ON THE CLIMATE AND VEGETATION OF THE KOONAMORE VEGETATION RESERVE TO 1931.

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(Plates xiii–xvii; ten Text-figures.)

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1. Introduction.

The present paper gives an account of the climate and flora of a restricted area in an arid district during a six-year period, 1925–1931. The area is the Koonamore Vegetation Reserve, the Arid Flora Research Station of the University of Adelaide, which is situated about 4½ miles S.W. of Koonamore Head Station. It lies about 40 miles N. of Yunta, a small township on the Peterborough–Broken Hill Railway, in the North-East District of South Australia, at an altitude of about 650 feet.

The primary object of the Reserve is to study the growth and regeneration of the arid flora in an area protected from grazing by stock and, as far as possible, from rabbits. Since the exploitation for pastoral purposes of the arid districts of Australia a far reaching change has occurred in the biota. The effect upon the indigenous flora has been particularly great in areas of heavy sheep concentration, leading, at times, to complete extinction of the shrub-steppe community. The area chosen for the Reserve at Koonamore was deliberately picked as being "the worst eaten-out portion of the paddock". At the same time it was selected to show a variety of plant communities, including the scrub vegetation as well as the steppe flora.

On this site a long-dated experiment was planned.

The Reserve (Osborn, 1925), which comprises an area of some 1,260 acres, was enclosed by rabbit- and sheep-proof fencing in July, 1925. The lease was generously transferred to the University of Adelaide by the then owners of Koonamore, Messrs. Hamilton, Wilcox Ltd., towards the end of that year. In order to accommodate research workers, a three-roomed hut was built by the donors at the entrance to the Reserve. This hut was not ready for occupation until May, 1926, when the first quadrats were set out upon the area.

The original plan of operations involved quarterly visits to the Reserve by members of the Botanical Department, University of Adelaide. The visits were arranged for May and August, i.e. during the two short vacations, and December and March at the beginning and end of the long vacation. It was considered that a party of three or four observers could be relied upon at these times. When the first-named author transferred to Sydney at the end of 1927 the future of the Reserve seemed uncertain. However, the Council for Scientific and Industrial

Research made available a grant* until June, 1931, enabling a field officer to be placed at the Reserve (from which base other research projects in the district were also conducted; Osborn, Wood and Paltridge, 1932). The original programme of work on the Reserve has been followed, and the results of five years' regular observations are now presented. Although the experiment is by no means completed, it is felt that the results already obtained are of sufficient interest to justify their publication at this stage. The results fall under the headings, climatic data during a drought cycle, methods of study employed, general biological observations, relation of the flora to climatic conditions, and the initial stages in regeneration of the perennial flora.

The control of the Reserve has now reverted to the University of Adelaide, and regular, though less frequent, observations are being continued.

2. Description of Reserve.

The Reserve is situated on an elevated peneplain surrounded by low hills. These hills are composed of Lower Pre-Cambrian gneisses and schists overlain by Upper Pre-Cambrian deposits consisting chiefly of quartzites and mudstones, penetrated in places by pegmatite dykes.

The soils of the plains are derived from these rocks during an arid cycle of erosion. The chief agencies are water, during flood times, leading to a deposit of silt, and wind, leading to the formation of more or less consolidated sand dunes. As a result of the interaction of these two agencies considerable variation in the soil may occur even in a small area, for such factors as the activity of watercourses and change in their beds have influenced the soil type considerably.

Reference to the sketch map (Text-fig. 1) will show that the Reserve has an undulating surface. It consists of a complex system of low sandhills alternating with harder soil on the intervening flats. These flats are a silty loam and subject to flooding in the centre and about the middle of the western side. Elsewhere they are of hard but coarser loam mingled with a good deal of nodular travertine limestone. On this latter soil type is developed the dwarf Chenopodiaceous shrub-steppe.

At the time of its enclosure practically all the original perennial flora other than the trees and tall shrubs had been destroyed. During a preliminary visit by one of us in August, 1925, possible sites for quadrats were located from the nature of the terrain and from the vestiges of the salt and blue bushes whose regeneration it was desired to study. These were the ten quadrats which have been charted regularly throughout the five years' work covered by this paper. Their location and relation to vegetation types is seen from Text-figure 1.

3. Soils.

Four main soil types, or, more accurately, soil groups, have been recognized. These are the soils of the sandhills, the sand-plains, the silty flats, and the shrub-steppes.

These soils belong to Glinka's ectodynamorphic division and to his fourth group, viz., soils formed under insufficient moisture conditions. Soil analyses were given in our paper on *Stipa* (1931) and are not repeated here.

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* My thanks are due to the Council for Scientific and Industrial Research for the generous grant which enabled the Koonamore investigations to be carried on upon an extended scale after my departure from Adelaide. I am also much indebted to the Council of the University of Adelaide for allowing me facilities for continued work at Koonamore after my appointment to Sydney.—T.G.B.O.

A. *The Sandhill Soils.*

The sandhills cannot be regarded as forming a soil in the true sense of the word. Glinka states, "In deserts an energetic mechanical disintegration of rocks takes place producing a fine grained mass of earthy material which does not constitute a soil. The strong winds which predominate in desert regions blow the greater portion of this fine grained material out of the desert into its borderland, leaving only coarser material behind. This consists of sand, gravel and stone fragments, and in places rocky ledges."

The sandhills in the north-east of South Australia are derived from two sources: from the denudation of the Pre-Cambrian hills in the south and from the denudation of the Cretaceous peneplain in the north. The sands, whether river-borne or wind-borne, drift here and there by the action of the winds, frequently forming ridges, usually with an east-west trend and generally separated from each other by clay pans. In other cases ridge formation occurs more rarely and a sand plain is formed in which the sand covers silty or travertine limestone soils.

In the sandhills the profile shows no change to a depth of 6 feet, and consists of a uniform buff-coloured coarse sand. These sandhills carry typically Mulga (*Acacia aneura*), Wattle (*Acacia Burkittii*), and Turpentine (*Eremophila Sturtii*), with *Stipa nitida* and other shorter-lived annuals as a ground cover.

On the sand-plains these species also occur, but other species are commonly present, depending on the depths of sand and the nature of the underlying soil.

The remaining soil groups show the characteristic features of dry steppe soils in that the humus horizon of these soils (when one is recognizable at all) has no definite level. When present it is seen only in a thin layer on the surface. The carbonates of the alkaline earths, chiefly calcium carbonate and gypsum, are universal constituents of the profile of the loamy varieties, but the horizons in which they accumulate lie nearer to the surface as a rule than in soils of the Tschernosem group. Chlorides and sulphates have usually disappeared from the upper horizons.

Of these soil types, two have immature profiles—the silty soils and sand-plain soils—whilst the other, the saltbush soil, shows a mature profile.

B. *Sand-plain Soil Group.*

The sand-plain soils vary in profile according to the (presumed) age of the soil and the nature of the material underlying the surface sand.

Characteristic features of the country adjacent to and inside the Reserve are monospecific communities of black oak (*Casuarina lepidophloia*), with *Bassia uniflora* as the accompanying undershrub. The soil profile in this society shows coarse sand to a depth of 5 feet, with layers of gypsum appearing first at a depth of about 3 feet. Frequently, owing to changes in the course of creeks or watercourses, finer soil material may be deposited on the sand and in this layer travertine limestone nodules and ironstone nodules may occur. When this is the case, other shrubs, and particularly *Kochia sedifolia*, may be present. A typical profile in Black Oak Creek, about half a mile south of the Reserve, illustrates this.

0-2 feet silty loam with little nodular travertine limestone, chocolate coloured.
2-8 feet sandy loam with river gravels.
8-11 feet hard red clay with ironstone nodules.

The country around this carries *Casuarina lepidophloia*, *Bassia uniflora* and *Kochia sedifolia*. In this soil the roots of *Casuarina lepidophloia* extend horizontally for some distance in the sandy loam and then run vertically into the clay.

Further south in the same river a more mature profile is seen, but showing a more varied history, which illustrates changes in river course and silt deposition. The profile is as follows:

0″-6″	silty loam, no limestone.
6″-2′ 6″	solid limestone crust.
2′ 6″-8′	sand-silt matrix with clay pockets and little lateritic ironstone.
8′-10′	red clay with ironstone.
10′-11′	sand with river gravels.
11′-15′	red clay.

Throughout this profile gypsum bands are developed at intervals from 4–15 feet.

This soil carries *Casuarina lepidophloia*, and in addition shrubs such as *Heterodendron oleaefolium*, *Pholidia scoparia*, *Cassia Sturtii*, *Cassia eremophila* and *Kochia sedifolia*.

Frequently over these soils sand of aeolian origin is found to various depths. On such areas mulga (*Acacia aneura*) is found.

The occurrence of bluebush (*Kochia sedifolia*) is bound up with the presence of limestone in the upper horizon and is probably correlated with the high lime content found in its ash (Wood, 1925).

C. *Silty Soil Type.*

The silty soils are found chiefly in the flood plains of water courses and in local depressions in which water accumulates and lies for some time. The silty layer is often of considerable depth (more than 5 ft.) and shows some signs of maturity in the accumulation of clay in lenticular pockets throughout the matrix in the B horizon. The matrix itself is buff-coloured and the pockets chocolate-brown.

These flats, after rain, carry a wealth of ephemeral plants. Permanent plants are few, the chief being the trees *Heterodendron oleaefolium* and *Eremophila longifolia*, *Myoporum platycarpum*. The shrubs *Pholidia scoparia* and *Cassia Sturtii* occur in the drier portions. Soils such as the above have a considerable amount of sand and do not crack on drying as do some of the silty-clay soils around freshwater lakes in the district.

D. *Shrub-Steppe Group.*

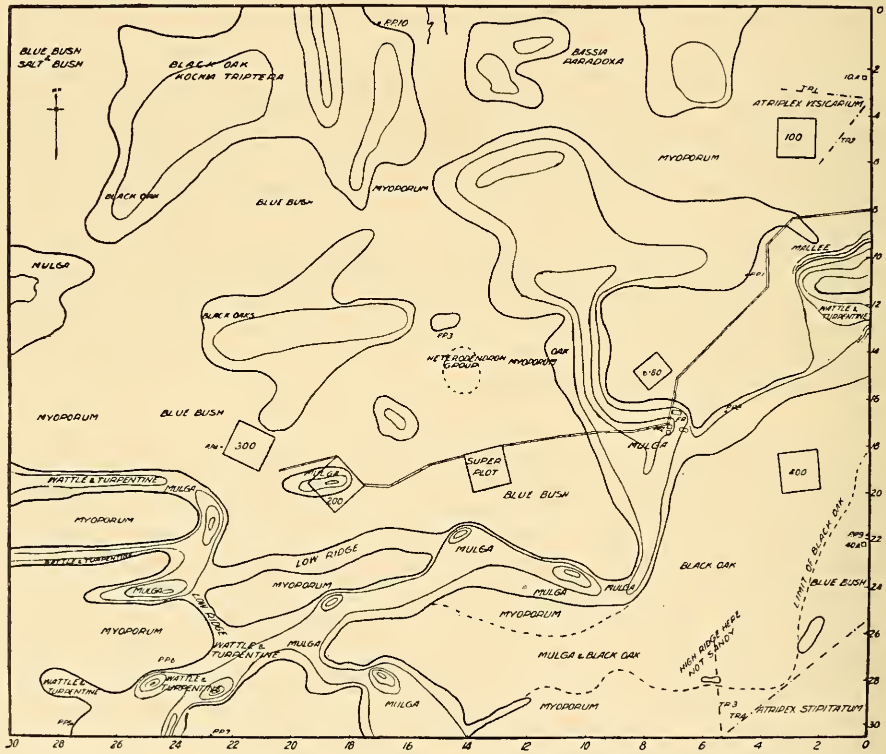
The soils belonging to the shrub-steppe group are typical of the more elevated plains and contain large quantities of limestone in the B horizon and are closely allied to the mallee soils of the wetter areas. These soils carry a shrubland of saltbush (*Atriplex vesicarium*) or bluebushes (*Kochia* spp.). The considerable amount of silt that is always associated with the sand seems to indicate that the soils were deposited on the flood plains of more ancient and extensive river systems of arid Australia. The plains are now above the level of the present watercourses and in their soils the travertine limestone has developed later. A typical profile and analysis of this soil type was given by us (1931, p. 308).

In these shrub-steppe soils the solid limestone crust is not a constant feature, the fraction with large limestone nodules giving place at greater depths to the smaller densely-packed nodules.

The vegetation on this soil type within the 10-inch isohyet is characteristically a Chenopodiaceous shrubland, but it may be modified in two ways. First, by the deposition of silt over the surface, such as occurs in times of flood and near hills and in such cases *Myoporum platycarpum*, *Cassia Sturtii*, *Pholidia scoparia* and *Heterodendron oleaefolium* are found occasionally scattered throughout the shrubland. And secondly, when a layer of sand is formed by drift over the surface, trees such as the Mulga and shrubs may be present along with the saltbushes and bluebushes.

Chemical analyses of the upper horizon of these soils have already been published (Osborn and Wood, 1923, and Wood, 1925). The percentage of soluble salts is low, usually about 0·10%, the pH averages 7·70 and the water at saturation about 38%.

It must be emphasized that although certain species are restricted to definite soil types, as for example *Kochia sedifolia*, the major factor determining distribution is *the water relations of the soil* rather than soil profile. The mulga (*Acacia aneura*) tends to dominance on both the rocky soils of the hills, also in the sandhills—both situations in which water tends to be conserved. Sandal-wood (*Myoporum platycarpum*), *Eremophila scoparia*, and *Heterodendron oleaefolium*, plants of the mallee districts, extend into the arid regions on soils of similar type in which moisture has been conserved by a sandy-silt mulch deeper than that found in the more typical shrub-steppe or mallee area itself.



Text-fig. 1.—Sketch map of the Koonamore Vegetation Reserve based on a prismatic compass survey. The form lines represent approximately 10-foot intervals. The heavier first form line is also a boundary between the sandy and loamy soil types. The position of the quadrat systems and transect lines within the Reserve is shown, also the various permanent photograph points (P.P.). The main vegetation types are indicated on the map. Scale, 1 inch = 500 metres. J.G.W. *fecit*.

Kochia sedifolia and *Atriplex vesicarium* are the character plants on a soil which is incapable of supporting any but an extremely drought-resistant vegetation. *Kochia sedifolia* has a deep root system and apparently a need for limestone in the soil. *Atriplex vesicarium*, on the other hand, has a shallow root system; it is able to absorb water through its leaves from an atmosphere of 85% saturation and shows great resistance to drought, when it becomes defoliated (Osborn, Wood and Paltridge, 1932). *Atriplex vesicarium*, however, because of its drought resistance, is not confined to one soil type but occurs also on the Red Earth soils towards Lake Frome, around claypans in the sandhill regions north of Koonamore and in some cases on more gentle hill slopes.

At the two extremes stand the shrub-steppe communities on the arid mature soil and the desert scrub on hills and sandhills with better water relations, but transitions between the two are common and overlapping of the two communities occurs. It will be seen from the map (Text-fig. 1) that the area selected for the Koonamore Vegetation Reserve is such a junction region.

4. Meteorological Data.

Complete meteorological records have been kept at the laboratory at Koonamore from July, 1928, to June, 1931, and these records have been utilized in the main for this section. The rainfall records of Koonamore Head Station are available for a longer period and have been obtained from the Commonwealth Bureau of Meteorology. The 1928–1931 records are given in detail, not only because the integration of all these factors is expressed in the growth of the plants, but also because certain of these records, and particularly temperature and humidity, have not hitherto been available for the north-east of South Australia.

The temperature and humidity instruments were housed in a standard Stevenson screen. All thermometers were tested by the National Physical Laboratory, Kew. Humidity records were obtained by means of an Edney thermo-hygrograph, and this was checked each morning at 9 o'clock by standard wet and dry bulb thermometers. Terrestrial radiation data were obtained by means of a standard thermometer placed in the open 2 inches above ground-level.

A. *Rainfall.*

The mean annual rainfall at Koonamore Head Stations, 4½ miles distant from the Vegetation Reserve, for a period of 27 years, is 8·12 inches, and in its distribution is fairly even throughout the year, 53% falling in the cold period from April to September, and 47% in the hot period from October to March. There is a tendency towards a winter maximum in May to September when the greatest number of rainy days are experienced. This is a reflection of the South Western Antarctic control experienced in Southern Australia.

It has been pointed out previously by Cannon (1921), Osborn and Wood (1923), and Osborn (1925) that the total rainfall in arid Australia does not give a true index of the amount of water available to plants, since light falls do not penetrate the ground to an extent sufficient to reach the roots of plants. Such rain is termed "ineffective", and Cannon (1921) considered 15 points of rain to be the minimum effective rainfall falling at one time during a dry period. Our observations, extending through one of the worst droughts in the history of South Australia, have shown that his figure is too low, and we consider 25 points to be the minimum amount of rain that is effective during a dry period. Lighter falls than this barely penetrate the surface mulch, although it must be realized that smaller falls are effective following rainy periods. In Table 1 are given the mean monthly rainfall figures in inches over a period of 27 years, and also the mean number of rainy days in each month and the mean number of days in which falls greater than 25 points were recorded. The two last are derived from 15 years' records.

TABLE 1.

Table showing mean rainfall figures based on records for 27 years, also mean number of rainy days and falls over 25 points.

Rainfall figures in points (100 points = 1 inch.)

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
Mean rainfall	70	45	61	64	93	108	46	63	58	81	64	59	812
Rainy days	2·0	2·2	1·1	1·4	3·6	3·6	3·9	3·8	3·4	2·4	2·5	2·7	32·5
Falls > 25 points ..	0·9	0·8	0·5	0·7	1·0	1·3	0·8	0·7	1·2	0·7	0·7	0·9	10·2

It is evident from these figures that the amount of rainfall is low, and approximately only one-third of it is of the effective type, and further, that this ratio holds also for each month in the year.

The region is characterized by much sunshine. In 1929, a drought year, records taken on 180 days recorded only 21 completely cloudy days, i.e., 12% of the total. In 1930, a rainy year, records taken on 187 days recorded 34 completely cloudy days or 19% of the total.

Droughts covering more or less extended periods are of frequent occurrence in arid Australia, and the rainfall data during the five years in which observations have been made on the Reserve and including the previous year are shown in Table 2. This table includes one of the worst drought periods experienced in this portion of South Australia.

In all these years the rainfall has been below the average, as has also the "effective rainfall". Over the 15 months from August, 1928, to October, 1929, only 1·76 inches of rain were recorded, and over this period only three days recorded amounts greater than 25 points (note the droughty appearance in Pl. xiv, fig. 2, Pl. xv, fig. 6, and Pl. xvi, fig. 5).

Falls of rain of more than 2 inches in one day occur fairly frequently in the complete rainfall records, usually as the result of local thunder-storms. Three such heavy falls are given in Table 1, viz., February, 1928, 365 points; December, 1929, 311 points; April, 1931, 336 points in one day. Little of these heavy falls is absorbed, and there is a high run off, and in bare or overstocked areas a considerable amount of soil erosion occurs; only the vegetation of the flooded areas or sandy soils benefits considerably by such downpours. The harder soil may be so scoured that there is little immediate response of the vegetation (cf. Pl. xvi, fig. 3).

The rate of erosion varies in a geometrical ratio with the slope, and also in a geometrical ratio with the size and swiftness of streams, so that by far its greater effect takes place during storms. As long as the soil of a region is mantled with vegetation, the mechanical action of the water is to a large extent impeded. The efficiency of different plant forms in checking erosion varies widely, and an open community, such as the saltbushes and bluebushes form, barely holds ground against stream erosion. In denuded country deep gullies of a canyon type with isolated buttes are formed, resulting in a considerable lowering of the water table.

TABLE 2.

Rainfall at Koonamore Head Station during the period 1925–June, 1931, also numbers of rainy days and falls over 25 points.

Year.		Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Tot.
1925	Rainfall	159	10	0	36	218	1	115	20	35	14	28	5	637
	Rainy days ..	3	1	0	2	9	1	6	2	1	1	2	1	29
	Falls > 25 points	2	0	0	1	3	0	2	0	1	0	0	0	9
1926	Rainfall	0	2	36	64	166	61	24	104	224	0	7	62	750
	Rainy days ..	0	1	2	3	6	3	6	8	6	0	1	4	40
	Falls > 25 points	0	0	1	1	2	1	0	2	3	0	0	1	11
1927	Rainfall	62	33	7	0	1	76	26	17	90	8	50	39	409
	Rainy days ..	4	2	1	0	2	5	5	1	5	4	4	3	36
	Falls > 25 points	1	1	0	0	0	2	0	0	2	0	0	0	6
1928	Rainfall	1	390	40	0	27	108	103	6	28	0	0	0	703
	Rainy days ..	1	4	3	0	2	6	5	1	2	0	0	0	24
	Falls > 25 points	0	1[1]	1	0	0	3	2	0	1	0	0	0	8
1929	Rainfall	0	0	15	18	0	9	12	26	62	0	35	327	504
	Rainy days ..	0	0	1	1	0	1	1	1	2	0	3	3	13
	Falls > 25 points	0	0	0	0	0	0	0	1	1	0	0	2[2]	4
1930	Rainfall	7	93	0	80	33	0	80	47	90	112	38	108	688
	Rainy days ..	1	4	0	2	3	0	6	4	3	6	2	3	34
	Falls > 25 points	0	1	0	2	0	0	1	0	2	2	1	3	12
1931	Rainfall	16	0	76	437	84	148							
	Rainy days ..	1	0	3	3	11	9							
	Falls > 25 points	0	0	2	2[3]	0	0							

[1] 365 points in 24 hours. [2] 311 points in 24 hours. [3] 336 points in 24 hours.

B. *Temperature.*

Temperature data are available for three complete years, and show little variation from month to month in the different years. Table 3 gives the mean monthly records for the three years, and Table 4 the mean values derived from these figures.

TABLE 3.

Year.		Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1927	Terrestrial radiation ..	—	—	46·6	32·3	24·1	28·8	27·0	30·3	35·5	43·7	50·1	56·1
1928	Daily maximum ..	—	—	—	—	—	—	58·5	69·6	68·8	75·9	94·0	91·7
	Daily minimum ..	—	—	—	—	—	—	36·3	38·7	40·5	47·4	62·0	61·3
	Terrestrial radiation ..	—	—	—	—	—	—	29·5	36·0	41·0	41·0	60·3	58·3
1929	Daily maximum ..	92·4	—	82·4	87·8	64·7	63·0	57·9	62·5	66·0	80·6	81·0	84·0
	Daily minimum ..	57·8	—	54·4	49·6	37·6	34·5	30·1	34·5	32·0	40·0	54·4	51·6
	Terrestrial radiation ..	57·5	—	51·0	40·2	37·2	32·0	26·5	32·5	27·1	45·6	51·7	45·0
1930	Daily maximum ..	—	90·0	87·6	87·0	59·0	60·8	61·0	69·2	69·3	79·7	87·7	89·3
	Daily minimum ..	—	67·6	56·6	43·9	34·5	37·0	39·0	37·2	41·6	50·9	53·3	59·3
	Terrestrial radiation ..	—	64·4	52·8	44·0	32·0	31·8	34·9	35·0	37·2	43·7	50·2	55·6
1931	Daily maximum ..	—	91·9	82·8	71·6	66·5							
	Daily minimum ..	—	55·3	54·3	46·3	41·4							
	Terrestrial radiation ..	—	47·0	48·8	42·9	41·5							

TABLE 4.
Mean Temperature Data.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Anl.
Mean maximum ..	92·4	91·0	83·3	82·1	63·4	61·9	59·4	65·8	67·6	80·1	84·3	86·7	74·9
Mean minimum ..	57·8	61·4	55·1	46·6	38·7	35·7	34·6	35·8	36·8	45·4	53·8	55·4	46·4
Mean	75·1	76·2	69·2	64·3	51·0	48·8	47·0	50·8	52·2	62·7	69·8	71·4	61·5
Terrestrial radiation ..	57·5	55·7	50·8	40·0	33·7	30·9	29·5	33·4	34·7	43·5	53·1	53·8	43·1
Mean diurnal range ..	34·6	29·6	28·2	35·5	24·7	26·2	24·8	30·0	30·8	34·7	30·5	31·3	30·1
Number of frosty days ..	0	0	0·1	1·5	4·2	15·4	15·7	11·4	5·1	0·1	0	0	53·5

The temperature shows the characters common to arid climates. The mean temperature tends towards a minimum in July, and there are two well-marked seasons—a hot season from October to March and a cold season from April to September. During the hot season the mean monthly maximum temperature ranges from 80° to 90°, and in the cold from 60° to 70°, the transition between the two seasons being well defined. During the hot seasons, temperatures exceeding 90° are very common, as can be gauged from the mean monthly figures, but accurate data cannot be given owing to gaps in the records in January due to the observer's absence.

The average number of frosty days per annum over a period of 8 years is 53·5 days, and these are confined to the cold season, the greatest number occurring in June and July, as reference to Table 4 will show. Records kept at Head Station show that during July, 1924, which was a dry winter, there were 27 frosts, of which 13 were severe, i.e., all outside pipes at the homestead remained frozen till 10 a.m.

A characteristic and important feature is the high diurnal range. The mean annual diurnal range (non-periodic amplitude) is 30·1° F., and it will be seen from Table 4 that the mean monthly range during both the hot and cold seasons closely approximates this figure. This high diurnal range has an important bearing on the humidity. Soil temperatures are not available, but they are high in the surface layer during summer, and the ground is often uncomfortably hot to the touch during the early afternoons.

C. *Humidity.*

The humidity data are of special interest owing to the fact that high relative humidities are frequently recorded, and high humidities are of importance to many of the plants of arid Australia, which can absorb water through their leaves from nearly saturated atmospheres (Wood, 1925).

The mean monthly relative humidity data are available for four years, and these are given in Table 5.

The mean relative humidity over the four years is high for an arid climate and is higher on the average than the monthly means for Adelaide. The mean, however, does not give a true picture of the degree of saturation of the air, since wide daily fluctuations occur. The mean maximum and mean minimum humidities are therefore of importance, and reference to Table 5 will show that in practically every month the mean maximum exceeds 80% humidity, and that, excluding the winter months, the mean minimum falls below 40%. We are therefore dealing

TABLE 5.
Relative Humidity.

Year.		Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Anl.
1927	Mean maximum	—	—	74	88	90	95	97	89	92	81	79	86	87
	Mean minimum	—	—	34	39	44	56	50	43	42	41	34	39	42
1928	Mean maximum	95	—	—	81	77	86	87	85	80	82	73	87	83
	Mean minimum	42	—	—	47	48	56	41	36	35	31	33	37	40
1929	Mean maximum	94	82	88	88	84	90	91	88	88	77	83	81	86
	Mean minimum	41	39	42	36	38	42	41	39	36	32	32	31	37
1930	Mean maximum	—	83	87	85	91	94	90	86	89	86	83	81	86
	Mean minimum	—	42	35	39	40	49	46	50	37	36	27	28	39
1931	Mean maximum	90	80	85	93	95								
	Mean minimum	28	23	27	34	45								
1927	Mean maximum	93	82	83	87	87	91	91	87	87	81	80	84	85
to	Mean minimum	37	35	34	39	43	51	47	42	37	35	31	35	39
1931	Mean	65	58	59	63	65	71	68	64	62	58	55	59	62
	Saturation deficit	0·31	0·40	0·30	0·22	0·13	0·10	0·10	0·14	0·15	0·24	0·35	0·35	

with a climate of extremes as regards humidity. The same day may be both moist and dry.

This variation in the humidity is a consequence of the high diurnal range of temperature, and since the relative humidity varies with the temperature, a more accurate picture of the degree of saturation of air is given by the *saturation deficit* which measures the difference in vapour pressure from saturated air in inches of mercury, and is independent of temperature. The highest relative humidity is recorded at the time of minimum temperature and the lowest relative humidity at the time of maximum temperature. The mean saturation deficits for each month are calculated therefore from the mean maximum temperature and mean minimum humidity, and from the mean minimum temperature and mean maximum humidity. The saturation deficits are shown in Table 6.

TABLE 6.
Saturation deficits in inches of mercury.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Mean maximum temperature ..	92·4	91·0	83·3	82·1	63·4	61·9	59·4	65·8	67·6	80·1	84·3	86·7
Mean minimum humidity ..	37	35	34	39	43	51	47	42	37	35	31	35
Saturation deficit	0·95	0·95	0·75	0·68	0·33	0·27	0·27	0·36	0·41	0·65	0·81	0·85
Mean minimum temperature ..	57·8	61·4	55·1	46·6	38·7	35·7	34·6	35·8	36·8	45·4	53·8	55·4
Mean maximum humidity ..	93	82	83	87	87	91	91	87	87	81	80	84
Saturation deficit	0·04	0·05	0·07	0·04	0·03	0·02	0·02	0·02	0·03	0·05	0·08	0·06

The figures for the saturation deficits bring out clearly that through every month, including the hot summer months, the air becomes almost saturated with water vapour for a part of the day. This fact, we believe, accounts for the success and ubiquity of the saltbush throughout the district. On the other hand the aridity of the environment is indicated by the high value for the deficit during the daytime.

In view of the importance of the high humidity to the vegetation, the length of time during which such high humidities prevail becomes important. Table 7 gives the mean number of hours per day per month during which the relative humidity is greater than 80%, also, as an indication of the rigorous arid conditions, the mean number of hours per day each month in which the relative humidity is less than 40%. These figures are derived from the thermohygrograph charts for a period of three years.

TABLE 7.

Showing mean number of hours per diem which the relative humidity exceeds 80% and during which it is less than 40%.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Number of hours exceeding 80%	n.r.	3·9	4·5	7·2	9·6	8·7	8·1	6·2	4·7	3·8	3·8	3·1
Number of hours less than 40%	5·5	6·9	5·9	3·1	2·4	1·0	1·8	4·1	6·0	6·9	8·9	7·6

The time during which the relative humidity is highest lies between midnight and 7 a.m., reaching a maximum usually just before sunrise. The time of lowest relative humidity is between 2 and 4 p.m.

Koonamore resembles the Kimberley District of South Africa, which has a mean annual range of temperature of 31·3° F., and a mean relative humidity of 46% in November and 65% in April to June.

The humidities recorded by Cannon (1921) for the Algerian Sahara are lower, ranging from 43% to 55% for the mean humidity. Hann (1903) records an average of 35% for the mean humidity for May in the Punjaub and north-western provinces of India, and in the south-western United States records a mean annual humidity of about 45%.

Fogs are relatively infrequent, but 7 fogs have been recorded since May, 1928, all in the cold months, and during these considerable amounts of water are condensed by trees and shrubs which drip as with rain. Pendant foliage such as that of *Myoporum platycarpum* causes a shower on the ground beneath. On one occasion the ground was appreciably moist beneath the canopy to a depth of 2·5 cm. Outside the canopy area the soil was quite dry.

No data are available for evaporation, but at Broken Hill, in a similar environment, the mean annual evaporation is 85·22 inches.

D. *Winds.*

Winds play an important part in the complex of environmental factors in arid regions.

The mean summer pressure at Koonamore is 29·957 inches, and the mean winter pressure 30·133 inches.

The winds from October to March (the hot season) have a south-westerly component, but in the cold season from April to September are variable. The winds have an effect in the first instance upon grazing, since sheep feed up wind in the summer and consequently the southern sides of paddocks tend to be more heavily grazed than the northern. The denuded state of the Reserve was due in part to its location at the southern boundary of the paddock, and also to the shelter that the scrub afforded the sheep.

The more direct effect of the wind is seen in the dust-storms which are frequent in summer in the North-East District. The storms originate in over-stocked areas around dams or watering-places, around townships, or from land that has been ploughed for agricultural purposes in essentially pastoral country. Noble (1904) records the removal by wind of 1 foot of soil from an area of more than 100,000 acres in New South Wales, and Free (1911) mentions the dust-storms of the spring of 1894 in Southern Russia as having removed soil to the depth of 6 inches over an area of 200 square miles. Free (loc. cit.) has made mechanical analyses of soils most liable to drift and removal by wind. These analyses approximate closely to the sands and sandy loams of the Koonamore area. It must be remembered, however, that these soils do not drift to any extent as long as they have a cover of vegetation.

As opposed to dust-storms, sand drift is of importance, i.e., the movement of the heavier sand particles along the ground. It also arises in overstocked areas, around watering places and from agricultural lands on the fringe of the pastoral country, especially from soils which have some depth of sand on the surface. The effect becomes accumulative since all vegetation in the path of the drift is destroyed.

5. Methods of Investigation.

A. *Permanent Quadrats.*

The principal method chosen for the study of regeneration and sequence of vegetation has been the permanent quadrat, charted and photographed from two fixed points at regular intervals. The location of these is shown on the sketch map (Text-fig. 1).

Three sizes of quadrats were employed. They were as follows:

(*a*) The Hundred series.—Quadrats with sides 100 metres long, giving an area of 1 hectare, approx. 2½ acres. Four such quadrats were originally set out in April, 1926, and a fifth added in December, 1927 (Plates xiii–xv).

(*b*) The Ten series.—Quadrats with sides 10 metres long giving an area of 100 sq. metres. Four were set out in April, 1926, and a fifth added in December, 1927 (Plate xvi).

(*c*) The Unit series.—Quadrats with 1 metre sides. Two only were set out in April, 1926 (Plate xvii).

The 'hundred' quadrats were primarily intended to study the changes in the tree and tall shrub vegetation, the position of the trunk and extent of canopy of each tree being shown on the chart. As it was not anticipated that any rapid changes would occur, these quadrats were surveyed every 15 months, thus shifting the season of observation throughout the work. They were photographed, however, quarterly. On charts of these quadrats the position of individual salt and blue bushes was also recorded.

The 'ten' quadrats were primarily intended to study the changes in the salt and blue bushes. On the scale used it has been possible to show the canopy area of each plant. The more important smaller plants, e.g., *Stipa*, *Bassia* and so on, have been indicated by symbols. These quadrats were charted quarterly, and photographed at the same time.

The 'unit' series recorded every plant, however small, growing on the area. These, too, were charted and photographed quarterly.

The corners of the quadrats were marked by 2 × 2″ jarrah stakes 6 ft. high, painted white for the top 2 ft., on which the number was recorded. In the case of the 'hundred' series, intermediate pegs, 2 ft. high, were placed at 20 metre intervals along the sides and throughout the area of the quadrat, thus dividing the whole into 25 squares, with 20 × 20 metre sides. When the quadrat was to be charted, lines were stretched across the whole length and breadth of the area from these intermediate pegs. Usually a party of three observers was engaged on the mapping, one recording the data on the chart and the other two carrying a metre tape to measure the distance of the particular plant from the sides of the square.

In the case of the 'ten' series, short intermediate pegs were placed every metre along the four sides. For charting a line was stretched across the square from opposite pegs so that the whole area was divided into one metre squares (vide Pl. xvi, figs. 4 and 6). With the aid of a metre rule, where necessary, the position of any plant could be rapidly plotted.

The charting of the unit series calls for no special comment.

It was decided at the outset that, as more than a hundred photographs and charts of the quadrats would be made each year, a card system of filing the records was most suitable. The 5 × 8 inch filing card was adopted. This is of sufficient size to allow of a quarter-plate photograph being pasted upon it, leaving room for essential data. For charting, a special card was prepared having one square decimetre divided into square millimetres printed upon it. This again left sufficient space at the side for the symbols and their explanation to be entered. The 5 × 8 inch cards have been found a very convenient size to handle, they are stiff enough to write upon in the field. The charting in the field was done with pencil and the card inked in the same day, using Indian ink.

We have found this uniform system of recording and filing our maps and photographs very convenient for the compilation, handling and consultation of the records.

At the commencement of the work there was no guide as to the size of quadrat likely to prove most useful. The 'ten' series has yielded less information about the regeneration of the perennial undershrubs than was hoped. The regenerating community is necessarily an open one, and more valuable information as to the actual rate of spread of saltbush has been obtained from the 'hundred' series than the 'ten'. At the same time, on the scale upon which the hundred series is recorded, it is impossible to note more than the presence or absence of a plant the size of *Atriplex*. The 'ten' series, on the other hand, allowed the canopy of each bush to be recorded. This series has also proved of much value in studying the growth of *Stipa* and the relation of the annual flora to litter and the accumulation of sandy soil around the perennial undershrubs. The unit series has afforded much detailed information as to the growth of the ephemeral flora which could not have been obtained by other means.

It will be seen from the map (Text-fig. 1) that the location of the quadrats was arranged to include the principal types of vegetation and soil, paying particular attention to the plants of the shrub steppe type. One may wish now that at least one other 'hundred' quadrat had been set out, but, having regard to the original plan of work, and the short time available for the working parties on their quarterly observations, this was impracticable.

B. *Permanent Photograph Points.*

In addition to the regular photographs of the quadrats, a number of other photograph points have been established and photographs taken from these at irregular intervals. The location of these is shown on the map (P.P.1, etc.). As the change in the perennial flora will necessarily be slow, it was felt that such photographs would be of value in years to come. Evidence will be given below to show that the rate of regeneration of the chenopodiaceous shrubs is in direct relation to the propinquity of a source of seed. Thus the photograph at the point known as P.P.6 (near S.W. corner of Reserve) was first taken in March, 1925, and used in the original note on the Reserve (Osborn, 1925, Pl. xxiv, fig. 3). The photograph repeated exactly 6 years later shows no change at all, the same scanty cover of *Bassia* being present, the same dead *Cassia* bushes, even the same fallen branch in the foreground. This area was once a saltbush flat with scattered *Cassia* bushes. It is shielded on the south by scrub-covered sandhills from a possible source of seed from the adjacent paddock. On the other hand, areas elsewhere on the Reserve, adjacent to sources of seed (e.g., in the south-east and north-east corners) show a good regeneration, sufficient to justify the setting out of transect system in August, 1930, though in 1925 hardly a saltbush was present on these areas.

C. *Sampling Methods.*

The method of sampling the vegetation by means of a metre frame dropped on predetermined spots was used largely by us in a study of the grass flora (Osborn, Wood and Paltridge, 1931). It is unnecessary to refer further to it here. A method of point sampling was tried. Ten 2-inch nails were driven through a metre rod at 1 decimetre intervals and the rod mounted on a stick. This implement was dropped points downward at frequent intervals, the object being to record the plants actually speared. So open was the flora, even during a favourable season, that the record was 0 plants speared after 100 tries, i.e., 1,000 individual points. The method was discontinued as being quite unsuited to the open vegetation of an arid area.

D. *Experimental Fires or Burns.*

Since scorching is known to have an important influence in accelerating the germination of the seeds of many species of *Acacia*, a number of bonfires of fallen trees and litter were lit in August, 1927. The results of these were so promising after the rains of February, 1928, that the experiment was repeated in June, 1929, on a more formal scale. As it was found that kangaroos selected the burnt areas to roll and lie upon, the experiments of 1929 were enclosed by fences and wire-netting from the outset. Some only of the 1927 series were netted. The results of these experiments are discussed below, in relation to the regeneration of *Acacia aneura* and the damage caused by rabbits (p. 425).

E. *Rabbit-proof Enclosures.*

During the 1929 drought it became obvious that rabbit damage was a most serious adverse factor. A series of netted enclosures, approx. 5 × 5 ft., were set up, four along each fence, two in the Reserve and two outside. The two enclosures of each pair are approximately 50 yards away from each other, on similar soil types. From these enclosures, which are large enough to furnish a square metre inside, free from any fence effect, it is hoped to obtain information as to absolute protection from rabbits, also from stock in the surrounding paddocks.

6. Biological Observations.

In our previous papers we have dealt in some measure with the effects of sheep and rabbits upon the vegetation. The influence of sheep or grazing by other domestic animals is not considered in the present communication. Since the Reserve fence was erected in 1925 none have been within the enclosure. The effects of sheep are still to be seen, not only in the profound change that their grazing had effected in the flora as a whole, recovery from which is one of the major problems of study, but on the soil itself. The trampling of thousands of hooves has the effect of compacting the soil, causing the lighter surface layer over the silt soils of the shrub-steppe to blow away or to remain in mounds around the perennial plants, especially the low divaricate perennials of the saltbush type. It is well known that sheep tend to move in lines following a leader; in this way definite 'pads' are still left on the Reserve trodden hard and sunken a centimetre or two below the general level of the ground even after six years enclosure. These 'pads' are quite destitute of vegetation, even after favourable rains.

It was hoped to exclude all alien fauna from the field of observation, but it has been found impossible to eliminate rabbits. And this in spite of the fact that the fence is netted against them and that there is no permanent water on the area. Towards the end of the five-year period rabbits began to breed up rapidly throughout the district, and a marked increase in their numbers was noticed on the Reserve. In 1932 at the conclusion of the period covered by this paper, the desperate remedy of ploughing in all burrows was undertaken, and as a result 7,000 rabbits were killed inside the Reserve. This drastic action was not taken during the period of quarterly observations because of the inevitable damage to much of the area. Probably at no time has the area been free from rabbits but, until the last year of the observations here recorded, it was a rare thing to see an animal or find an "active" burrow. When seen, all such burrows were immediately blocked, often after treating with cyanide dust. We shall refer later to specific instances of rabbit damage and discuss their action in inhibiting all regeneration of trees and shrubs. As an instance of the incalculable harm that they must do to annual plants it may be recorded here that in August, 1929, during the height of the drought there was no green herbaceous plant to be seen on the whole Reserve, except within a small rabbit-proof enclosure. Inside this, in spite of the fact that there had been only 88 points of rain in the preceding twelve months, there were a few green plants of *Stipa nitida*, *Erodium cygnodium* and *Tetragonia eremea*.

In 'good seasons', when there is an abundance of herbage, plagues of caterpillars take heavy toll of succulent-leaved annuals such as *Tetragonia eremea*. In June, 1928, there was such a plague. The insect concerned was *Heliothis leucatura*, one of the Noctuidae.

The prevalence of gall-forming insects of all kinds is noticeable, especially on mulgas (*Acacia aneura*), *Acacia Burkittii* and *Heterodendron*. These must reduce the seed output considerably. Even more noticeable are the galls formed by the rust, *Uromycladium Tepperianum* on *Acacia aneura*. So severe are the attacks of this fungus that trees are not infrequently killed by it.

Phanerogamic parasites are a common feature of the flora in arid Australia. Species of *Loranthus* heavily infest certain of the trees and shrubs, which sometimes succumb to the attack, notably *Heterodendron* from a heavy attack of *Loranthus Exocarpi*. This is the most polyphagous of the local loranths, occurring also on *Eremophila Sturtii* in the Koonamore district, while *L. Maidenii* appears restricted to the mulga. Root parasites belonging to the Santalaceae are *Exocarpus aphylla*, *Eucarya acuminata*, the quondong, which is common, and the much less frequent *Eucarya spicata*, a commercial species of sandalwood. Haustoria of this latter were traced to the roots of the mulga.

Two adverse factors directly affecting seed production should be mentioned. Firstly, the very heavy toll that must be taken by bird life, particularly such gregarious birds as the galah (*Kakatoe roseicapilla*). Flocks of these birds ranging from a dozen or so to several hundred settle on any patch of vegetation at the seeding stage. Not only do they pick up fallen seed but they attack ripening fruits. A flock was put up from a patch of fruiting saltbush (*Atriplex vesicarium*) and the ground examined. It was littered with hundreds of fallen fruits, each neatly cut open with a semicircular incision and the seed removed. Moreover, there were many shoots of the shrub lying around, cut off by the powerful beaks of the birds.

Secondly, the sudden onset of hot weather before the seed has matured may cause the abortion of great numbers of seed. Thus all the awned mericarps of *Erodium cygnorum* collected in October, 1928, from a dense society of this plant that had germinated after the rains of February–July were found to have empty carpels. The 1928–29 drought set in with a burst of hot dry weather before the seed had matured.

In spite of the severe natural loss of seed from various causes, the amazing number of seedlings that appear after suitable rain, provided that there is a seed bed, is a feature of this, as of other arid districts. The fate of these therophytes is considered later.

Bird distribution of seed or fruit is not obvious, but a few cases have come under our observation. Emus spread the quondong (*E. acuminata*), the stones being common in their droppings when quondongs are in fruit. They also eat largely of the succulent berries of loranths (*L. Preissii* especially being noted), but in this case they can be of no service in dissemination. Succulent fruits are rare in Australia generally, but it is noteworthy that the succulent-fruited Chenopodiaceous genera, *Rhagodia* and *Enchylaena*, appear to be bird distributed. It is very noticeable that the young plants of *Rhagodia Gaudichaudiana*, which have appeared on quadrat No. 400 and other parts of the Reserve, have done so under trees that had served as perching places for birds.

Flood waters distribute many fruits. The remarkable woody capitula of *Erodiophyllum Elderi* appear particularly suited to such dispersal. The plant is essentially one of flooded flats. *Bassia paradoxa*, with its remarkable compound caltrop-like burrs, fully 1 cm. in diameter and consisting of about 10 concrescent woody perianths with their projecting stout spines, is essentially a plant of washes and flooded areas, though not altogether confined to this habitat in wet seasons.

The common occurrence of spines or awns on fruits is notable. The function of the awns of *Stipa* and *Erodium* in burying the seed is well known. After heavy fruiting of *Stipa nitida* at the end of 1928, masses a foot in diameter of entangled awns were common amongst the plants. Most of these appeared to have buried their caryopses, the loose awns lying on the ground. The biological significance of the spines upon the many fruits which bear them is less obvious. Spines of greater or less size characterize the fruits of all the *Bassia* species, of *Tribulus*, *Calotis*, *Aristida*, while *Lappula*, *Daucus*, and *Tragus racemosus* have shorter spines or hooked appendages, i.e., are burrs. We hesitate to suggest any significance for animal distribution. We do note, however, that spines become entangled in litter. At times the litter of fruits and small branches of *Bassia patenticuspis* (containing other fruits) has covered many square metres of our quadrats.

Many fruits have wind dispersal mechanisms; such are the bladdery perianths of *Atriplex vesicarium*, *A. spongiosum*, *A. halimoides*, the papery perianths of several other *Atriplex* species (*A. limbatum*, *A. campanulatum*, *A. stipitatum*, *A. velutinellum*). Most of the *Kochia* species have more or less winged fruits, many of the Compositae have a plumose or scarious pappus, in *Eremophila Sturtii* the calyx persists and enlarges as it does in some other species of the genus, and the nutlet of *Casuarina lepidophloia* is winged.

Dehiscence mechanisms leading to a scattering of the seed are not common. Seed of *Acacia* is usually found immediately below the plant; so is the seed of *Templetonia egena*, though both have dry dehiscent pods. The capsules of *Zygophyllum* split with some violence when dry, ejecting the seed.

We offer no suggestion as to the significance of the aril, a feature of *Acacia* seeds and very noticeable also in *Heterodendron* where it is strikingly coloured red and half invests a black seed. Ants, which are not so much a feature of the insect life of the arid parts of Australia as they are of better rainfall areas, were abundant on and around fruiting *Heterodendron* trees.

Reference to the importance of a seed-bed was made in our paper on *Stipa* (1931, pp. 310–312). The effect of overstocking and subsequent wind erosion has been to destroy seed beds. The two very heavy falls of rain (February, 1928, and December, 1929) provided very little response in the germination of seedlings, except in areas that became flooded. The run-off from hard soil surfaces is too rapid, the erosion effect is intensified. The seeds of some of the plants characteristic of flooded ground contain a considerable quantity of mucilage, e.g., *Zygophyllum* spp. and *Clianthus*. The biological significance of the peculiar mucilaginous investment of the fruits of *Boerhaavia* is less obvious. When the fruits are ripe it swells rapidly after only a few points of rain. Fallen fruits with a glairy gelatinous investment were abundant round the dying plants in May, 1928, after a light shower. The plant did not reappear on the quadrats till March, 1930.

Time of flowering appears to be determined more by the rainfall than the season of the year. On the whole most perennials flower between July and October, but flowering is by no means of regular annual occurrence. It is rare in the case of *Acacia aneura*, *Heterodendron*, *Casuarina* and *Eucarya*. Of the Chenopodiaceous shrubs *Kochia sedifolia* rarely is found with flowers or fruits; this is very noticeable in comparison with *K. planifolia* or *K. Georgei*, which appear to flower freely in good seasons. Three plants are rarely without some flowers, *Pholidia scoparia* (with pale mauve corolla), *Kochia pyramidata* and *Bassia patenticuspis*.

7. Results from Study of Quadrats.

A. *Trees*.

(i) *Acacia aneura* (the mulga).

Quadrat 200 (Text-fig. 2) includes a portion of a typical mulga grove (Plates xiii–xiv). The trees occur in pure community, growing so densely that their crowns may interlace. The extent of the crown may be as much as 10 metres in diameter, but the narrow phyllodes, which usually stand more or less erect, do not cast a dense shade. The ground beneath the tree usually has a fairly extensive litter of fallen phyllodes. In height, the trees range up to 10 metres. They are very graceful with their light tracery of obliquely ascending branches and silvery-green foliage.

The trees of a mulga grove are usually of only one or two ages. Flowering is irregular following rain, and never as heavy as in most other acacias. Seed is apparently rarely set; we have found much difficulty in collecting even an ounce. The trees are often severely damaged or even killed by the gall-forming fungus, *Uromycladium Tepperianum* (Osborn and Samuel). They are also parasitized by *Loranthus*.

The distribution of the mulgas on quadrat 200 is not continuous over the whole quadrat (Text-fig. 2). This is because there is a change in soil type along the southern sides in the north-east corner. The mulga is limited to the sandy soil. Text-figure 3, which shows the distribution of saltbush and of seedlings of *C. eremophila* on this quadrat, shows clearly that other perennials do not readily establish themselves under growing mulgas.

Seedlings of mulga are rarely seen unless germination is stimulated by fire. Apparently they only occur after heavy summer rains. Five only were observed in February, 1930, on quadrats 200, 300 and 6–80 (an area of 2·48 hectares in the aggregate), following the rain of December, 1929, though at this date all quadrats were searched carefully for seedlings of trees and shrubs. Only one had been recorded after the rain of February, 1928.

On the other hand, after fire, germination is not infrequent. As mentioned previously, in August, 1927, a number of experimental bonfires were lit near mulga trees, the ground immediately around the burnt area serving as a control. In June, 1928, 10 months after the fire and four months after heavy rain, there were 23 mulga seedlings on these burnt areas, 12 being on one patch of about 4 square metres. Three more seedlings appeared by December, 1928; thereafter no more have germinated.

A second series of burns shows a somewhat similar history. The fires were lit in June, 1929, during the drought. Rain fell at the end of December, 1929, and in the March following 4 mulgas were noted at the edge of one of the two burnt patches. A fifth seedling appeared about 7 months later, since when there have been no more. The other burnt patch has shown no seedlings.

It is clear from these two experiments that germination of mulga can be induced around the edges of local burns, that the majority of the seeds that will germinate do so shortly after a heavy summer rain, but that there are a few laggard seeds which do not germinate till 9 or 10 months later. The young mulgas are much sought after by rabbits. No seedling in the Reserve has survived more than a few months except on areas specially protected. Further reference is made to this below (page 426) when discussing rabbit damage.

Though the adult tree is erect with usually only a single stem, the seedling stem is always oblique, sometimes inclined at an angle of 35°–45° to the vertical. More than one stem is commonly present. The plant is slow growing, but as the severe drought affected the 1928 germination, useful information cannot be given. In January, 1931, these plants, at approximately three years, were 20–25 cm. high. They were no larger than those of the 1930 germination which had only made 15 months' growth.

(ii) *Other tree species.*

The mulga is the only tree upon which detailed observations on the regeneration have been made, but the following notes on the three other important tree species are given.

Quadrat No. 400 was set out to include portion of a woodland of *Casuarina lepidophloia* (belah or black oak). This species is the tallest growing tree in the district, specimens 10–14 metres high being known to us. The trees are more or less gregarious, with a single trunk that breaks up into several obliquely ascending limbs at 2–3 metres. The diameter at breast height of the biggest tree on the Reserve is 0·5 metre. Trees much larger than this must have existed. The decorticated stump of one occurring in a water-course close to the south of the Reserve is 1·1 m. in diameter. The foliage shoots persist for some years; when they fall they form a more or less continuous litter around the trees and help to suppress other vegetation.

The species is monoecious, and in the Reserve staminate inflorescences have only been noted on a few trees on two occasions. Seeding is apparently rare, no seedlings having been recorded.

The main root system is superficial and there is clear evidence that root budding occurs, giving rise to new upright stems of considerable size. In other cases, on quadrat No. 400, trees have blown over and rooted again with 2 or 3 upright stems from the prostrate trunk.

Heterodendron oleaefolium occurs scattered over the rises on the Reserve as low trees, 3–4 metres. This plant only attains large size where it can receive occasional flooding. There it forms a low spreading tree of 6 metres high with a dense rounded canopy of foliage. A clump of such trees occurs about the centre of the Reserve. The shade cast by such well-grown Heterodendrons is remarkably dense for a plant of an arid climate. Flowering is irregular, but occasional trees have been seen with heavy crop of seed. These are very strikingly coloured, black with a red aril. Reproduction from root buds occurs. Suckers have been observed several times, but none have been noted as persisting.

The most important tree on the Reserve, after the mulga, is *Myoporum platycarpum*, the "sandal" wood of the district. This occurs scattered over large areas, giving a park-like effect. It grows principally on hard loamy soil with more or less travertine limestone. Quadrat 100 was laid out to observe this tree (Text-figs. 4 and 5).

Most specimens grow 6–8 metres high and are about 20–30 cm. in diameter at breast height. At about 2–3 metres the trunk breaks up into a few obliquely ascending branches. The foliage forms an irregularly rounded crown, usually with a fair amount of dead wood. The main trunk and branches have a dark deeply-furrowed bark, showing an appreciably greater development on the northern side. The ultimate branches are smooth, greyish and with slender semiflexuose twigs. The simple leaves are rather thick, glabrous, with characteristic oil glands. When young they are protected by a resinous secretion or lacquer. They persist for two or three years, the older ones falling in late summer. During the 1928–1929 drought the trees became almost defoliated, and many of the branches died back. Such defoliation is seen in the trees shown on Plate xvi (cf. figs. 1 and 4, also 5 and 6). In March, 1931, many trees were noted as developing strong new branches from the level of the main forking, the older limbs dying out.

The root system is largely superficial and the several trees on the Reserve have been noted as blown over during strong winds. When this is so, a quantity of soil is torn up with the superficial roots. Such trees show an indication of a tap root, but at 30–50 cm. depth this tapers to a few centimetres in diameter.

Flowering occurs freely from a series of buds borne in the axil of each leaf on the ultimate branches. Seed has not been observed to be set in more than very small amounts. Occasional seedlings have been noted from time to time, but none have survived for long, except in the rabbit-proof enclosures.

B. *Shrubs.*

There are five important shrub species on the Reserve. These are *Acacia Burkittii* on the sand hills, *Eremophila Sturtii* and *Pholidia scoparia* principally on loamy soil, and *Cassia Sturtii* and *C. eremophila.*

No special study was made of *Acacia Burkittii.* Seedlings were rarely found. It will be seen from Table 11 that a few appeared in connection with the experimental fire areas. Germination cannot be common without such stimulus. No seedlings were recorded on the quadrats in February, 1930, when a special search for all seedling shrubs was made.

Eremophila Sturtii is widespread over the Reserve, except on open hard loam plains, either as isolated bushes or as thickets. Of all the plants it appears to suffer least from grazing and rabbits. The bushes are dense, upright in habit, with large numbers of characteristic linear leaves, recurved at the tips and showing an appreciable amount of lacquer even in the old stages. Flowering is infrequent and seed rarely set. Only occasional seedlings have been noticed.

Pholidia scoparia, as the local name, the broom-bush, implies, has a strict erect habit. The leaves and young branches are silver-grey owing to the covering scales. Though plants usually show some flowers, seeding is not common and no seedling was recorded.

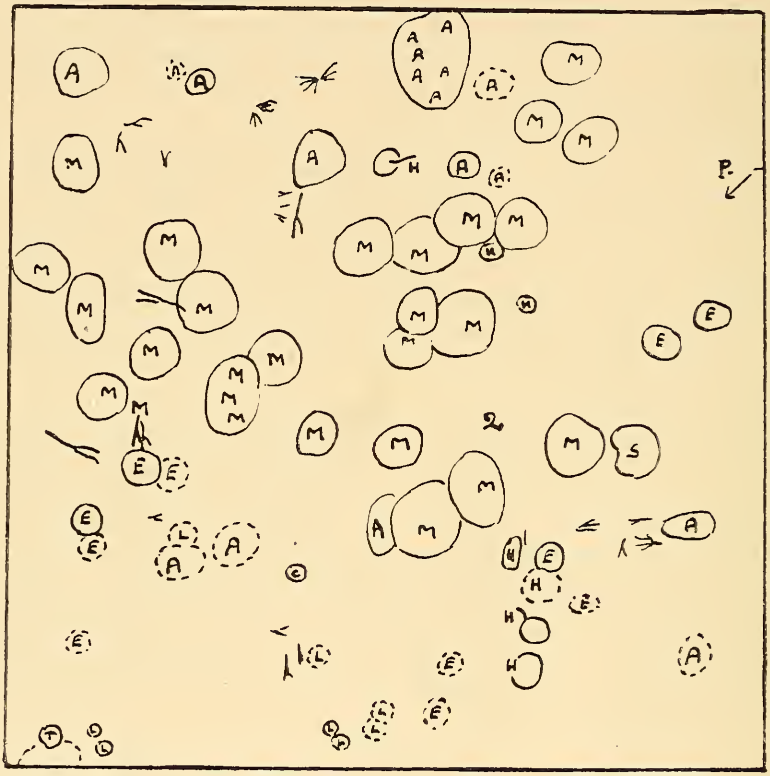
It is quite otherwise with the two species of *Cassia.* Both after fires and after the heavy summer rain of December, 1929, seedlings of the two species were abundant. The frequent occurrence of seedlings of *C. eremophila* is interesting, for the species is extinct on the Reserve, all the bushes having been killed before the enclosure was made. *C. Sturtii* is only represented by occasional old bushes. These have a straggling upright stem, 1–1·5 m. high, and a small crown of foliage shoots. They show obvious signs of having been heavily grazed. Both these species appeared with numbers of seedlings after the experimental burns and were first recorded in June, 1928 (Table 11). The heavy rainfall of December, 1929, caused them to germinate freely over the whole Reserve. They were specially searched for when the hundred quadrat series was mapped in February, 1930. The results are as follows:

Quadrat.	*C. eremophila.*	*C. Sturtii.*
100	—	65
200	48	1
300	5	25
400	1	5
6-800	28	14

Text-figure 3 shows the distribution of the seedlings on quadrat No. 200. *C. eremophila* is evidently a plant of the sandhills and areas of light soil liable to flooding. *C. Sturtii,* on the other hand, occurs more on the harder loam soils where it grows with *Atriplex vesicarium* and *Myoporum platycarpum* (cf. quadrat No. 100, Text-fig. 5).

C. *Dominants of the Shrub-Steppe.*

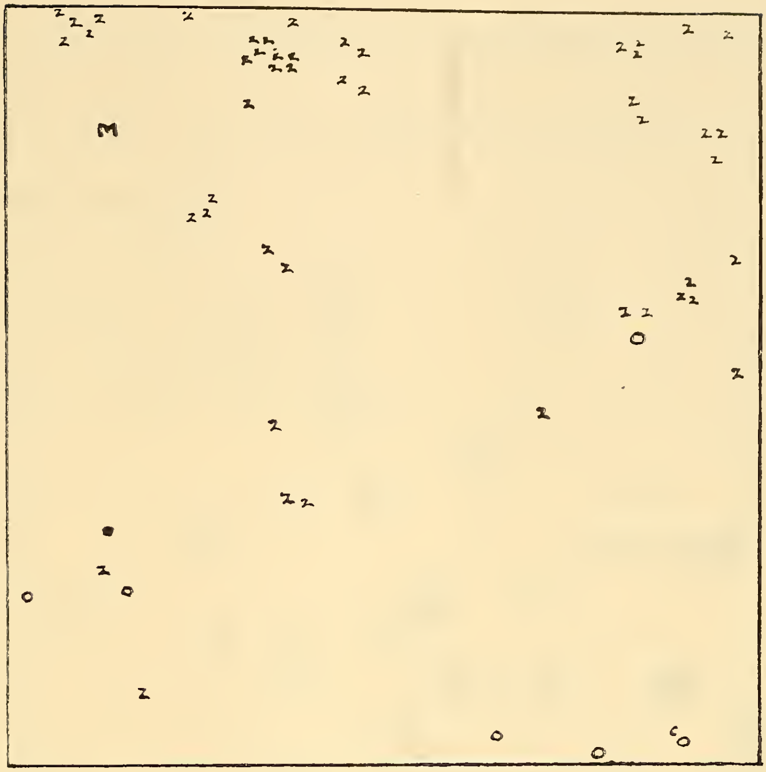
(i) *Atriplex.*—In a previous communication we have considered the growth of *Atriplex vesicarium* at some length. We shall confine ourselves here to an account of its regeneration under protection. Originally, a considerable part of the Reserve, except the sandhills, must have been shrub-steppe covered with either *A. vesicarium* or *A. stipitatum,* or both in association. Quadrat 200 shows well that the mulga-covered sandhills and the loamy plain with *A. vesicarium* are distinct communities. In Text-figure 2 the distribution of the mulgas on this quadrat is shown. They do not extend along the southern or eastern sides where the soil is loamy. Text-figure 3, based on the chart of February, 1930, shows that it is along these areas *Atriplex* began to appear. In June, 1931, five of these seven bushes were still growing and six more were present, all on the loamy soil.



Text-fig. 2.—Quadrat chart of 200, 27/2/30 (scale 1/1,000), showing the distribution of the tree and shrub vegetation. A full line indicates the canopy of a living tree, a broken line the extent of a dead standing tree. The chief fallen trees indicated by forking lines. M = *Acacia aneura*, A = *Ac. Burkittii*, H = *Heterodendron oleaefolium*, E = *Eremophila Sturtii*, L = *Lycium australe*, T = *Templetonia egena*. 2 marks position of quadrat 2, P with an arrow the position of camera and direction of the photographs, Plates xiii and xiv.

Quadrat 100 has been particularly useful for studying the spread of *Atriplex*. In May, 1926, there were four saltbushes only on the hectare. One of these was alive and growing vigorously in 1931, a large sprawling bush 160 cm. in diameter, but the remainder died before or just after the 1927 mapping. Text-figure 6 shows the distribution of the saltbush in June, 1931, 72 plants (53 *A. vesicarium* and 19 *A. stipitatum*) being present.

Below is given in tabular form (Table 8) the results of our quadrats of 100-metre scale, showing the increase of *Atriplex* during the five-year period.



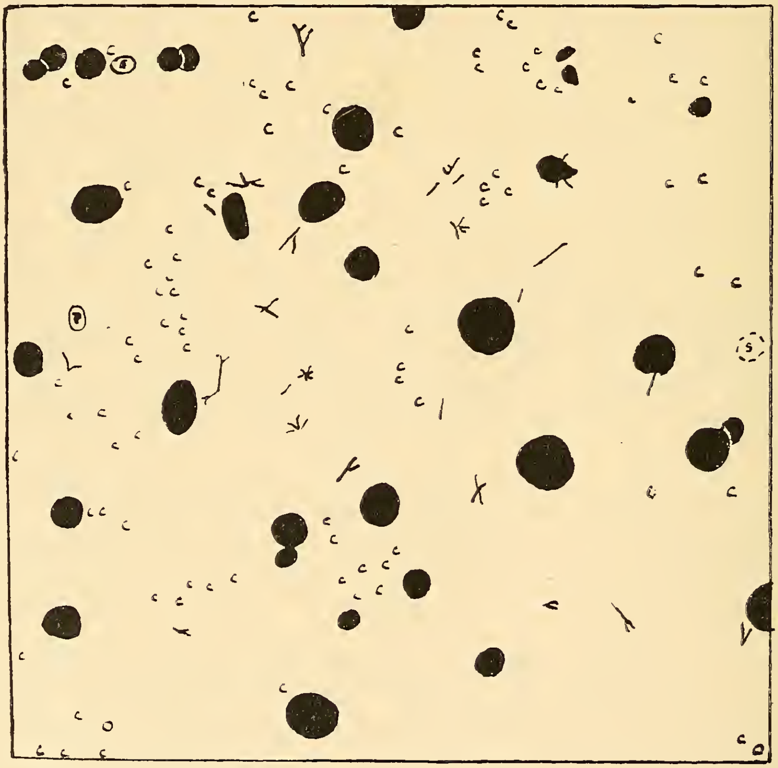
Text-fig. 3.—Quadrat chart of 200, 27/2/35 (scale 1/1,000), showing distribution of seedlings and saltbushes. M = *Acacia aneura*, Z = *Cassia eremophila*, C = *C. Sturtii*, o = *Atriplex vesicarium*, and a full dot = *A. stipitatum*. *C. eremophila* occurs on the sandy soil which also supports mulga and *A. Burkittii*, also on the NE. side of the quadrat where flooding occurs. *Atriplex* occurs on the southern side where the soil is hard loam, with *Lycium*, *Eremophila* and *Heterodendron*, but no mulgas.

TABLE 8.
Spread of Atriplex vesicarium *and* A. stipitatum *in hectare quadrats.*
Number of quadrat.

Charted.	100.			200.			300.			400.		
	No. Mapped.	Gross Increase.	Survived.	No. Mapped.	Gross Increase.	Survived.	No. Mapped.	Gross Increase.	Survived.	No. Mapped.	Gross Increase.	Survived.
May, 1926 ..	4	—	2	—	—	—	—	—	—	1	—	1
Sept., 1927 ..	28	26	25	—	—	—	4	4	3	17	17	13
Dec., 1928 ..	55	30	48	4	4	3	13	10	12	18	5	18
March, 1930 ..	62	14	60	7	4	5	27	15	26	30	12	26
May, 1931 ..	72	12	—	11	6	—	30	4	—	30	4	—

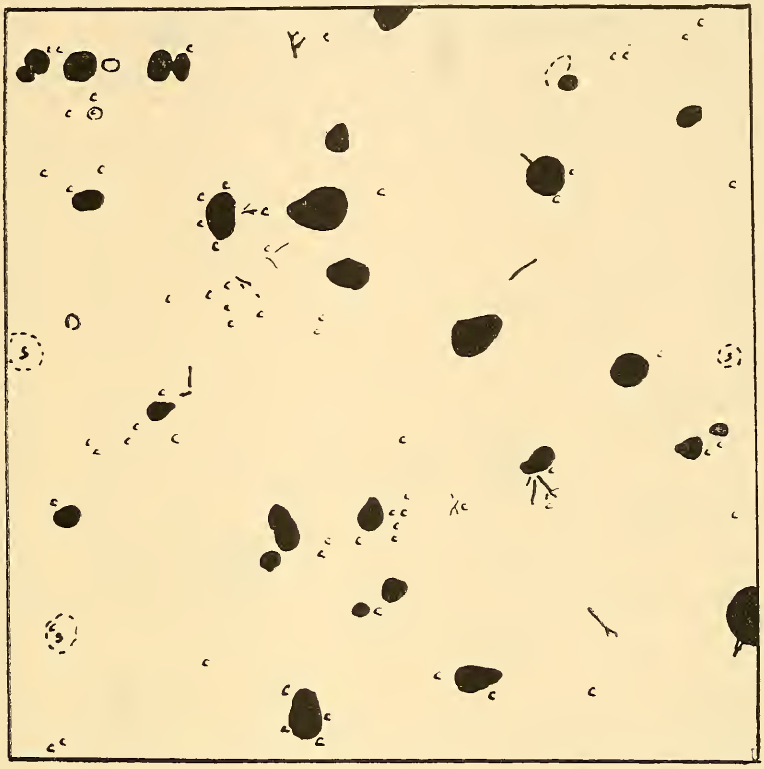
The figures show that the rate of return is slow, particularly when the area is removed from a possible source of wind-blown seed (cf. Nos. 100 and 300). The difficulty that plants have in establishing themselves without a proper seed-bed is clearly brought out by a detailed study of No. 100. The heavy rainfall of December, 1929, scoured the surface of this quadrat, and the increase in the number of saltbushes seen upon it between December, 1928, and February, 1930, is proportionately much less than in the other quadrats.

Quadrat 10 A (Plate xvi, figs. 1–4) was laid out in May, 1926, at the margin of a fairly vigorous saltbush colony. By comparing Text-figures 7 and 8, it is seen that in the five years most of the bushes then established have grown well and increased their cover, but that few new plants have appeared. The bare area along the north (top of Text-figs. 7 and 8) of this quadrat is very striking. There are several square metres of eroded surface here on which no plant of any description has been recorded in any of our quarterly observations throughout the whole five years (cf. foreground, Pl. xvi, figs. 1–4). Our observations on the Reserve show, if further evidence were needed, the fatal results of overstocking to such a degree that the surface soil is eroded.



Text-fig. 4.—Quadrat chart of 100, 24/5/26 (scale 1/1,000), showing the distribution of *Myoporum platycarpum*. Living trees shown in full black, dead trees with broken line and S. E = *Eremophila Sturtii*, P = *Pholidia scoparia*, C = dead but standing bushes of *Cassia Sturtii*, and o = plants of *Atriplex vesicarium*. Fallen timber indicated by lines.

Atriplex stipitatum differs somewhat from *A. vesicarium* in its habit and habitat requirements. It is generally a more erect growing plant with smaller, more glossy leaves. It is apparently less palatable to stock on account of its bitter taste.

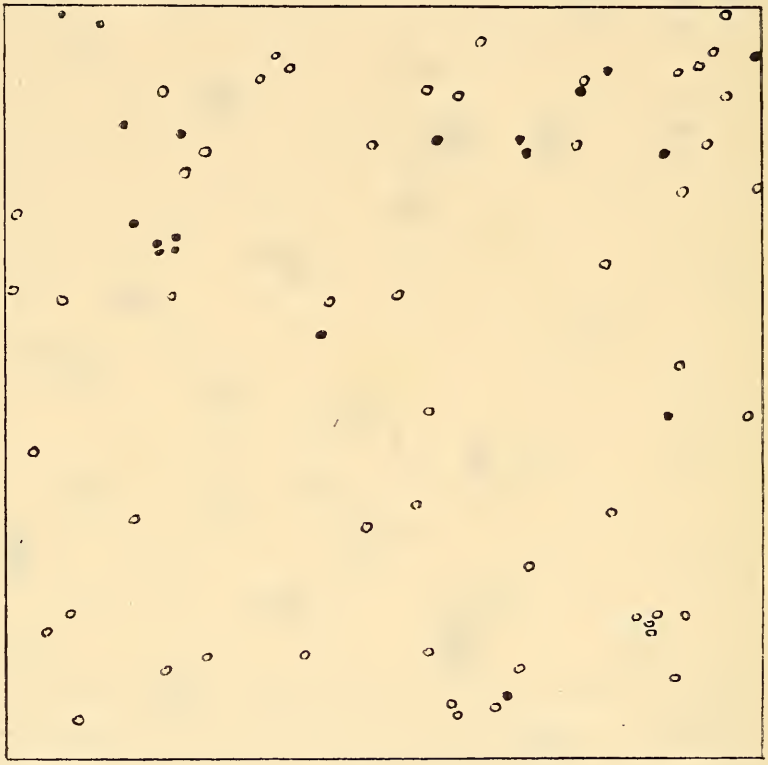


Text-fig. 5.—Quadrat chart of 100, 27/2/30 (scale 1/1,000), showing reduction in extent of canopy of *Myoporum platycarpum* after the 1928-1929 drought. Some trees have died (S and broken line). On the other hand, there has been a considerable germination of *Cassia Sturtii*; the symbol C here shows seedling plants.

Though the two species grow together on the Reserve, *A. stipitatum* is not a constituent of the big open plains, the typical *A. vesicarium* habitat dealt with by us in our previous paper. *A. stipitatum* on the Reserve occurs most abundantly in and around patches of scrub. Its main centre is in the south-east corner, where it is associated with a woodland of *Casuarina lepidophloia*. Its spread in this corner has been rapid, a source of seed being along the northern side of the adjacent paddock.

(ii) *Kochia sedifolia.*—*Kochia sedifolia*, the blue bush, is sometimes called "old man" blue bush because of its size, to distinguish it from the lower growing species, such as *K. planifolia*, which also forms an important element in certain shrub-steppes.

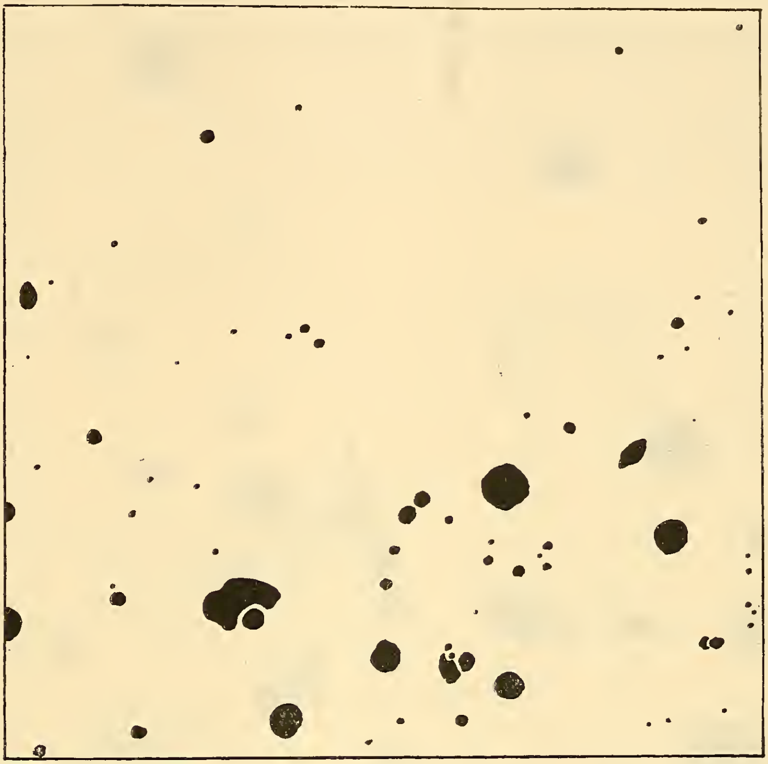
·Plants of *K. sedifolia* may exceed 1 metre in height. They form dense rounded or columnar plants with several main stems and densely interlacing lateral branches. The ultimate tips of the finer lateral branches are often pendent. The stems are clothed with numerous short (averaging about 0·5 cm.), clavate, rather fleshy leaves which are covered by a dense tomentum, thus causing the blue-white appearance. The leaves apparently persist for several years, but are shed in times of severe drought when this plant becomes more or less aphyllous.



Text-fig. 6.—Quadrat chart of 100, 1/6/31 (scale 1/1,000), showing distribution of *Atriplex* over the area. o = *A. vesicarium*, and full dot = *A. stipitatum*. Only one of these plants, that in the SW. corner, was present on 24/5/26 when the quadrat was set out.

As will be seen from the sketch map (Text-fig. 1), blue bush occurs in patches over the Reserve, notably at the south-east side, near quadrat 40 A (Pl. xvi, figs. 5, 6), across the middle of the Reserve, and on the north-west corner. The soil in all these places is hard loam with much travertine limestone. The plant may be regarded as definitely calcicolous.

At the time of its enclosure, all the *Kochia* plants on the Reserve had been grazed and broken down to mere woody stumps. Clusters of these, holding more or less blown soil occurred in areas mentioned. Text-figure 9, A, shows a dissection of such a clump. It is seen to be a complex system of branches, ascending obliquely in the main, but bearing upright shoots. In 1925 and 1926 such stumps looked dead, as in fact many of them were. Shortly after enclosure, however, some of them began to shoot and others, apparently dead, did so during the following year. Slowly, the area round 40 A and the plain by the *Heterodendron*



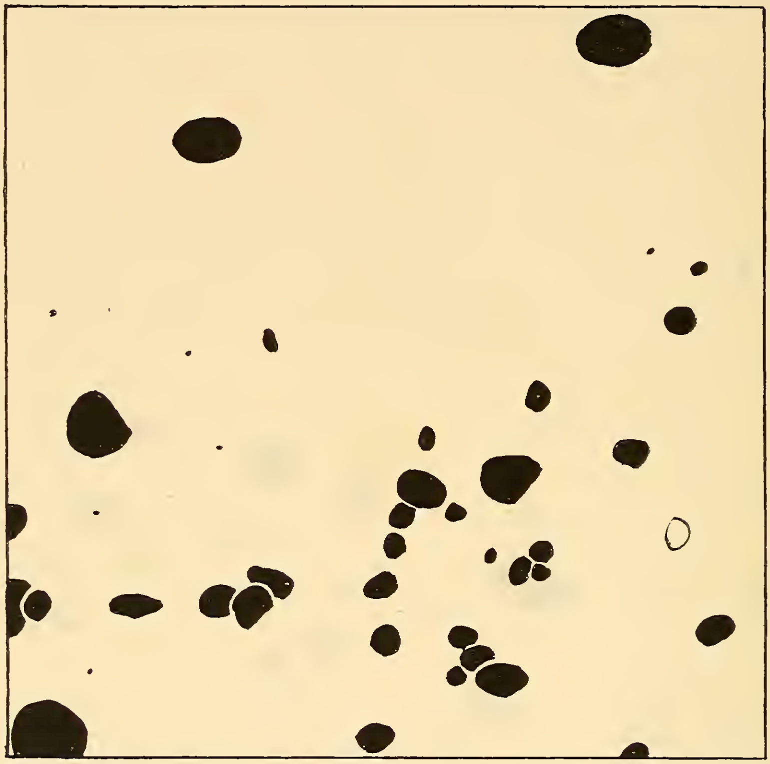
Text-fig. 7.—Quadrat chart of 10A, 24/5/26 (1/100), showing distribution and extent of cover of *Atriplex vesicarium*; cf. Pl. xvi, fig. 1.

clump in the middle of the Reserve became lightly covered with a re-growth of the *Kochia*. After the first season's active growth, further development of the individual plants proceeded slowly, so that at the end of five years few of the bushes exceeded 40 cm. high. They were largely defoliated during the 1929 drought but most of them had recovered by 1931 (Pl. xvi, fig. 6).

An excavation of the root-system of a plant of *Kochia sedifolia* is seen in Text-figure 9 (B, C). The roots are in the main spreading. They extend 5–6 metres from the plant at a depth of 20–30 cm. The individual roots follow a rather tortuous course and become much contorted before they branch. The ultimate branches (which may be of the 5th or 6th order) are slender and are evidently deciduous rootlets such as occur in the case of *A. vesicarium*. Though the root-system is in the main spreading, there is a marked development of secondary roots which descend vertically to a depth of more than 2 metres. These roots taper gradually from a diameter of 2 cm. to less than 1 mm. at their apices. All roots except the feeding groups are covered with an almost black bark.

Frequently a whole branch of the root-system dies back close to the main stock for no apparent reason.

Kochia sedifolia flowers and fruits very sparingly and at infrequent intervals. No plant on the Reserve is recorded as having flowered.* The paucity of seed



Text-fig. 8.—Quadrat chart of 10A, 2/6/31 (scale 1/100), showing distribution and extent of cover of *Atriplex vesicarium*. One dead plant, outline only, is shown; cf. Pl. xvi, fig. 4.

production may account for the rare occurrence of seedlings in our quadrats. Two only have been recorded, both on quadrat No. 400, in August, 1927, and neither survived until the next mapping in December, 1928. We know that one, which fell within quadrat No. 40, was destroyed by caterpillars in August, 1928.

It is evident that when a *K. sedifolia* shrub-steppe has suffered from severe overstocking it can only regenerate from seed with great difficulty. On the other hand, observations that we have made elsewhere in the district show that when vigorous plants are severely grazed and knocked about by sheep for a limited time only they recover well and rapidly, but, so far as our observations go, they do so by shooting from the butts of old plants, and not from seedlings. It appears to us that this is largely due to lack of suitable seed-bed. The hard loam with travertine, in which *K. sedifolia* grows, rapidly loses its surface mulch of

* This was flowering fairly abundantly outside the eastern fence in August, 1932.

finer soil under the combined influence of trampling and wind. The only seedlings that we have observed were growing on quadrat No. 400 in places in which there had been a local accumulation of silt after rain.

D. *Other Chenopodiaceous Species.*

Four other Chenopodiaceous species which play a subsidiary part in the normal flora have appeared on the hectare quadrats. They are *Kochia Georgii*, *K. tomentosa*, *Rhagodia spinescens* and *R. Gaudichaudiana*. The first three are low-growing much-branched shrubs, the last a more straggling bush. Both species of *Kochia* flower and fruit freely; the fruits have the typical membraneous wing. In *Rhagodia* the fruit is a very small red berry (approx. 3 mm. diam.). As noticed

Text-fig. 9.—*Kochia sedifolia*. A. Dissection of base of a large bush showing complex of obliquely ascending stems from which erect aerial branches arise as well as vertically descending roots. These "stumps" have great power of resistance, and all regrowth of *K. sedifolia* on the reserve has taken place from them (Pl. xvi, figs. 5, 6). × $^{1}/_{50}$. B. Plan of surface root system. C. Section of root system. T.B.P. *ad nat. del.*

Text-fig. 10.—Sectional view of root-system of *Bassia patenticuspis* showing the surface system and the deep descending portion. Root systems of two young plants shown to right. T.B.P. *ad nat. del.*

previously, it is interesting to observe that all the young plants of *R. Gaudichaudiana*, ten in number, have appeared beneath small trees which had served as perching places for birds.

Lastly reference must be made to some of the species of *Bassia*, notably *B. patenticuspis*. This is a low-growing short-lived perennial with weakly woody stems and very numerous cylindrical leaves, 0·5–1 cm. long, grey in colour because of their dense tomentum. From a very early stage the plant begins to flower. Post-fertilization development of the perianth leads, in this species, to the development of two sharp slender spines near the apex of the indurated perianth tube. These spines, which are from 0·5 to 0·8 cm. in length, make the whole plant intensely prickly. Though the plant rarely grows more than 20 cm. in height, it has a root-system which has been found to penetrate to 140 cm. A drawing of an excavated root-system is given in Text-figure 10. The deep descending main root appears in the very young plant. Later, there is some development of a horizontal system near the surface, but this gives rise to several strong branches which descend vertically almost to the depth of the main root itself.

When the Reserve was enclosed in 1925, *B. patenticuspis* was the most abundant low-growing plant in the loamy soils over the whole area. Quadrat No. 100 was covered with it and the detailed study of a small part of this, quadrat No. 1, enables us to speak with certainty of the length of life and regeneration of this species. The plants recorded in the first charting, May, 1926, were then fully grown. They died back during 1927, shedding most of their branches which formed in places a continuous prickly mat. The heavy rain of February, 1928, caused a germination of seed, but the young plants did not survive the onset of the drought and died before the end of the year. Heavy rain fell in December, 1929, and seedlings were recorded in March, 1930. These plants were still at the seedling stage in June, but by August most of them covered an area that could be charted. By December, 1930, they were full grown and were still vigorous in June, 1931, when the observations recorded were concluded (Pl. xvi, fig. 6, foreground). At that time the loamy soil portions of the Reserve had a heavy covering of *Bassia patenticuspis*, similar to that observed in 1925–1926. Examination of the rainfall data, Table 1, shows that the sequence of rainfalls had been very similar. Germination began in each case after a heavy fall in early summer (381 points Nov., 1925, and 327 points Dec., 1929), and in each case the rainfall during the succeeding winter and spring was reasonably good.

Bassia patenticuspis is normally a pioneer plant in the succession leading to shrub-steppe. When the climax communities of *Atriplex vesicarium* or *Kochia sedifolia* are destroyed it can become the dominant ground cover over very large areas. In spite of its spines it is, when young, eaten readily by sheep.

Other important *Bassia* species on the Reserve are *B. obliquicuspis*, *B. uniflora*, *B. sclerolaenioides* (white plants in foreground, Pl. xvi, fig. 6), and *B. paradoxa*.

E. *Herbaceous Plants.*

A general impression of the abundance of the therophytic flora and the sequence in its composition can be obtained by comparing the series of photographs of quadrats 200 and 300 (Pl. xiii, xiv, xv). Detailed information as to the time of appearance and persistence of the various therophytes is best obtained from the two 1 sq. metre quadrats, No. 1 on hard loam and No. 2 on sandy soil (vide Tables 9 and 10). When these were set out, extreme conditions, such as eroded surfaces, areas liable to flooding or shelter of trees, were avoided, but, with these reservations, the areas were selected as the result of a random throw upon the hectare quadrats Nos. 100 and 200 respectively.

It has been our custom to record the annual plants on the quadrats of the tens series also, although on the scale of these quadrats it was impossible to map them accurately. The individual plant records so gained have been helpful,

TABLE 9. *Quadrat 1, 1 sq. metre.*

	1926.			1927.				1928.				1929.				1930.				1931.
	May.	Sept.	Dec.	Mar.	May.	Aug.	Dec.	Apr.	May.	Aug.	Dec.	Feb.	June.	Sept.	Dec.	Mar.	June.	Aug.	Dec.	Mar.
Rainfall during preceding three months, in points	102	251	231	157	8	119	148	430	67	217	28	0	33	47	97	427	113	127	240	124
Stipa nitida	1	12	13	13	12	12	12	12	10	20	6	1	—	—	—	—	—	—	—	—
Atriplex campanulatum	1	1	1	1	1	1	—	—	—	1	1	1	—	—	—	—	—	1	1	1
Bassia patenticuspis	25	39	42	22	17	9	7	33	24	8	1	—	—	—	—	25	27	29	26	24
Salsola Kali	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	1	1	1	1	1
Tetragonia eremaea	21	40	12	—	—	—	—	—	—	—	—	—	—	—	—	—	—	10	—	—
Zygophyllum ovatum	1	6	1	—	—	—	—	13	8	—	—	—	—	—	—	6	1	1	—	—
Erodium botrys	—	9	1	—	—	—	—	2	2	2	—	—	—	—	—	—	—	—	—	—
Total number of individuals	49	131	69	36	30	22	19	60	44	31	8	2	0	0	0	32	29	41	27	25
Total number of species	5	14	5	3	3	3	2	4	4	4	3	2	0	0	0	3	3	4	2	2

The following species, with numbers of individuals in brackets, were recorded in the Aug., 1926, charting only: *Trisetum pumilum* (1), *Schismus calycinus* (1), *Zygophyllum prismatothecum* (8), *Stenopetalum lineare* (5), *Plagiobothrys plurisepala* (4), *Brachycome pachyptera* (3), *Rutidosis pumilo* (1).

TABLE 10. *Quadrat 2, 1 sq. metre.* (Cf. Plate xvii, references to particular figures in which are given in relevant columns.)

	1926.			1927.				1928.				1929.				1930.				1931.
	May. Fig. 1	Sept. Fig. 2	Dec. Fig. 3	Mar.	May.	Aug. Fig. 4	Dec.	Apr.	May.	Aug. Fig. 5	Dec.	Feb. Fig. 6	June.	Sept.	Dec.	Mar.	June.	Aug.	Dec.	Mar. Fig. 7
Rainfall during preceding three months, in points	102	251	231	157	8	119	148	430	67	217	28	0	33	47	97	427	113	127	240	124
Schismus calycinus	10	13	10	—	16	474	—	—	—	38	9	—	—	—	—	—	—	—	—	—
Stipa nitida	—	10	9	9	9	9	9	51	47	69	50	—	—	—	—	—	94	115	18	—
Chenopodium cristatum	—	28	8	—	—	—	—	111	82	98	—	—	—	—	—	129	28	43	—	—
Bassia patenticuspis	3	8	7	5	4	13	3	3	2	5	2	—	—	—	—	—	3	6	4	3
Salsola Kali	1	2	2	2	1	3	—	—	—	—	—	—	—	—	—	3	4	4	4	—
Boerhaavia diffusa	—	—	—	—	—	—	—	14	9	—	—	—	—	—	—	13	—	—	—	—
Tetragonia eremaea	310	193	—	—	—	—	—	3	7	4	—	—	—	—	—	—	513	532	—	—
Geococcus pusilius	48	15	—	—	—	5	—	—	—	2	—	—	—	—	—	—	6	26	—	—
Erodium cicutarium	21	13	—	—	—	12	—	3	2	2	—	—	—	—	—	—	8	7	—	—
Erodium cygnorum	2	3	—	—	—	—	—	1	6	4	—	—	—	—	—	—	9	11	—	—
Zygophyllum ammophilum	1	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—
Euphorbia Drummondii	—	—	—	—	—	—	—	1	1	1	—	—	—	—	—	2	4	4	—	—
Lappula concava	—	3	—	—	—	2	—	—	—	10	—	—	—	—	—	—	—	2	—	—
Plagiobothrys plurisepala	—	34	—	—	1	74	—	—	—	28	—	—	—	—	—	—	5	14	—	—
Calotis hispidula	—	16	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	15	—	—
Helipterum moschatum	—	1	—	—	—	—	—	1	1	3	—	—	—	—	—	—	14	70	—	—
Angianthus pusillus	—	6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—
Total number of individuals ..	396	369	36	16	31	592	12	188	157	265	61	0	0	0	0	147	688	852	26	3
Total number of species	8	21	5	3	5	8	2	9	9	13	3	0	0	0	0	4	11	16	3	1

The following species, with numbers of individuals in brackets, were recorded in Aug., 1926, charting only: *Trisetum pumilum* (1), *Calandrinia volubilis* (3), *Stenopetalum lineare* (1), *Crassula colorata* (2), *Isoetopsis graminifolia* (5), *Rutidosis pumilo* (9), and *Toxanthus Muelleri* (1) in Aug., 1930.

especially from quadrat No. 30, which is on loamy ground, a part of it being liable to flooding.

The number of individual plants has been found to vary from 0 per sq. metre, during the drought of 1929, to as many as approximately 852, belonging to 16 different genera, on quadrat No. 2 in August, 1930. Of this number some 532 (approx.) were seedlings or young plants of *Tetragonia eremea*, not one of which survived until the following December. It was almost as abundant the following June (Pl. xvii, fig. 8).

Twenty-one species, belonging to 20 genera, was the greatest variety in the flora found growing at any one date upon one sq. metre (quadrat No. 2, August, 1926).

The richness of the ephemeral flora growing at any given time obviously depends upon the rainfall during the preceding few months. The results for quadrats Nos. 1 and 2 for the whole period are set out in Tables 9 and 10. It will be noticed that during the three-monthly periods immediately following the two heavy falls of rain (February, 1928, and late December, 1929) the therophyte response was poor (Pl. xvii, fig. 7). This is due to the rapid rate of run-off and consequent erosion of the surface and removal of the seeds.* The peak numbers of individuals have always been found following a winter rainfall of 250 points and upwards, distributed over the months April to August.

There is a distinct change in the facies of the flora, depending upon the season at which the rain falls. The following plants are characteristically summer growing, but some of them evidently require a certain amount of flooding before they will germinate. They are marked F in the following list, these records being obtained from quadrat No. 30.

Stipa nitida (especially on sandy soil).
Chenopodium cristatum (especially on sandy soil).
Bassia patenticuspis.
Salsola Kali (especially on sandy soil), Pl. xiv, fig. 3; Pl. xv, fig. 7.
Boerhaavia diffusa (especially on sandy soil).
Tribulus terrestris (F).
Zygophyllum iodocarpum (F).
Z. ovatum.
Z. prismatothecum (F).
Lotus australis (F).
Convolvulus erubescens (F).
Heliotropium europaeum (F).

But, with the exceptions noted in the previous list, the majority of the ephemerals are plants of winter growth. The following plants have always appeared with a wealth of seedlings after winter rains:

Plagiobothrys plurisepala.
Helipterum moschatum.
Bassia sclerolaenioides.
Tetragonia eremea.
Erodium cygnorum.

Clianthus speciosus, the brilliant scarlet and black flowered Sturt's desert pea, on the other hand, has been found blooming in spectacular profusion on flooded ground after both summer and winter rains.

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* It seems significant that the chief herbaceous plants following these two heavy rains either had spinescent fruits (i.e., *Stipa, Bassia, Erodium*) or mucilaginous seeds (*Zygophyllum*), Pl. xvi, fig. 2, the low dark plant.

8. Lichens.

Lichens play an important part in the ground flora of hard loam surfaces, i.e., the soil type upon which the shrub-steppe develops. They are crustaceous species which live at or just below the surface of the soil. The most obvious is an undetermined species of *Acarospora** which forms white patches 8 cm. or more in diameter. The thalli swell after rain and, becoming somewhat puffed up above the level of the soil, have a superficial resemblance to fragments of travertine limestone. Three other species are chiefly conspicuous because of their apothecia, the thalli being usually hidden in the dust of the ground. One of these, *Lecidia decipiens* Ach., has clusters of pinkish apothecia with white margins. It is widespread and very obvious after rain. The other two are *Dermatocarpon hepaticum* Th. Fr., and *Biatorina caeruleo-nigrum*; both are general, but not so conspicuous as the two preceding.

Most exposed surfaces of travertine limestone have the saxicolous species *Rinodina diffractella* Mull. Arg. growing upon them.

Two species of foliaceous lichen occur on the ground. They are *Parmelia australiensis* Cromb. and *P. adhaerens* Cromb. Neither develops rhizinae or is attached to the soil, but the thallus, when moist, lies flat upon the surface of the wet soil though quite free from it. When the wet period is over the thallus dries up and, curling inwards, forms a loose mat-like mass. The dried plants of *P. australiensis* may be 2 inches or more in diameter. They are rolled about on the ground by the wind or caught in projecting twigs. This lichen is widely distributed, but it became definitely more abundant inside the Reserve under protection than it was in the adjacent paddocks. The second species forms much smaller plants and is less frequent.

Corticolous lichens are generally rare on Australian trees but lignicolous lichens are not uncommon. We have four species of the latter from Koonamore, all growing on the dead decorticated stems of shrubs, generally *Cassia* bushes.

Parmelia caperata Arch. is the most common, covering the stems over lengths of 2 inches or more. Less abundant, but forming even larger patches when it does occur, is the golden-yellow *Candelaria concolor* Wain. *Theloschistes chrysophthalmus* Th. Fr. and an undetermined species of *Calopacea*, the latter with a partially submerged thallus, are the two other species.

9. Factors Affecting Regeneration.

After regular observations upon the regeneration of the flora of the Reserve extending over five years it is possible to arrive at certain conclusions as to the factors which affect the regeneration rate.

The change in the soil condition which has followed erosion due to the removal of the perennial vegetation has destroyed the seed-bed over a large part of the area. The hard loamy soil, having lost its surface mulch, offers particularly great difficulties to the establishment of any seedlings. Anything favouring the accumulation of litter or blown soil helps to develop a seed-bed. The abundance of seedlings and their much more thrifty growth in and amongst fallen bushes or even the mounds of soil held by stumps and dead plants are very marked. We have drawn attention to this in our work on *Stipa* (1931), and reference may be made to some of the quadrats figured there (e.g., Text-figs. 3 and 5).

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* We are indebted to the Royal Botanic Gardens, Kew, for naming the lichens which were forwarded at the suggestion of the Director, after his visit to Koonamore in December, 1927.

Obviously high temperatures, strong winds and low rainfall are climatic factors that have harmful effect upon the growth of plants, especially on herbaceous plants or seedlings of perennials. What is less to be expected in arid Australia is the effect of low temperatures and heavy rainfall, yet both are experienced, as is shown by the climatic data that we have given. The effect of frosts in checking the growth, especially of the herbage during the winter months, has frequently been noted by us.

On three occasions during the progress of our work has there been a rainfall of 3 inches or more within 24 hours. In 1928 and 1929 these falls were more than half of the total precipitation for the whole year. Such heavy falls cause destruction of the seed-bed. The surface soil is removed over large areas and deposited as sand or silt upon others. The heavy rainfall of December, 1929, was definitely harmful to the regeneration of *Atriplex* on quadrat No. 100, for the hard loam was scoured severely by the violence of the rain. On the other hand, areas receiving a considerable deposit of silt are also unsuitable for the growth of plants. There are extensive areas in the south-west corner of the Reserve, which have been flooded regularly after heavy rainfalls, but upon which no germination has occurred.

The most aggressively harmful factor to the regeneration of woody plants has certainly been the rabbit. Of the 42 seedlings of both species of *Cassia* recorded in February, 1930, on quadrat No. 6–80, only two, both *Cassia eremophila*, survived until June, 1931. Quadrat No. 200 suffered severely from rabbit damage, for a burrow was established in the sand-hill near its north-western corner. Only 10 of the 48 *Cassia eremophila* seedlings recorded upon it in February, 1930, survived till June, 1931. These had all been eaten back and were still showing their juvenile foliage on short secondary shoots growing from the crown of the roots. *Cassia* seedlings of similar age on quadrat No. 300 were at that time bushes from 60 to 70 cm. high and some were coming into flower. The majority

TABLE 11.

Fire Regeneration Experiments.

Burns made 28/8/27. Areas first charted after rains of Feb., 1928.

N.B.—All seedlings occurred at margins of burns or, occasionally, on burnt areas. None recorded within enclosures away from the fire influence.

No. of Experiment.	Fenced.		22/6/28.	14/12/28.	9/6/29.	20/3/31.
F.R.2	Yes.	*Ac. aneura.*	3	4	4	4
		Ac. Burkittii.	1	2	4	3
		C. eremophila.	2	2	2	3
F.R.4	Yes.	*Ac. aneura*	16	16	18[1]	1
		Ac. Burkittii	2	2	1	—
		C. eremophila	10	12	13	10
		C. Sturtii	2	3	2	3
F.R.6	Yes.	*Ac. Burkittii*	1	1	1	1
		C. eremophila	8	6	5	5
		C. Sturtii	6	11	12	11
F.R.7	No.	*Ac. aneura*	4	2	—	—
F.R.8	No.	*C. eremophila*	4	2	1	—
		C. Sturtii	11	13	1	—

[1] On the night 4–5 July, 1929, a rabbit burrowed under the netting and ate all the mulgas.

of the *C. Sturtii* seedlings on quadrat No. 100, recorded in February, 1930, were growing as sturdy young plants in June, 1931.

Table 11 gives the history of five of the experimental burns started to stimulate germination of mulga and other shrubs. It is seen that only when the area was protected by netting was there any survival of the young shrubs for one season. The amount of damage that a single rabbit can cause is seen from the records of quadrat No. F.R.4. There 18 one-year-old mulgas were destroyed in a single night. Until some means of controlling the rabbit is discovered, all hope of regeneration of woody perennials is vain.

Summary.

1. The investigations described in this paper were conducted at the Koonamore Vegetation Reserve in the north-eastern district of South Australia during the period May, 1926, to June, 1931. The Reserve is the Arid Flora Research Station of the University of Adelaide. The work herein described was aided by a grant from the Commonwealth Council for Scientific and Industrial Research from March, 1928, to June, 1931.

2. The Reserve is shortly described and its soils discussed.

3. The following meteorological data are given for the area: mean rainfall; monthly rainfall, number of rainy days and falls exceeding 25 points, 1925–31; temperature records, and relative humidities March, 1927, to June, 1931, and saturation deficits.

4. The methods of investigation are described, particularly a series of permanent quadrats.

5. Some account of the biology of the plants is given.

6. Results as to the distribution and regeneration of the principal trees and shrubs, also the dominants of the Chenopodiaceous shrub-steppe, are described.

7. The sequence and abundance of the herbaceous plants is described, with special reference to two 1 sq. m. permanent quadrats.

8. Regeneration of the perennial flora is found to be a slow process, the rate of which is much influenced by the recurring droughts. Rabbits are found to prevent almost completely the regrowth of woody perennials.

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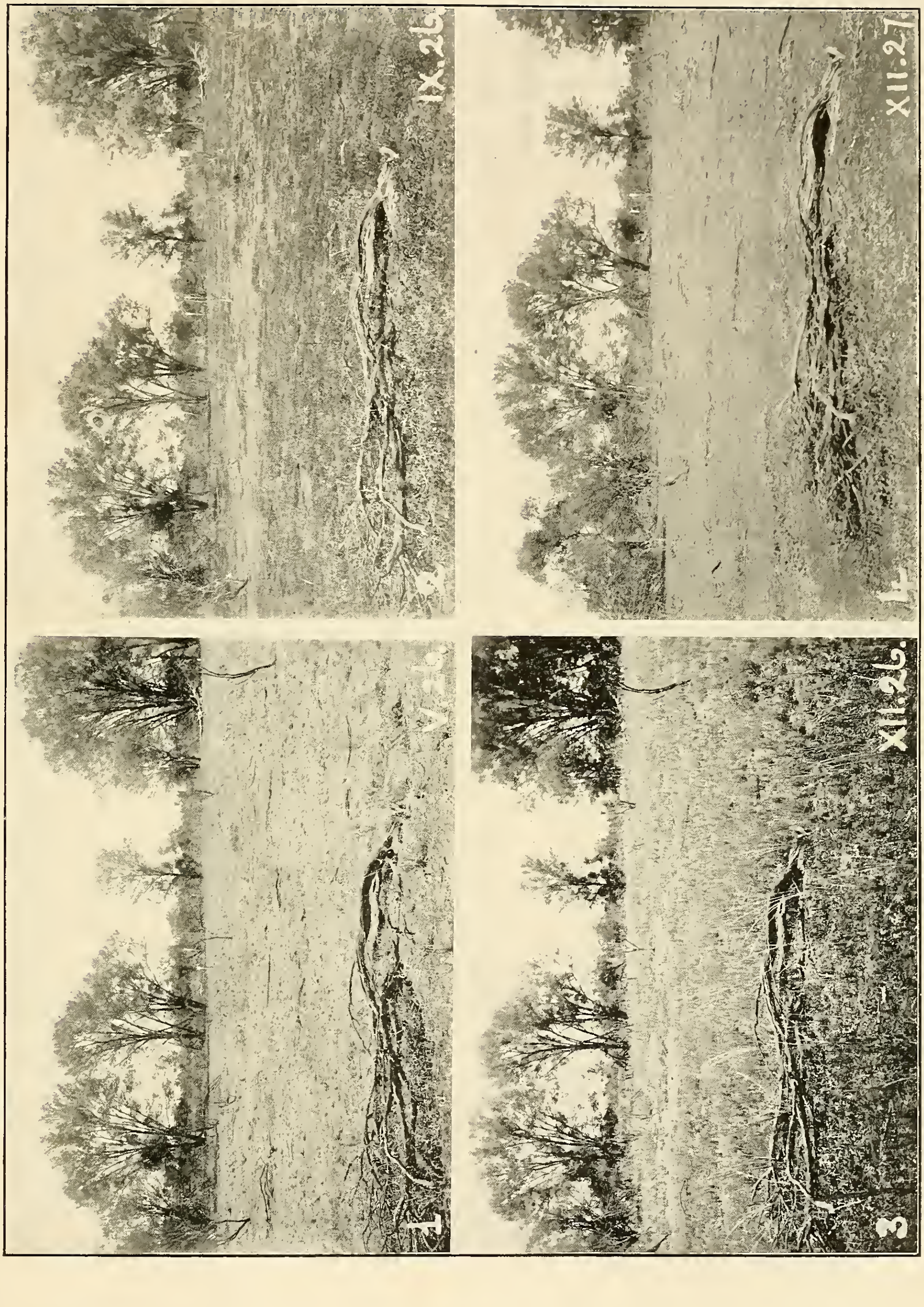

Koonamore Vegetation Reserve. Quadrat 200.