazing *per se*.

The economics of pastoral enterprise are at present in a state of flux. Nonetheless, grazing in the rangelands is likely to continue in the foreseeable future, particularly as the demand for animal protein grows. Both this and past studies indicate that the grazing by domestic ungulates, of plants which evolved in the absence of such herbivores, is resulting in a general degradation. In the past, this degradation has sometimes been very rapid. At present, the situation appears relatively stable, yet the indications are that, on the whole, a slow attrition of the vegetation resource is inevitable under present management systems. Investigations are required, not only aimed at documenting the situation as this one has been, but also to determine the root causes of this decline, and to devise viable alternatives to the present systems.

BIBLIOGRAPHY

ALBERTSON, F.W., RIEGEL, A., and LAUNCHBAUGH, J.L. (1957). Ecology of drought cycles and grazing intensity on grasslands of the central Great Plains. *Ecol. Monogr.* *27*, 27-44.

ALEXANDER, G.I., and CARRAILL, R.M. (1973). The beef cattle industry, pp143-170 in *The Pastoral Industries of Australia,* G. Alexander and O.B. Williams (eds). Sydney Univ. Press, Sydney.

ANDERSON, D.J. (1971). Pattern in desert perennials. *J. Ecol. 59,* 555-560.

ANON. (1901) Royal Commission for the New South Wales Govt. Reported in CAIN (1962).

ARES, J.O., and LEON, R.J.C. (1972). An ecological assessment of the influence of grazing on plant community structure. *J. Ecol.* *60*, 333- .

AUSTIN, M.P. (1968). Pattern in a *Zerna erecta* dominated community. *J. Ecol. 56*, 197-218.

__________. (1971). Role of regression analysis in plant ecology. *Proc. Ecol. Soc. Aust. 6*, 63-75.

__________., and GRIEG-SMITH, P. (1968). The application of quantitative methods to vegetation survey II. Some methodological problems of data from rain forest. *J. Ecol. 56*, 827-844.

BARKER, S. (1970). Quondong Station, South Australia: a field context for applied rangeland research. *Trans. Roy. Soc. S. Aust. 94,* 179-190.

__________., and LANGE, R.T. (1969). Effects of moderate sheep stocking on plant populations of a Blackoak-Bluebush association. *Aust. J. Bot. 17*, 527-537.

__________., and LANGE, R.T. (1970). Population ecology of *Atriplex* under sheep stocking. pp105-120 in *The Biology of Atriplex*, R. Jones (ed.). CSIRO Div. Plant Industry.

BARNARD, A. (1969). Aspects of the economic history of the arid land pastoral industry. pp209-228 in *Arid Lands of Australia*, R.O. Slatyer and R.A. Perry (eds). Aust. National Univ. Press, Canberra.

BEADLE, N.C.W. (1948). *The Vegetation and Pastures of Western New South Wales.* N.S.W. Dept of Conservation and Govt Printer, Sydney.

__________. (1952). Studies in halophytes I. The germination of the seed and establishment of the seedlings of five species of *Atriplex* in Australia. *Ecology 33*, 49=62.

BEADLE, N.C.W. (1959). Some aspects of ecological research in semi-arid Australia. pp452-460 in *Mongraphiae Biologicae VIII: Biogeography and Ecology in Australia.* Dr W. Junk, Den Haag.

__________., and TCHAN, Y.T. (1955). Nitrogen economy in semi-arid plant communities I. The environment and general considerations. *Proc. Linn. Soc. N.S.W. 89*, 273-286.

BENNETT, D., MORLEY, F.H.W., CLARK, K.W., and DUDZINSKI, M.L. (1970). The effect of grazing cattle and sheep together. *Aust. J. Exptal Agric. Anim. Husbandry 10*, 694-709.

BENNETT, J.B., KENNEY, F.R., and CHAPLINE, W.R. (1938). The problem: subhumid areas. pp68-76 in *USDA Yearbook of Agriculture 1938.* U.S. Govt Printing Office, Washington.

BLACK, J.M. (1943-1957). *Flora of South Australia,* vols I-IV. Govt Printer, Adelaide.

BLEAK, A.T., FRISHKNECHT, N.C., PLUMMER, A.P., and ECKERT, R.E. (1965). Problems in artificial and natural re-vegetation of the arid Shadscale vegetation zone of Utah and Nevada. *J. Range Manage. 8*, 59-65.

BONSMA, J.C. (1949). Breeding cattle for increased adaptability to tropical and subtropical environments. *J. Agric. Sci. 39*, 204-221.

BORDEAU, P.F. (1953). A test of random versus systematic ecological sampling. *Ecology 34*, 499-512.

BOWES, K.R. (1968). Land settlement in South Australia 1857-1890. Libraries Board of South Australia, Adelaide.

BOX, T.W., and PERRY, R.A. (1971). Rangeland management in Australia. *J. Range Manage. 24*,167-171.

BOYLAND, . . ( ). Ecological and floristic studies in the Simpson Desert National Park, south western Queensland. *Proc. Roy. Soc. Qld 82*, 1-16.

BROWN, G.D., and HUTCHINSON, J.C.D. (1973). Climate and animal production. pp336-370 in *The Pastoral Industries of Australia,* G. Alexander and O.B. Williams (eds). Sydney Univ. Press, Sydney.

BURBIDGE, N.T. (1945). Germination studies of Australian Chenopodiaceae with special reference to the conditions necessary for regeneration I. *Atriplex vesicaria* Heward. *Trans. Roy. Soc. S. Aust. 69*,73-84.

CAIN, N. (1962). Companies and squatting in the Western Division of New Sout Wales, 1896-1905. pp453-456 in *The Simple Fleece: Studies in the Australian Wool industry,* A. Barnard (ed). Aust. National Univ. and Melbourne Univ. Presses, Melbourne.

CAMPBELL, N.A., and ARNOLD, G.W. (1973). The visual assessment of pasture yield. *Aust. J. Exptal Agric. Anim. Husbandry 13, 263-267.*

CARRODUS, B.B., SPECHT, R.L., and JACKMAN, M.E. (1965). The vegetation of Koonamore station, South Australia. *Trans. Roy. Soc. S. Aust., 89,* 41-57.

CHARLEY, J.L., and COWLING, S.W. (1968). Changes in soil nutrient status resulting from overgrazing, and their consequences in plant communities of semi-arid areas. *Proc. Ecol. Soc. Aust.* *3*, 28-38.

CHIPPENDALE, G.M. (1968). *A study of the diet of cattle in Central Australia as determined by rumen samples.* N.T. Administration, Primary Industries Branch, Tech. Paper *1*.

CLARY, W.P., and PEARSON, H.A. (1969). Cattle preferences for forage species in northern Arizona. *J. Range Manage.* *22*, 114-117.

CONDON, R.W., and KNOWLES, G.H. (1952). Saltbushes. *J. Soil Conservat. Service N.S.W.* *8*, 149-157.

CONDON, R.W., NEWMAN,J.C., and CUNNINGHAM, G.M. (1969). Soil erosion and pasture degeneration in Central Australia I. Soil erosion and degeneration of pastures and topfeeds. *J. Soil Conserv.* *25*, 47-92.

COOK, C.W., HARRIS, L.E., and YOUNG, M.C. (1967). Botanical and nutritive content of diets of cattle and sheep under single and common use on mountain range. *J. Anim. Sci.* *26*, 1169-1174.

CROCKER, R.L. (1946). The Simpson Desert expedition 1939. Scientific report no. 8. The soils and vegetation of the Simpson Desert and its borders. *Trans. Roy. Soc. S. Aust.* *70*, 235-258.

___________., and SKEWES, H.R. (1941). The principal soil and vegetation relationships on Yudnapinna station, South Australia. *Trans. Eoy. Soc. S. Aust.* *65*, 44-60.

DIXON, S. (1892). The effects of settlement and pastoral occupation in Australia upon the indigenous vegetation. *Trans. Roy. Soc. S. Aust.* *15*, 195-206.

EICHLER, Hj. (1965). Supplement to J. M. Black's *Flora of South Australia, 2nd Edition.* Govt. Printer, Adelaide.

GALT, H.D., THEURER, B., EHRENREICH, J.H., HALE, W.H., and MARTIN, S.C. (1969). Botanical composition of the diet of steers grazing a desert grassland range. *J. Range Manage.* *22*, 14-18.

GENTILLI, J. (ed) (1971).. *Climates of Australia and New Zealand.* Vol. 13 of *World survey of climatology.* Amsterdam.

___________. (1972). *Australian climate patterns.* Nelson, Melbourne.

GIBBS, W.J. (1969). Meteorology and climatology. pp33-54 in *Arid lands of Australia,* R.O. Slatyer and R.A. Perry (eds). Aust. National Univ. Press, Canberra.

GOODALL, D.W. (1952). Some considerations in the use of point quadrats for the analysis of vegetation. *Aust. J. Sci. Res. Ser. B* *5*, 1-41.

___________. (1970). Statistical plant ecology. *Ann. Rev. Ecol. Syst.* *1*, 99-124.

GRIEG-SMITH, P. (1964). *Quantitative Plant Ecology.* 2nd edition. Butterworths, London.

______________., AUSTIN, M.P., and WHITMORE, T.C. (1967). the application of quantitative methods to vegetation survey I. Association analysis and principal component ordination of rainforest data. *J. Ecol. 55*, 483-503.

______________, and CHADWICK, M.J. (1965). Data on pattern within plant communities III. *Acacia - Capparis* semi-succulent scrub in the Sudan. *J. Ecol. 53*, 465- .

HALL, E.A.A., SPECHT, R.L., and EARDLEY, C.M. (1964). Regeneration of the vegetation on the Koonamore Vegetation Reserve 1926-1962. *Aust. J. Bot. 12*, 205-264.

HARKER, K.W. (1960). Defaecating habits of a herd of Zebu cattle. *Trop. Agric. (Trinidad) 37*, 193-200.

HARRINGTON, G.N., and PRATCHETT, D. (1973). Cattle diet on Ankole rangeland at different seasons. *Trop. Agric. (Trinidad) 50*, 211-219.

HEADY, H.F. (1964). Palatability of herbage and animal preference. *J. Range Manage. 17*, 76-82.

__________. (1966). Influence of grazing on the composition of *Themeda triandra* grassland, East Africa. *J. Ecol. 54*, 705-727.

HEATHCOTE, R.L. (1965). *Back of Bourke: a study of land appraisal and settlement in semi-arid Australia.* Melbourne Univ- Press, Melbourne.

______________. (1969). Land tenure systems: past and present. pp185-208 in *Arid Lands of Australia*, R.O. Slatyer and R.A. Perry (eds). Aust. National Univ. Press, Canberra.

HERBEL, C.H., ARES, F.N., and NELSON, A.B. (1967). Grazing distribution patterns of Hereford and Santa Gertrudis on a southern New Mexico range. *J. Range Manage. 20*, 296-298.

HILDER, E.J. (1964). The distribution of plant nutrients by sheep at pasture. *Proc. Aust Soc. Anim. Prod. 5*, 241-248.

HUTCHINGS, S.S., and SCHMAUTZ, J.E. (1969). A field test of the relative weight estimate method for determining herbage production. *J. Range Manage. 22*, 408-411.

IVIMEY-COOK, R.B., and PROCTOR, M.C.F. (1967). Factor analysis of data from an East Devon heath: a comparison of principle component and rotated solutions. *J. Ecol. 55*, 405-419.

JACKSON, E.A. (1958). *A study of soils and some aspects of the hydrology of Yudnapinna station, South Australia.* CSIRO Soils and Land Use series, No. 24.

JESSUP, R.W. (1951). The soils, geology and vegetation of northwestern South Australia. *Trans. Roy. Soc. S. Aust. 74*, 189-273.

JONES, R. (ed) (1970). *The biology of* Atriplex. CSIRO Div. of Plant Industry, Canberra.

KERSHAW, K.A. (1968). Classification and ordination of Nigerian savannah vegetation. *J. Ecol 56*, 467-482.

__________. (1973). *Quantitative and dynamic plant ecology.* 2nd edn. Edward Arnold, London.

KNOWLES, G.H. (1951). Some western pasture species--Bluebush, cotton-bush and other perennial chenopods. *J. Soil Conservat. Ser. N.S.W. 7*, 180-198.

LANGE, R.T. (1965). Growth ring characteristics in an arid zone conifer *Callitris columellaris* near Woomera. *Trans. Roy. Soc. S. Aust. 89*, 133-137.

__________. (1967). Nitrogen, sodium and potassium in foliage from some arid and temperate zone shrubs. *Aust. J. Biol. Sci. 20*, 1029-1032.

__________. (1968). Influence analysis in vegetation. *Aust. J. Bot. 16*, 555-564.

__________. (1969). The piosphere: sheep track and dung patterns. *J. Rnage Manage. 22*, 396-400.

__________. (1971). Influence analysis and prescriptive management of rangeland vegetations. *Proc. Ecol Soc. Aust. 6*, 153-158.

LAYCOCK, W.A., BUCHANAN, H., and KRUEGER, W.C. (1972). Three methods of determining diet, utilization and trampling damage on sheep ranges. *J. Range Manage. 25*, 352-356.

LEIGH, J.H., and MULHAM, W.E. (1965). *Pastoral plants of the Riverine plain.* Jacaranda, Melbourne.

__________. and __________. (1966a). Selection of diet by sheep grazing semi-arid pastures on the Riverine plain I. A bladder saltbush (*Atriplex vesicaria*)--cotton bush (*Kochia aphylla)* community. *Aust. J. Exptal Agric. Anim. Husbandry 6*, 460-467.

__________., and __________. (1966b). Selection of diet by sheep grazing semi-arid pastures on the Riverine plain II. A cotton bush (*Kochia aphylla)*--grassland (*Stipa-Danthonia caespitosa)* community. *Aust. j. Exptal Agric. Anim. Husbandry 6*, 468-474.

__________., and __________. (1967). Selestion of diet by sheep grazing semi-arid pastures on the Riverine plain III. A bladder saltbush (*Atriplex vesicaria*)--pigface (*Disphyma australe)* community. *Aust. J. Exptal Agric. Anim. Husbandry 7*, 421-425.

__________., and NOBLE, J.C. (1969). Vegetation resources. pp73-92 in *Arid lands of Australia*, R.O. Slatyer and R.A. Perry, eds. Aust. National Univ. Press, Canberra.

LEIGH, J.H., WILSON, A.D., and MULHAM, W.E. (1968). A study of merino sheep grazing on cotton bush (*Kochia aphylla*)--grassland (*Stipa variabilis-Danthonia caespitosa*) communtiy on the Riverine plain. *Aust. J. Agric. Res. 19*, 947-961.

LITCHFIELD, W.H. (1962). *Soils of the Alice Springs area.* CSIRO Aust. Land Res. Ser. No. 6.

LOCK, J.M. (1972). The effects of hippopotamus grazing on grasslands. *J. Ecol 60*, 445-467.

LOW, W.A. (1972). Community preference by free ranging shorthorns in the Alice Springs district. *Aust. Soc. Anim. Prod. 9*, .

________. (1973). Feeding interactions of red kangaroos and cattle in an arid ecosystem. (A paper given at III World Conference on Animal Production, at Melbourne, 1973.)

LYNCH, J.J. (1967). Ranging behaviour of sheep in large areas. *Proc. Ecol. Soc. Aust. 2*, 167-169.

__________. (1973). Merino sheep: some factors affecting their distribution in very large paddocks. (Proceedings, conference on Behaviour of Ungulates and its Relations to Management,Calgary, 1971). Publ. Internat. Union for Conservation of Nature, Morges, Suisse.

__________., and ALEXANDER, G. (1973). Animal behaviour and the pastoral industries. pp371-400 in *The pastoral industries of Australia*, G. Alexander and O.B. Williams (eds). Sydney Univ. Press, Sydney.

LYON, L.J. (1968). Evaluation of density sampling methods in a shrub community. *J. Range Manage. 21*, 16-20.

MACFARLANE, W.V. (1964). Terrestrial animals in dry environments: ungulates. *Am. Handbook Physiol. 4*, 509- .

_______________. (1968). Protein from the wasteland: water and the physiological ecolgy of ruminants. *Aust. J. Sci. 31*, 20-30.

_______________., MORRIS, R.J.H., and HOWARD, B. (1956). The water economy of tropical merino sheep. *Nature 178*, 304-305.

_______________., HOWARD, B, and SIEBERT, B.D. (1967). Water metabolism of merino and Border Leicester sheep grazing saltbush. *Aust. J Agric. Res. 18*, 947-958.

McINTYRE, G.A. (1953). Estimation of plant density using line transects. *J. Ecol. 41*, 319-330.

MACONOCHIE, J.R., and NELSON, D.J. (1972). Regeneration of vegetation in Central Australia. *Pastoral Review 1972*, pp16-17.

MADIGAN, C.T. (1936). The Australian sandridge deserts. *Geog. Rev. 26*, 205-227.

MANNETJE, L.'t., and HAYDOCK, K.P. (1963). The dry weight rank method for the botanical analysis of pasture. *J. Brit. Grassld Soc. 18*, 268-275.

MARSHALL, J.K. (1973). Drought, land use and soil erosion. pp55-77 in *The environmental, economic and social significance of drought*, J.V. Lovett (ed). Angus and Robertson, Sydney.

MEAD, R. (1971). A note on the use and misuse of regression models in ecology. *J.Ecol. 59*, 215-219.

MEIGS, P. (1953). World distributions of arid and semi-arid homoclimates. pp203-209 in *Reviews of research on arid zone hydrology*. UNESCO, Paris.

MOORE, C.W.E. (1953a). The vegetation of the south-east Riverina, New South Wales I. The climax communities. *Aust. J. Bot. 1*, 485-547.

____________. (1953b). The vegetation of the south east Riverina,New South Wales II. The disclimax communities. *Aust. J. Bot. 1*, 548-571.

MOORE, R.M. (1959). Ecological observations on plant communities grazed by sheep in Australia. pp500-513 in *Monographiae Biologicae VIII: Biogeography and Ecology in Australia*. Dr W. Junk, Den Haag.

MORLEY, F.H.W., BENNETT, D., and CLARK, K.W. (1964). The estimation of patsure yield in large grazing experiments. *Field Sta. Rec. Div. Plant Industry CSIRO (Aust) 3*, 43-47.

MURRAY, B.J. (1931), A study of the vegetation of the Lake Torrens plateau, South Australia. *Trans. Roy. Soc. S. Aust. 55*; 91-112.

MUTOOROO PASTORAL COMPANY (1951). *The Mutooroo Pastoral Company after 50 years*. Advertiser Printing Office, Adelaide.

NEWMAN, D.M.R. (1969). The chemical composition, digestibility and intake of some native pasture species in Central Australia during winter. *Aust. J. Exptal Agric. Anim. Husbandry 9*, 599-602.

NEWMAN, J.C., and CONDON, R.W. (1969). Land use and present condition. pp105-132 in *Arid Lands of Australia*, R.O. Slatyer and R.A. Perry (eds). Aust. National Univ. Press, Canberra.

NOBLE, I.R. (1974). Trend in rangeland vegetation. Paper given at the U.S.-Australia Rangelands Workshop at Alice Springs, 1974. (In press, Society for Range Management, Denver.)

NORTHCOTE, K.H. (1965). *A factual key for the recognition of Australian soils*. CSIRO Div. Soils Div. Report 2/65.

____________. (1971). *A factual key for the recognition of Australian soils*, 3rd edition. Rellim Technical Publications, Adelaide.

NOY-MEIR, I. (1971). Multivariate analysis of the semi-arid vegetation in south-eastern Aystralia: nodal ordination by component analysis. *Proc. Ecol. Soc. Aust. 6*, 159-193.

____________. (1974). Multivariate analysis of the semi-arid vegetation in south-eastern Australia II. Vegetation catenae and environmental gradients. *Aust. J. Bot. 22*, 115-140.

OGDEN, J.C., BROWN, R.A., and SALESKY, N. (1973). Grazing by the Echinoid *Diadema antillarum* Philipi: formation of halos around West Indian patch reefs. *Science 182 (4113)*, 715-717.

ORLOCI, L. (1966). Geometric models in ecology I. The theory and application of some ordination methods. *J. Ecol. 54*, 193-215.

OSBORN, T.G.B. (1925). On the ecology of the vegetation of arid Australia I. Introduction and general description of the Koonamore reserve. *Trans. Roy. Soc. S. Aust. 49*, 290-296.

____________., WOOD, J.G., and PALTRIDGE, T.B. (1931). On the autecology of *Stipa nitida*: a study of a fodder grass in arid Australia. *Proc. Linn. Soc. N.S.W. 56*, 299-324.

____________., __________., and ____________. (1932). On the growth and reaction to grazing of the perennial saltbush *Atriplex vesicarium*. *Proc. Linn. Soc. N.S.W. 47*, 377- .

____________., __________., and ____________. (1935). On the climate and vegetation of the Koonamore Vegetation Reserve to 1931. *Proc. Linn. Soc. N.S.W. 60*, 392-427.

PATTEN, B.C. (1972). A simulation of the shortgrass prairie ecosystem. *Simulation 19*, 177-186.

PECHANEC, J.F., and PICKFORD, G.D. (1937). A weight estimate method for the determination of range or pasture production. *J. Am. Soc. Agron. 29*, 894-904.

____________., and STEWART, G. (1940). Sagebrush-grass range sampling studies: size and structure of the sampling unit. *J. Am. Soc. Agron. 32*, 669-682.

PERRY, R.A. (1967). The need for rangelands research in Australia. *Proc. Ecol. Soc. Aust. 2*, 1-14.

__________. (1969). Rangelands research and extension. pp291-302 in *Arid Lands of Australia*, R.O. Slatyer and R.A. Perry (eds). Aust. National Univ. Press, Canberra.

__________. (1970). Ecological guidelines for resource management. *Proc. Ecol. Soc. Aust.* 5, 1-11.

PIDGEON, I.M., and ASHBY, E. (1940). Statistical analysis of regeneration following protection from grazing. *Proc. Linn. Soc. N.S.W. 65*, 123-143.

PIELOU, E.C. (1969). *Introduction to Mathematical Ecology*. John Wiley and Sons, New York.

PREECE, P.B. (1971a). Contributions to the biology of Mulga I. Flowering. *Aust. J. Bot. 19*, 21-38.

__________. (1971b). Contributions to the biology of Mulga II. Germination. *Aust. J. Bot. 19*, 39-49.

RATCLIFFE, F.N. (1936). *Soil drift in the arid pastoral areas of South Australia*. CSIRO pamphlet No. *64*.

RATCLIFFE, F.N. (1947). *Flying Fox and Drifting Sand.* Angus and Robertson, Sydney.

REID, G.K.R. (1968). Economic aspects of the sheep industry in the pastoral zone. *Q. Rev. Agric. Econ. 21,* 36-49.

RICHARDSON, N.A. (1925). *The Pioneers of the NorthWest of South Australia.* Thomas and Co., Adelaide. Facsimile edition 1969, S. Aust. Libraries board, Adelaide.

ROBARDS, G.E., LEIGH, J.H., and MULHAM, W.E. (1967). Selection of diet by sheep grazing semi-arid pastures of the Riverine plain IV. A grassland (*Danthonia caespitosa*) community. *Aust. J. Exptal Agric. Anim. Husbandry 7,* 426-433.

ROBEL, R.J., BRIGGS, J.N., DAYTON, A.D., and HULBERT, L.C. (1970). Relationships between visual obstruction measurements and weight of grassland vegetation. *J. Range Manage. 23,* 295-297.

ROBERTS, S.H. (1924). *History of Australian land settlement.* Macmillan Melbourne; reissued 1968.

ROGERS, R.W., and LANGE, R.T. (1971). Lichen populations on arid soil crusts around sheep watering places in South Australia.*Oikos 22,* 93-100.

___________., LANGE, R.T., and NICHOLAS, D.J.D. (1966). Nitrogen fixation by lichens of arid soil crusts. *Nature 209 (5018),* 96-97.

SCHMIDT, P.J. (1969). *Behaviour of cattle in a hot dry climate.* Unpub. M. Rur. Sc. Thesis, University of New England, Armidale, N.S.W..

SCHMIDT-NIELSEN, K. (1964). *Desert Animals.* Oxford.

SEARS, P.D. (1949). Soil fertility and pasture growth. pp103-125 in *Sheepfarming Annual,* Massey Agricultural College, New Zealand.

SHOWN, L.M., MILLER, R.F.,and BRANSON, F.A. (1969). Sagebrush conversion to grassland as affected by precipitation, soil and cultural practices. *J. Range Manage. 22,* 303-311.

SOKAL, R., and ROHLF, F.J. (1969). *Biometry.* Freeman, San Francisco.

SPECHT, R.L. (1972). *The Vegetation of South Australia* (2nd edition). Govt Printer, Adelaide.

SQUIRES, V.R., and HINDLEY, N.L. (1970). Paddock size and location of watering points as factors in the drought survival of sheep on the central Riverine plain. *Wool Technol. and Sheep Breeding 17,*49-54.

___________., and WILSON, A.D. (1971). Distance between food and water supply and its effect on drinking frequency, food and water intake of Merino and Border Leicester sheep. *Aust. J. Agric. Res. 22,* 283-290.

SYMON, D.E. (1969). A checklist of flowering plants of the Simpson Desert and its immediate environs- Australia. *Trans. Roy. Soc. S. Aust. 93,* 17-38.

THETFORD, P.O., PIEPER, R.D., and NELSON, A.B. (1971). Botanical and chemical composition of cattle and sheep diets on Pinyon- Juniper grassland range. *J. Range Manage. 24,* 425-431.

THOMPSON, O. (1971). *The Wool Crisis: a national survey of the Australian wool industry.* The Australian, Sydney.

THREADGILL, B. (1922). *South Australian Land Exploration.* Govt Printer, Adelaide; for the Public Libraries Board, S.A..

TRUMBLE, H.C. (1949). The ecological relations of pastures in South Australia. *J. Brit. Grassld Soc. 4,* 135-159.

__________., and WOODROFFE, K. (1954). Influence of climatic factors on reaction of desert shrubs ot grazing by sheep. pp129-147 in *Biology of Hot and Cold Deserts,* S.L. Cloudsley-Thompson (ed). Inst Biol. Symposium, 1954.

VALENTINE, K.A. (1947). Distance from water as a factor in grazing capacity of rangeland. *J. Forest. 45,* 749-754.

VAN DYNE, G.M., and HEADY, H.F. (1965a). Botanical composition of sheep and cattle diet on a mature annual range. *Hilgardia, 36,* 465-492.

__________., and __________. (1965b). Dietary chemical composition of sheep and cattle grazing in common on a dry annual range. *J. Range Manage. 18,* 78-86.

WALKER, B.H. (1970). An evaluation of eight methods of botanical analysis on grasslands in Rhodesia. *J. Appl. Ecol. 7,*403-416.

WARING, E.J.C. (1969). Some economic aspects of the pastoral industry in Australia. pp229-257 in *Arid Lands of Australia,* R.O. Slatyer and R.A. Perry (eds). Aust. National Univ. Press, Canberra.

WEIR, W.C., and TORELL, D.T. (1959). Selective grazing by sheep as shown by a comparison of the chemical composition of range and pasture forage obtained by hand clipping and that collected by esophageal fistulated sheep. *J. Anim. Sci. 18,* 641-649.

WESTON, E.J., and MOIR, K.W. (1969). Grazing preferences of sheep and nutritive value of plant components in a Mitchell Grass association in north-western Queensland. *Qld. J. Agric. Anim. Sci. 26,* 639-650.

WESTON, R.H., and HOGAN, J.P. (1973), Nutrition of herbage-fed ruminants. pp233-268 in *The Pastoral Industries of Australia,* G. Alexander and O.B. Williams (eds). Sydney Univ. Press, Sydney.

WIEDEMANN, A.M. (1972). Vegetation studies in the Simpson Desert, Northern Territory. *Aust. J. Bot. 19,* 99-124.

WIGHT, J.R. (1967). The sampling unit and its effect on saltbush yield estimates. *J. Range Manage. 20,* 323-325.

WILLIAMS, O.B. (1956). Studies in the ecology of the Riverine plain II. Plant-soil relationships in three semi- arid grasslands. *Aust. J. Agric. Res. 7,* 127-139.

_____________. (1962). The Riverina and its pastoral industry 1860-1869. pp411-434 in *The Simple fleece: Studies in the Australian Wool Industry,* A. Barnard (ed.). Aust. National Univ. and Melbourne Univ. Press, Melbourne.

_____________. (1968). That uneasy state between animal and plant in the manipulated situation. *Proc. Ecol. Soc. Aust. 3,* 167-174.

WILLIAMS, W.T. (1971). Strategy and tactics in the acquisition of ecological data. *Proc. Ecol. Soc. Aust. 6,* 57-62.

WILSON, A.D. (1966). The value of *Atriplex* (saltbush) and *Kochia* (bluebush) species as food for sheep. *Aust. J. Agric. Res. 17,* 147-153.

_____________, and LEIGH, J.H. (1969). Use of water intakes in estimation of saltbush intake by grazing sheep. *Field Sta. Rec. Div. Plant Industry CSIRO (Aust.) 8,* 1-8.

____________., LEIGH, J.H., and MULHAM, W.E. (1969). Study of merino sheep grazing a bladder saltbush (*Atriplex vesicaria*)--cotton bush *(Kochia aphylla)* community on the Riverine plain. *Aust. J. Agric. Res. 20,* 1123-1136.

WILSON, J.W., and LEIGH, J.H. (1964). Vegetation patterns on an unusual gilgai soil in New South Wales. *J. Ecol. 52,* 379-389.

WIMBUSH, D.J., BARROW, M.D. and COSTIN, A.B. (1967). Colour stereophotography for the measurement of vegetation. *Ecology 48,* 150-152.

WOOD, J.G. (1936). Regeneration of the vegetation on the Koonamore Vegetation Reserve. *Trans. Roy. Soc. S. Aust. 60,* 96-111.

___________. (1937). *Vegetation of South Australia.* Govt. Printer, Adelaide.

YARRANTON, G.A. (1971). Mathematical representations and models in plant ecology: response to a note by R. Mead. *J. Ecol. 59,* 221-224.

APPENDIX 1.

DATA FOR CHAPTERS 3 AND 4

(a) Density of pasture species.

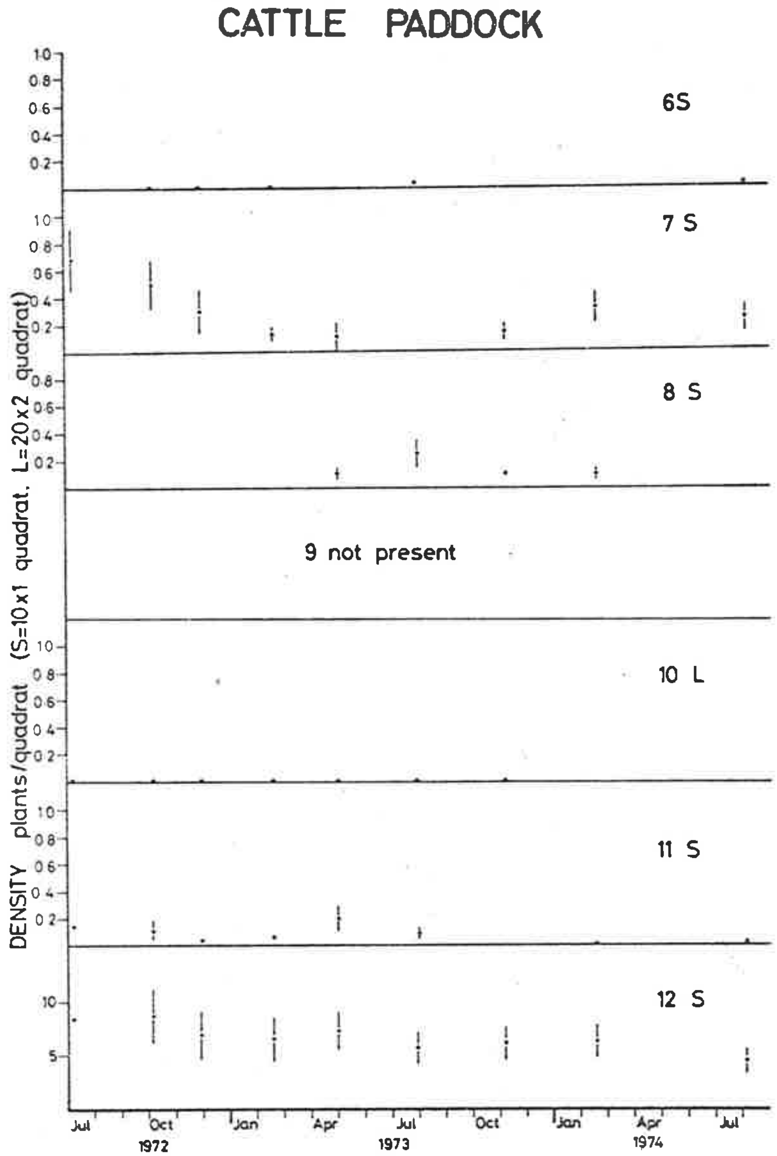
(b) Examples of photopoint series.

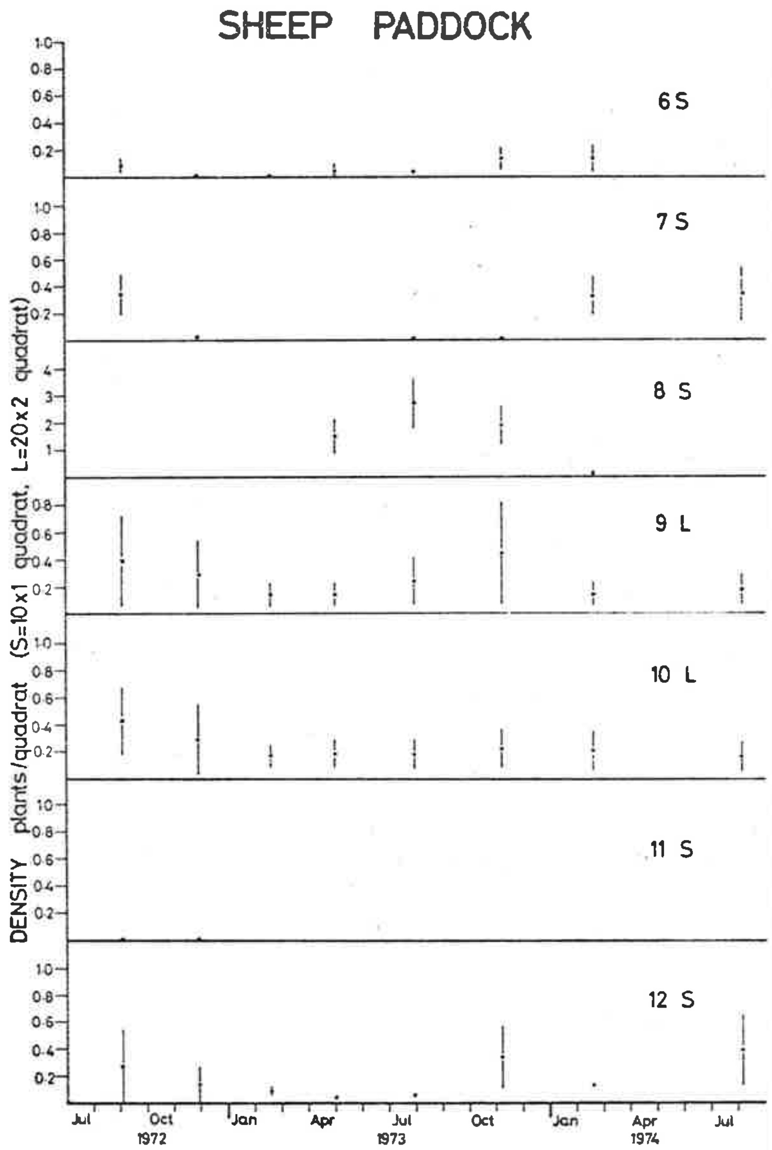
The following graphs show the mean densities of pasture species encountered in the Mt Victor study. Species are arranged by field number as follows.

1. *Stipa nitida*
2. *Enneapogon* spp.
3. *Aristida contorta*
4. *Kochia astrotricha*
5. *K. pyramidata*

(Results for the above given in text)

6. *Abutilon otocarpum*
7. *Atriplex limbata*
8. *A. spongiosa*
9. *A. stipitata*
10. *A. vesicaria*
11. *Bassia biflora*
12. *B. decurrens*
13. *B. diacantha*
14. *B. divaricata*
15. *B. lanicuspis*
16. *B. limbata*
17. *B. obliquicuspis*
18. *B. patenticuspis*
19. *B. paradoxa*
20. *B. sclerolaenoides*
21. *Dactyloctenium radulans*
22. *Convolvulus erubescens*
23. *Dodonaea microzyga*
24. *Enchylaena tomentosa*
25. *Eragrostis dielsii*
26. *Erodium cygnorum*
27. *Euphorbia drummondii*
28. *Brachyscome ciliaris*
29. *Kochia aphylla*
30. *K. excavata*
31. *Kochia georgei*
32. *K. sedifolia*
33. *K. tomentosa*
34. *Minuria leptophylla*
35. *Malacocera tricorne*
36. *Ptilotus obovatus*
37. *Triraphis mollis*
38. *Rhagodia spinescens var deltophylla*
39. *Salsola kali*
40. *Sida corrugata*
42. *S. intricata*
43. *S. virgata*
44. *Helipterum floribundum*
45. *Clianthus formosus*
46. *Tragus australianus*
47. *Tribulus terrestris*
50. *Bulbine semibarbata*
51. *Angianthus pusillus*
52. *Calocephalus dittrichii*
53. *Eremophila duttonii*
54. *Eragrostis laniflora*
55. *Chenopodium desertorum*
56. *Bassia brachyptera*
57. *Sida corrugata var angustifolia*


CATTLE PADDOCK
6S
7 S
8 S
9 not present
10 L
11 S
12 S
DENSITY plants/quadrat (S=10x1 quadrat, L=20x2 quadrat)
Jul
Oct
1972
Jan
Apr
Jul
1973
Oct
Jan
Apr
1974
Jul


SHEEP PADDOCK
6 S
7 S
8 S
9 L
10 L
11 S
12 S
DENSITY plants/quadrat (S=10x1 quadrat, L=20x2 quadrat)
Jul
Oct
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Jul
1973
Oct
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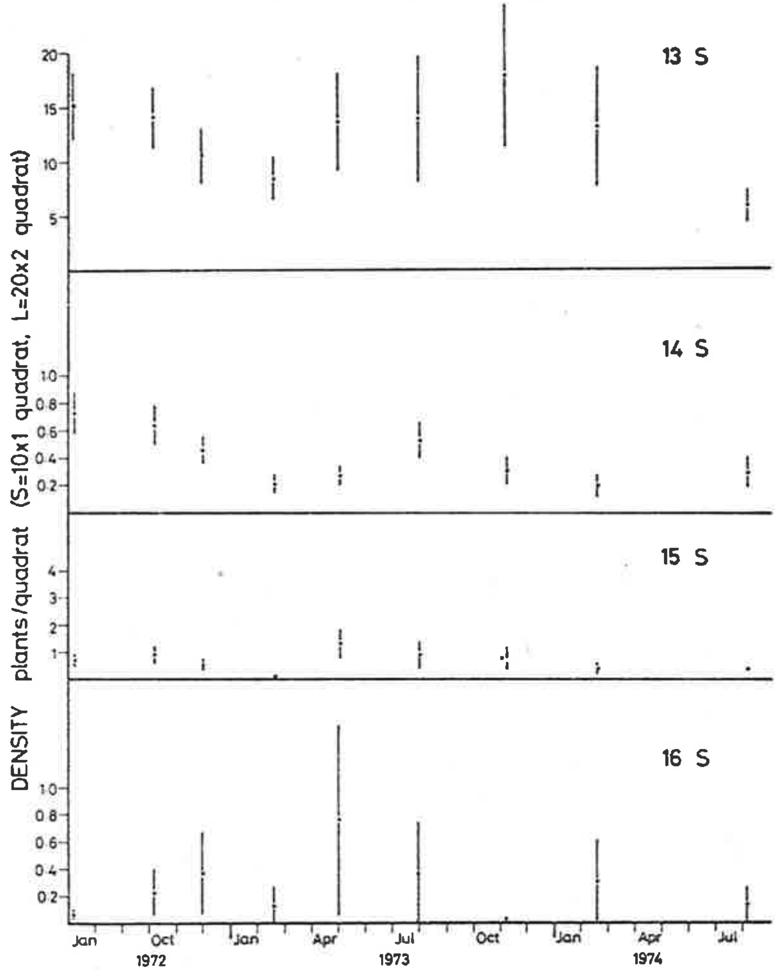
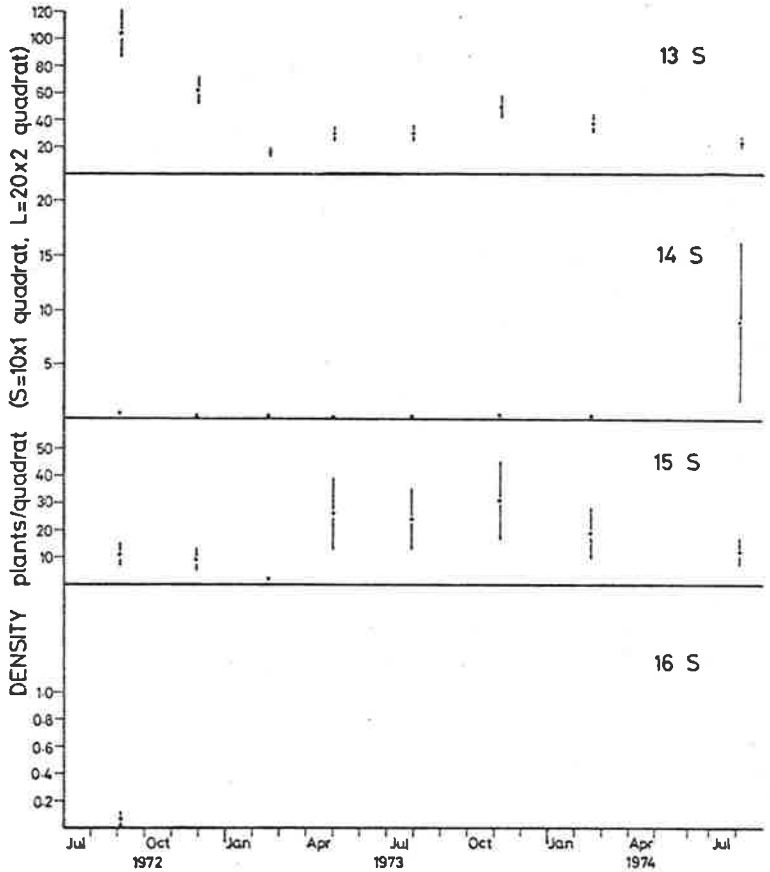
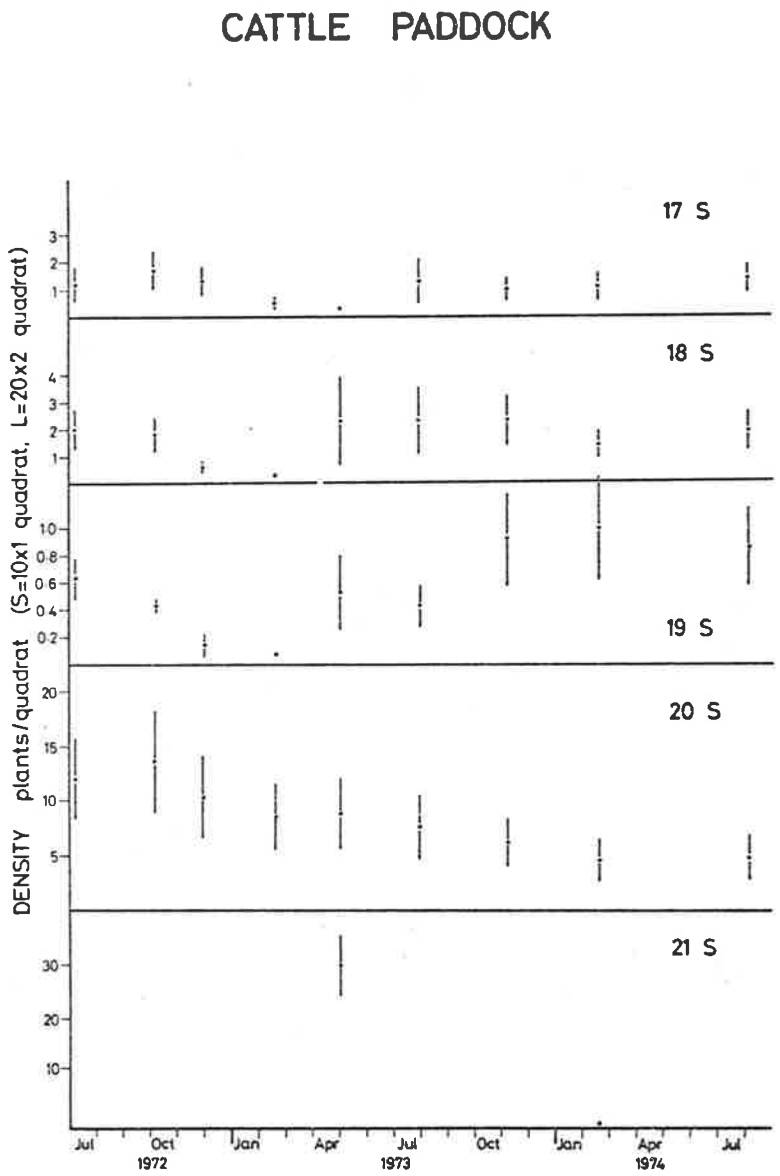
Apr
1974
Jul

CATTLE PADDOCK



SHEEP PADDOCK




CATTLE PADDOCK
17 S
18 S
19 S
20 S
21 S
DENSITY plants/quadrat (S=10x1 quadrat, L=20x2 quadrat)
Jul
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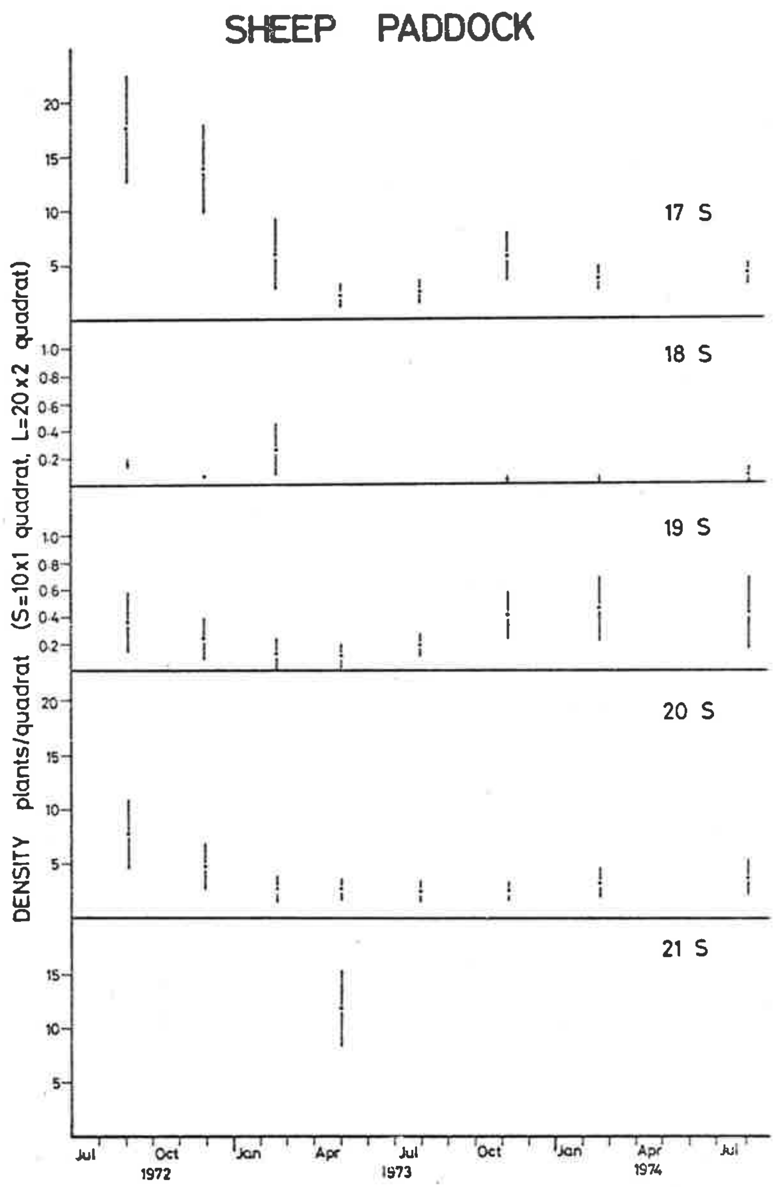
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17 S
18 S
19 S
20 S
21 S
DENSITY plants/quadrat (S=10x1 quadrat, L=20x2 quadrat)
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1974
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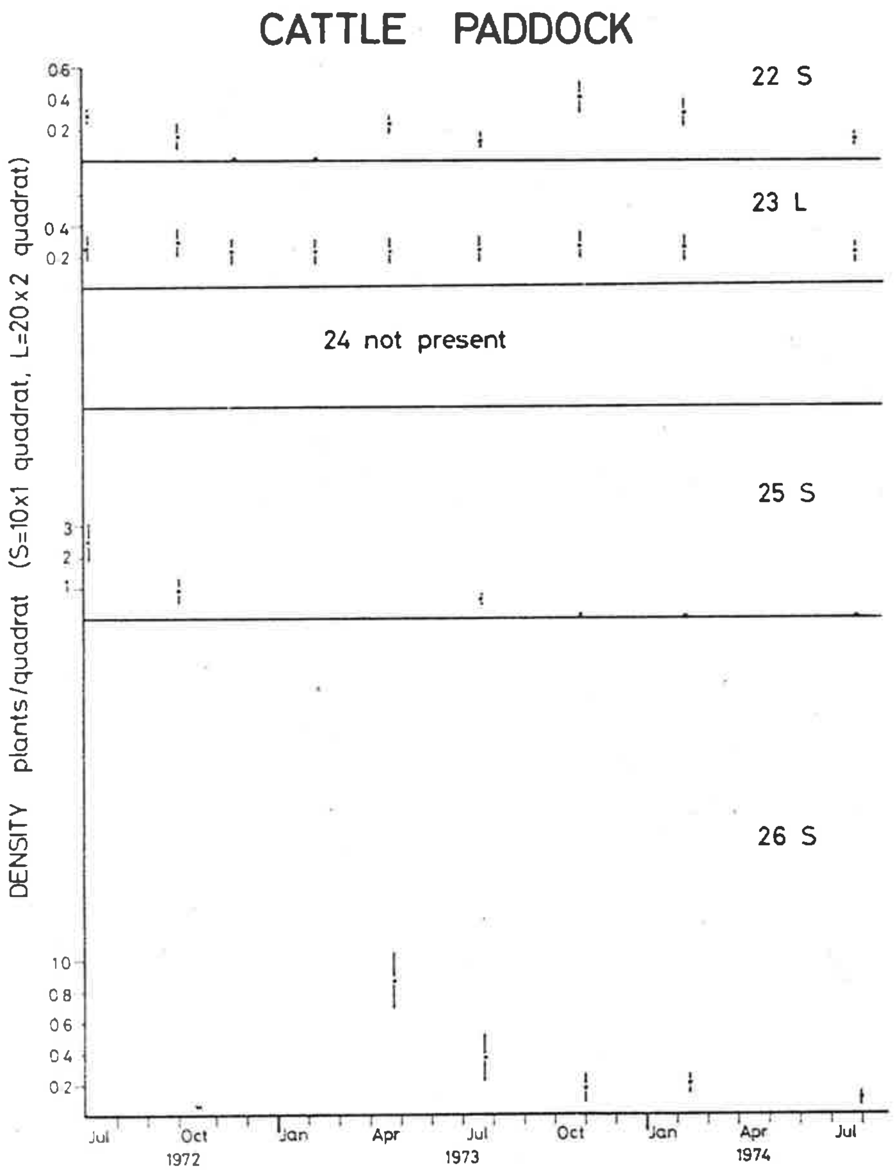
CATTLE PADDOCK
22 S
23 L
24 not present
25 S
26 S
DENSITY plants/quadrat (S=10x1 quadrat, L=20x2 quadrat)
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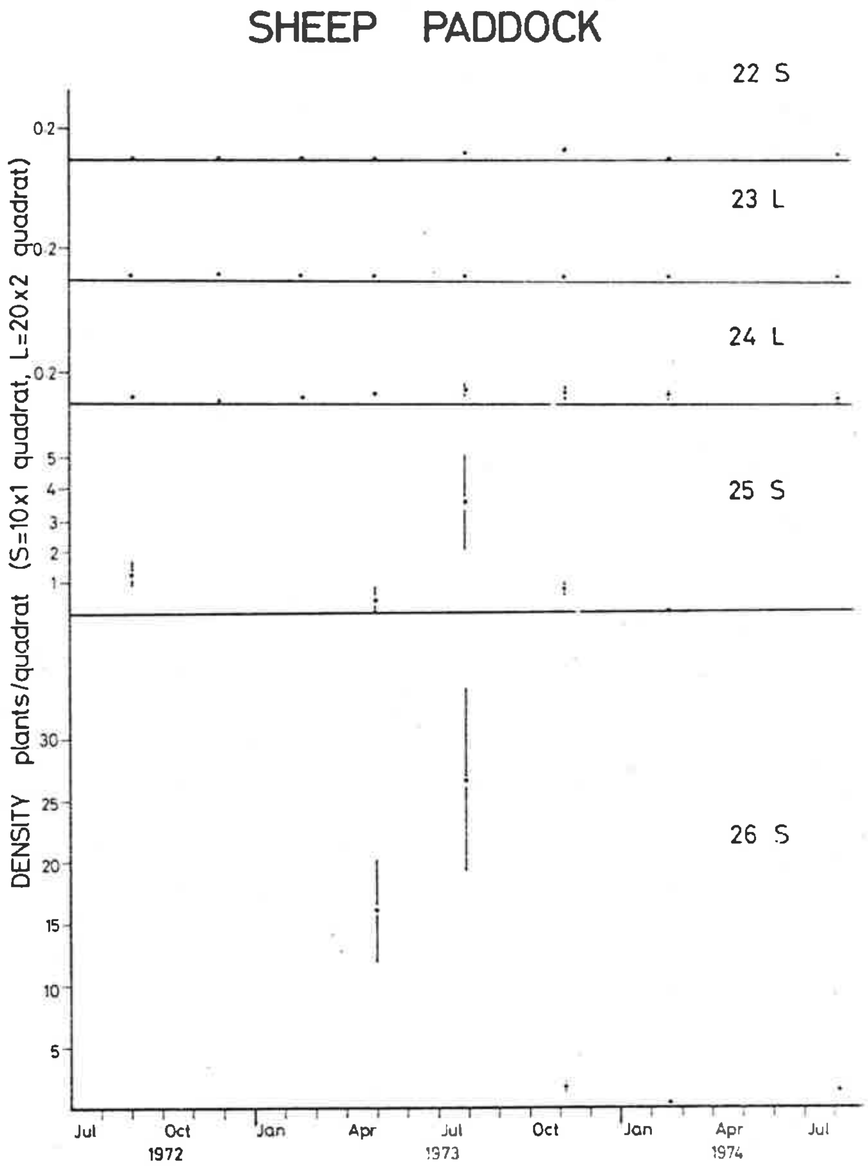
Jul
1972
1973
1974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22 S
23 L
24 L
25 S
26 S
DENSITY plants/quadrat (S=10x1 quadrat, L=20x2 quadrat)
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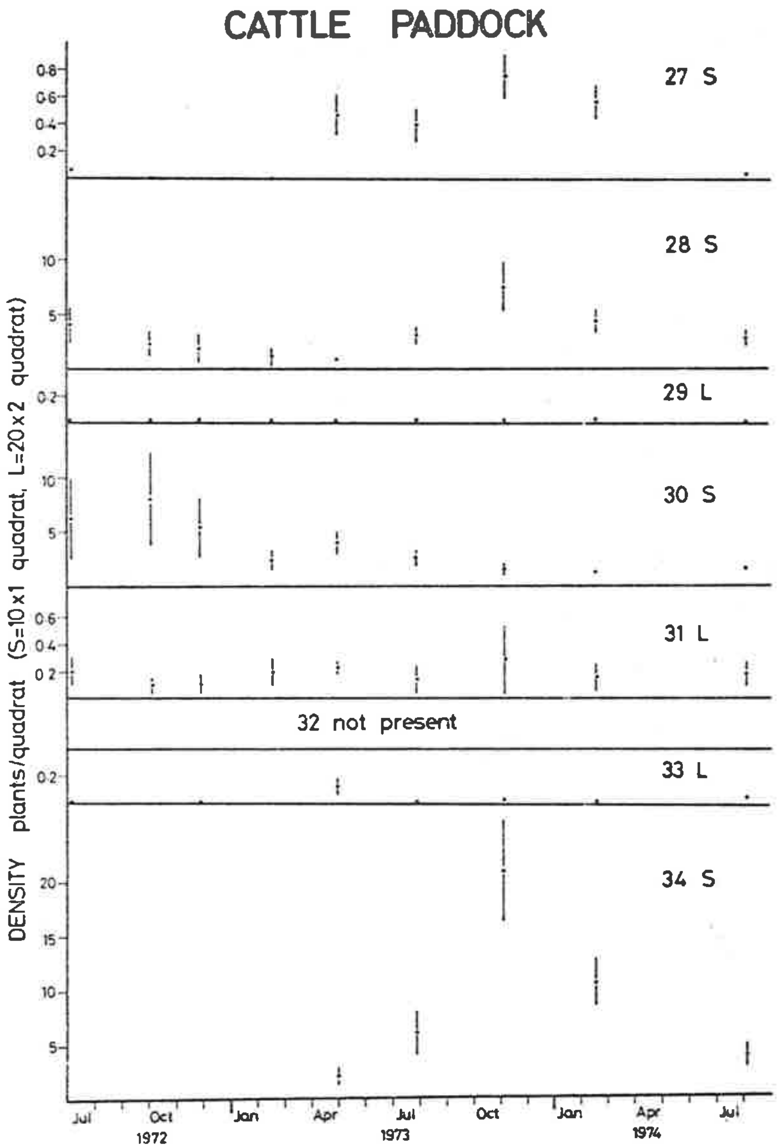

CATTLE PADDOCK
27 S
28 S
29 L
30 S
31 L
32 not present
33 L
34 S
DENSITY plants/quadrat (S=10 x 1 quadrat, L=20 x 2 quadrat)
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Jan
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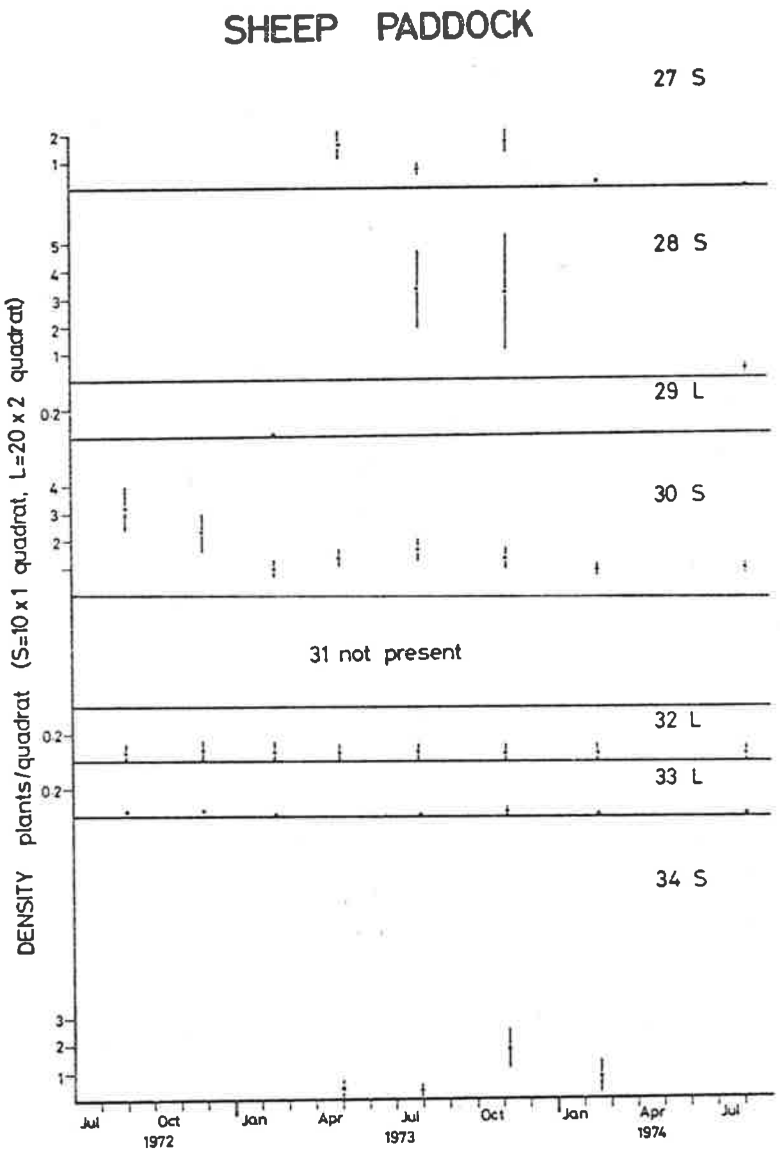
1974
Jul



SHEEP PADDOCK
27 S
28 S
29 L
30 S
31 not present
32 L
33 L
34 S
DENSITY plants/quadrat (S=10 x 1 quadrat, L=20 x 2 quadrat)
Jul
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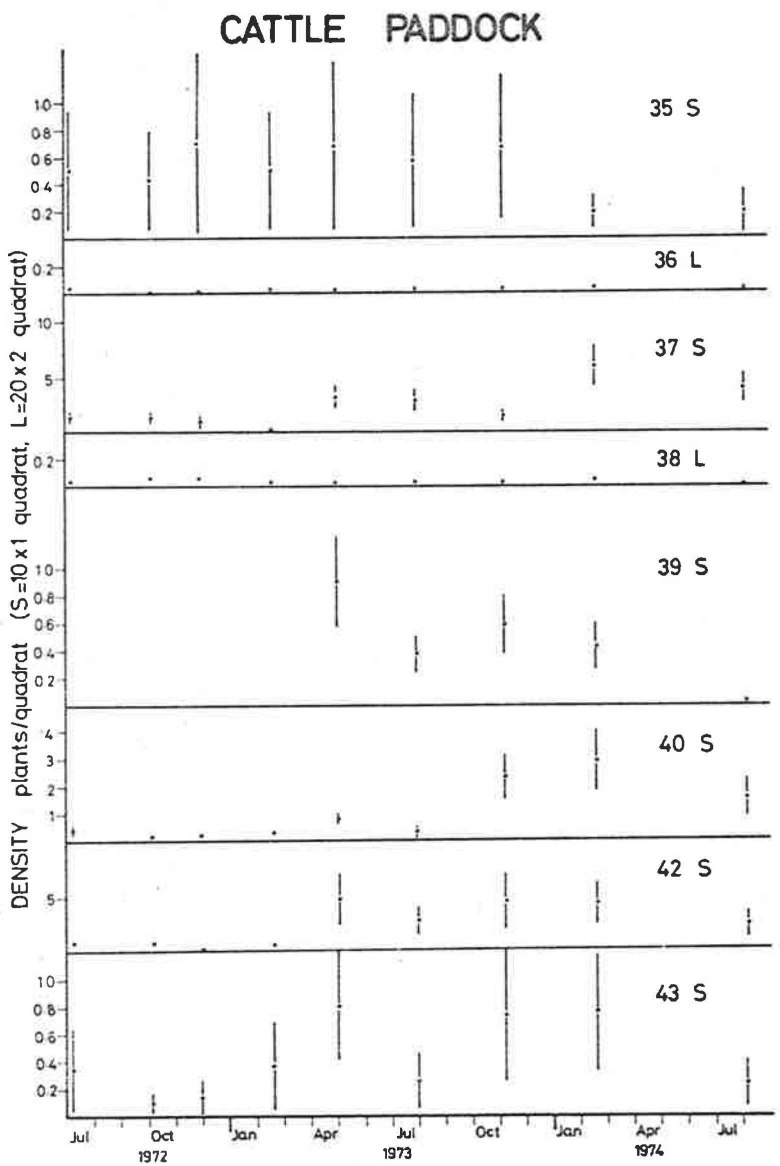
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35 S
36 L
37 S
38 L
39 S
40 S
42 S
43 S
DENSITY plants/quadrat (S=10x1 quadrat, L=20x2 quadrat)
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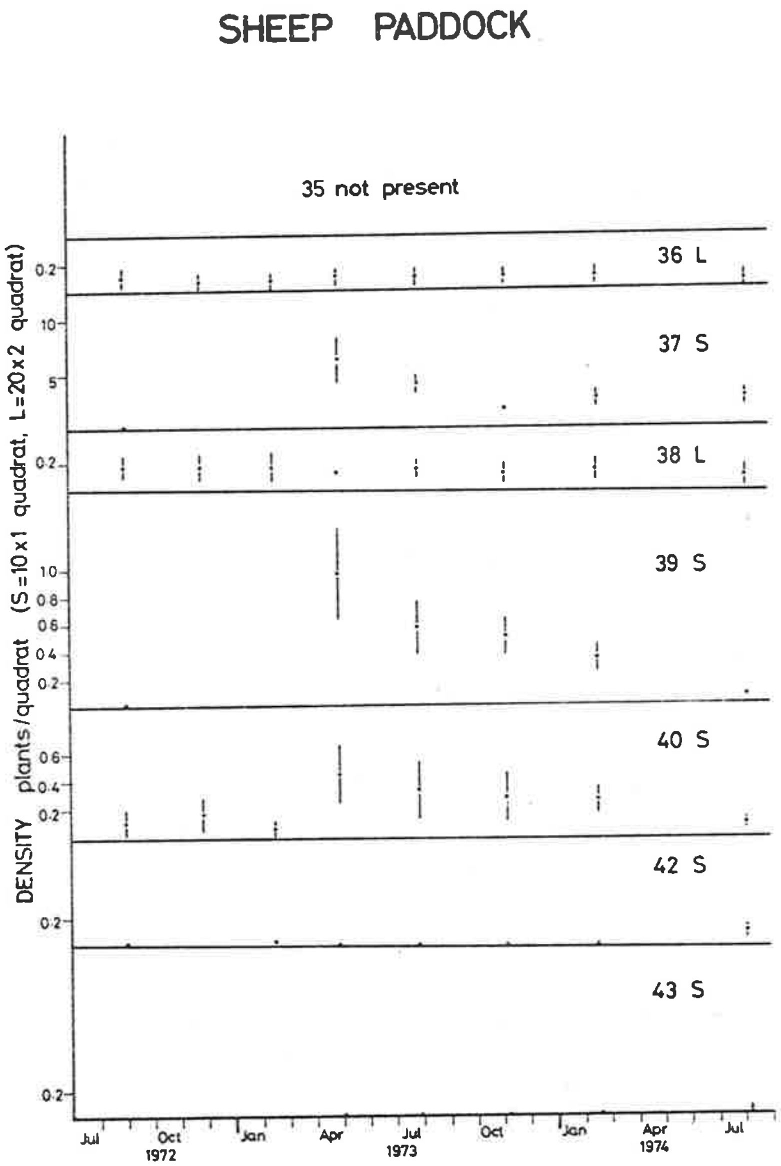
SHEEP PADDOCK
35 not present
36 L
37 S
38 L
39 S
40 S
42 S
43 S
DENSITY plants/quadrat (S=10x1 quadrat, L=20x2 quadrat)
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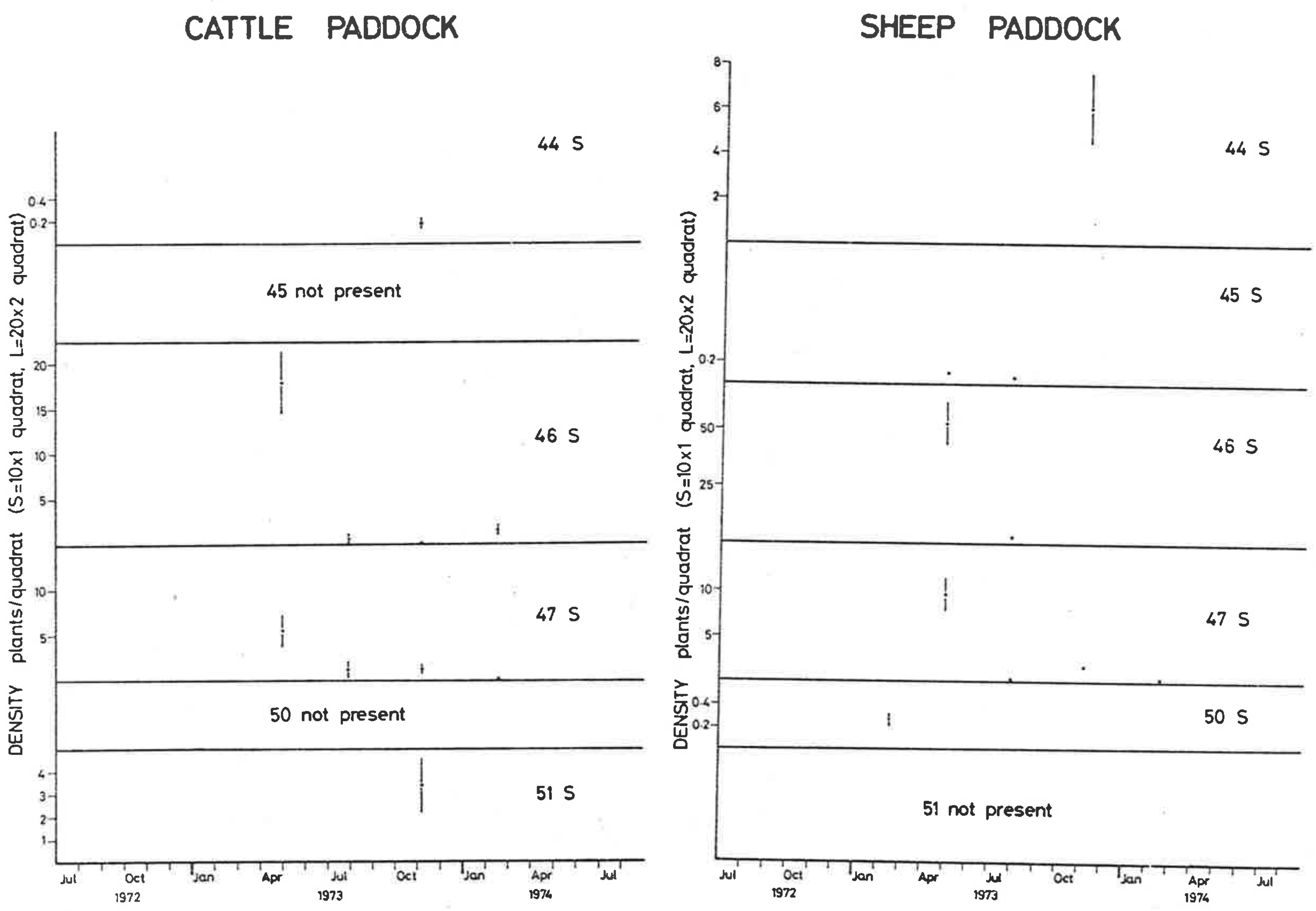
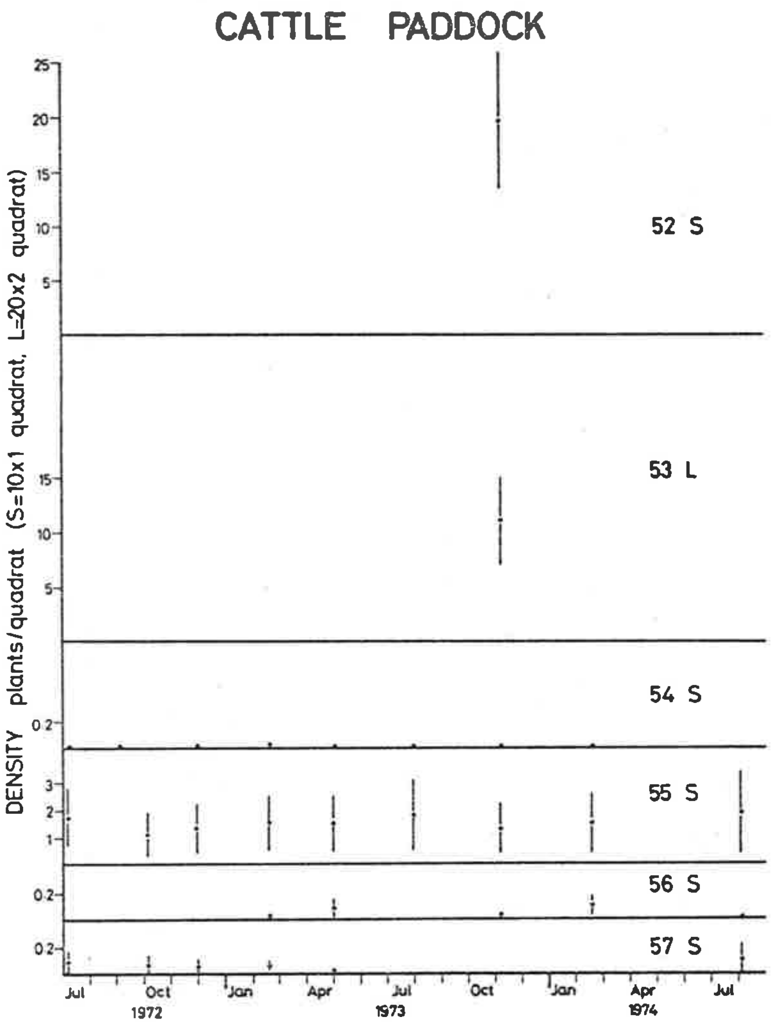
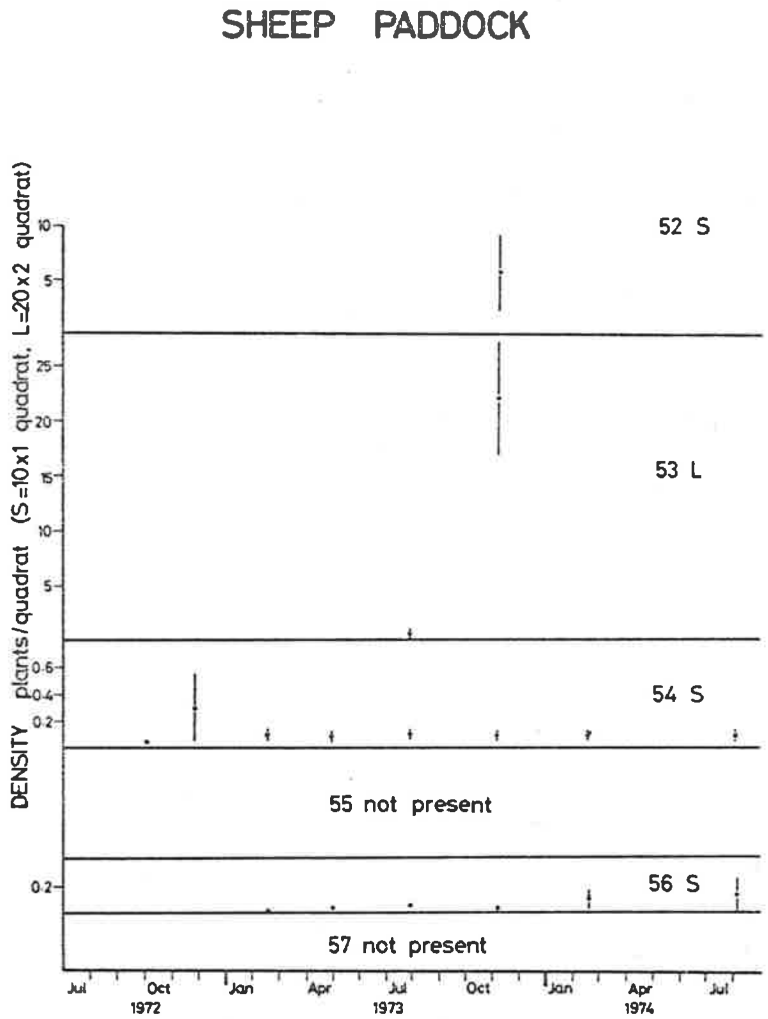


CATTLE PADDOCK
SHEEP PADDOCK
DENSITY plants/quadrat (S=10x1 quadrat, L=20x2 quadrat)
44 S
45 not present
46 S
47 S
50 not present
51 S
45 S
50 S
51 not present
Jul
Oct
Jan
Apr
1972
1973
1974


CATTLE PADDOCK
DENSITY plants/quadrat (S=10x1 quadrat, L=20x2 quadrat)
52 S
53 L
54 S
55 S
56 S
57 S
Jul
Oct
Jan
Apr
Jul
Oct
Jan
Apr
Jul
1972
1973
1974


SHEEP PADDOCK
DENSITY plants/quadrat (S=10x1 quadrat, L=20x2 quadrat)
52 S
53 L
54 S
55 not present
56 S
57 not present
Jul
Oct
Jan
Apr
Jul
Oct
Jan
Apr
Jul
1972
1973
1974

Appendix 1.

The following are examples of the photopoint series discussed in chapters 3 and 4. In each series, only one member of the stereo pair is shown. The photopoints are:

CATTLE
PADDOCK

Photopoint 4: 1.4mi north of Black Hill Dam. *Kochia astrotricha* (low bushes), *Enneapogon* species (grasses) and *Eremophila duttonii* (large bush). The fence in the left hand corner is exclosure 2.

Photopoint 20: 2.5mi northeast of Black Hill Dam. *Kochia astrotricha* (low bushes), *Enneapogon* species (A), *Aristida contorta* (B) and *Stipa nitida* (C).

Exclosure 2: 1.4mi north of Black Hill Dam. *Kochia astrotricha* (low bushes), *Enneapogon* species (grasses).

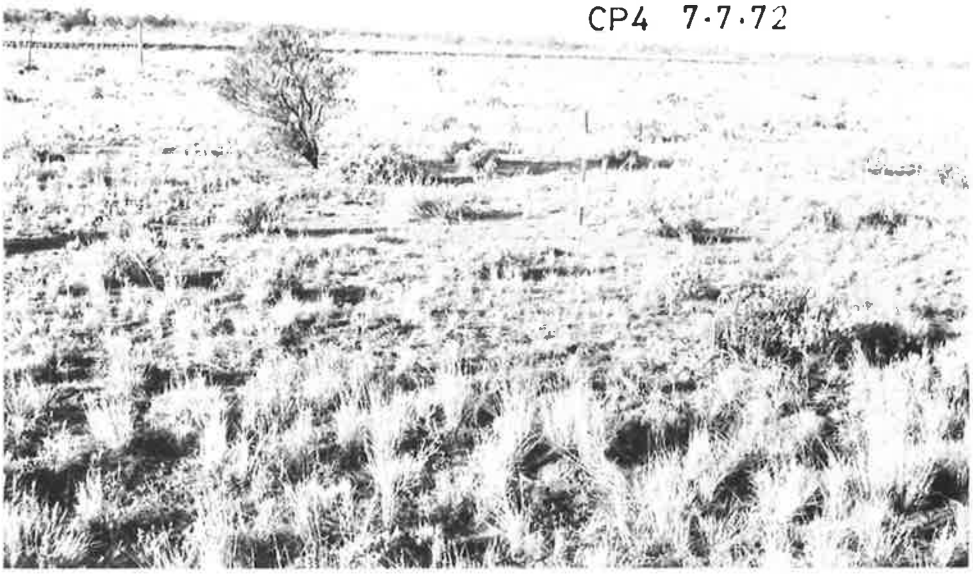
SHEEP
PADDOCK

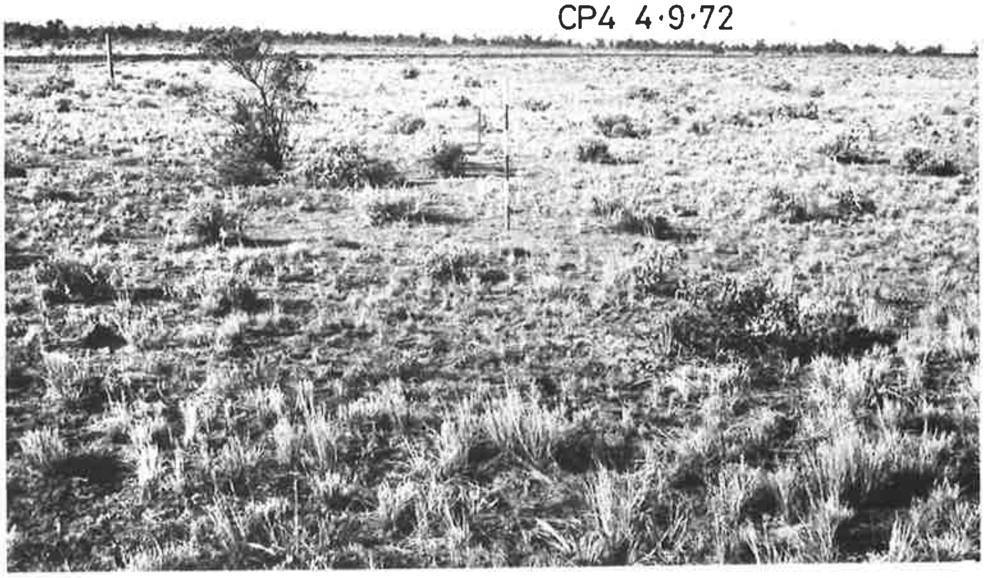
Photopoint 1: Emu Leg Gate. *Kochia astrotricha* (low bushes), *Enneapogon* species (grasses), *Heterodendrum oleaefolium* (tree, centre), *Acacia aneura* (tree, far right). Note growth of *Stipa* between 13/2/74 and 1/8/74.

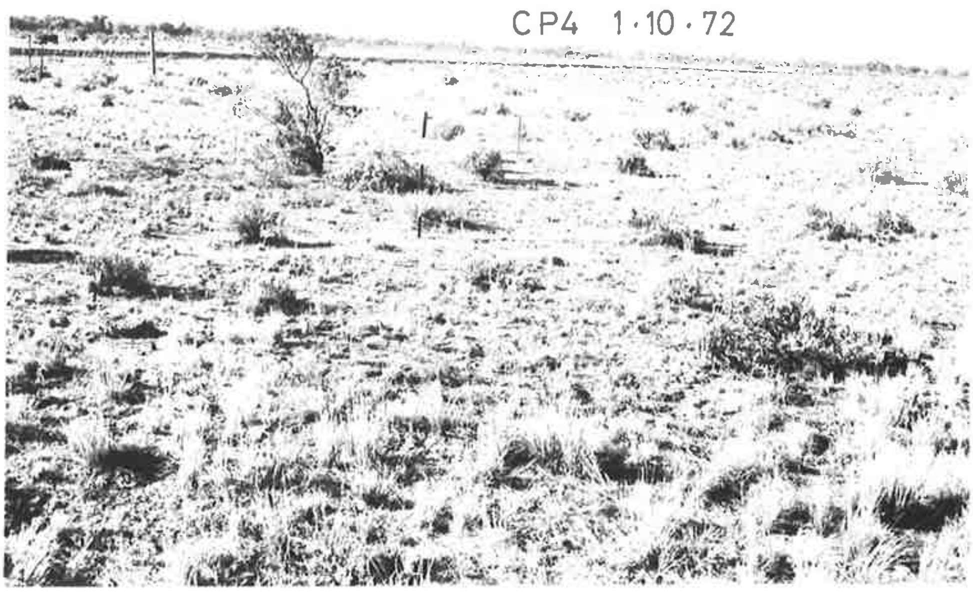
Photopoint 10: 1.8mi west of gate. *Kochia astrotricha* (low bushes) *Enneapogon* species (short grasses), *Stipa nitida* (tall grass).

Exclosure 1: 0.1mi east of gate. *Kochia astrotricha* (low bushes) *Enneapogon* species (A), *Stipa nitida* (B). The tree in the far corner is a *Heterodendrum*.

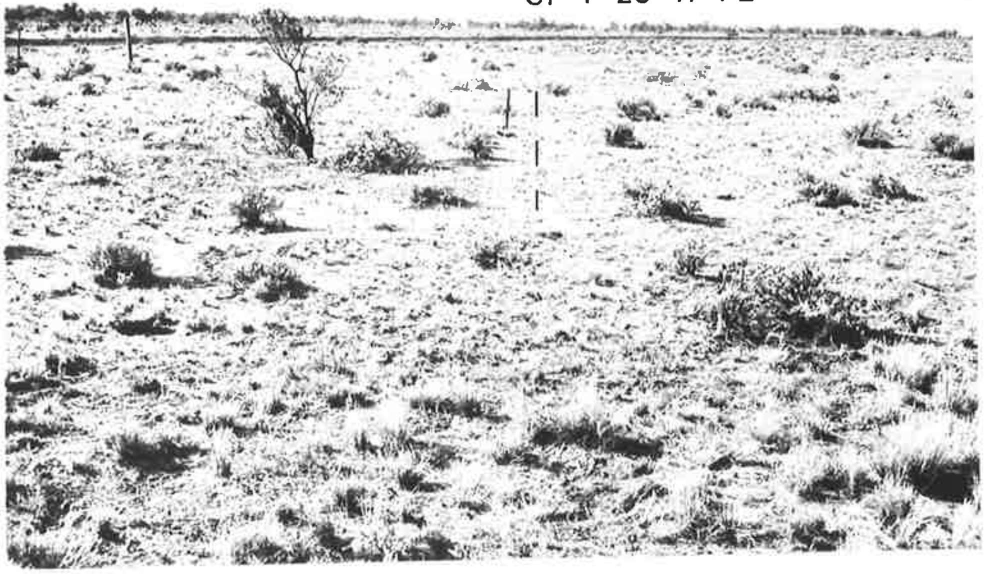
Relative changes in apparent biomass for these photopoints are given in figures 4.19 to 4.22 inclusive.


CP4 7·7·72

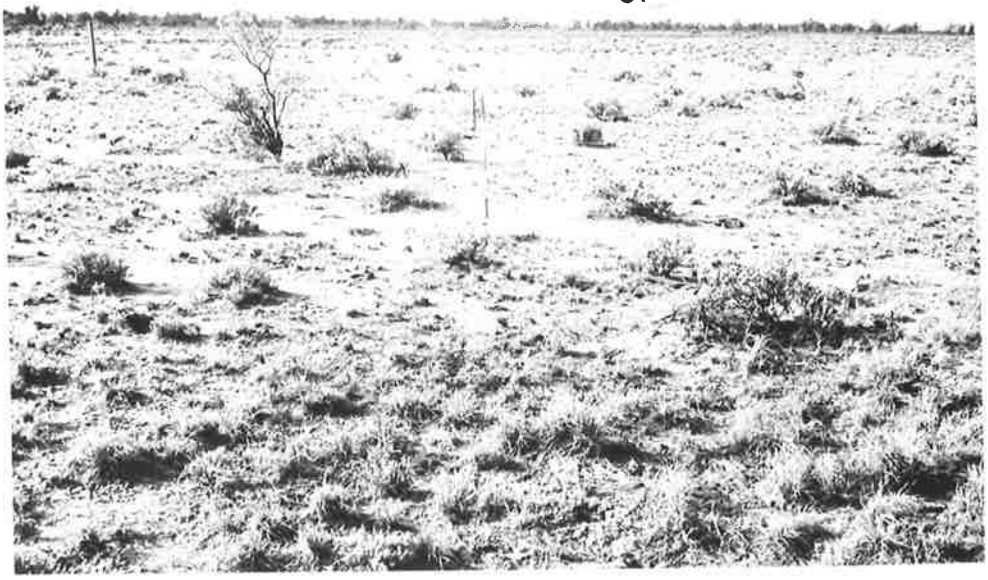

CP4 4·9·72


CP4 1·10·72

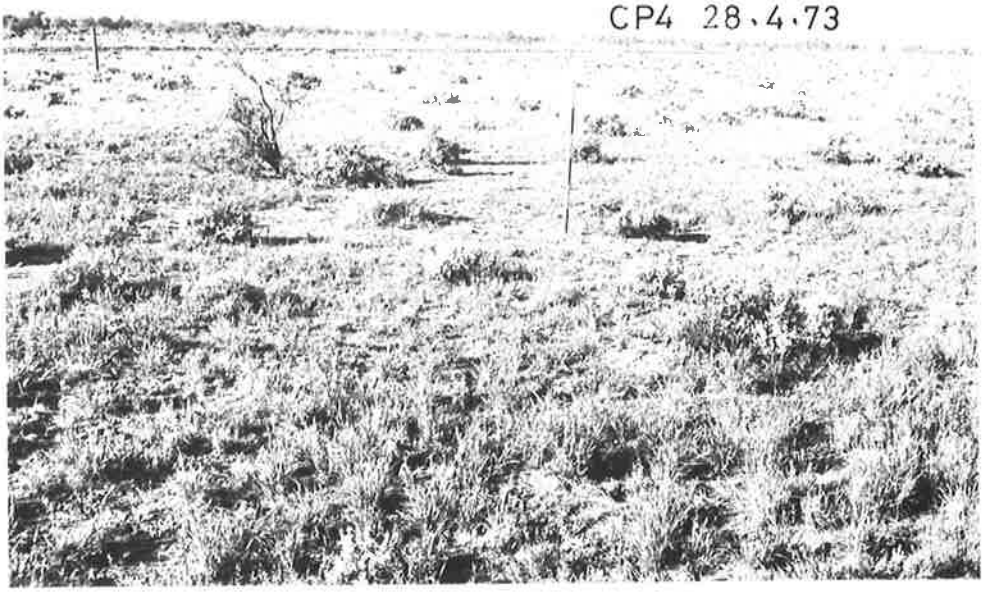
CP4 28·11·72

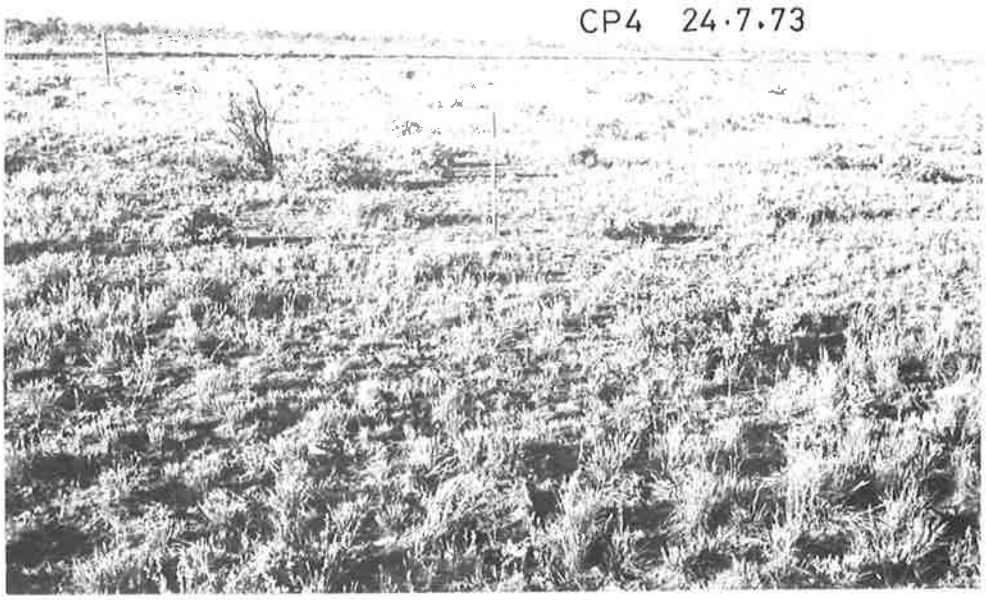


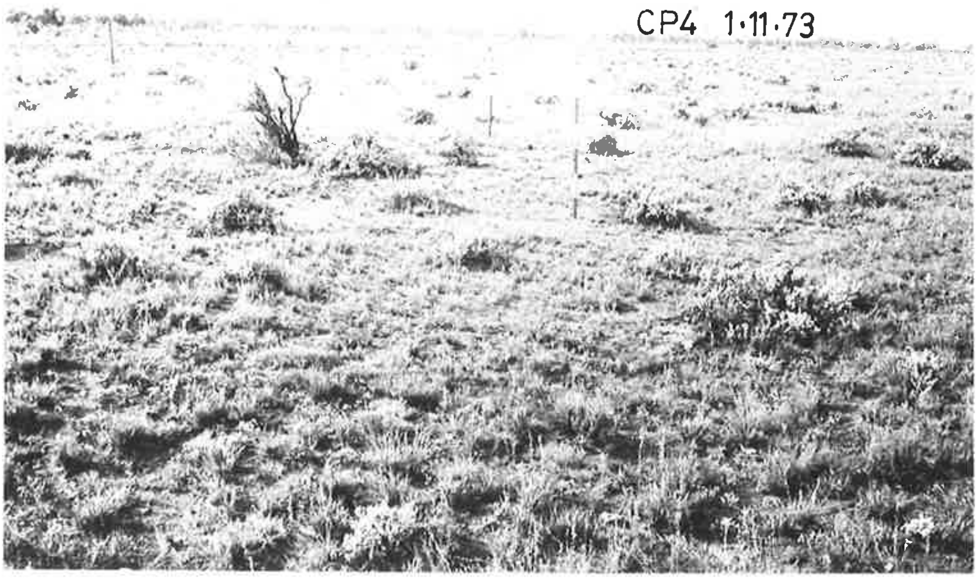
CP4 13·2·73



CP4 28·4·73



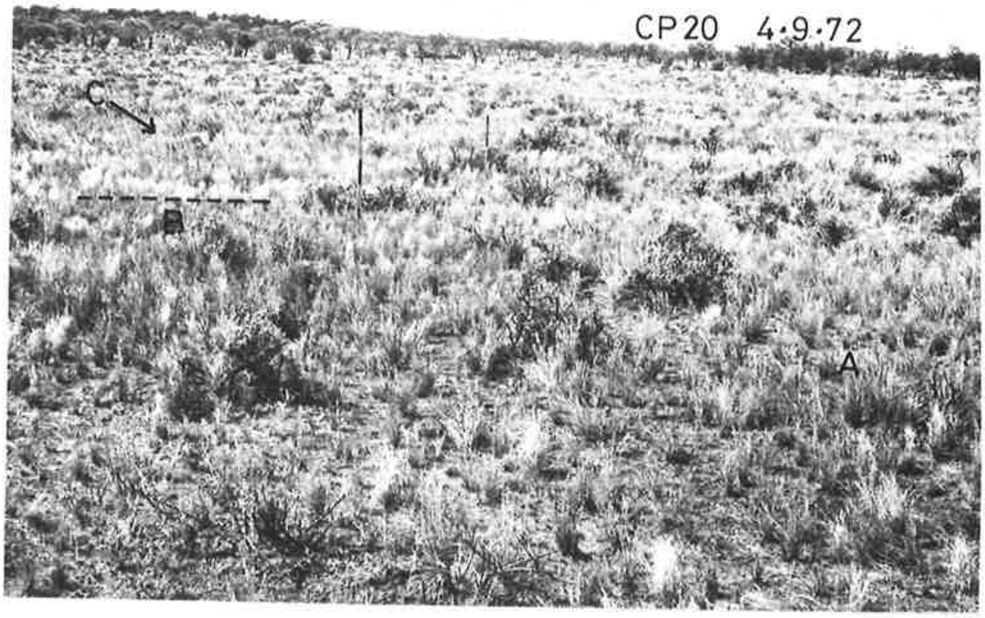

CP4 24·7·73

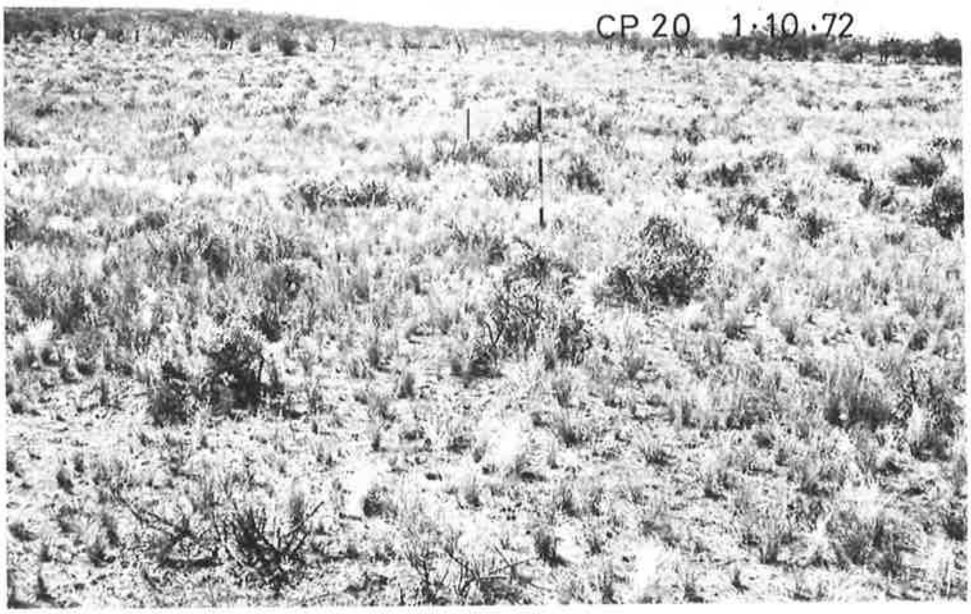

CP4 1·11·73


CP4 13·2·74

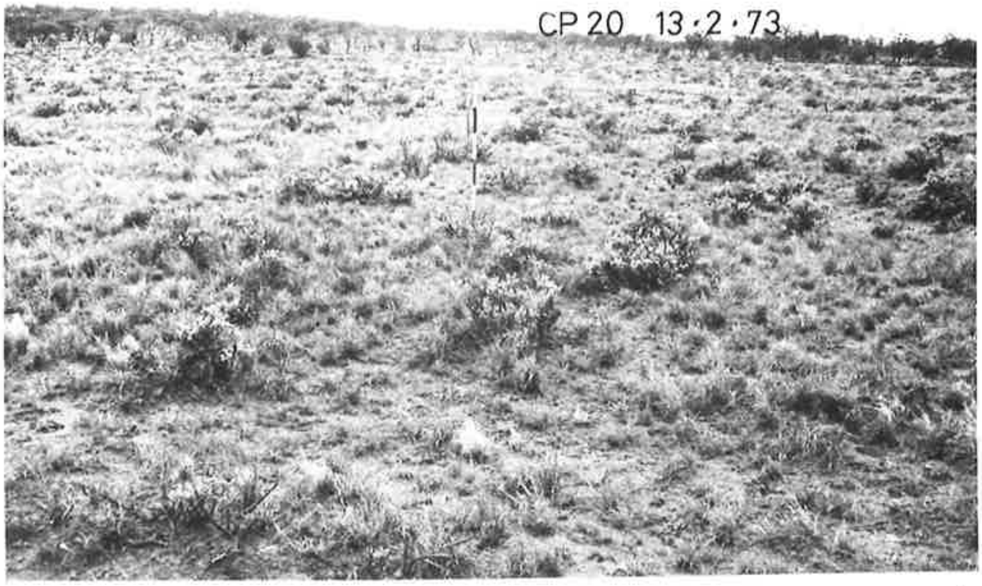
CP4 1·8·74

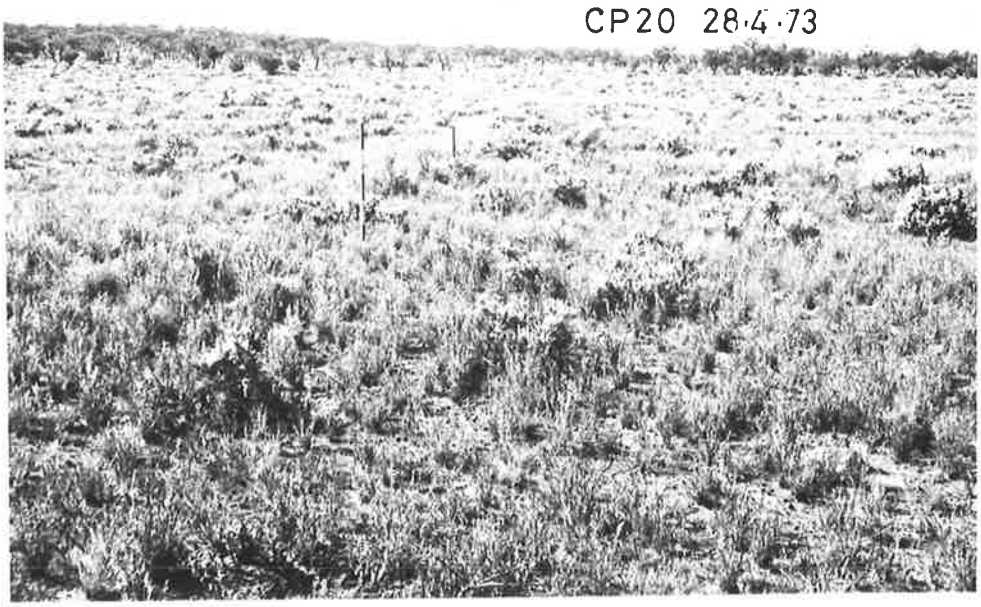

CP20 7·7·72


CP20 4·9·72
C
B
A

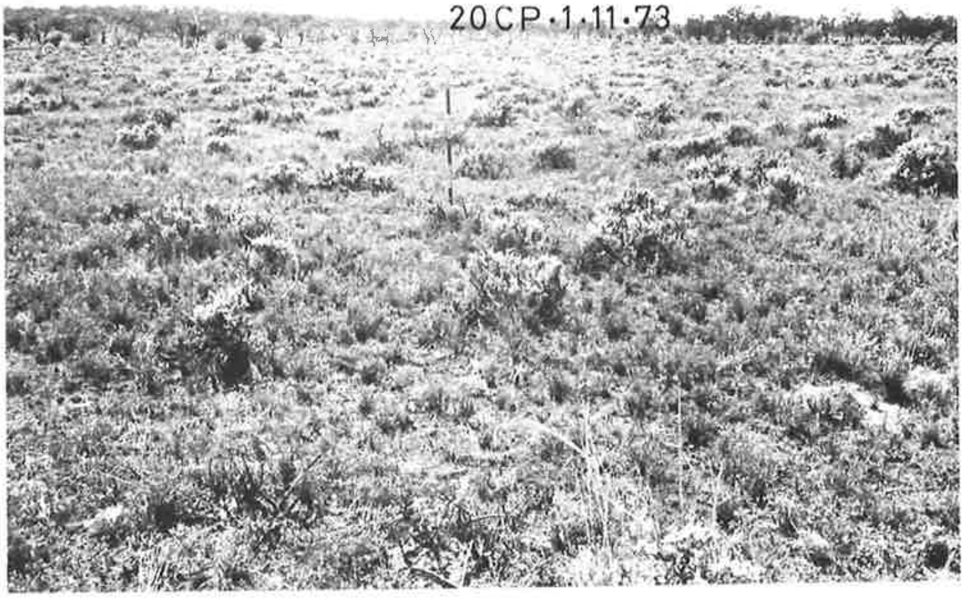

CP 20 1·10·72

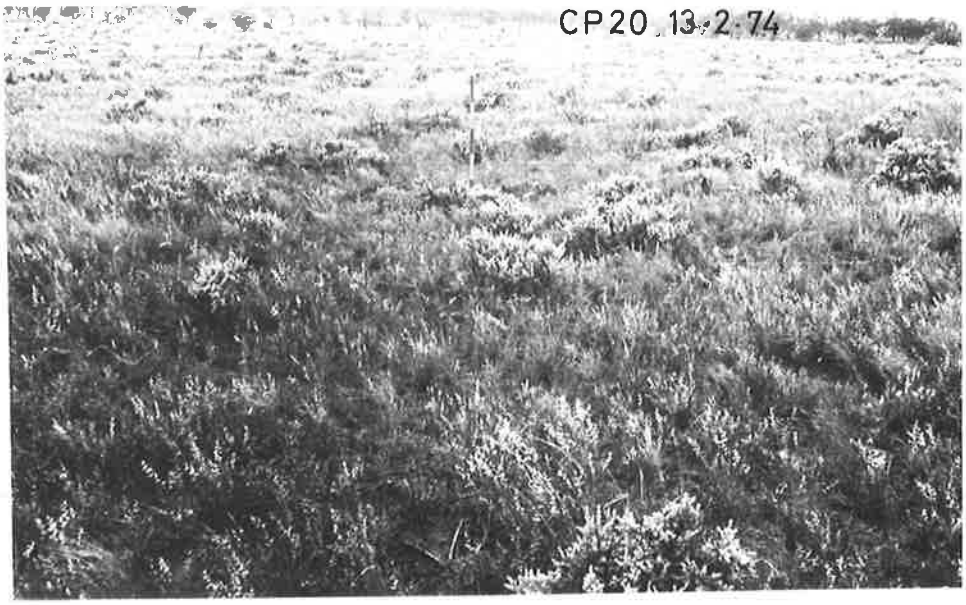

CP20 28·11·72


CP20 13·2·73


CP20 28·4·73

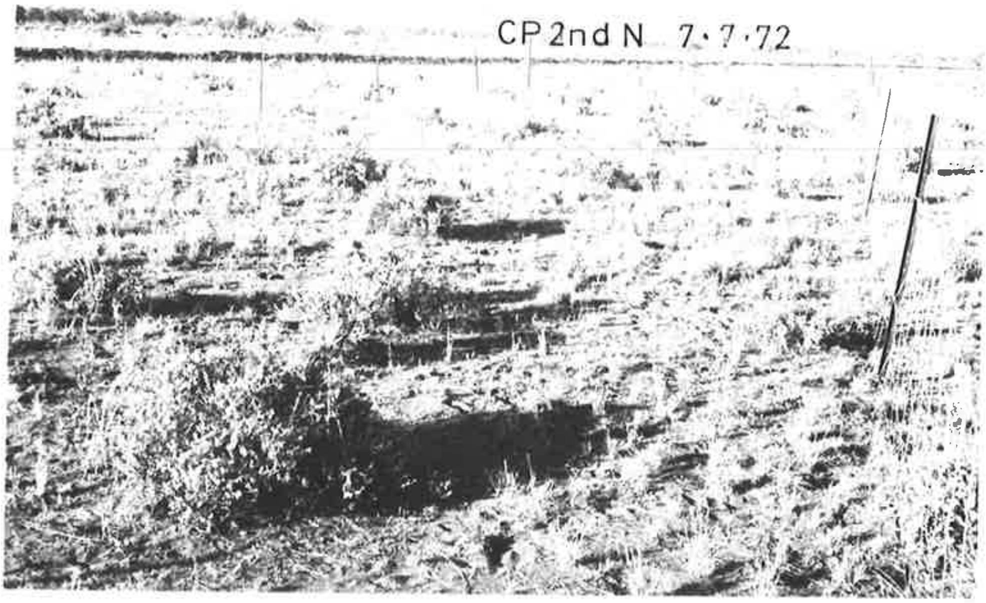
CP20 24.7.73



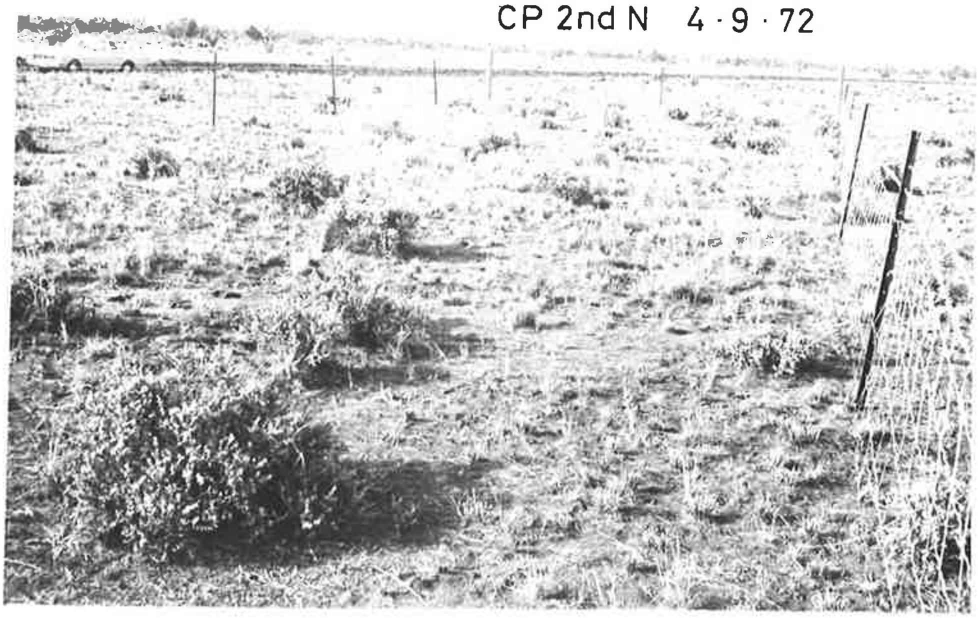


CP 20 1·8·74

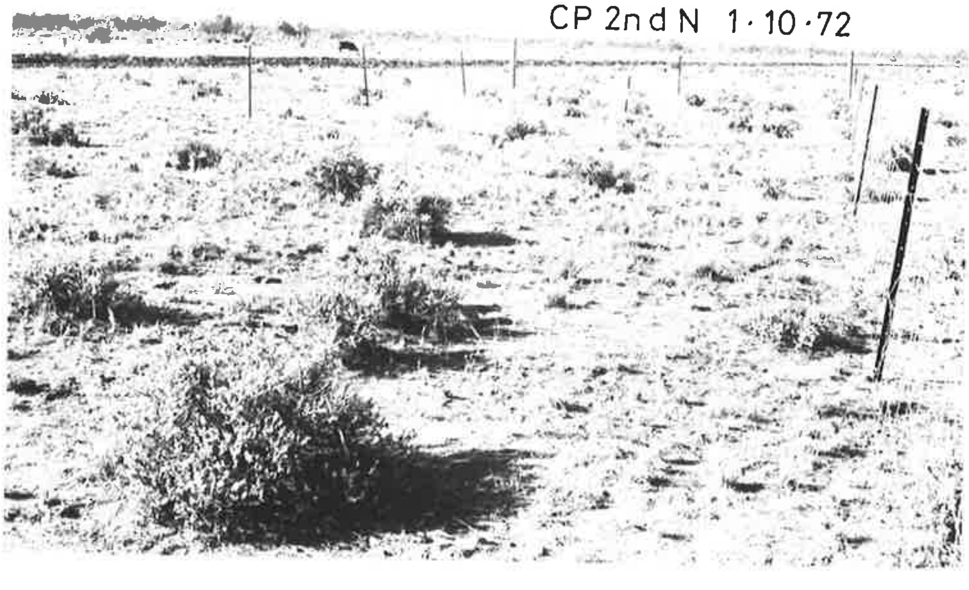
CP 2nd N 7·7·72



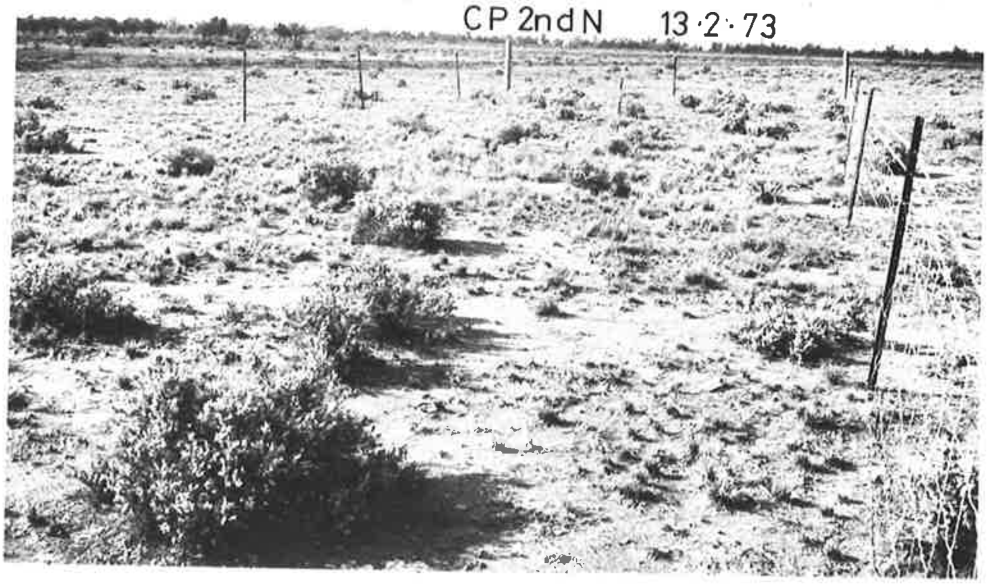
CP 2nd N 4·9·72



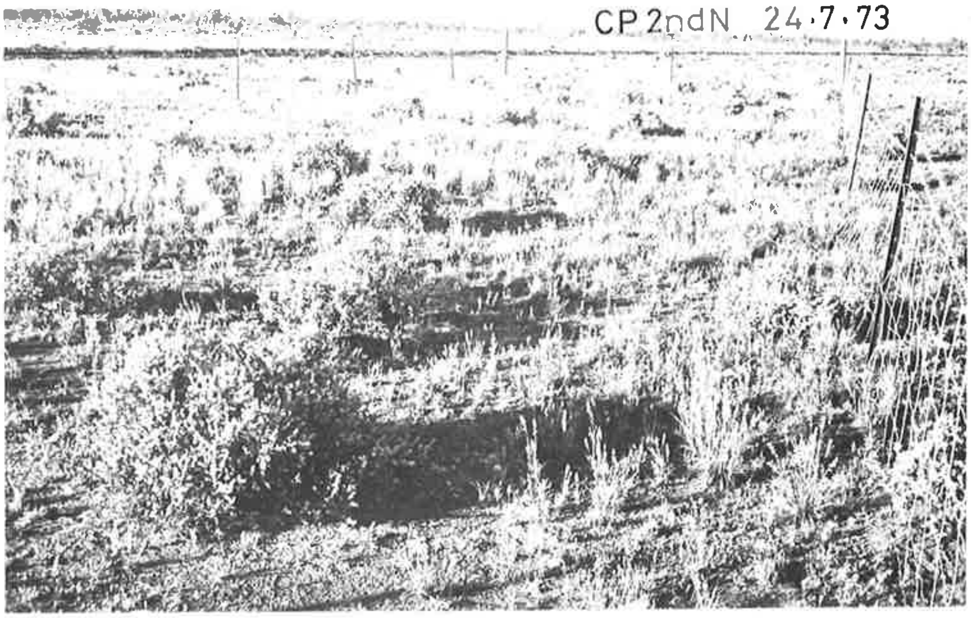
CP 2nd N 1·10·72



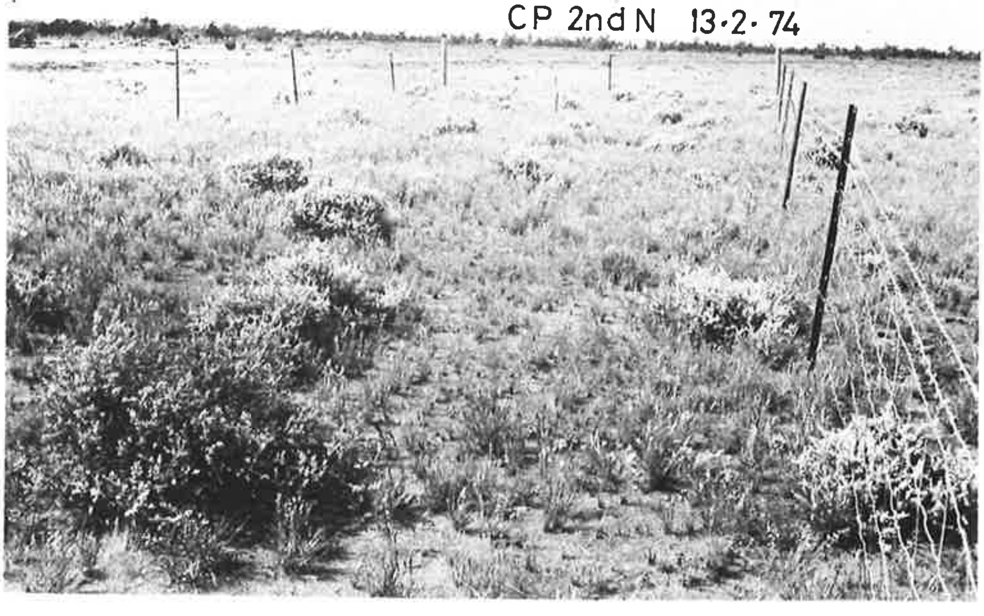

CP 2nd N 28.11.72


CP 2nd N 13.2.73


CP 2nd N 28.4.73

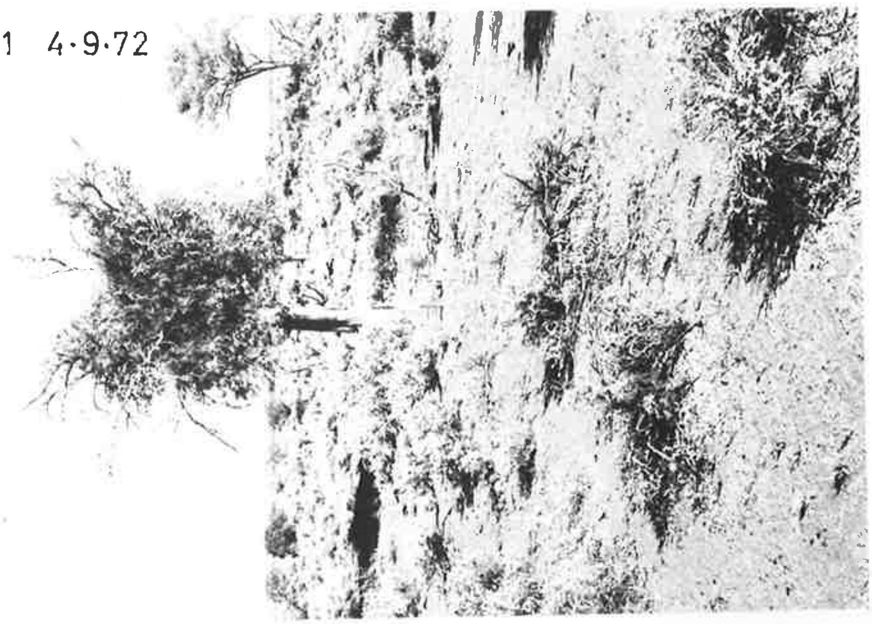

CP 2nd N 24·7·73


CP 2nd N 1·11·73


CP 2nd N 13·2·74

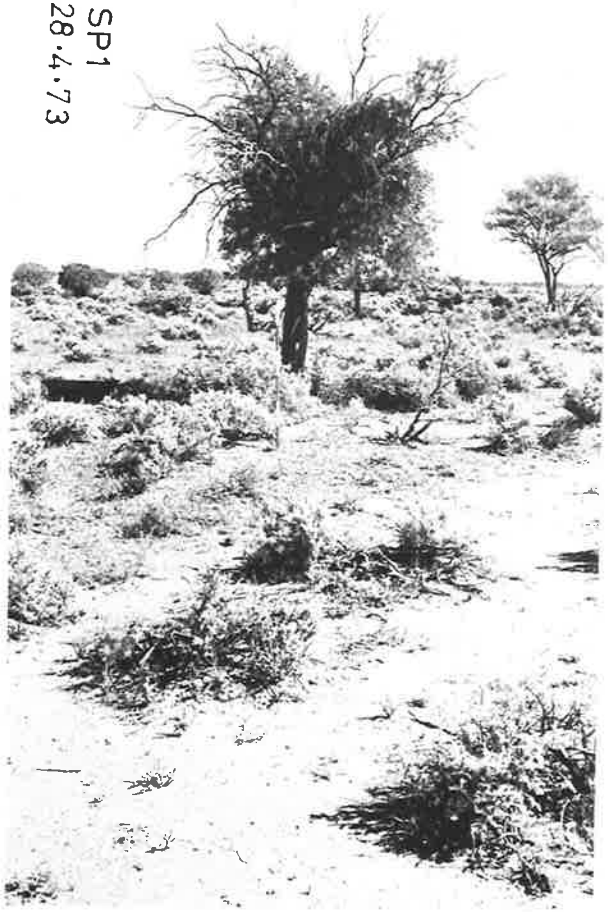

CP 2nd N 1·8·74

SP1 4·9·72

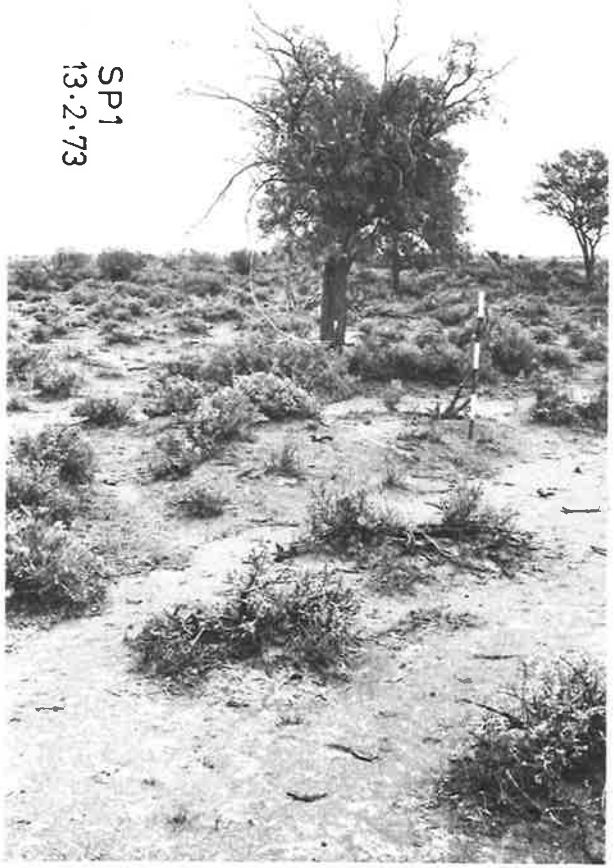


SP1
5·10·72

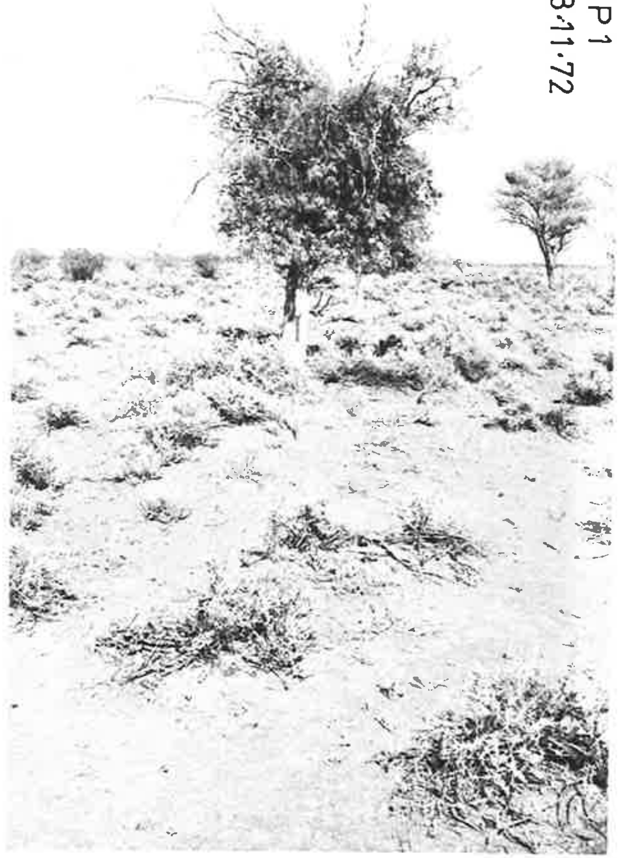
SP1
28·4·73



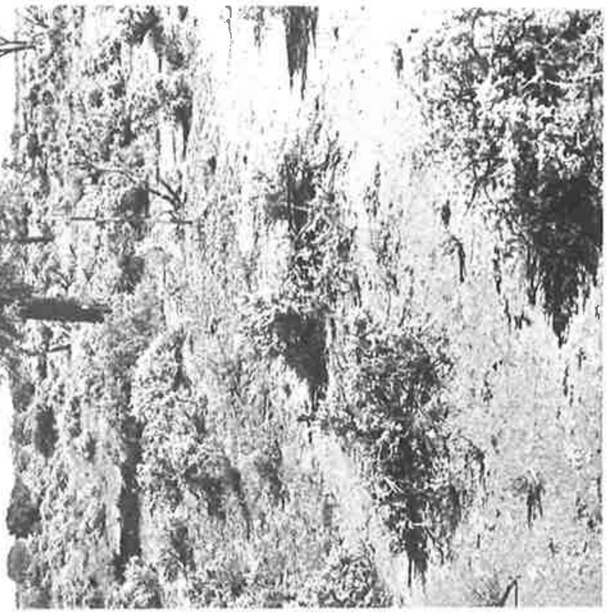
SP1
13·2·73



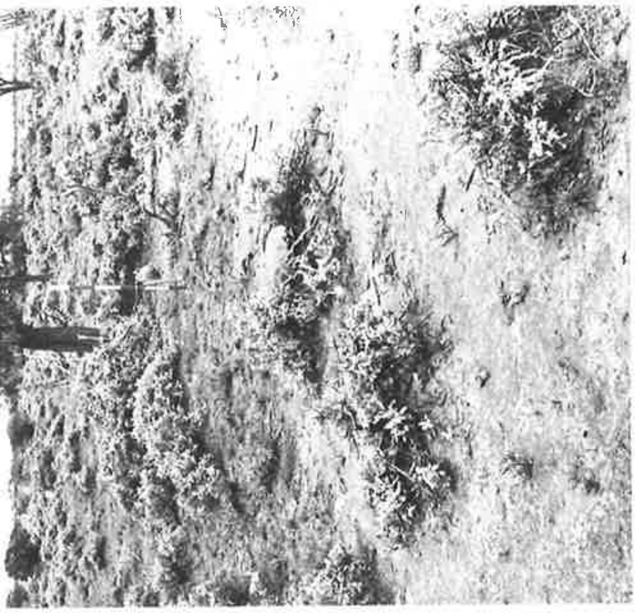
SP1
28·11·72



SP1
24·7·73

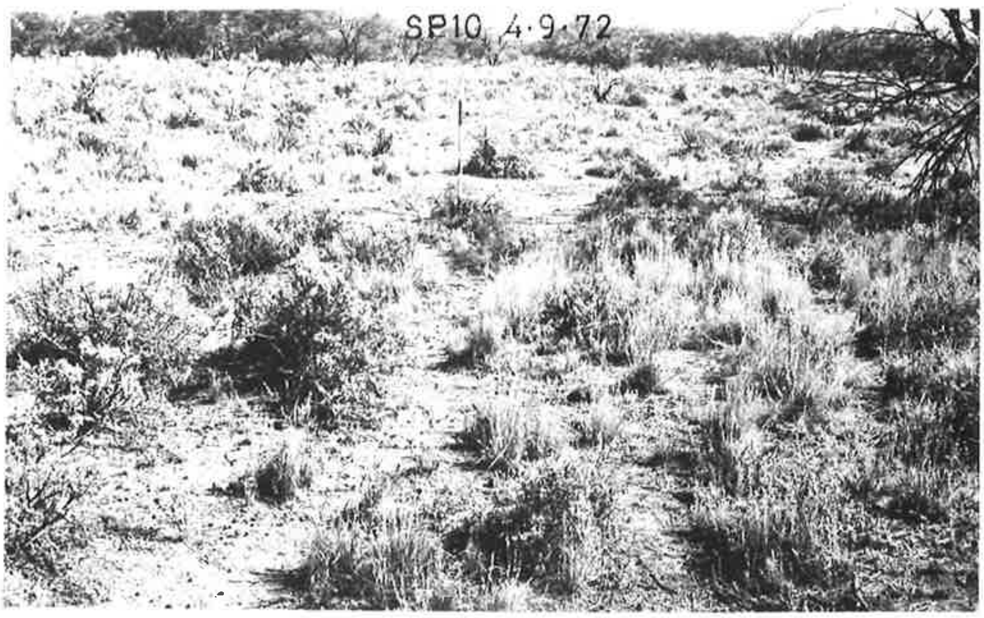


SP1
1·11·73



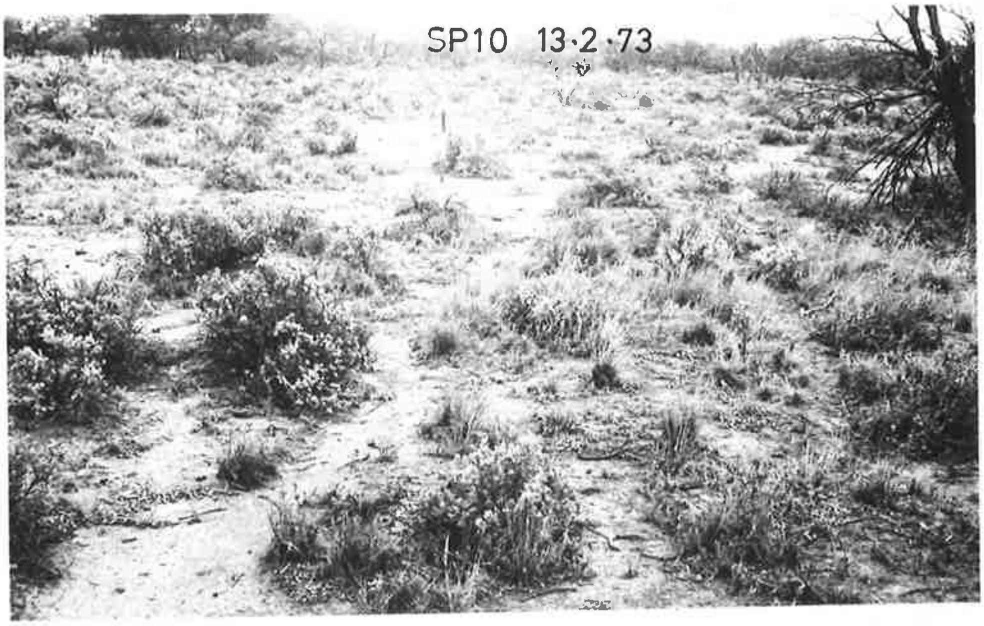
SP1
13·2·74

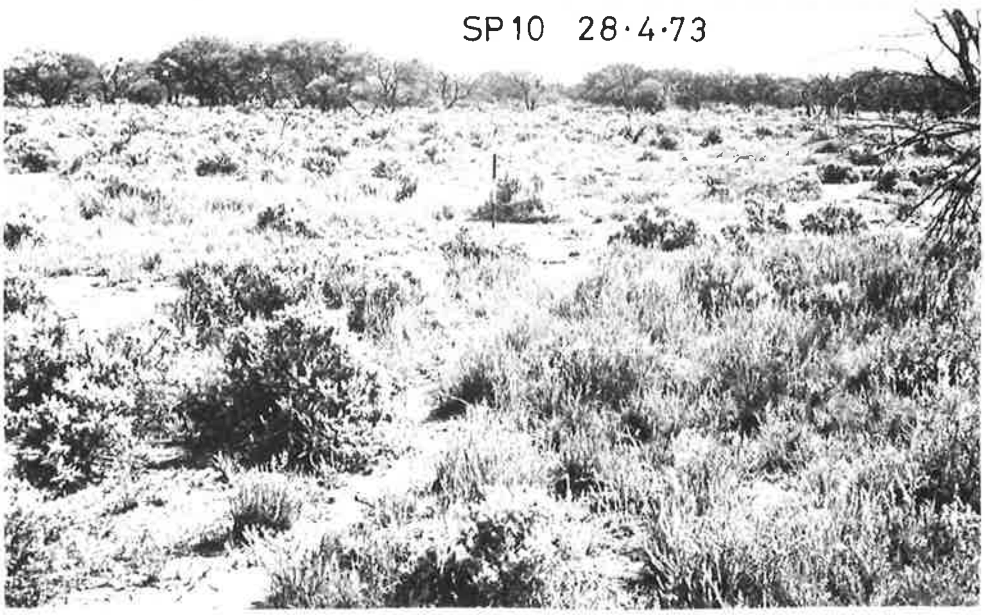
SP1
1·8·74


SP10 4·9·72


SP10 5·10·72


SP10 28.11.72

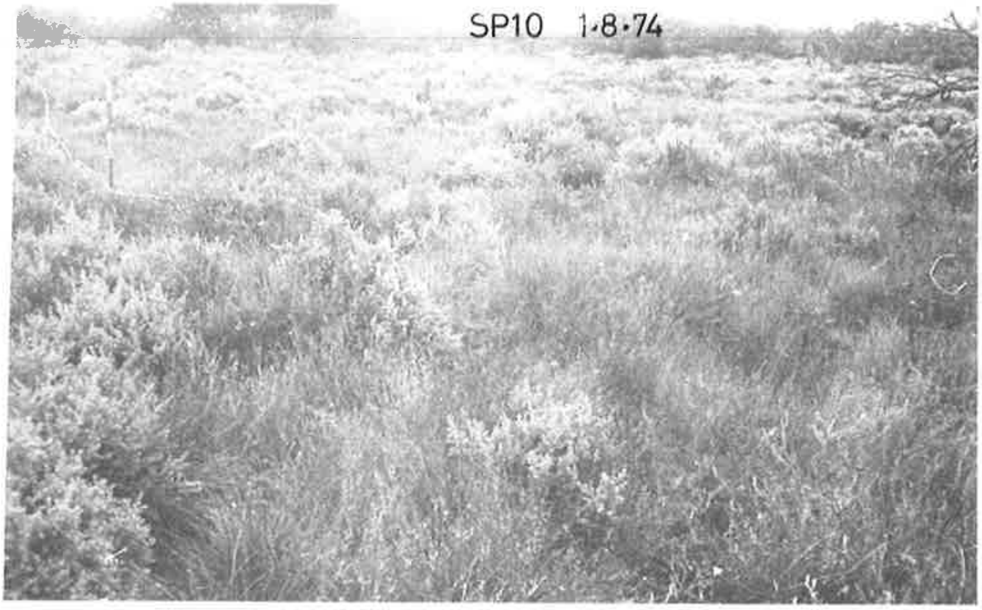

SP10 13·2·73

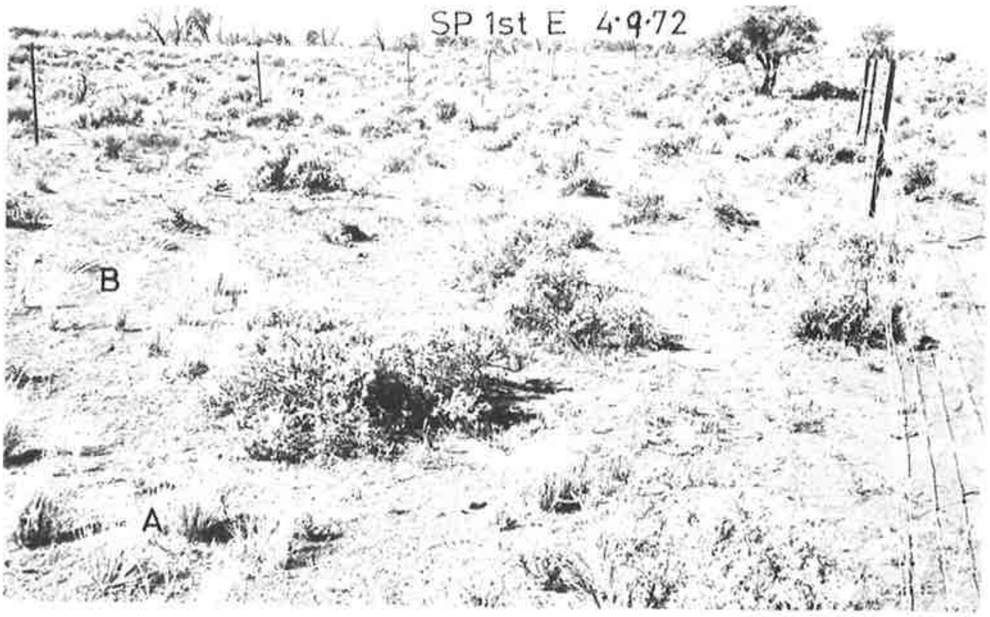

SP10 28·4·73


SP10 24·7·73


SP10 1·11·73


SP10 13·2·74


SP10 1·8·74


SP 1st E 4·9·72
B
A


SP 1stE 5·10·72


SP 1st E 28·11·72


SP 1st E 13·2·73


SP 1st E 28·4·73

SP1stE 24·7·73

SP1stE 1·11·73

SP1stE 13·2·74


SP 1stE 1·8·74

APPENDIX 2.

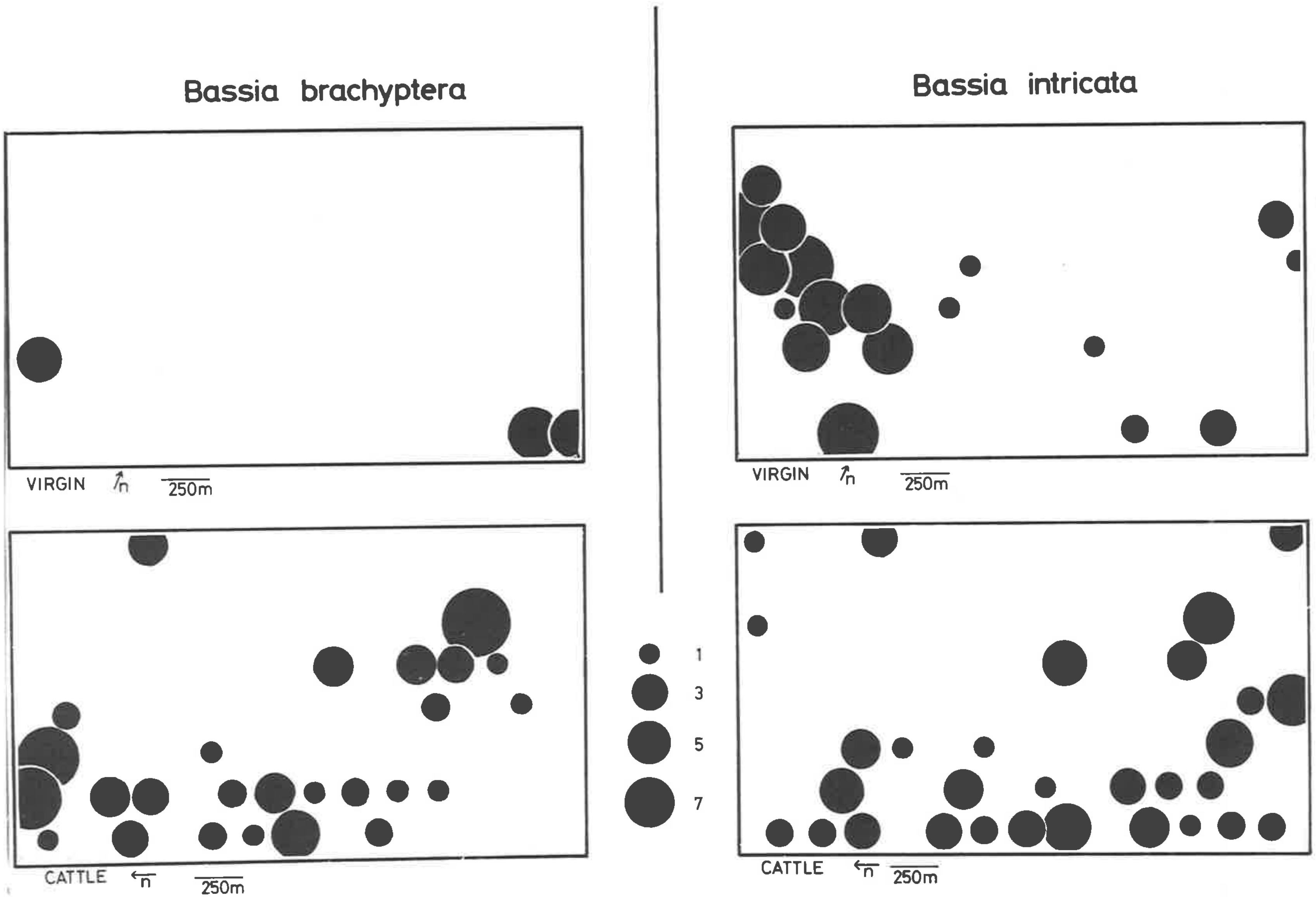
DENSITY DATA FOR CHAPTER 5.

(a) Distributions of species in the virgin/cattle survey.

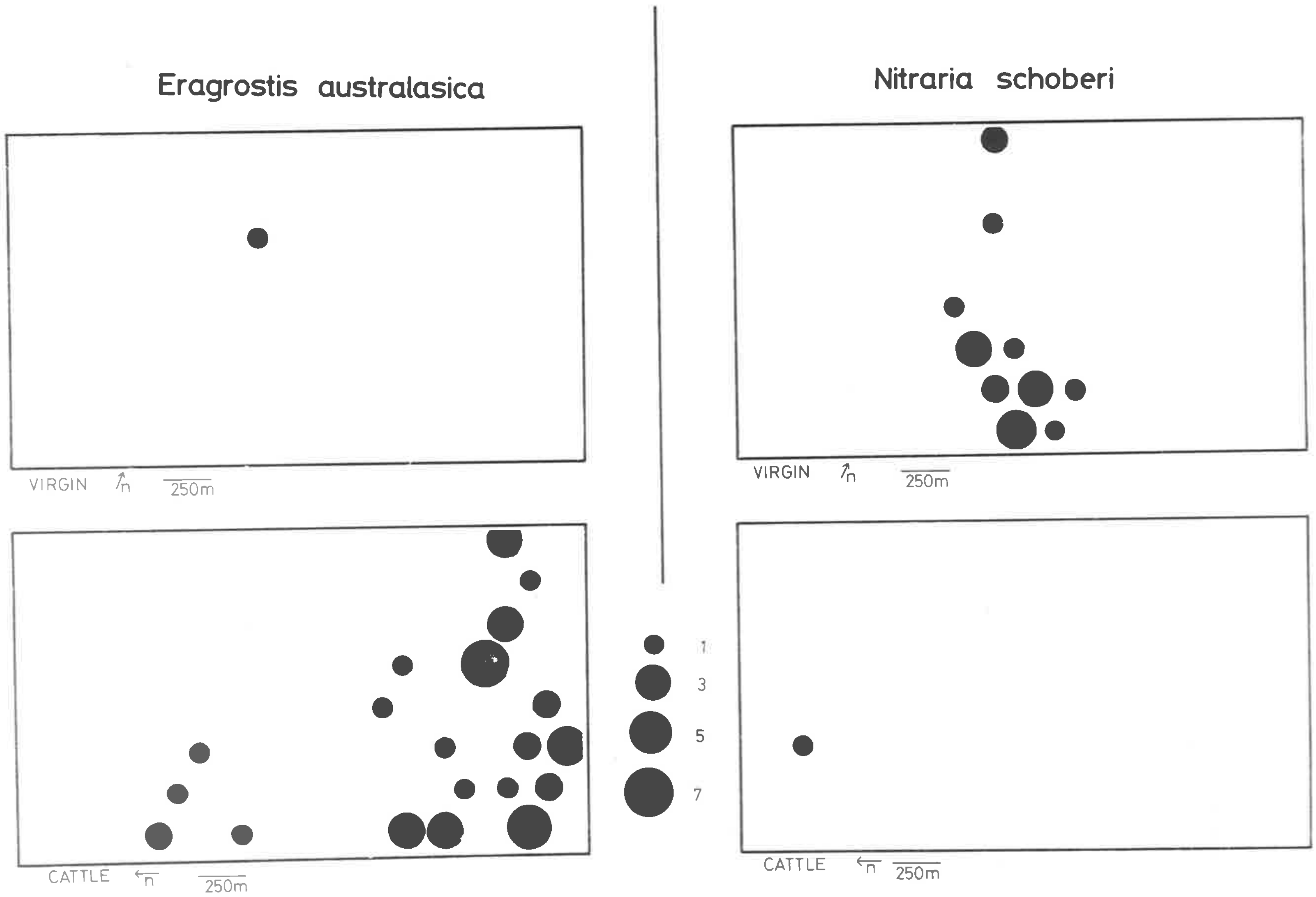
(b) Distributions of species in the cattle/sheep survey.

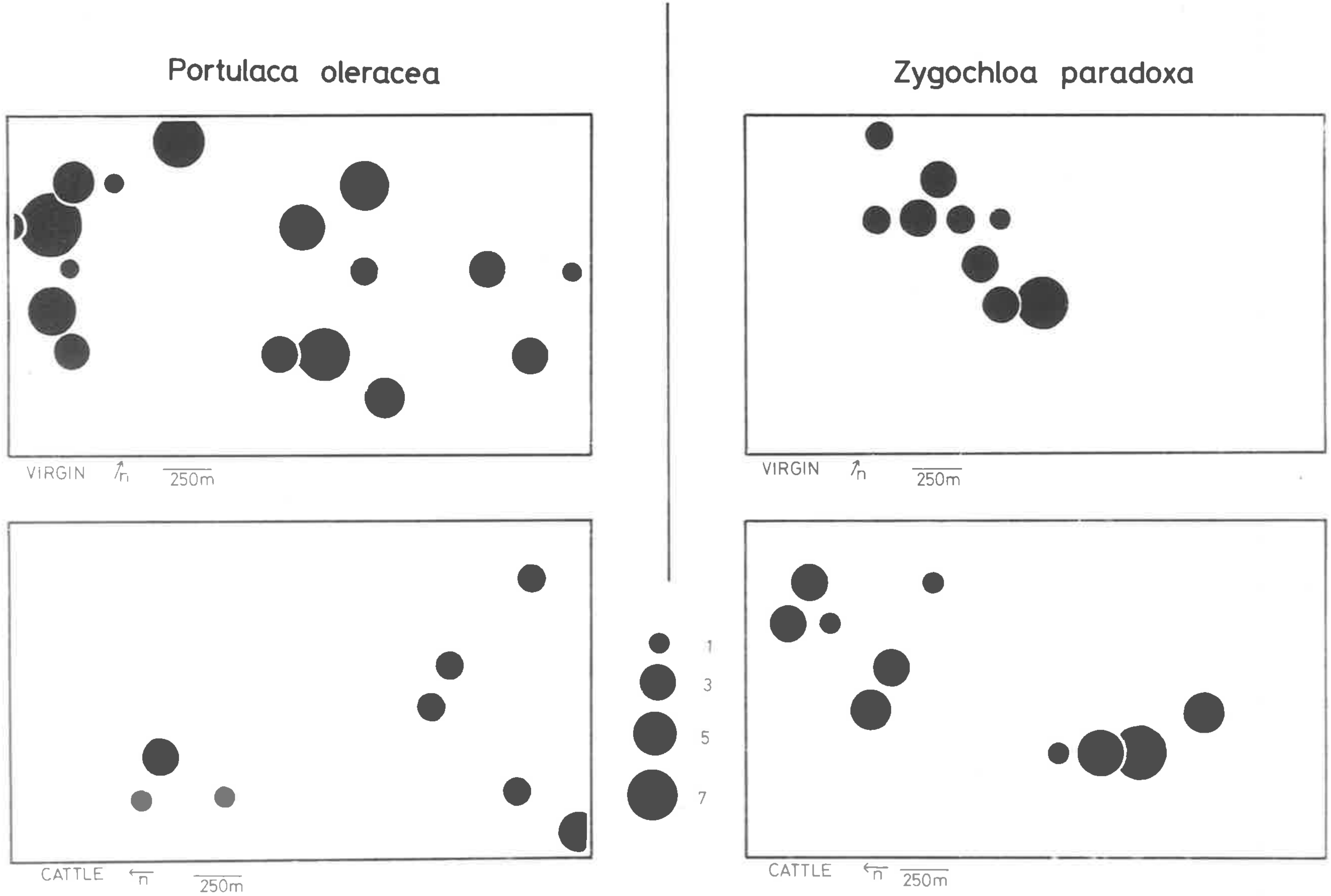
(a) Distributions of species in the virgin/cattle survey .

The following are maps of species' abundances in the study areas on Pernatty station. Species' maps are arranged in three sets with differing scales. The first set comprise those species for which frequency was estimated: the scale numbers refer to the number, out of ten, of $2x1m^2$ quadrats in which the species occurred. The remaining sets are density maps: two scales were necessary because of the wide variations in abundance. Species are arranged alphabetically within sets. Density counts are given as plants per quadrat.



Bassia brachyptera
Bassia intricata
VIRGIN
n
250m
VIRGIN
n
250m
CATTLE
n
250m
CATTLE
n
250m
1
3
5
7

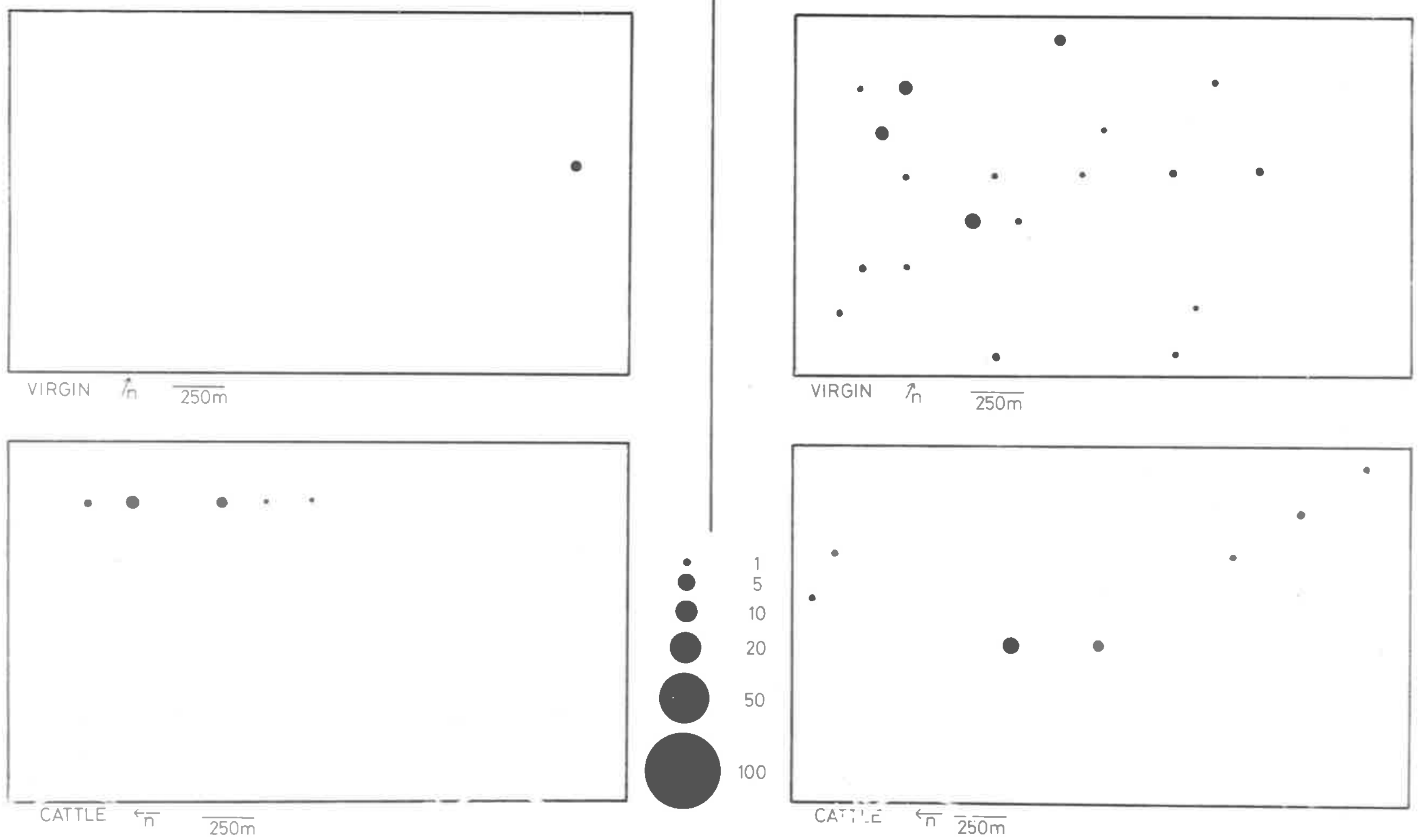

Eragrostis australasica
Nitraria schoberi
VIRGIN
n
250m
VIRGIN
n
250m
CATTLE
n
250m
CATTLE
n
250m
1
3
5
7



Portulaca oleracea
Zygochloa paradoxa
VIRGIN
n
250m
VIRGIN
n
250m
CATTLE
n
250m
CATTLE
n
250m
1
3
5
7

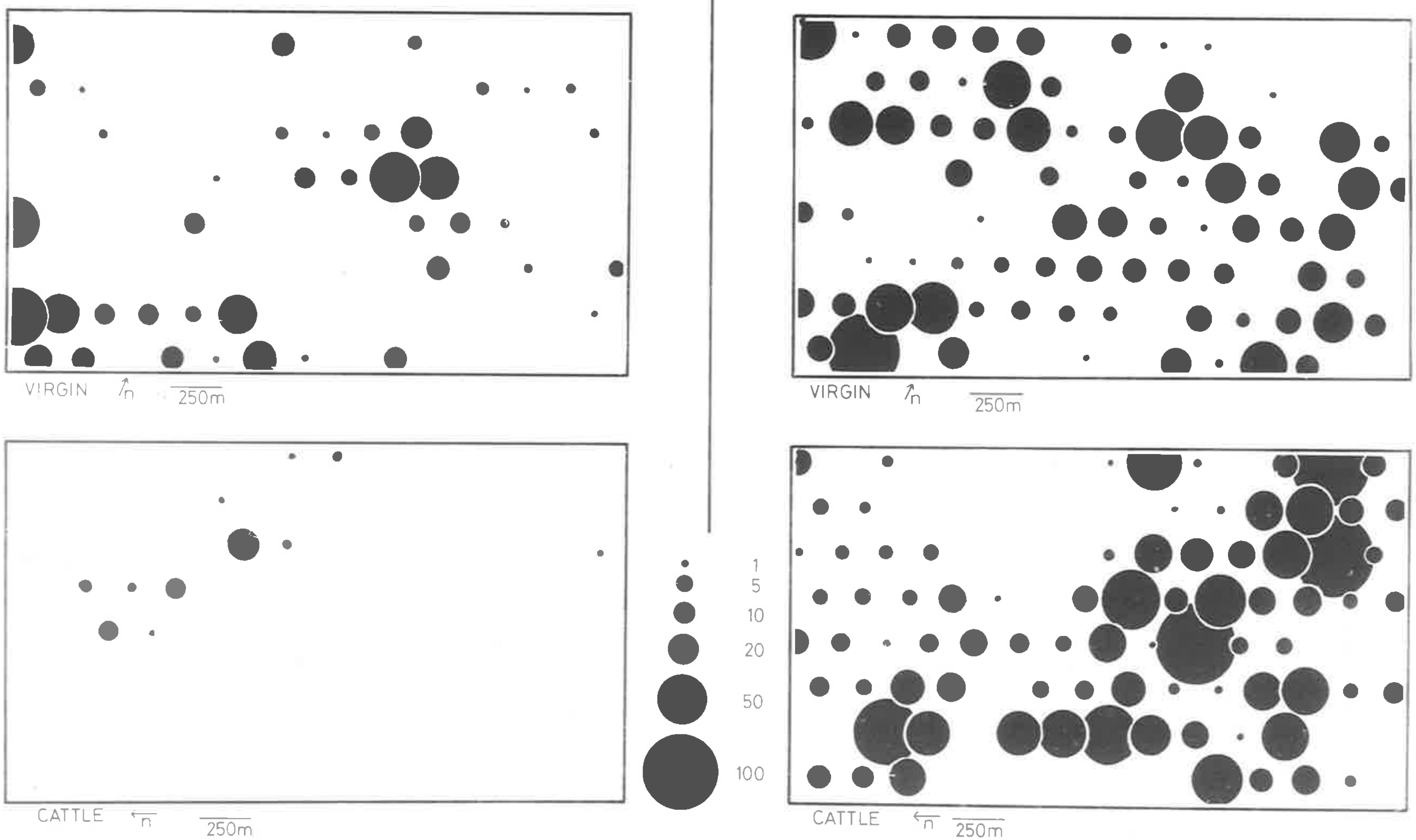
Abutilon otocarpum

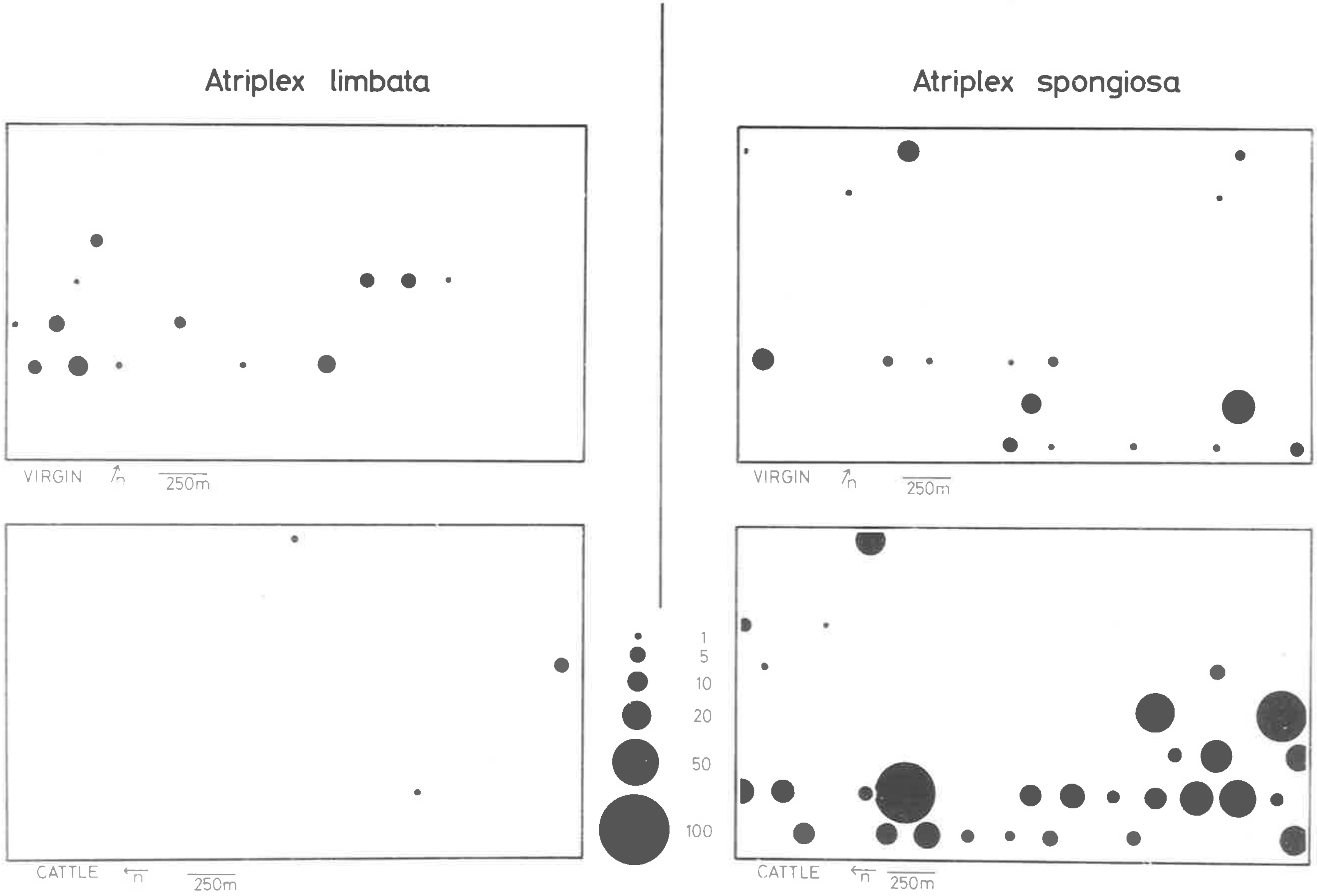
Aizoon quadrifidum

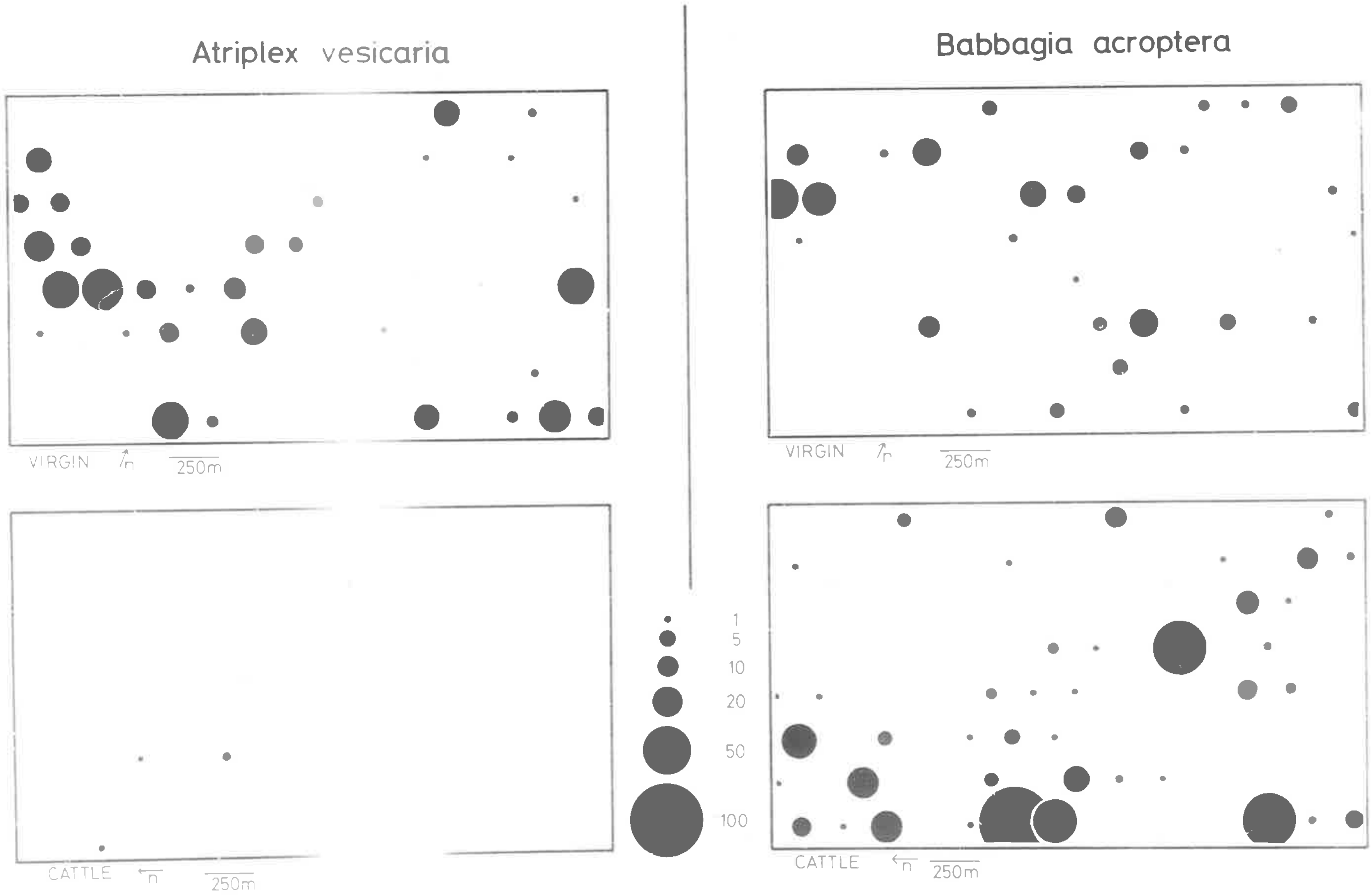


Aristida contorta

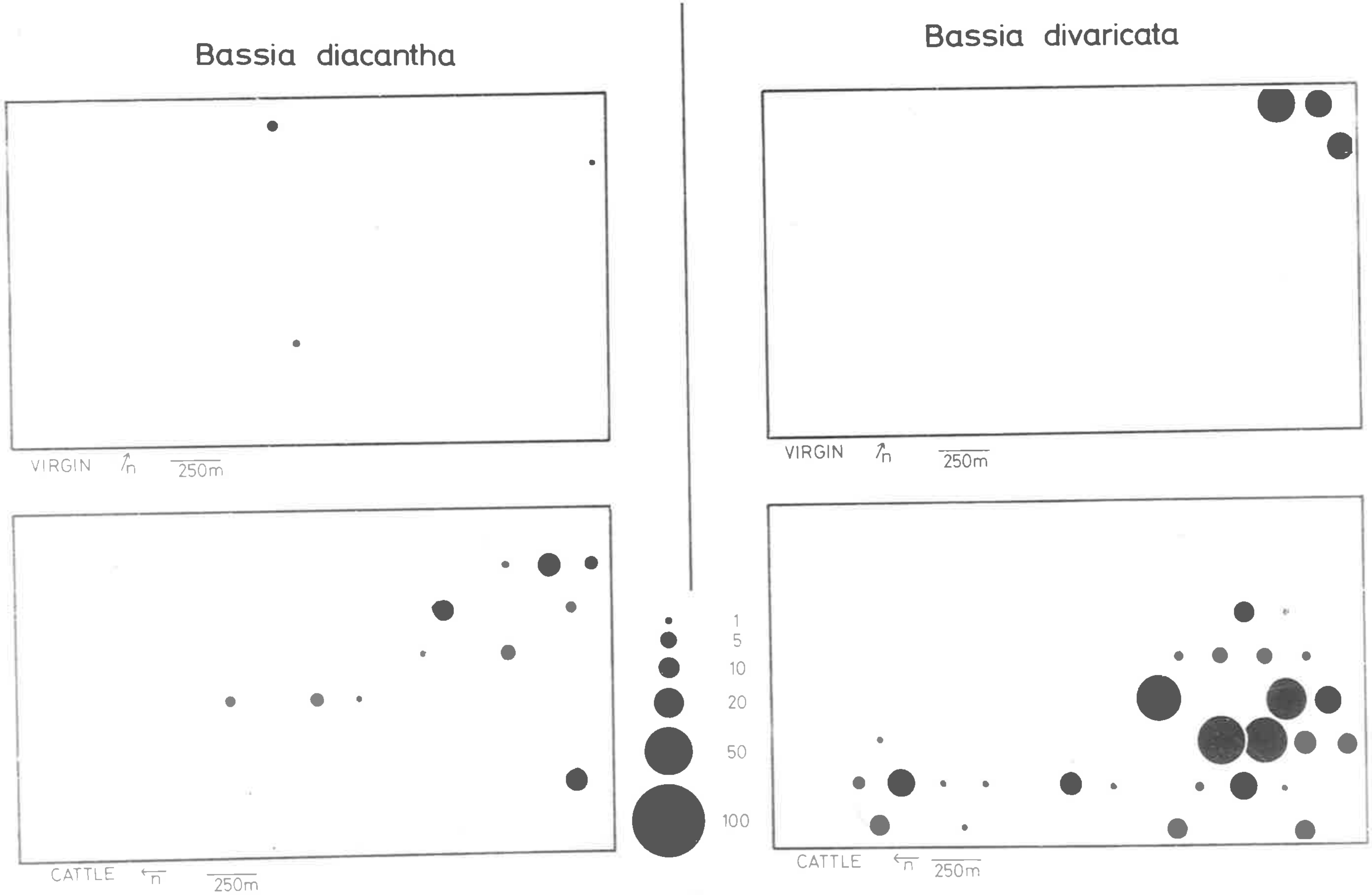
Atriplex inflata

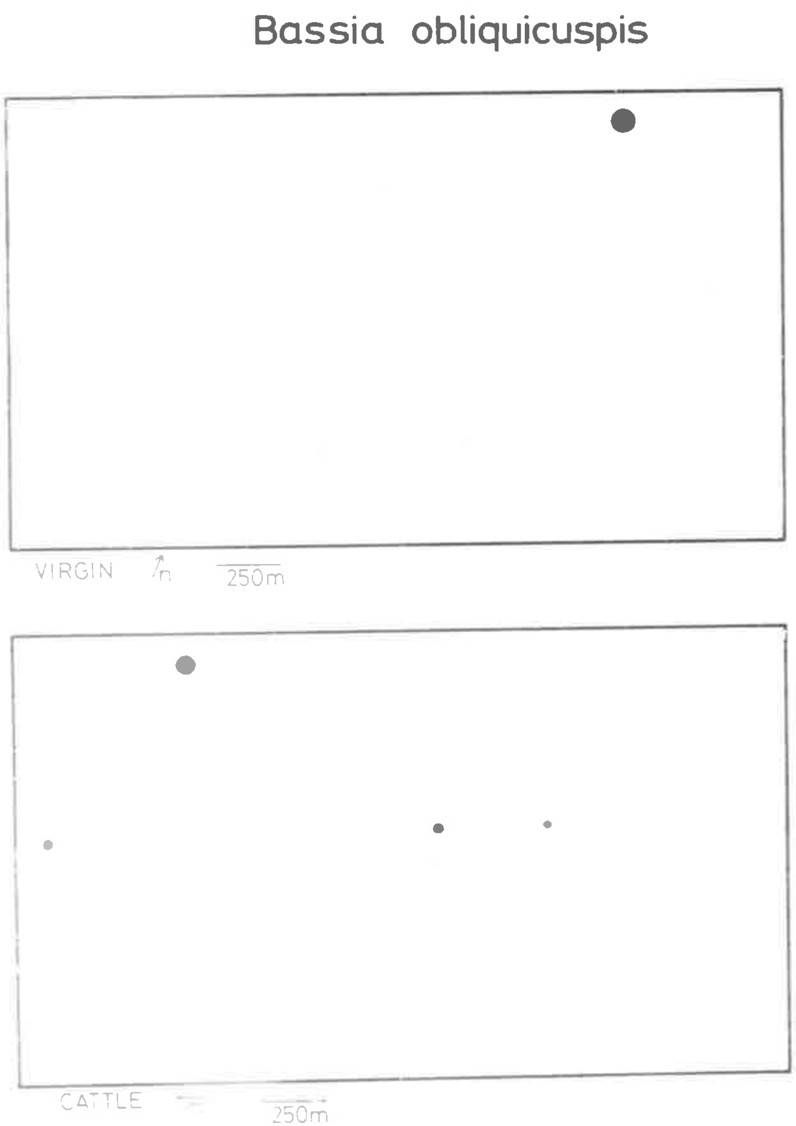


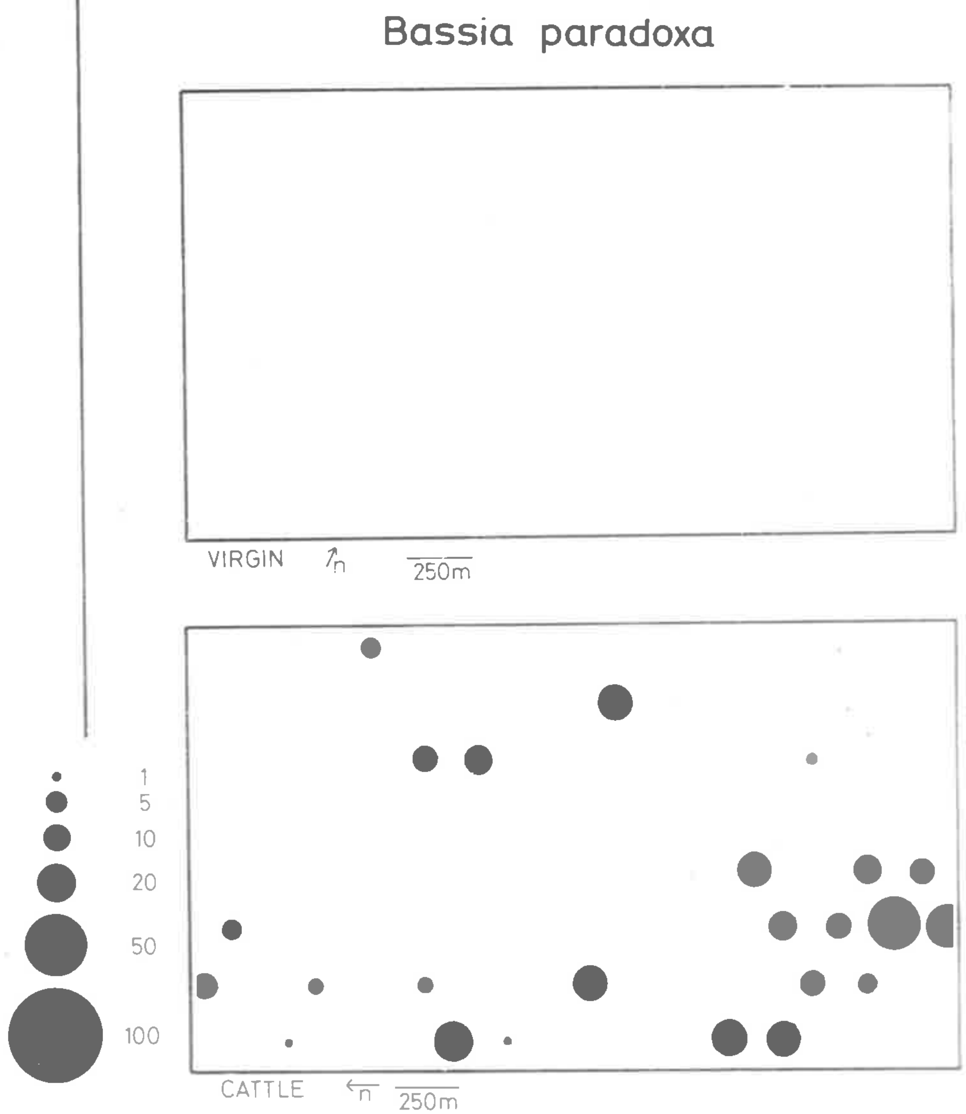

Atriplex limbata
Atriplex spongiosa
VIRGIN
250m
VIRGIN
250m
CATTLE
250m
CATTLE
250m
1
5
10
20
50
100

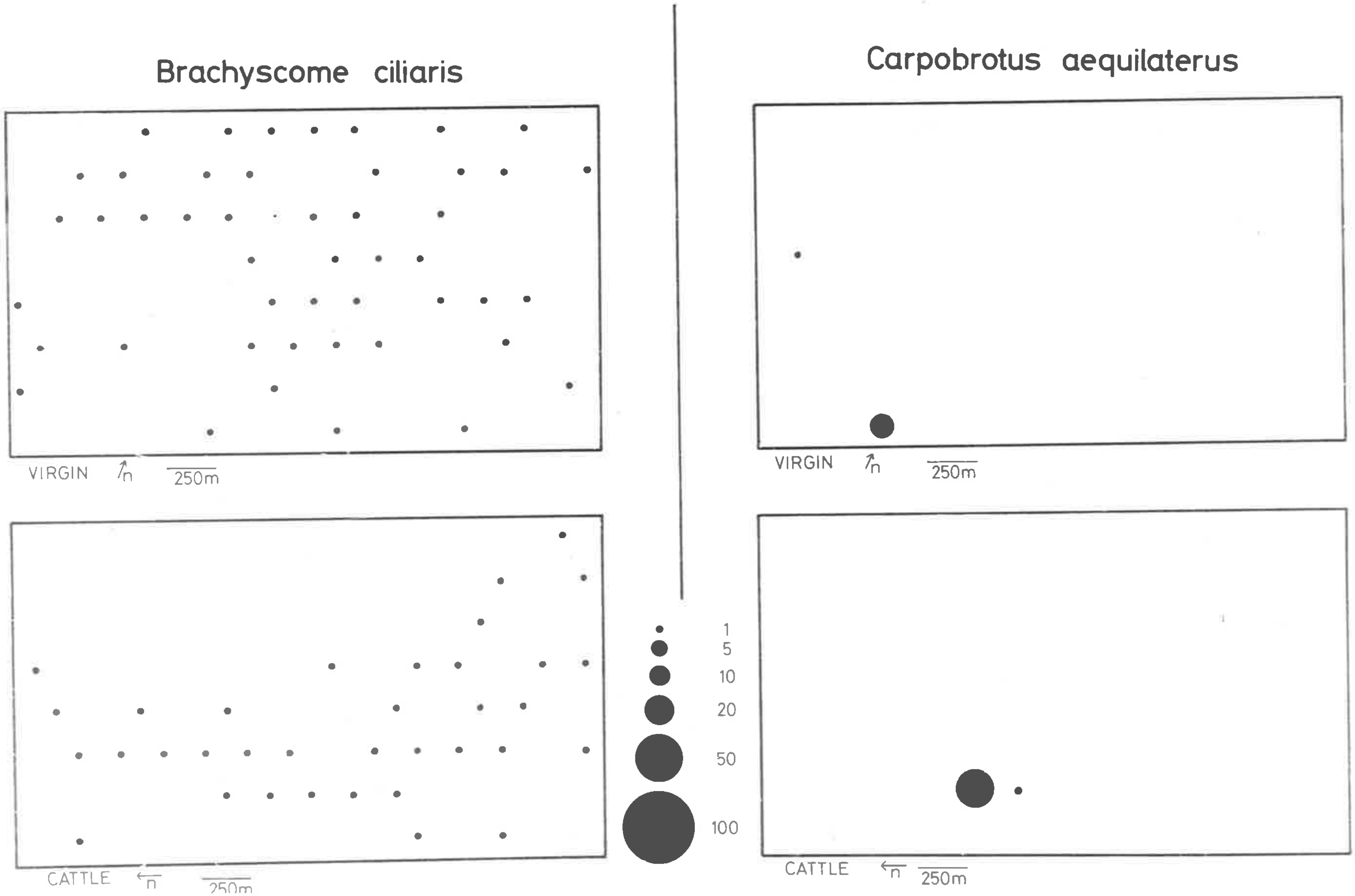


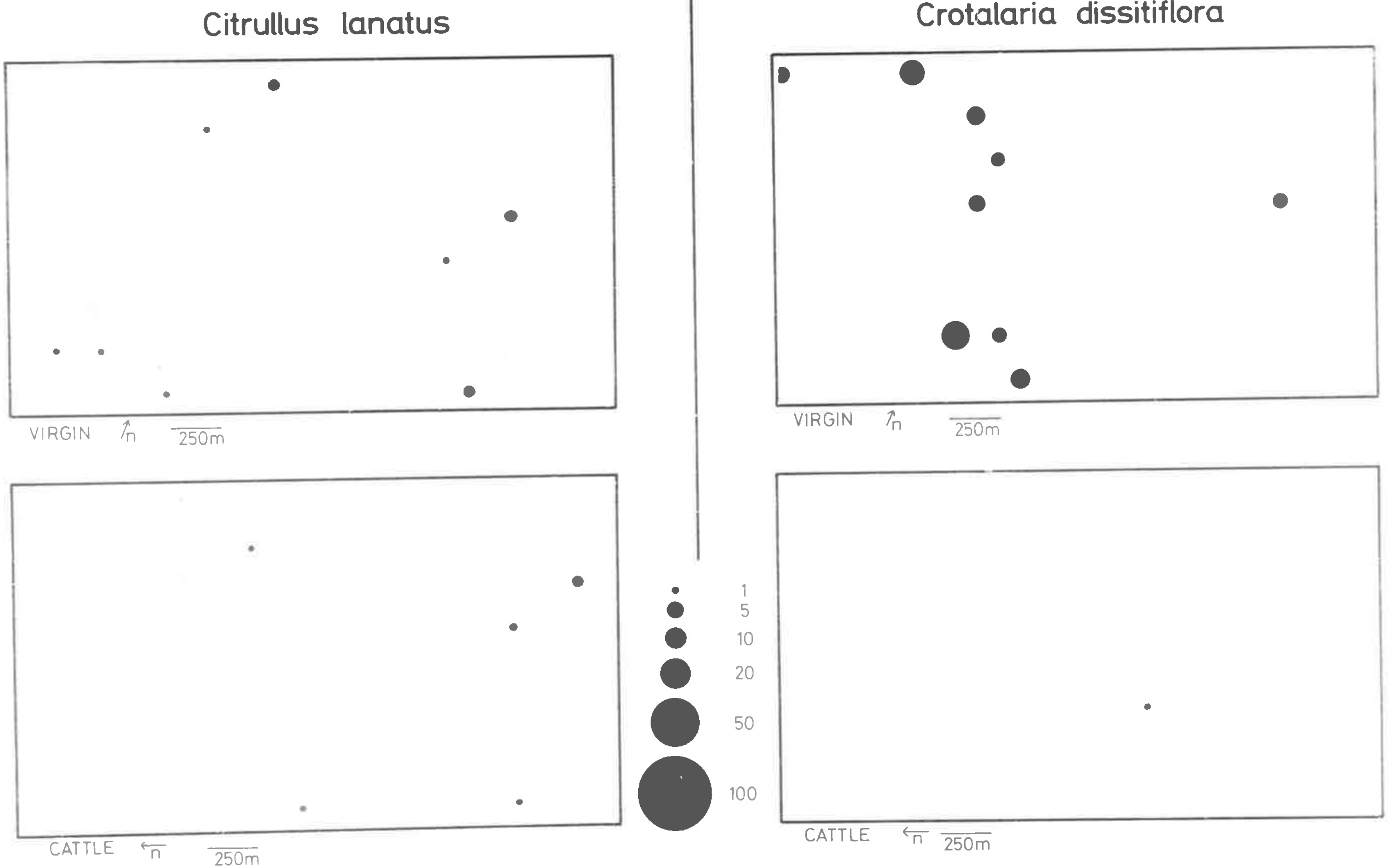
Atriplex vesicaria
Babbagia acroptera
VIRGIN
250m
VIRGIN
250m
CATTLE
250m
CATTLE
250m
1
5
10
20
50
100


Bassia diacantha
Bassia divaricata
VIRGIN
250m
CATTLE
250m
VIRGIN
250m
CATTLE
250m
1
5
10
20
50
100


Bassia obliquicuspis
VIRGIN
n
250m
CATTLE
250m

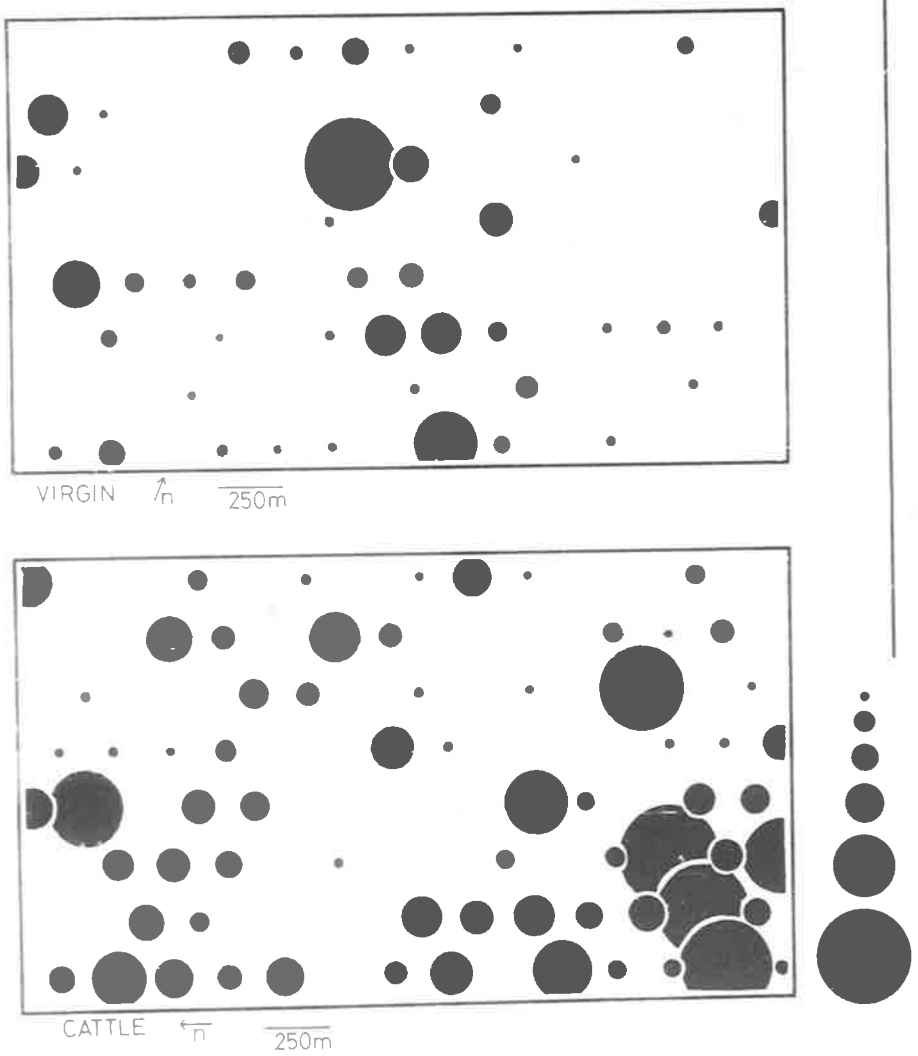

Bassia paradoxa
VIRGIN
n
250m
CATTLE
n
250m
1
5
10
20
50
100


Brachyscome ciliaris
Carpobrotus aequilaterus
VIRGIN
n
250m
CATTLE
n
250m
VIRGIN
n
250m
CATTLE
n
250m
1
5
10
20
50
100

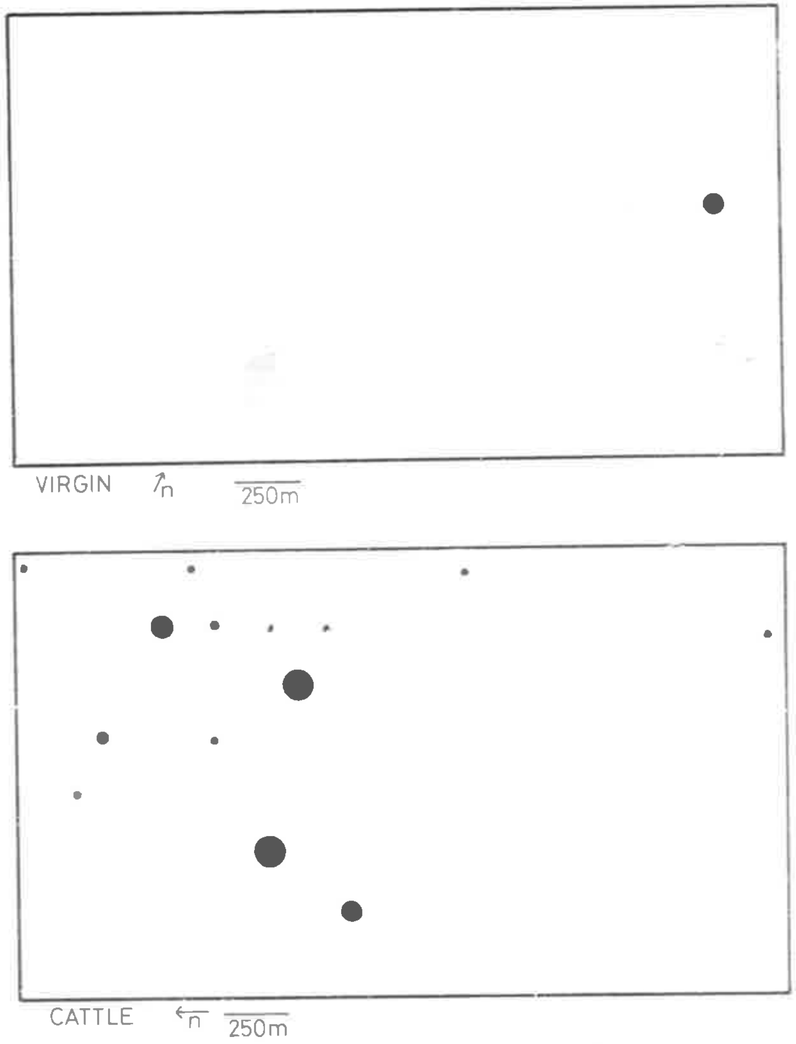

Citrullus lanatus
Crotalaria dissitiflora
VIRGIN
n
250m
VIRGIN
n
250m
1
5
10
20
50
100
CATTLE
n
250m
CATTLE
n
250m

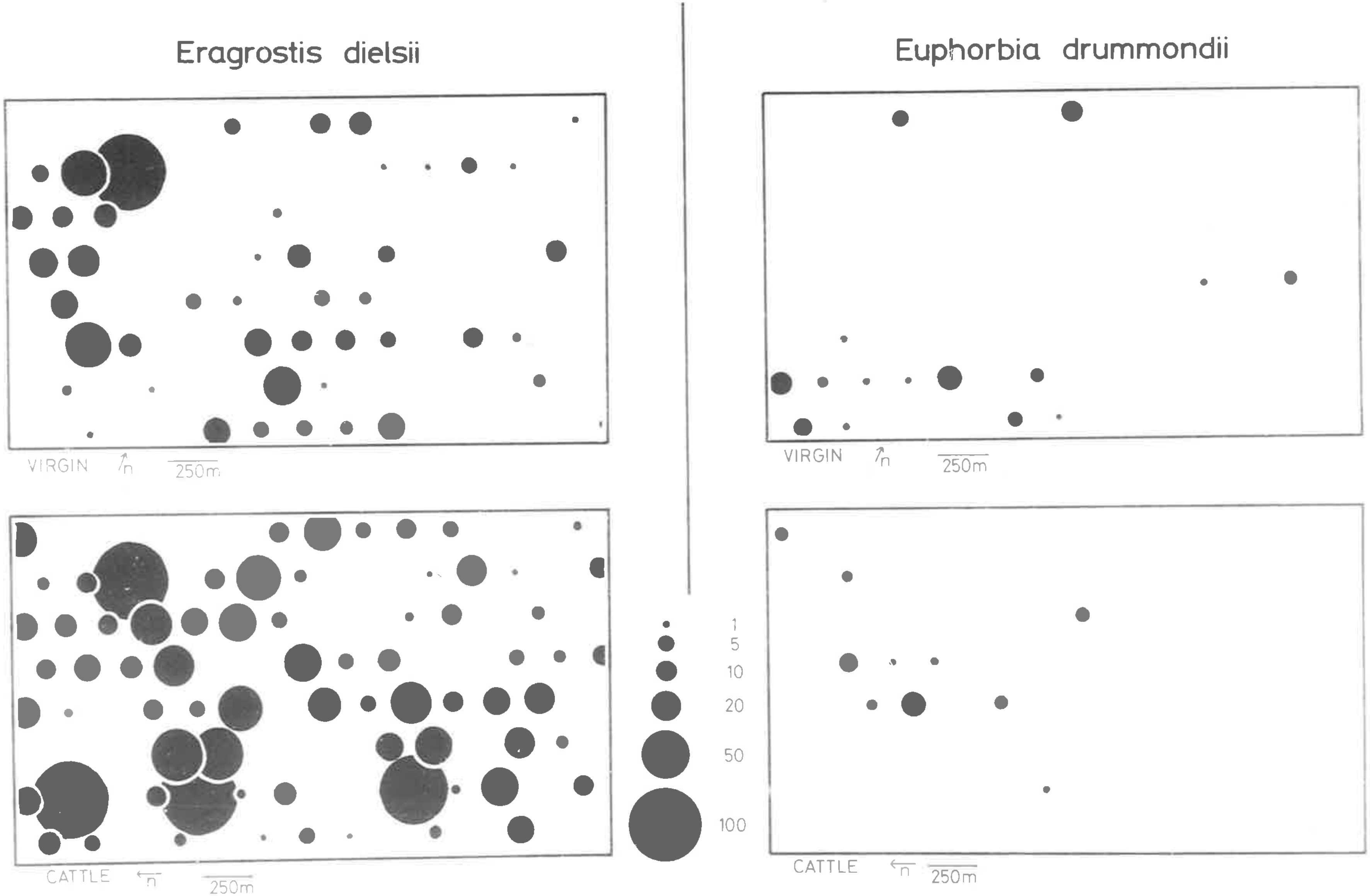
Dactyloctenium radulans

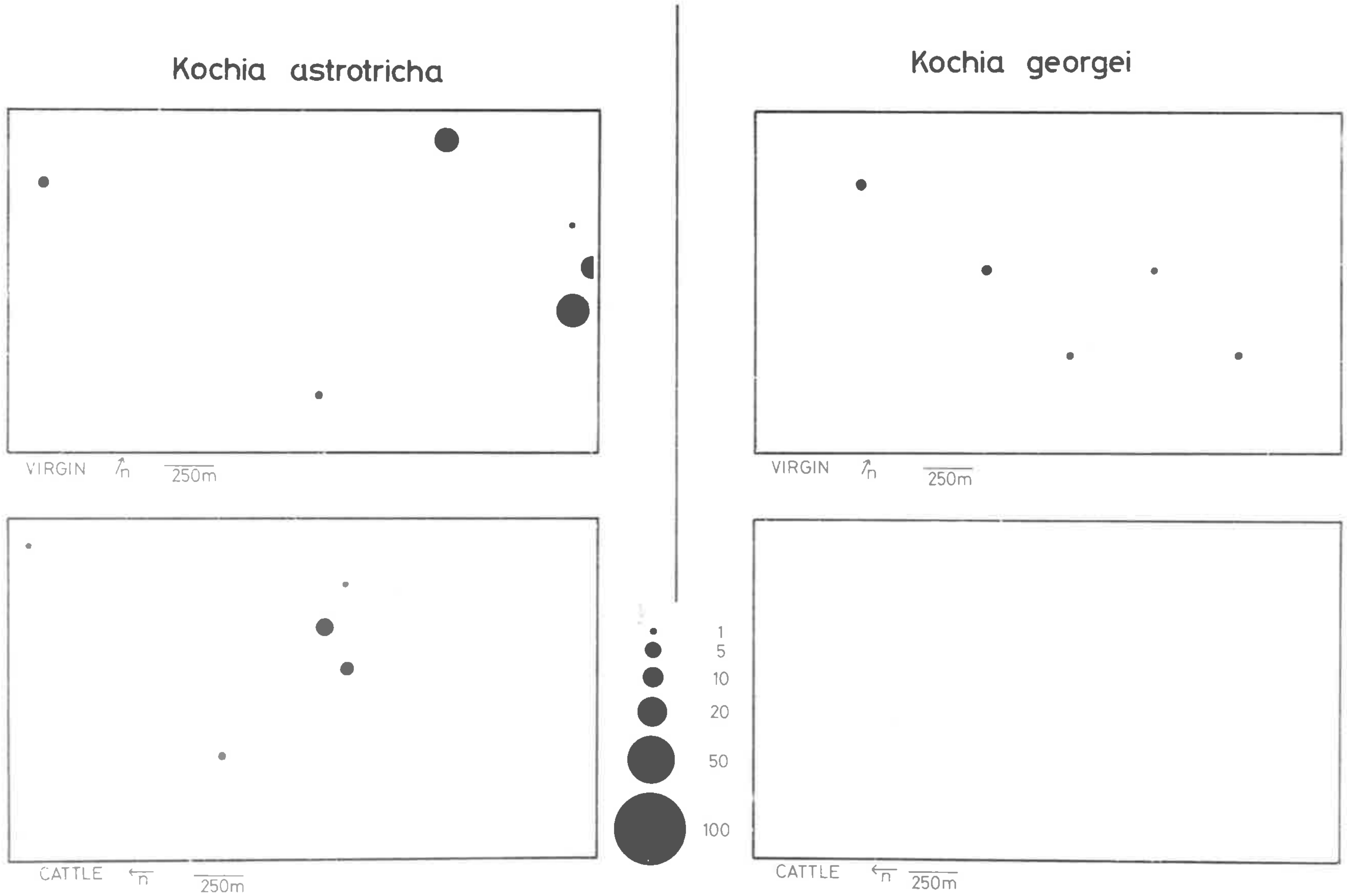
Tragus australianus



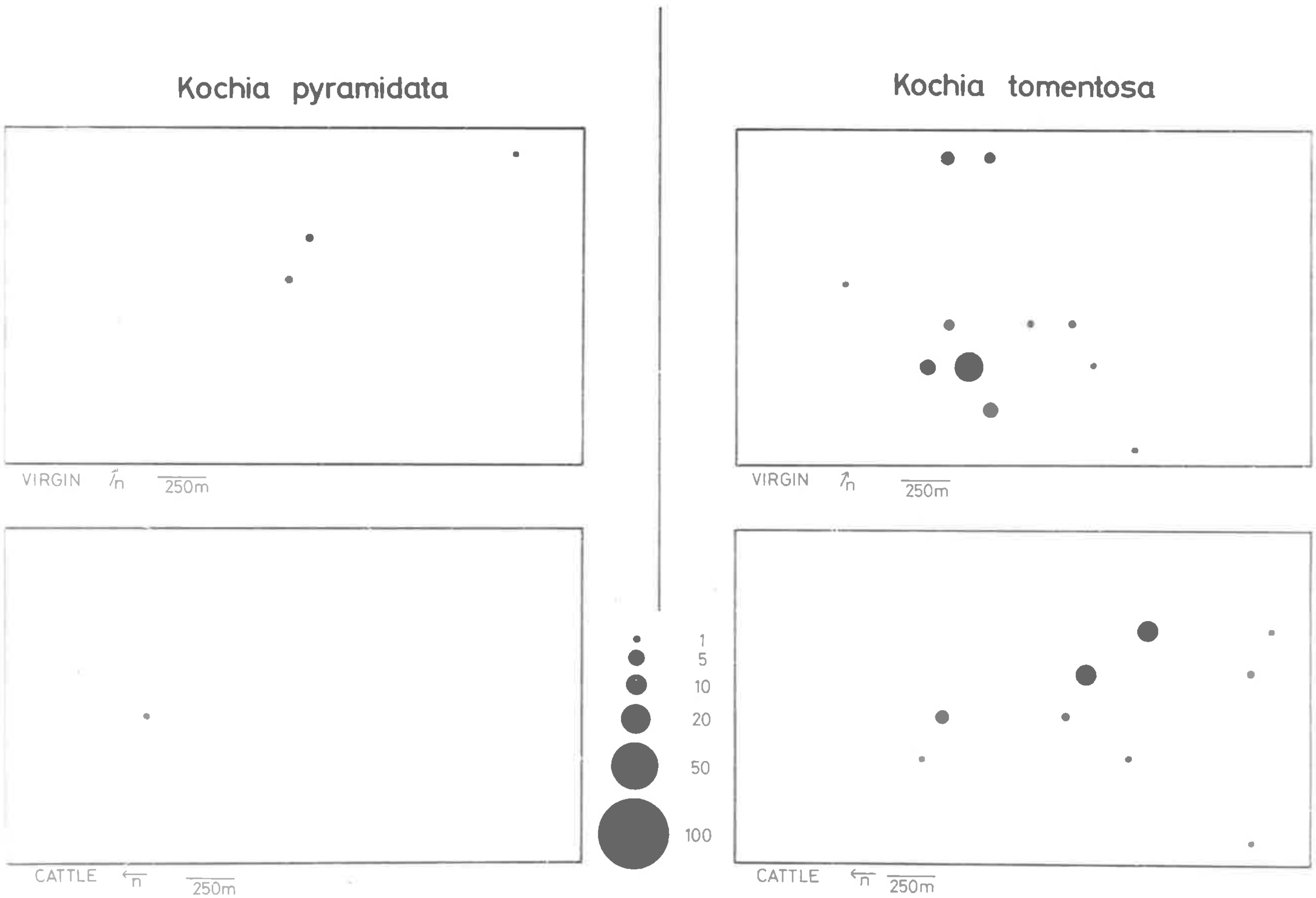
Enneapogon avenaceus



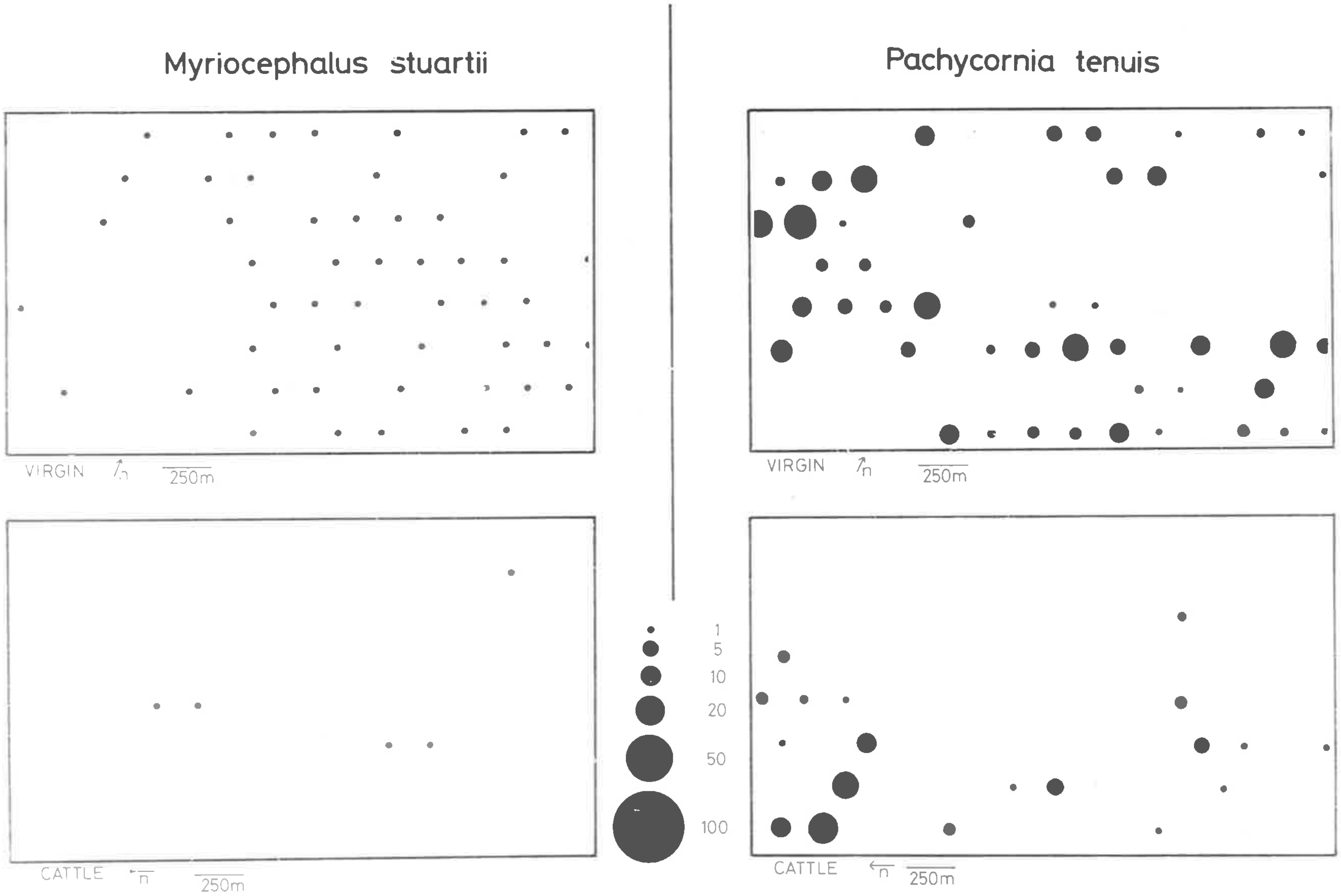

Eragrostis dielsii
Euphorbia drummondii
VIRGIN
n
250m
VIRGIN
n
250m
CATTLE
n
250m
CATTLE
n
250m
1
5
10
20
50
100

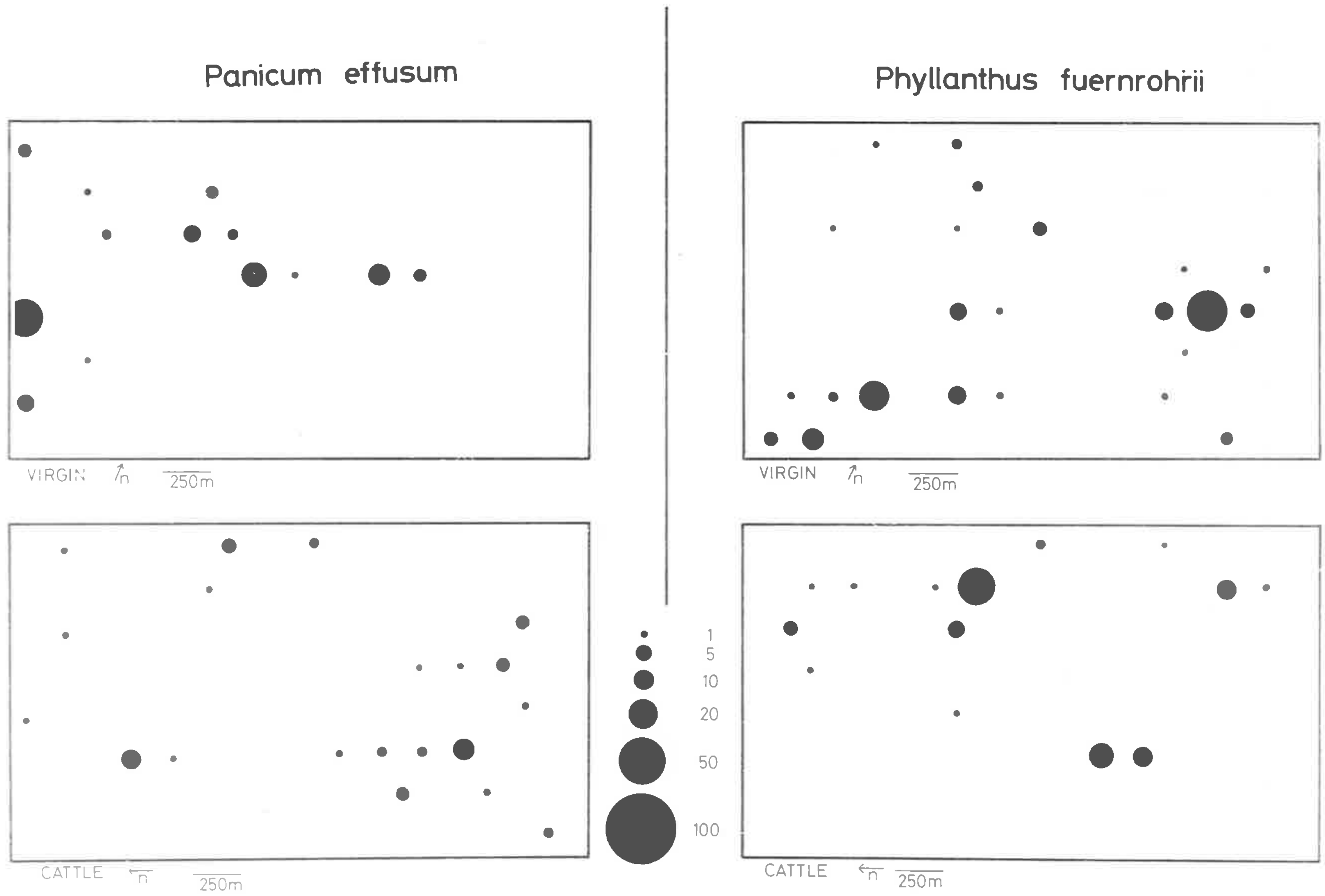


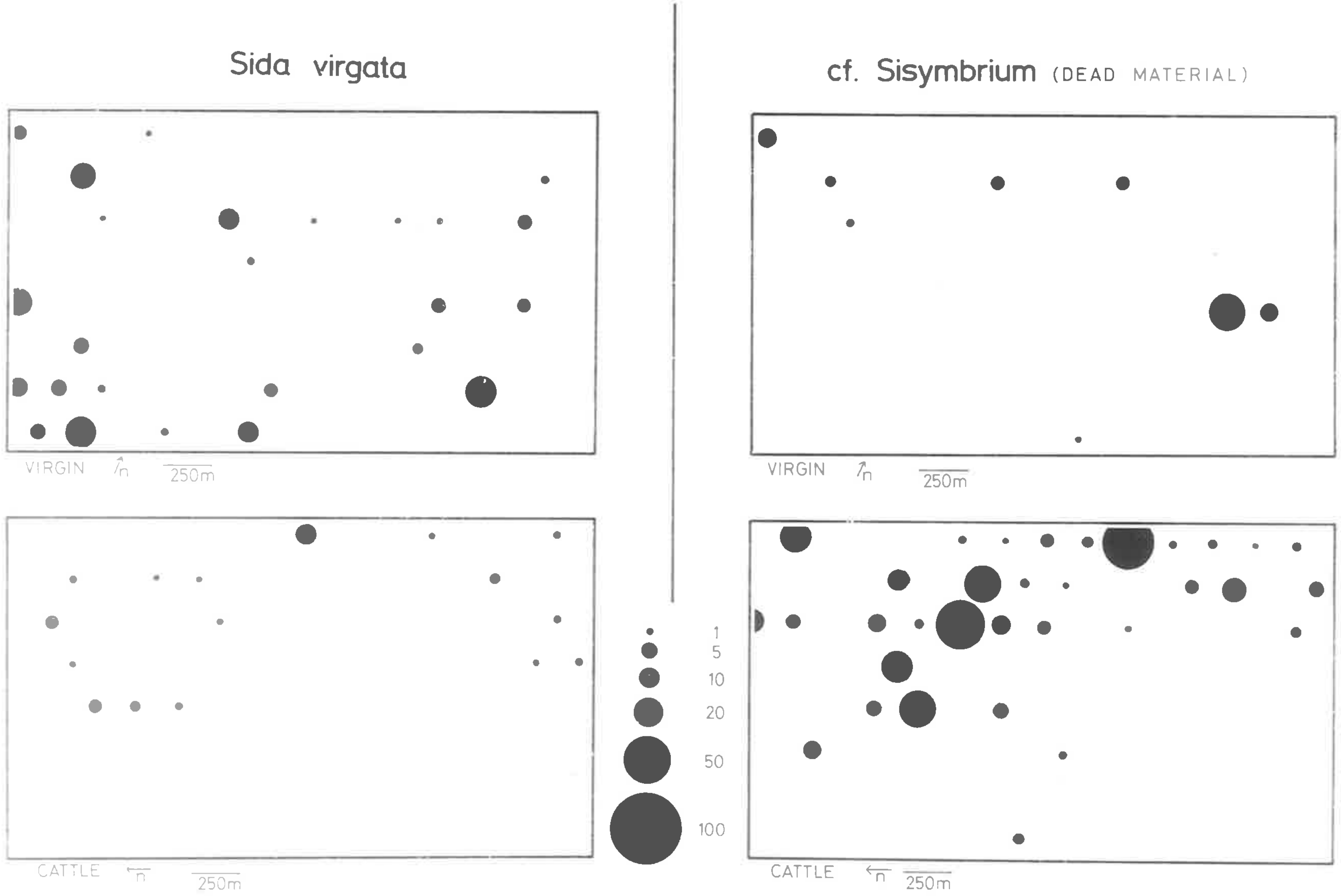
Kochia astrotricha
Kochia georgei
VIRGIN
250m
VIRGIN
250m
CATTLE
250m
CATTLE
250m
1
5
10
20
50
100

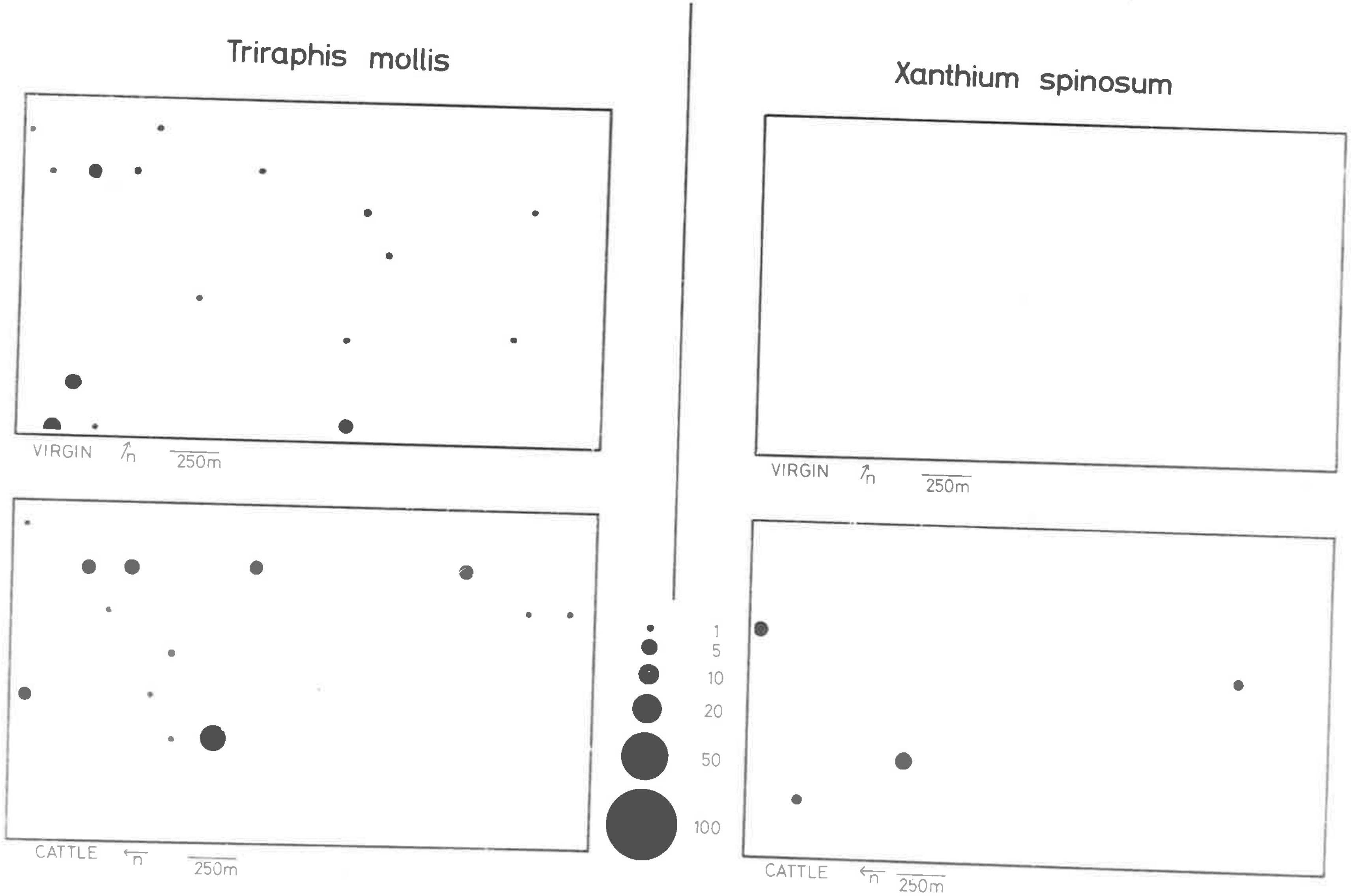


Kochia pyramidata
Kochia tomentosa
VIRGIN
n
250m
CATTLE
n
250m
VIRGIN
n
250m
CATTLE
n
250m
1
5
10
20
50
100


Myriocephalus stuartii
Pachycornia tenuis
VIRGIN
250m
VIRGIN
250m
CATTLE
n
250m
CATTLE
n
250m
1
5
10
20
50
100

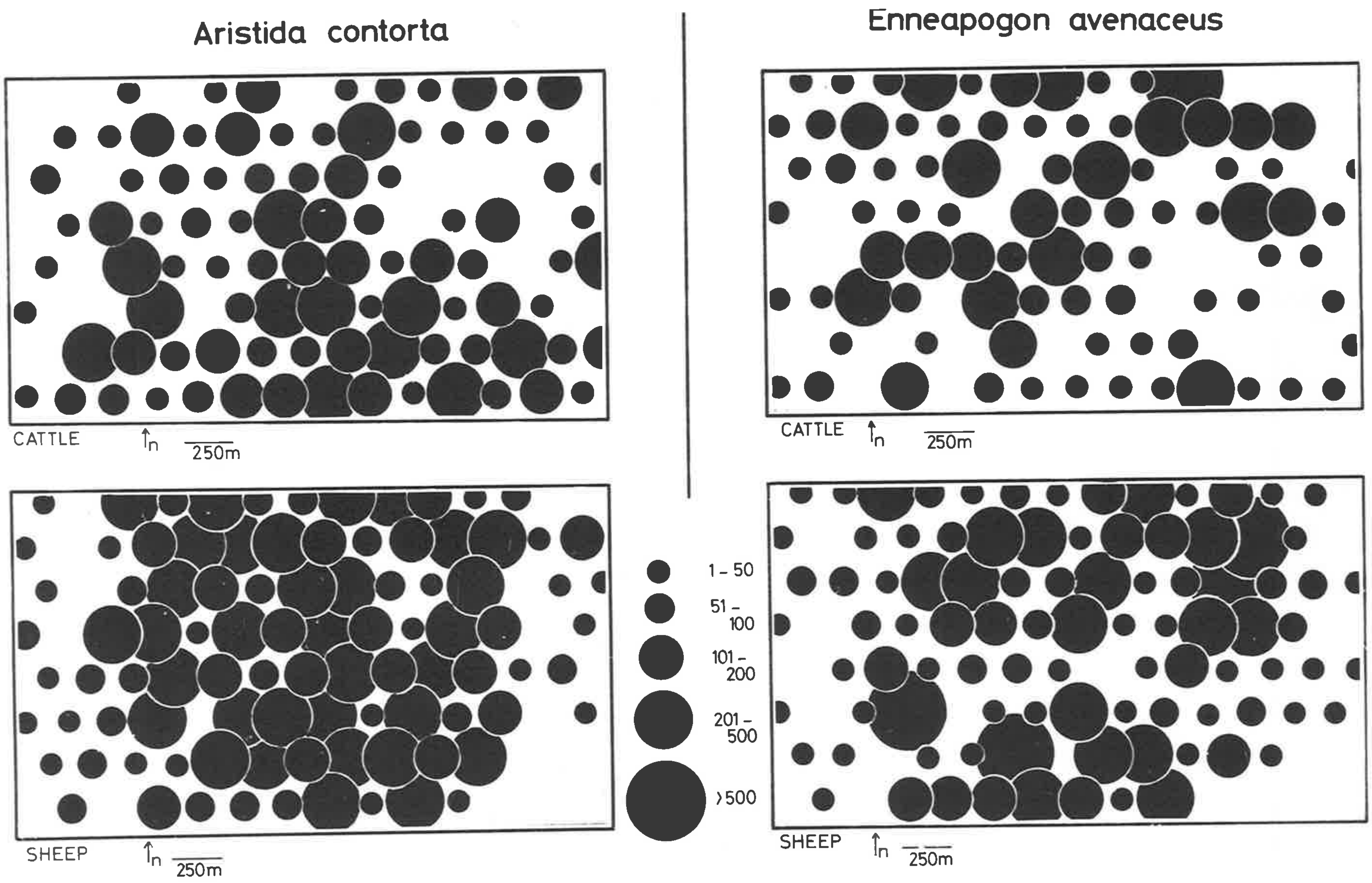

Panicum effusum
Phyllanthus fuernrohrii
VIRGIN
n
250m
CATTLE
1
5
10
20
50
100


Sida virgata
cf. Sisymbrium (DEAD MATERIAL)
VIRGIN
n
250m
VIRGIN
n
250m
CATTLE
n
250m
CATTLE
n
250m
1
5
10
20
50
100


Triraphis mollis
Xanthium spinosum
VIRGIN
n
250m
CATTLE
n
250m
VIRGIN
n
250m
CATTLE
n
250m
1
5
10
20
50
100

(b) Distributions of species in the cattle/sheep survey.

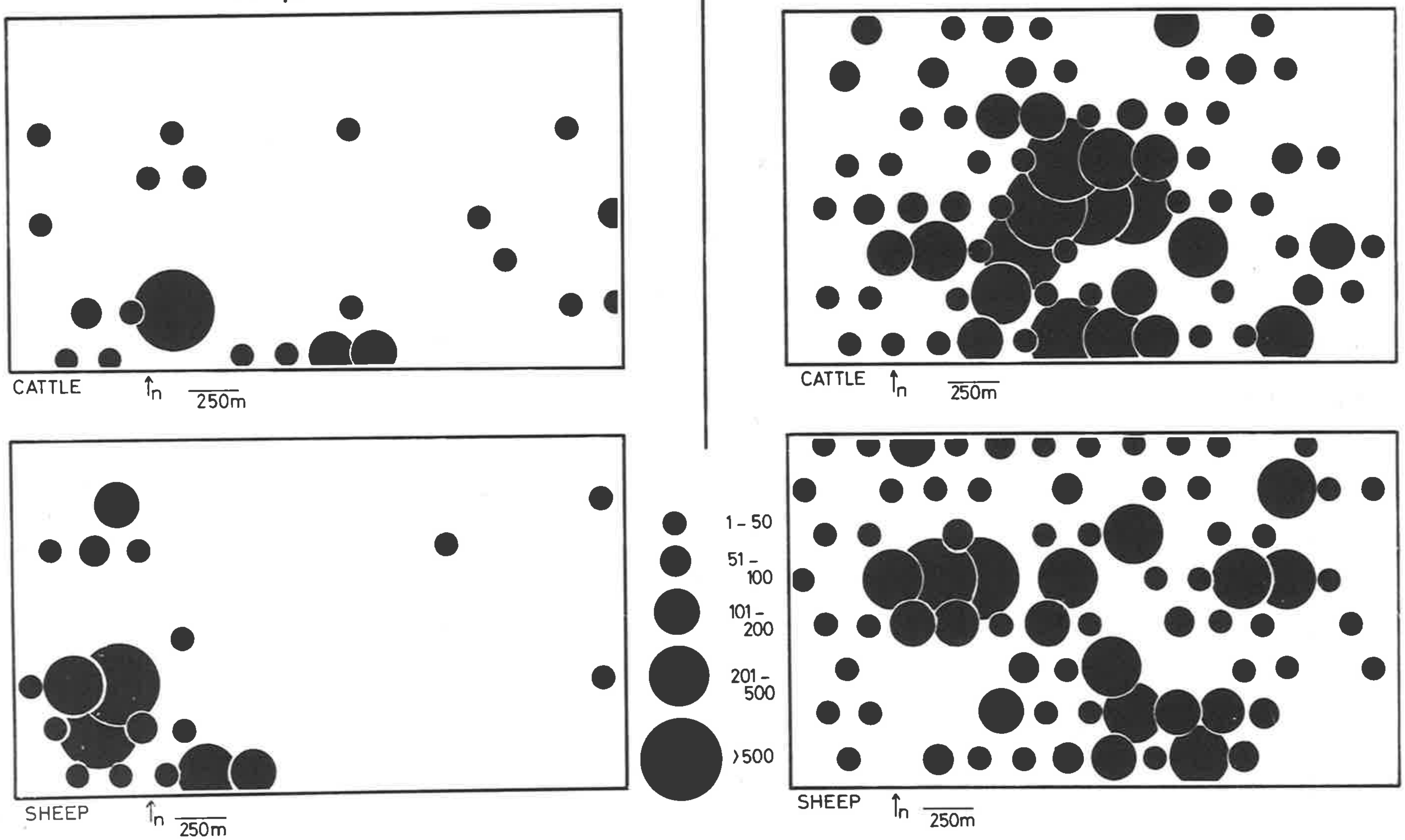
The following are maps of species' abundances in the study areas on Roxby Downs station. Species' density maps are arranged in two sets because of the wide range of abundances. Species are arranged alphabetically within sets. In all cases, counts are given as plants per quadrat.



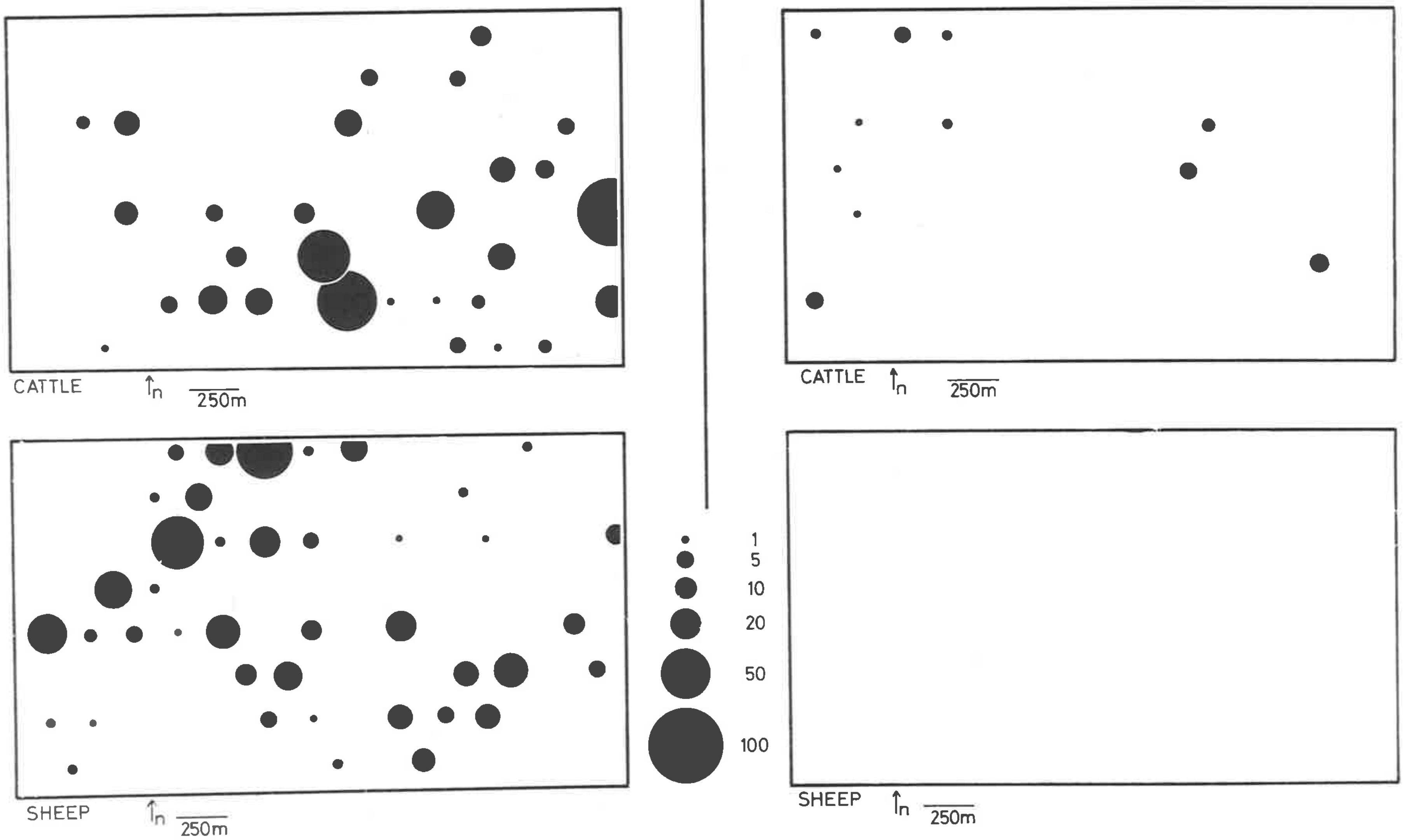
Aristida contorta
Enneapogon avenaceus
CATTLE
n
250m
CATTLE
n
250m
SHEEP
n
250m
SHEEP
n
250m
1 - 50
51 - 100
101 - 200
201 - 500
›500

Goodenia cycloptera
G. pinnatifida

Tragus australianus

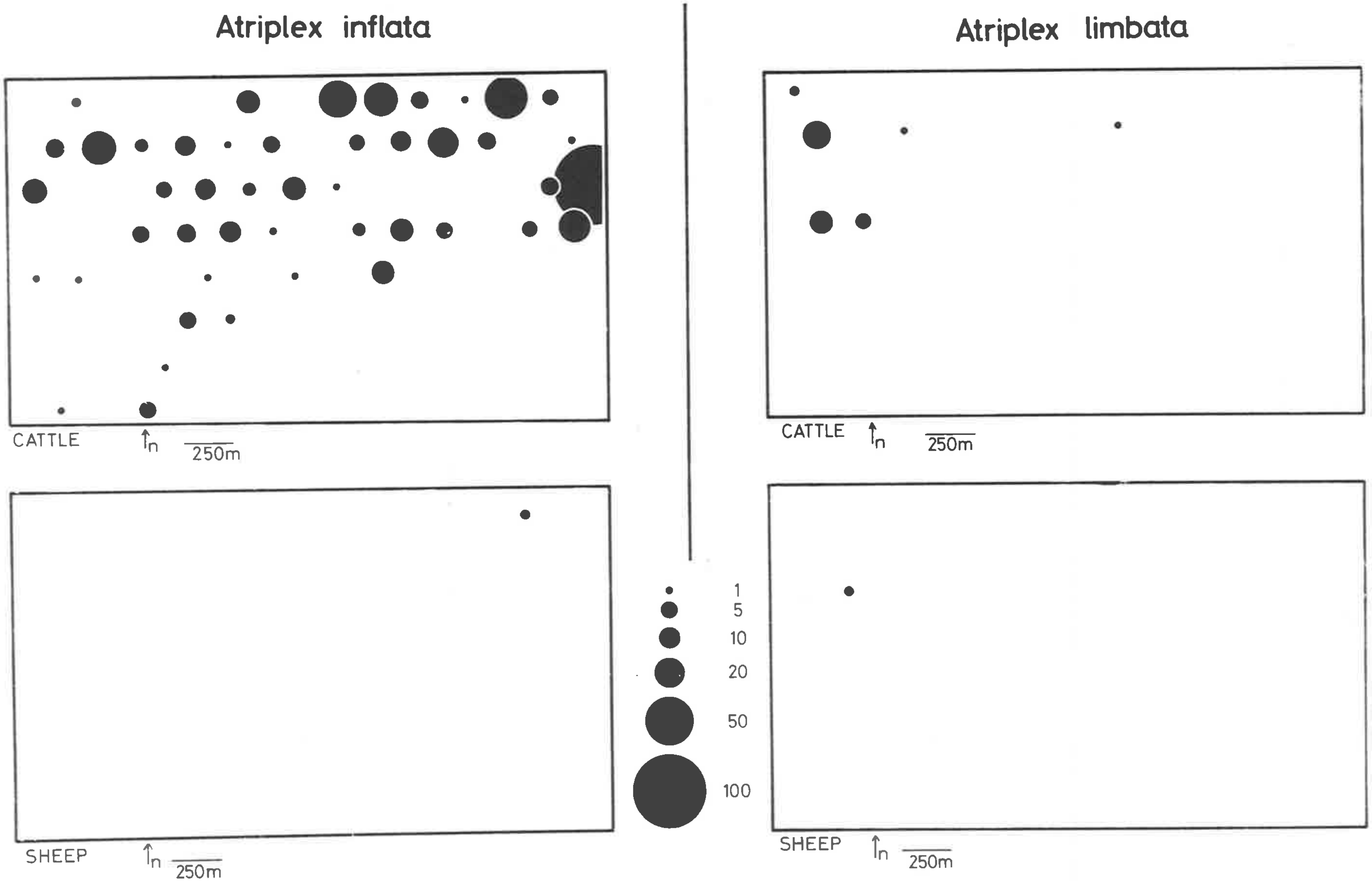


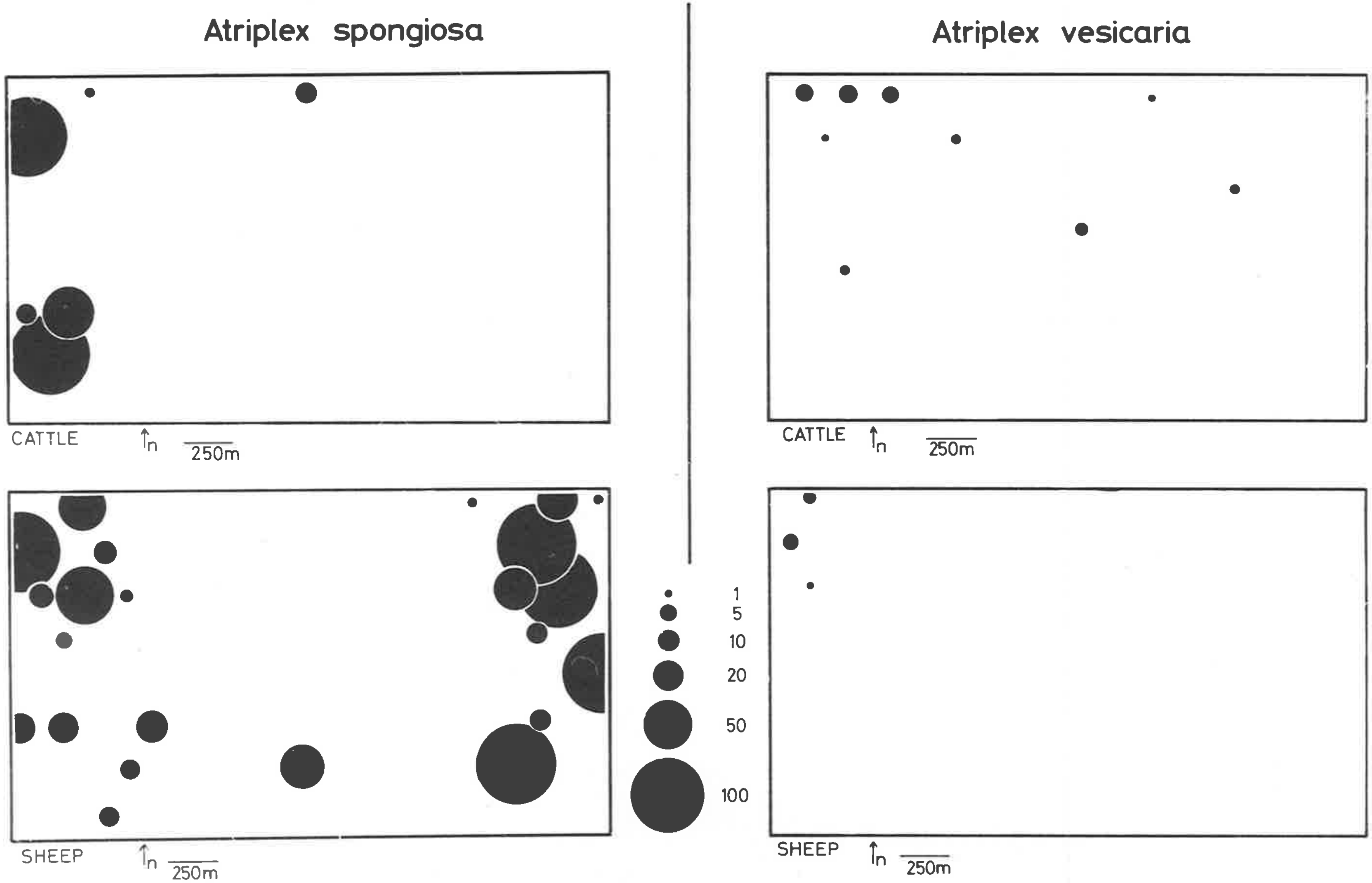
Abutilon otocarpum | *Aizoon quadrifidum*

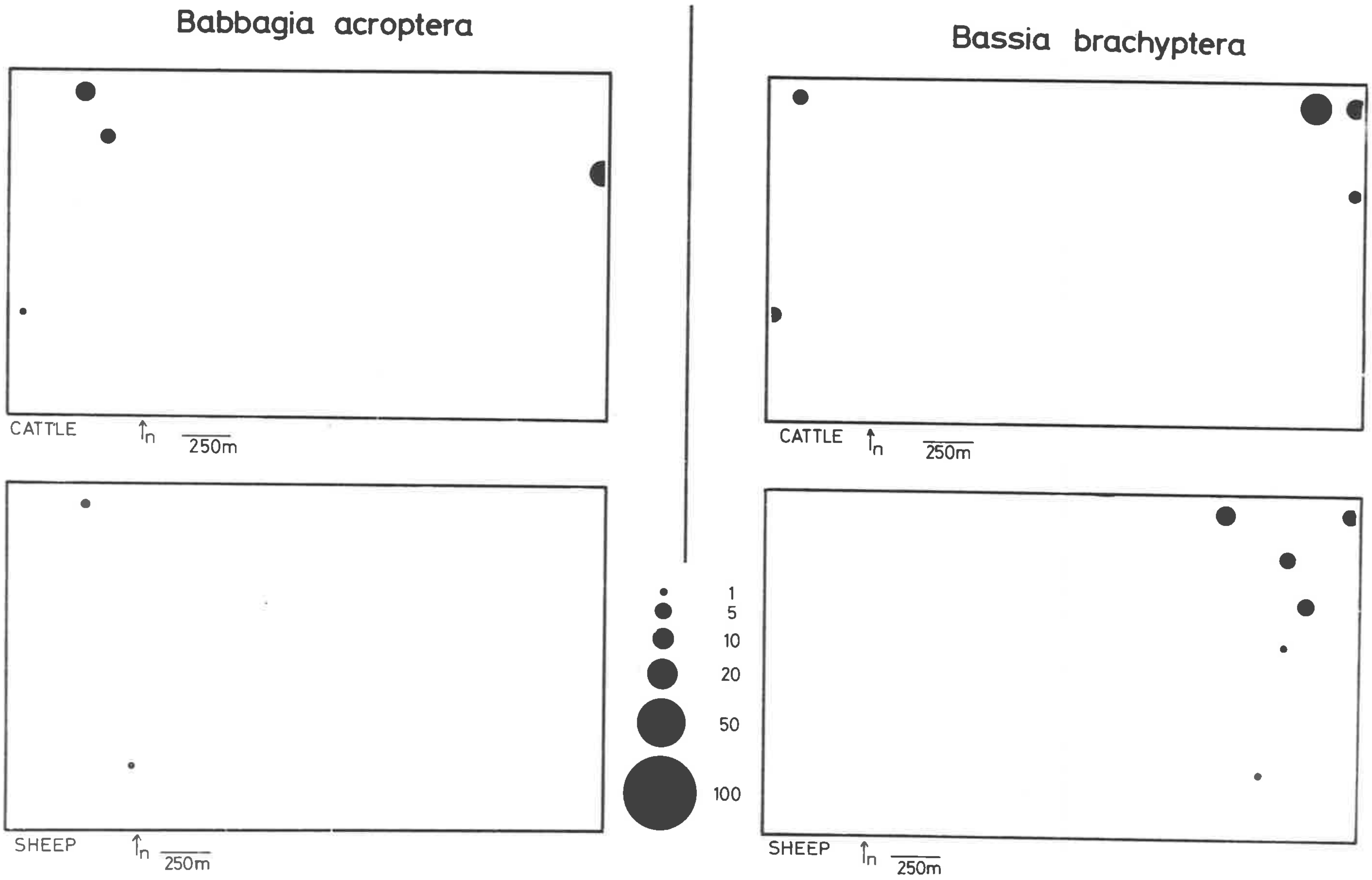


Atriplex inflata

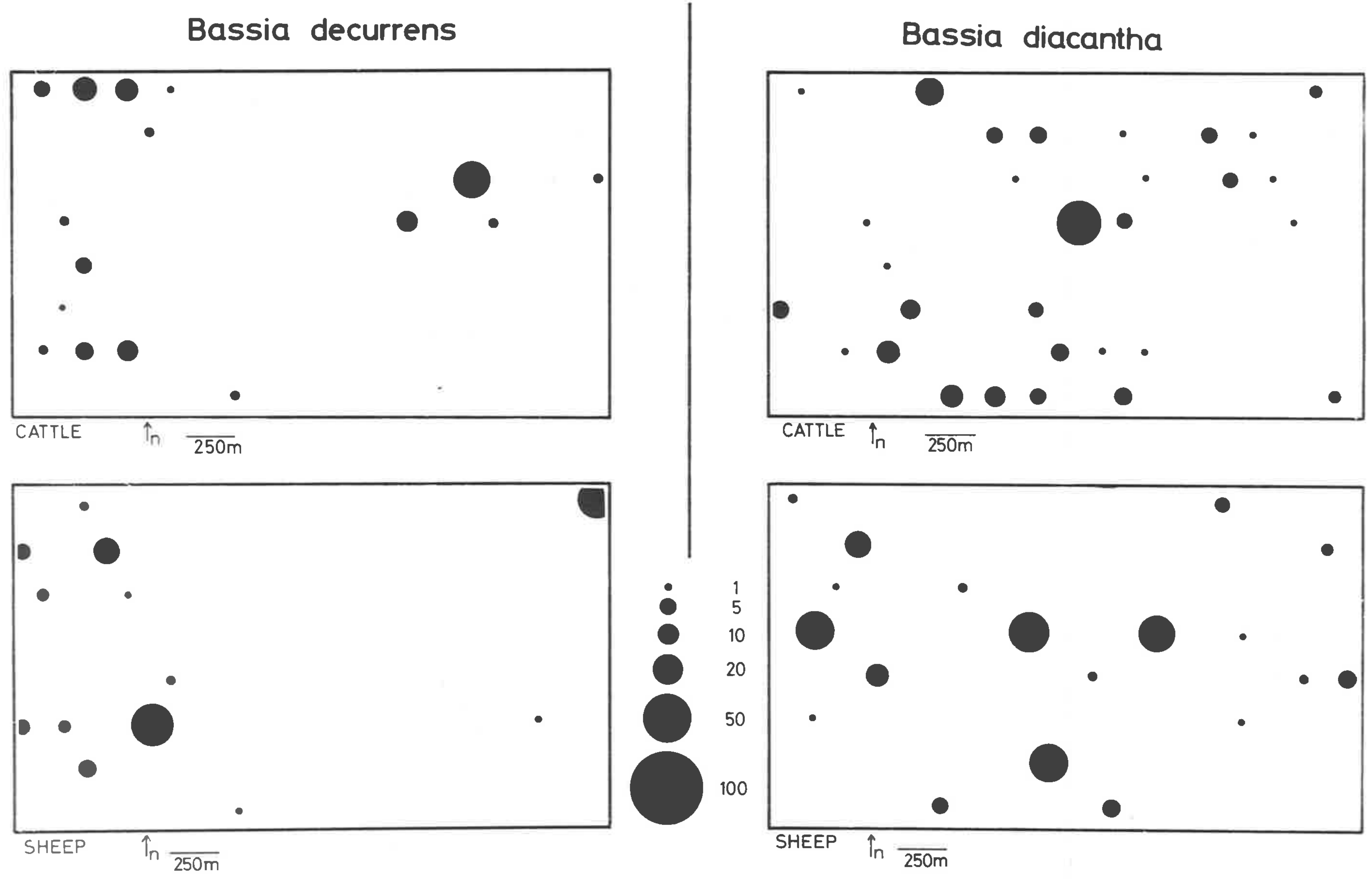
Atriplex limbata



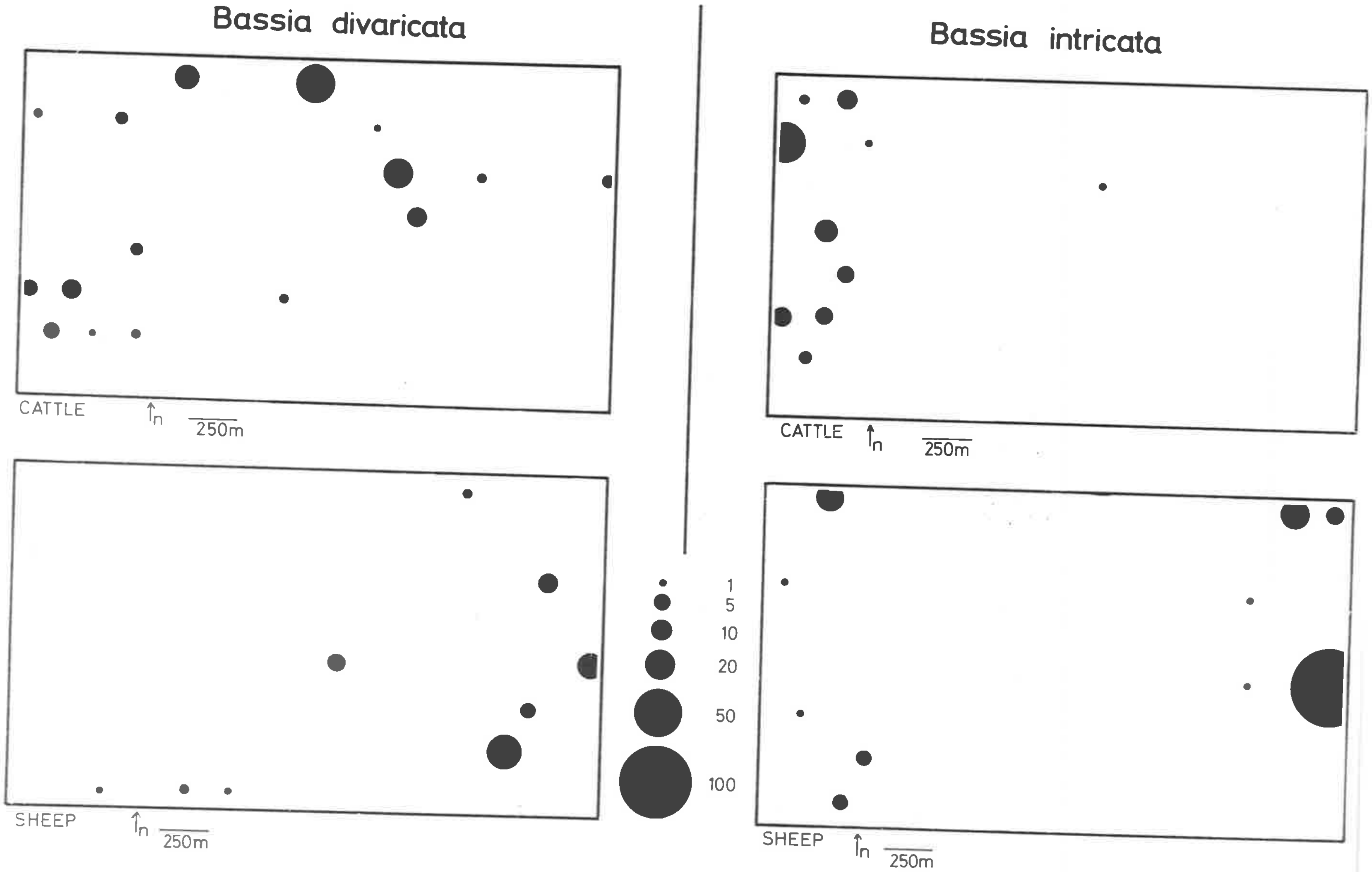

Atriplex spongiosa
Atriplex vesicaria
CATTLE
n
250m
SHEEP
1
5
10
20
50
100



Babbagia acroptera
Bassia brachyptera
CATTLE
n
250m
CATTLE
n
250m
SHEEP
n
250m
SHEEP
n
250m
1
5
10
20
50
100



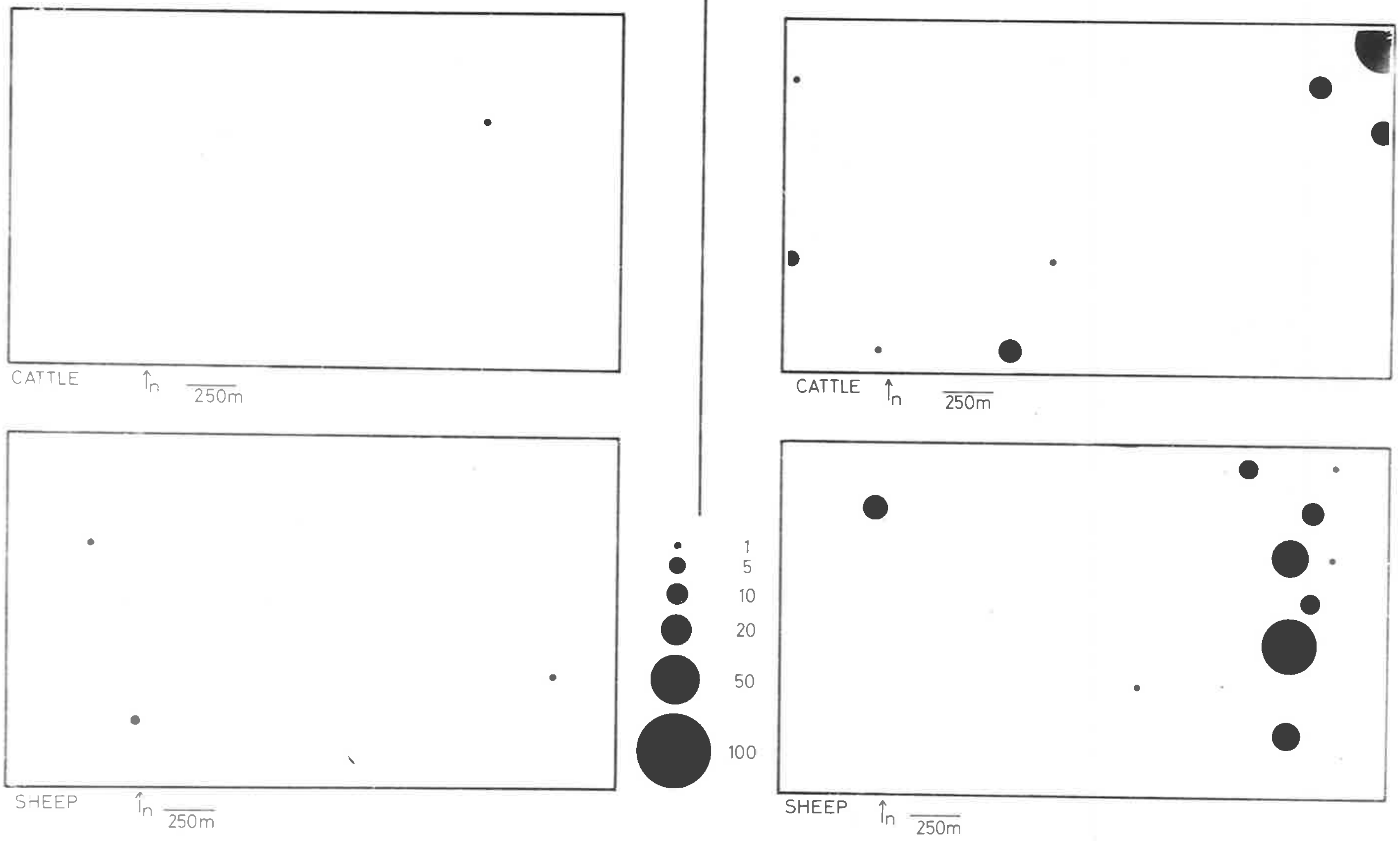
Bassia decurrens
Bassia diacantha
CATTLE
n
250m
SHEEP
1
5
10
20
50
100



Bassia divaricata
Bassia intricata
CATTLE
n
250m
SHEEP
1
5
10
20
50
100

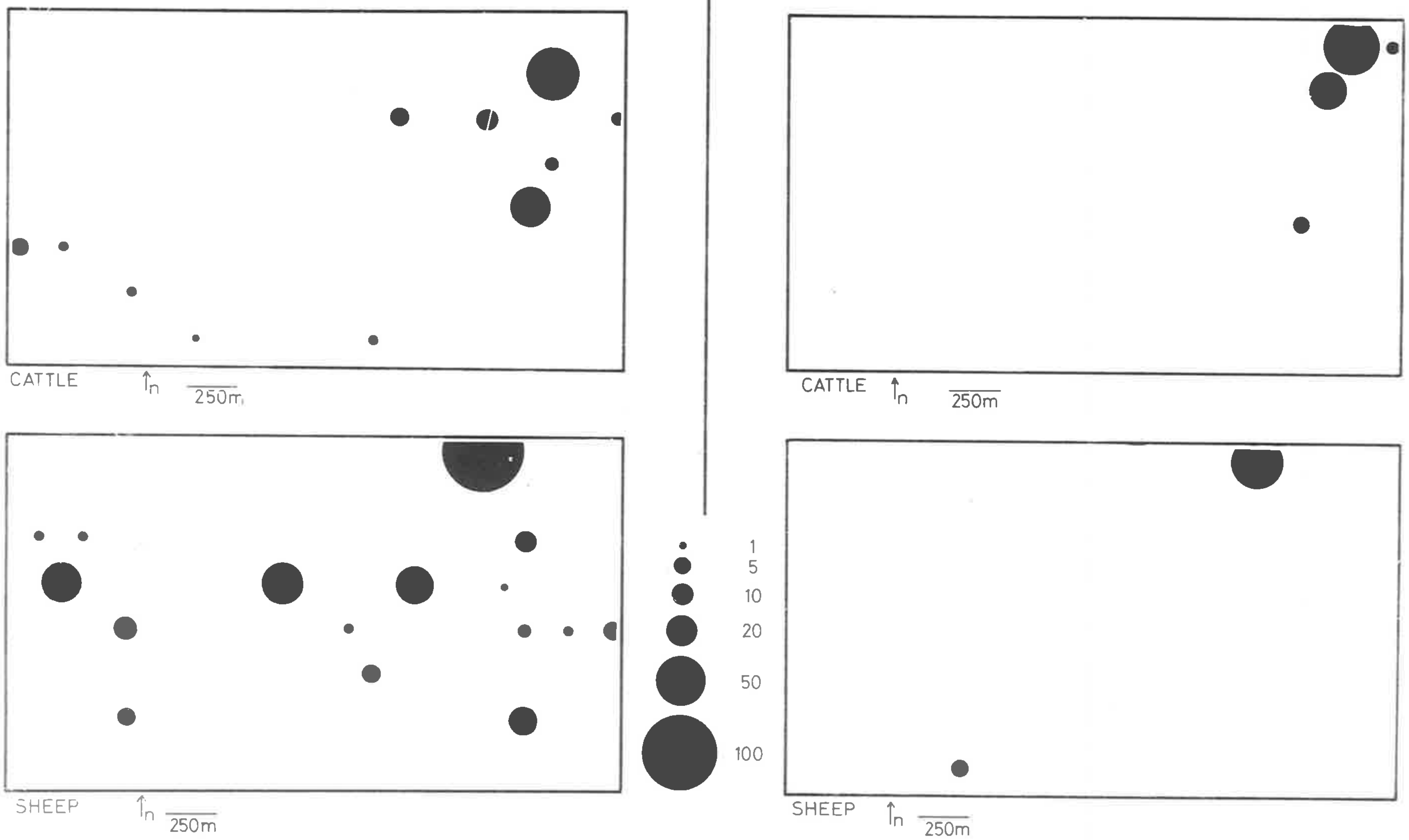
Bassia obliquicuspis

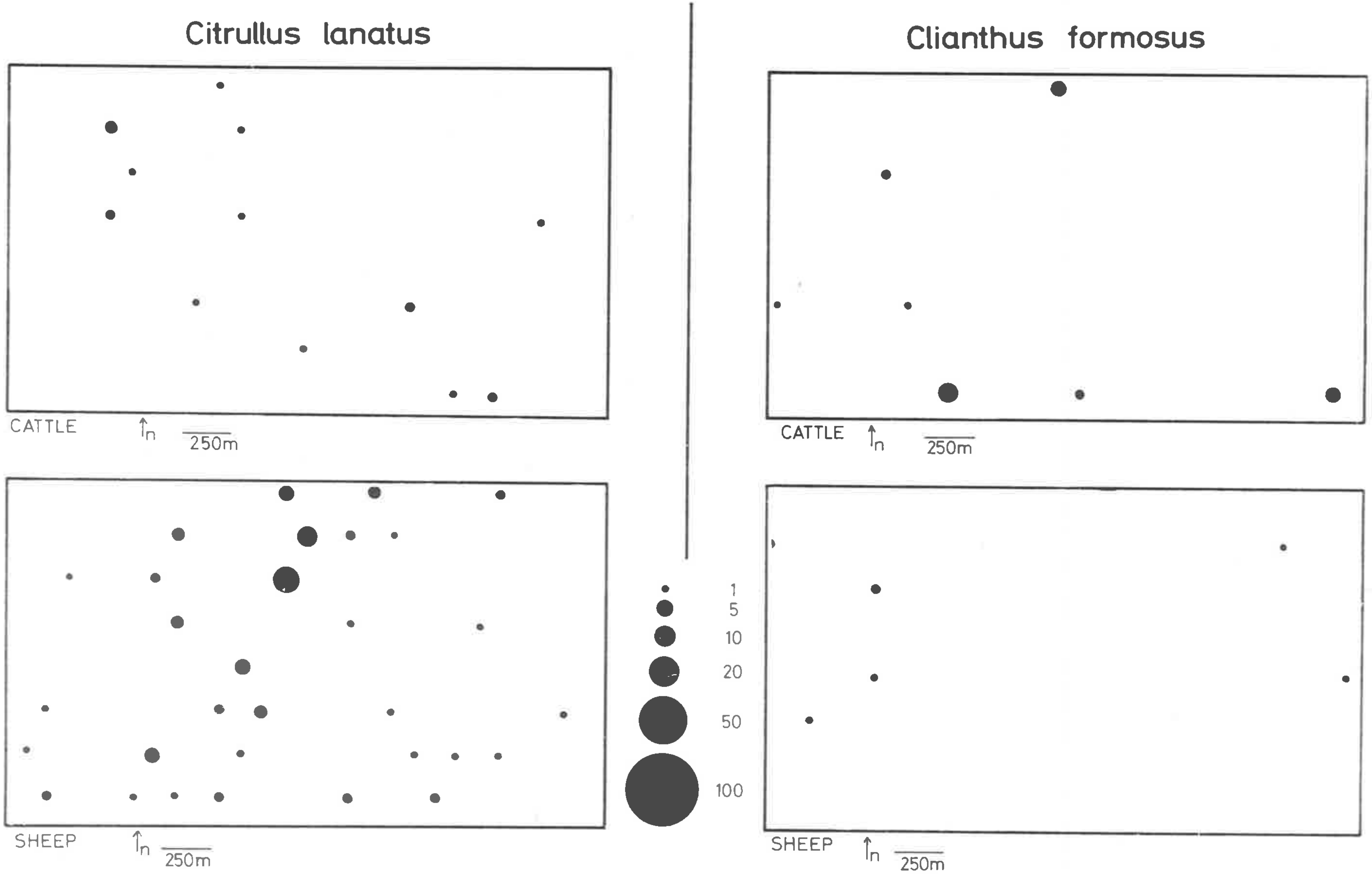
Bassia paradoxa

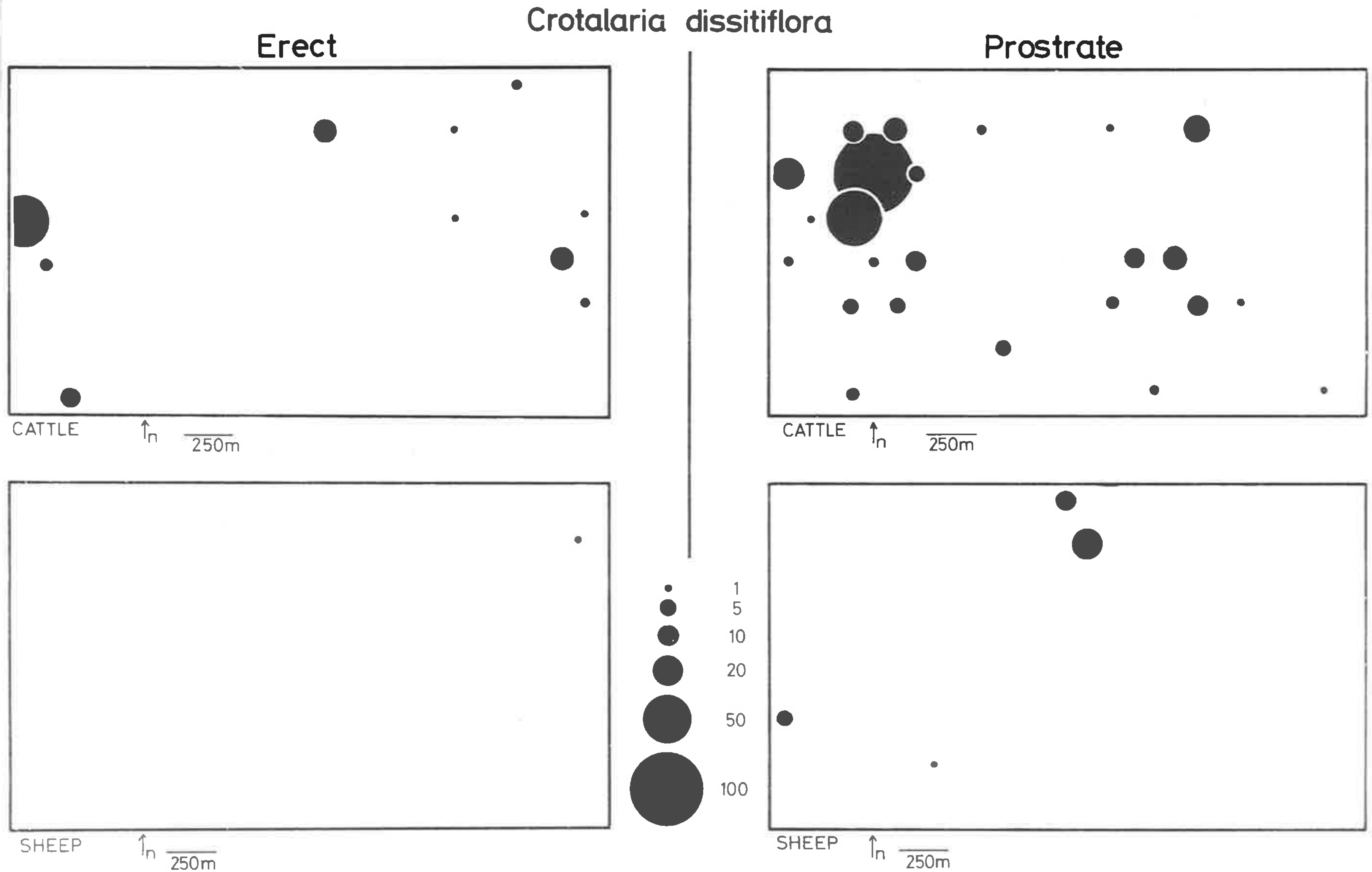


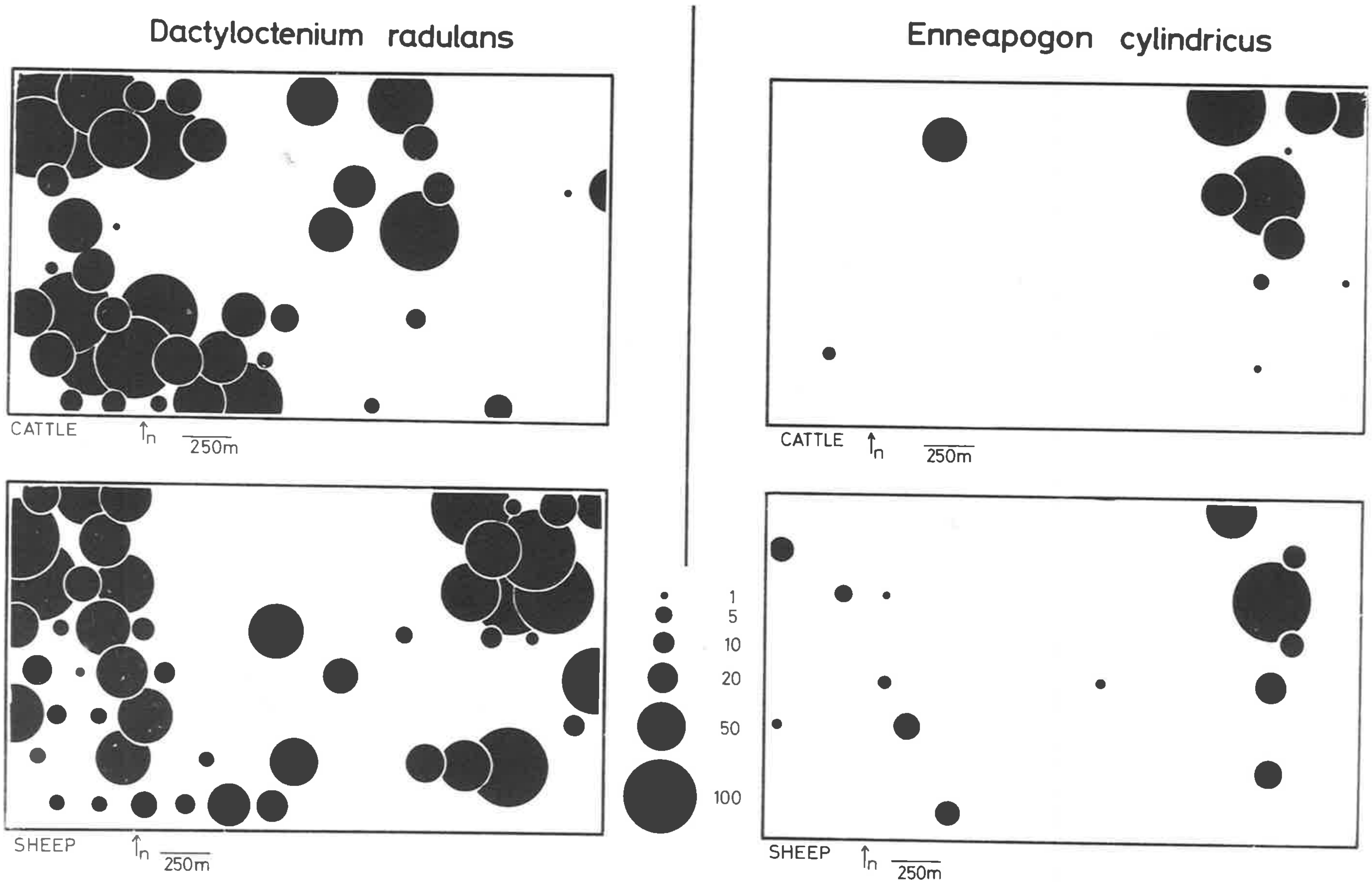
Bassia patenticuspis

Bassia sclerolaenoides




Citrullus lanatus
Clianthus formosus
CATTLE
n
250m
CATTLE
n
250m
SHEEP
n
250m
SHEEP
n
250m
1
5
10
20
50
100

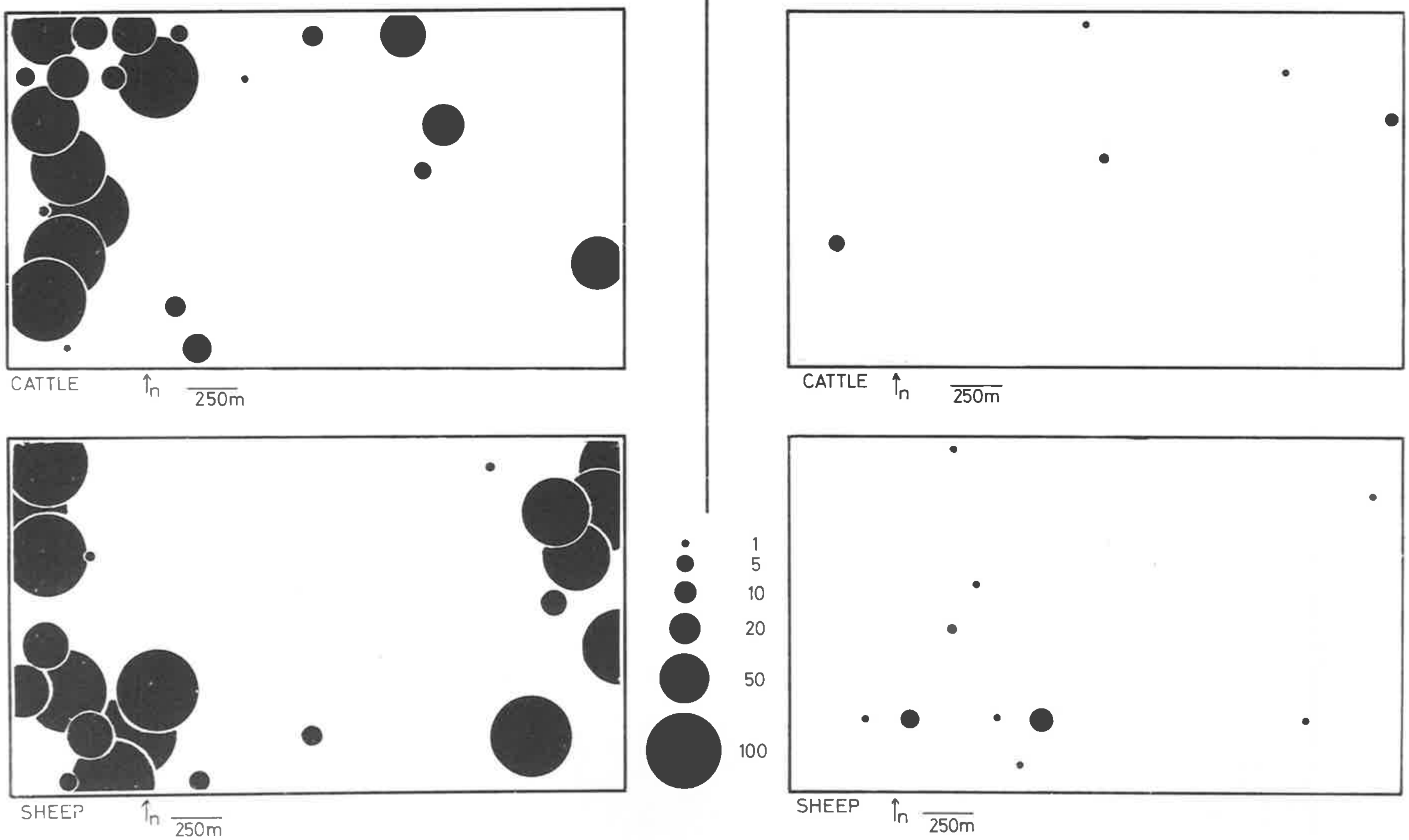

Crotalaria dissitiflora
Erect
Prostrate
CATTLE
250m
CATTLE
250m
SHEEP
250m
SHEEP
250m
1
5
10
20
50
100

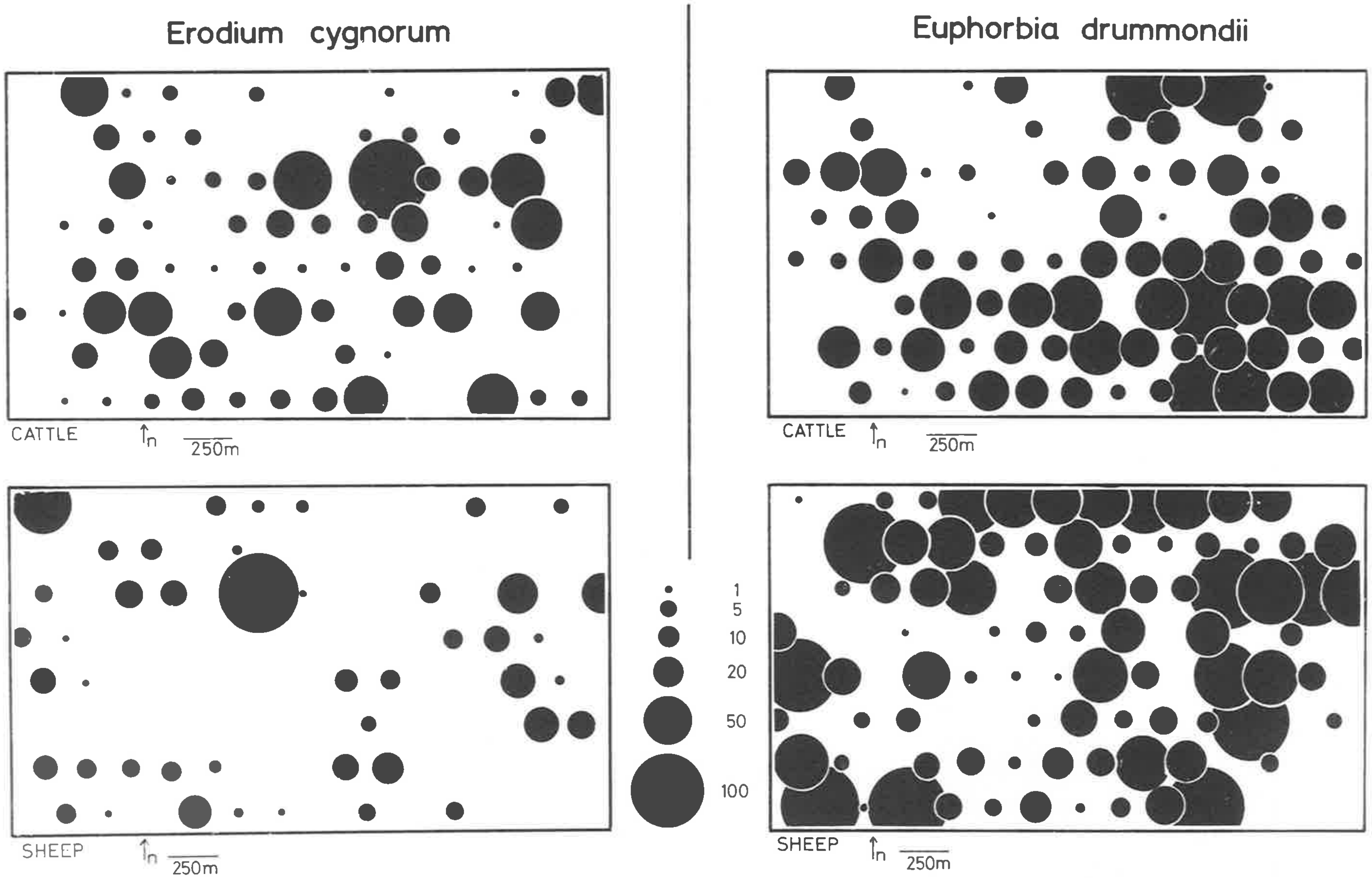


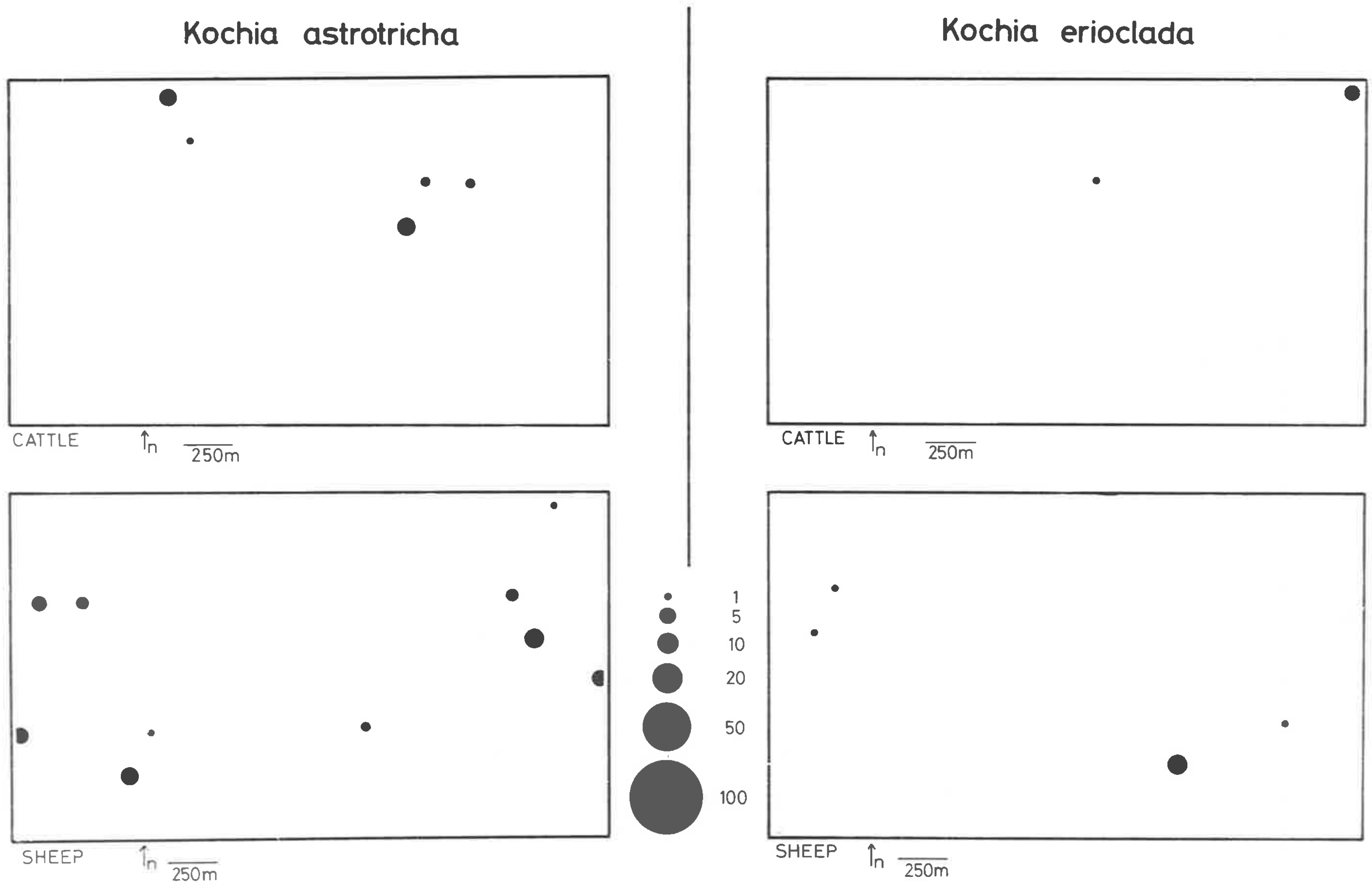
Dactyloctenium radulans
Enneapogon cylindricus
CATTLE
n
250m
CATTLE
n
250m
SHEEP
n
250m
SHEEP
n
250m
1
5
10
20
50
100

Eragrostis dielsii

Eragrostis eriopoda

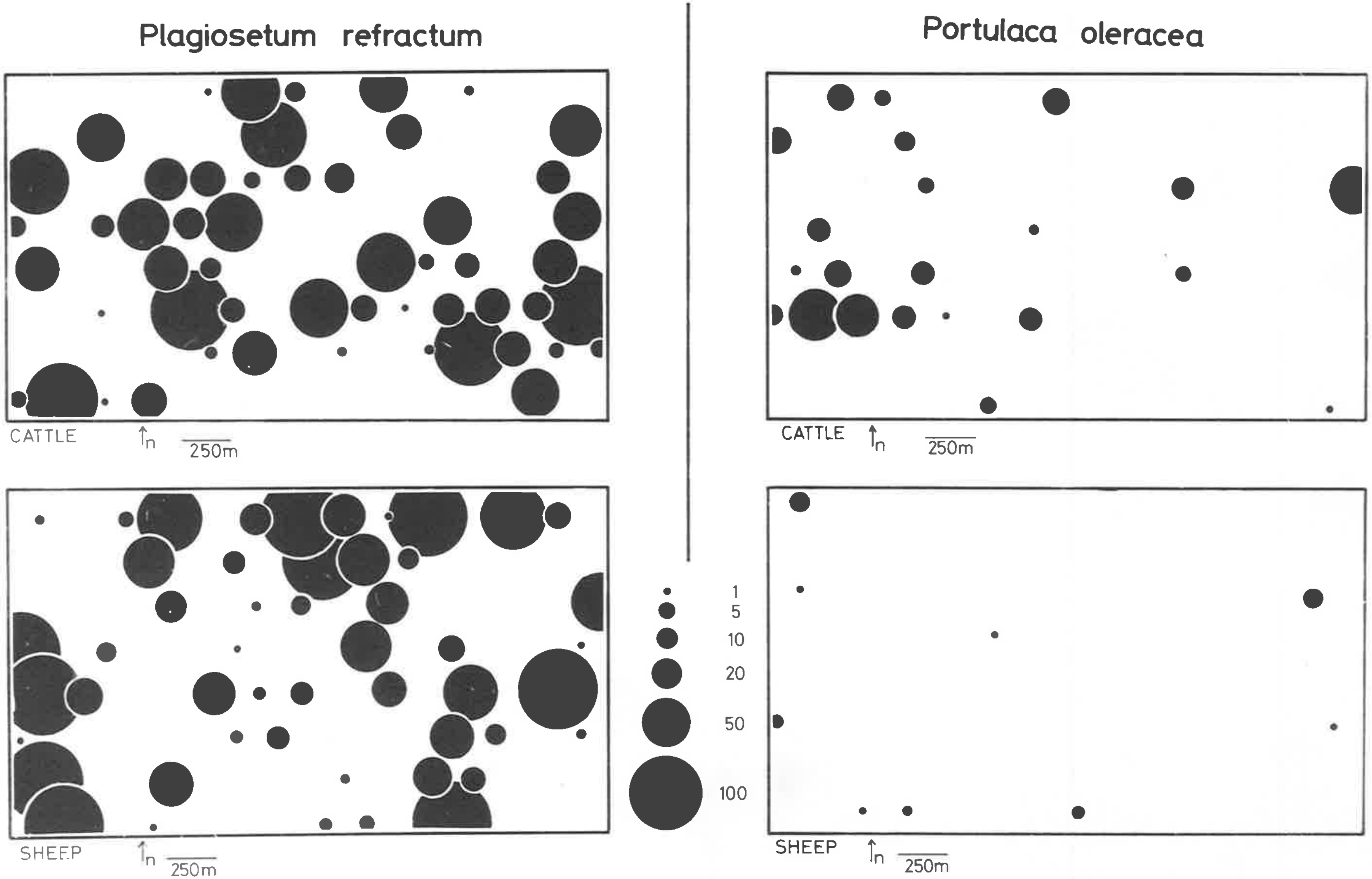


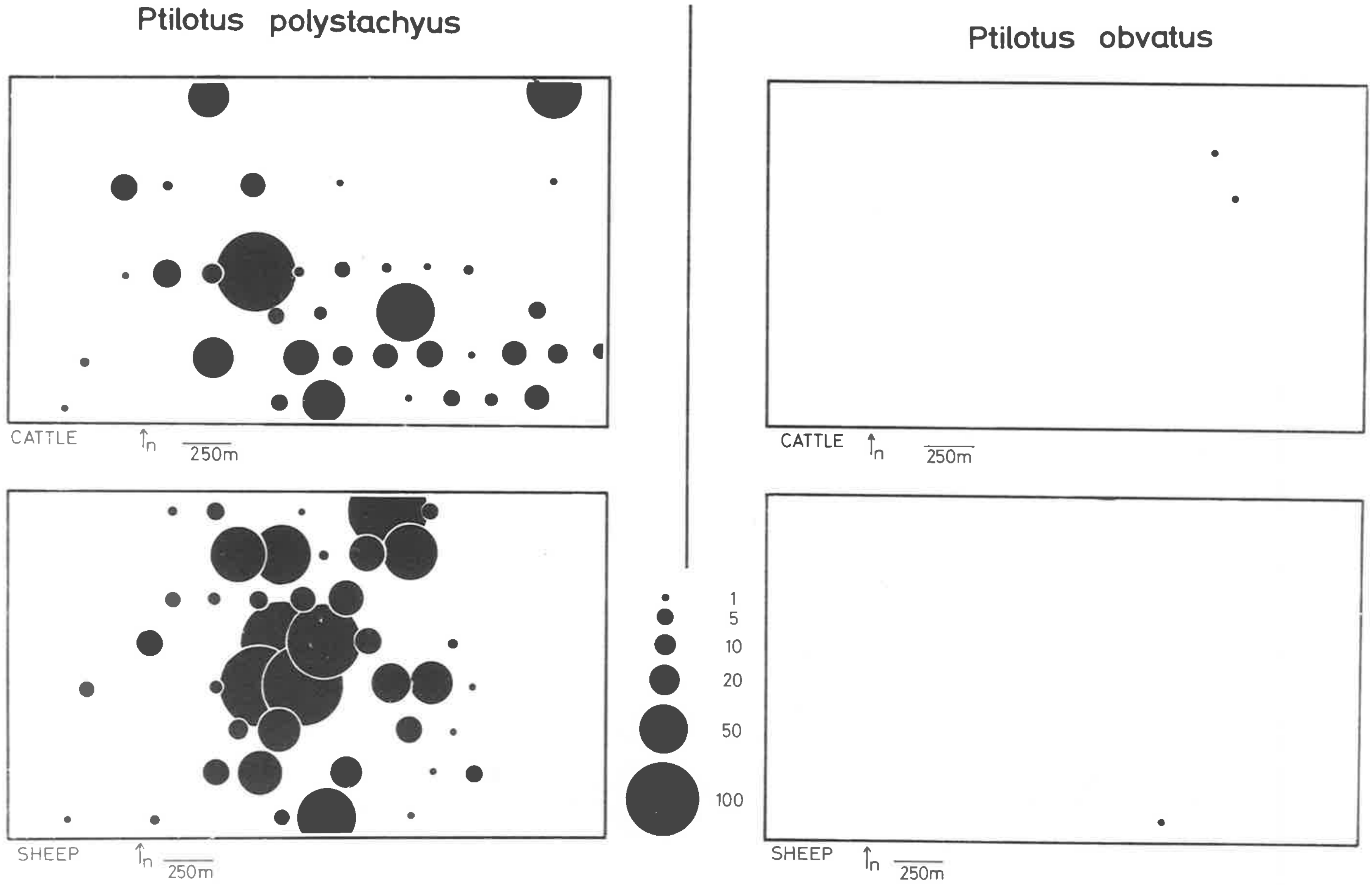

Erodium cygnorum
Euphorbia drummondii
CATTLE
n
250m
CATTLE
n
250m
SHEEP
n
250m
SHEEP
n
250m
1
5
10
20
50
100

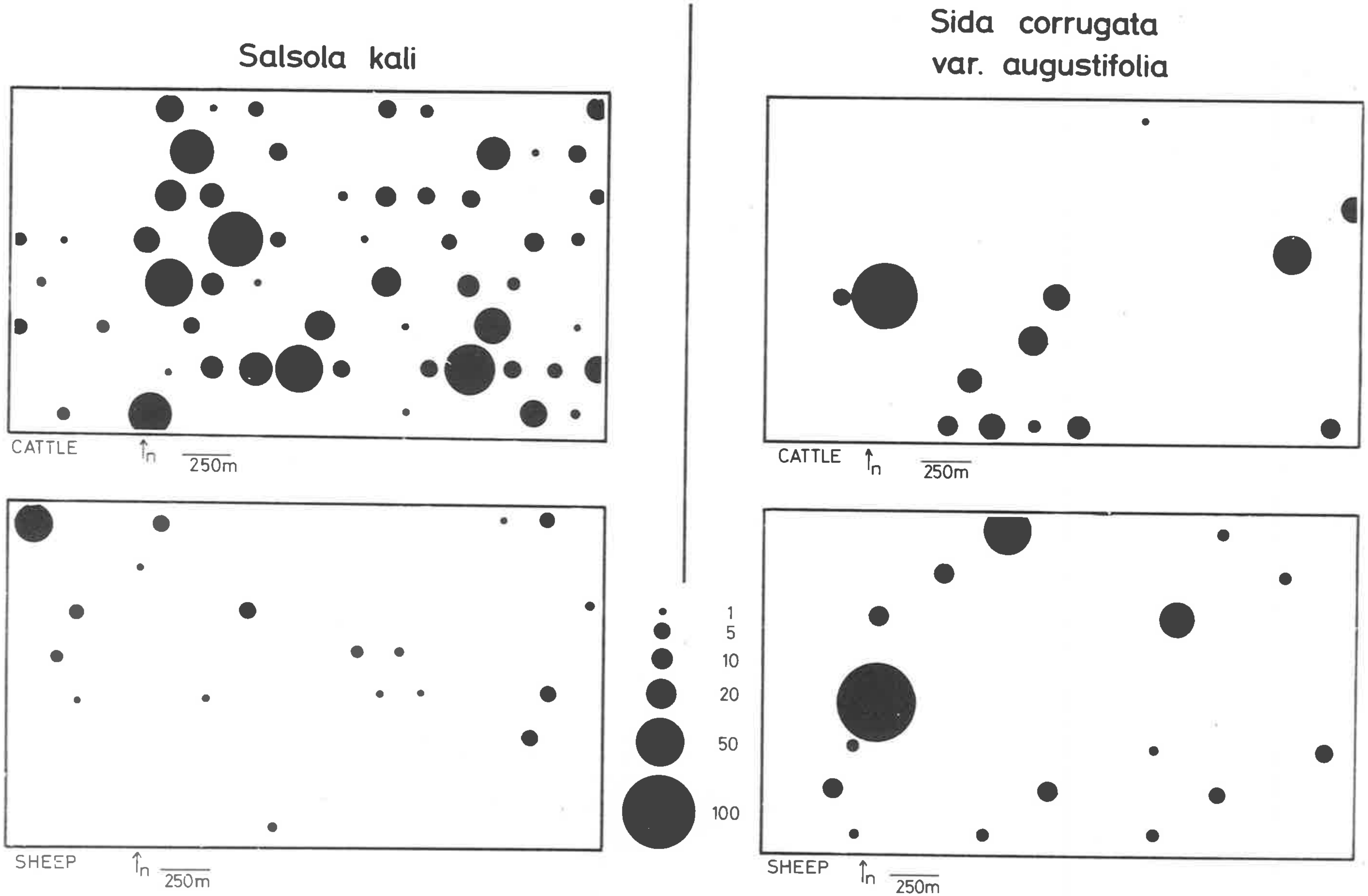


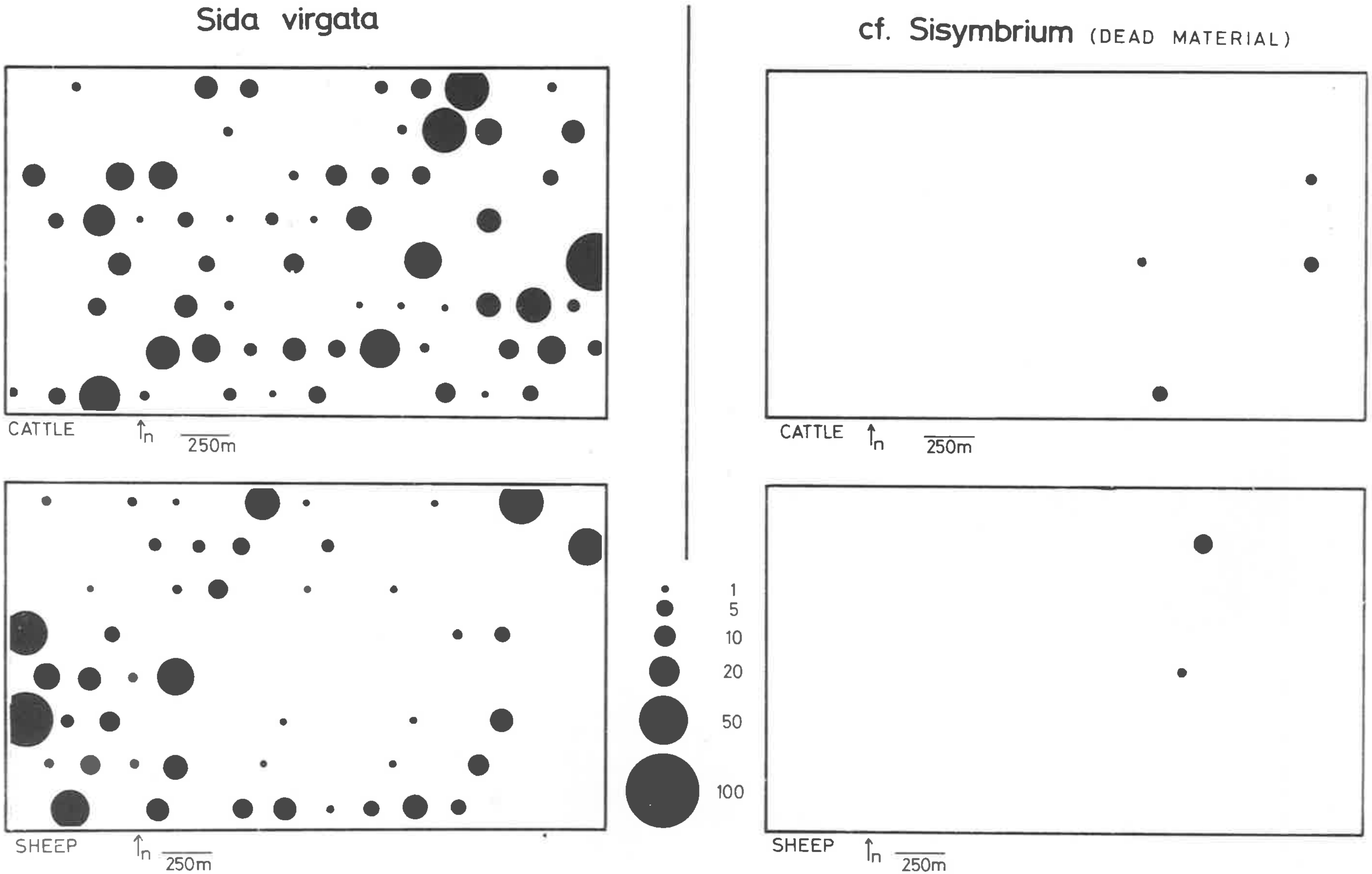
Kochia astrotricha
Kochia erioclada
CATTLE
n
250m
SHEEP
n
250m
CATTLE
n
250m
SHEEP
n
250m
1
5
10
20
50
100

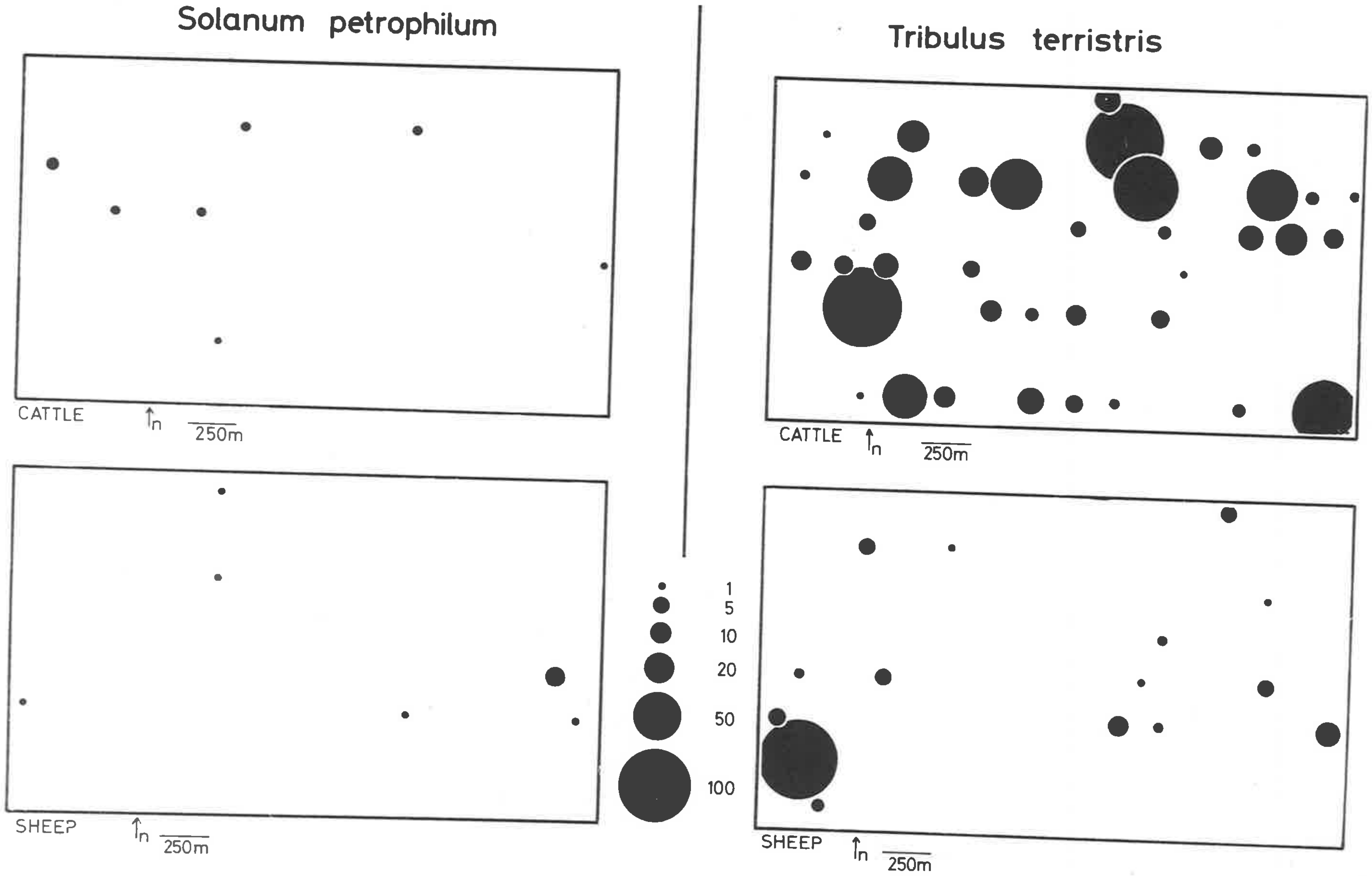
Plagiosetum refractum   Portulaca oleracea

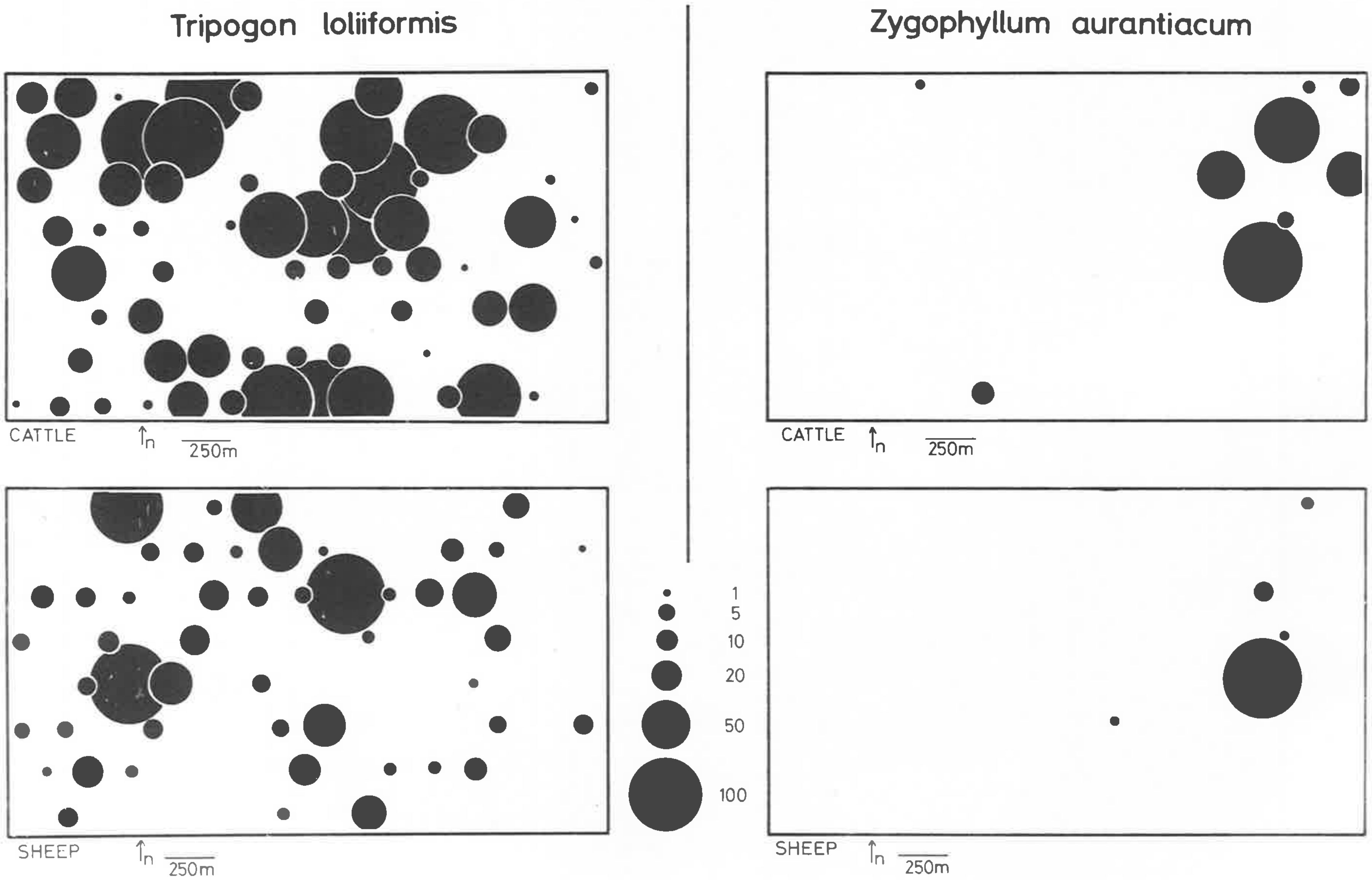



Ptilotus polystachyus
Ptilotus obvatus
CATTLE
n
250m
CATTLE
n
250m
SHEEP
n
250m
SHEEP
n
250m
1
5
10
20
50
100


Salsola kali
Sida corrugata
var. augustifolia
CATTLE
250m
CATTLE
250m
SHEEP
250m
SHEEP
250m
1
5
10
20
50
100


Sida virgata
cf. Sisymbrium (DEAD MATERIAL)
CATTLE
n
250m
CATTLE
n
250m
SHEEP
n
250m
SHEEP
n
250m
1
5
10
20
50
100


Solanum petrophilum
Tribulus terristris
CATTLE
250m
SHEEP
250m
CATTLE
250m
SHEEP
250m
1
5
10
20
50
100


Tripogon loliiformis
Zygophyllum aurantiacum
CATTLE
n
250m
CATTLE
n
250m
SHEEP
n
250m
SHEEP
n
250m
1
5
10
20
50
100