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Surveys of the Distribution and Density of Kangaroos in the Pastoral Zone of South Australia, and their Bearing on the Feasibility of Aerial Survey in Large and Remote Areas

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Abstract

Kangaroos were censused from the air in 1978, and again in 1979, within the pastoral zone of South Australia, an area of 242,000 km^2, three and a half times the size of Tasmania. Logistical problems were minimal despite the remoteness of much of the area, but more than half the time in the air was spent in flying to and between transects. Red kangaroos occurred throughout the zone at the mean density of 4·62 km^{-2}. Western grey kangaroos averaged a density of 1·22 km^{-2} over the whole area but were restricted to its southern half. Although the area was sampled at the low intensity of 1·3% the estimates were reasonably precise, that for red kangaroos having coefficient of variation of 7% at each survey, that for grey kangaroos, 13%. Estimated numbers did not differ significantly between years. Maps of density and distribution are given for each species. The cost of such a survey is around 6c per km^2 for each 1% of sampling intensity.

Introduction

We report the results of two aerial censuses of red kangaroos, *Macropus rufus*, and western grey kangaroos, *M. fuliginosus*, in the pastoral zone of South Australia, an area of approximately 242,000 km^2. The surveys had these aims:

(1) to estimate the size of these populations for purposes of setting harvesting quotas;

(2) to determine how precise an estimate could be obtained from an extensive survey with low sampling intensity;

(3) to check by repeating the survey whether there had been a detectable change in numbers over the intervening year;

(4) to establish regional variation in density within the pastoral zone;

(5) to gauge the magnitude of the logistical problems facing an extensive survey of a remote area;

(6) to determine the economic feasibility of a scanning survey of this kind.

Methods

The pastoral zone was surveyed between 10 August and 8 October 1978, and again between 15 August and 29 September 1979, by standard methods for aerial survey of kangaroos (Caughley *et al.* 1976; Caughley 1977; Grigg 1979). Lines flown on both surveys are shown in Fig. 1.

For estimation of regional densities the area was subdivided into 17 blocks corresponding to map sheets (1 : 250,000 series) or bounded by natural geographic features (Fig. 2). The area of each block and the intensity with which it was sampled are given in Table 1. In the estimation of block areas and kangaroo densities, large lakes have been excluded from the area: Torrens, Harris, Everard, Gairdner, MacFarlane and Island Lagoon. All other lakes are included in the estimates of block areas. Parts of the Woomera Restricted Airspace are excluded from the survey area, specifically a small area between Woomera and Island Lagoon designated R.242 by the Department of Transport, and that part of R.239

within a box area Kingoonya–Mt Eba–Parakylia–Roxby Downs–Woomera (Fig. 2). Also excluded are the Flinders Ranges above the 500-m (1640-ft) contour because of the difficulty of flying over steep terrain at a constant height above ground. These exclusions reduced the survey area from about 242,000 to 207,000 km^2.

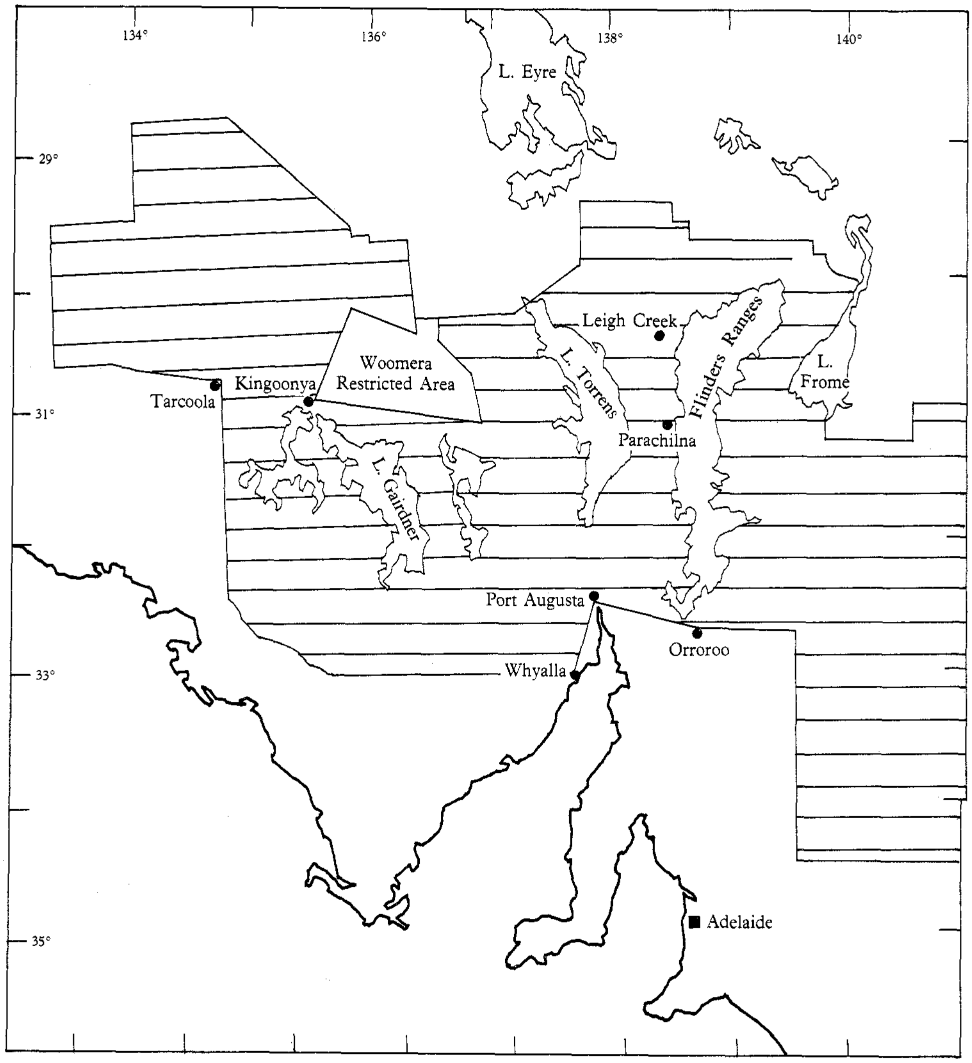

Fig. 1. The survey area in the pastoral zone of South Australia, and the transect lines.

Counting Procedure

The survey team comprised a pilot-navigator (G. C. G.), a front-right observer (G. J. C.), a back-left observer (R. G. Sinclair, P. Harlow or G. Ross) and a trainee observer in the back-right position (G. Ross, P. Harlow or L. Smith). Counts from the latter position were not used in estimating numbers. An observer was graduated to operational counting only after he or she had logged 50 h as a trainee.

Kangaroos were counted on parallel east–west transects spaced at 28-km (15 nautical mile) intervals, from a height above ground of 76 m (250 ft) and at a ground-speed of 185 km h^{-1} (100 knots). Width of transect was demarcated for each observer by two streamers attached to the wing strut. Between these the observer viewed a strip of 200 m on the ground when the plane was at survey altitude. For two observers, the transect was 400 m wide and of variable length. After each 5 km of track (a distance covered in 97 s) an electronic timer triggered a whistle that lasted 7 s. In those 7 s the observer wrote down the tally and checked with the other observer that they agreed on the serial number of the segment. The track covered in the pause for recording was excluded from the area of the transect.

The transect therefore comprised a series of 2-km^2 segments (5 km long by 0·4 km wide), each of which was separated from the next by a gap of 370 m. The position of a segment can be located accurately on a map and hence variation in density can be followed along a transect. This aspect

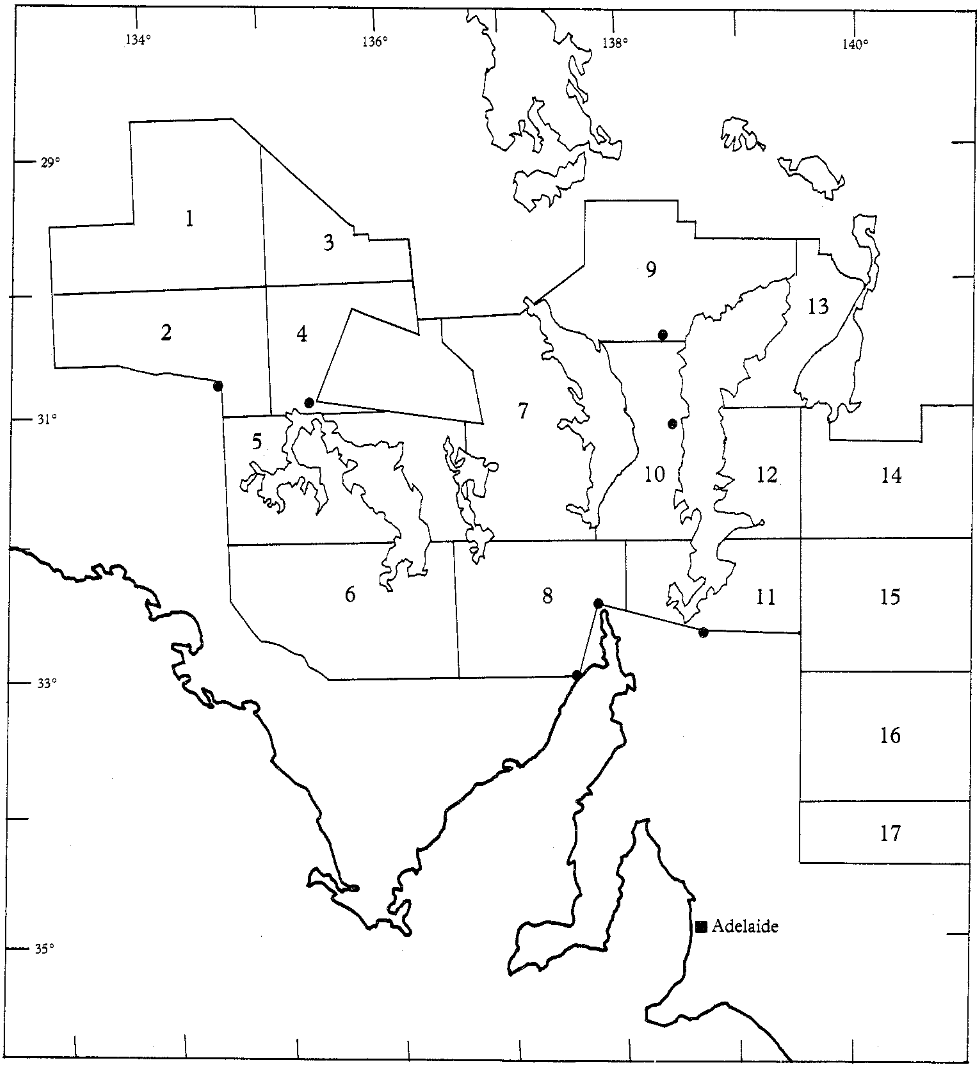

Fig. 2. The survey area showing the survey blocks. For place-names, see Fig. 1.

of the design was utilized in producing the density distribution maps. However, for purposes of calculating number of kangaroos per block, the segment counts were pooled and the data analysed on a transect basis.

Counts over open country were multiplied by 2·29 and those over wooded country by 2·43. In conditions of intermediate visibility a factor of 2·36 was used. Derivation of these factors to correct for kangaroos missed by observers is given in Caughley *et al.* (1976). The factor of 2·43 is probably too low for the mallee country of block 6, and consequently the estimates from there are conservative.

Analysis

This notation is used:
a, area of a transect, in km^2;
A, area of the block, in km^2;
N, total number of transects that could be fitted into a block;
n, number of transects sampled;
y, counts of animals (corrected for visibility bias) on a transect;
s^2, variance of corrected counts among transects within a block;
$\hat{Y}$, estimated number on the block;
SE($\hat{Y}$), standard error of estimated numbers;
$\hat{D}$, estimated density per km^2 on a block;
SE($\hat{D}$), standard error of estimated density.

Table 1. Areas of the survey blocks, and sampling intensities

Block	Area (km^2)	Sampling (%)	Block	Area (km^2)	Sampling (%)
1	18340	1·31	10	9150	1·29
2	13810	1·30	11	8650	1·43
3	7300	1·23	12	6250	1·18
4	7380	1·17	13	6190	1·00
5	16160	1·44	14	13140	1·29
6	17350	1·33	15	15500	1·30
7	15990	1·20	16	15400	1·30
8	13820	1·27	17	7400	1·35
9	15330	1·23			
Total area 207,160 km^2			Mean sampling rate 1·29%		

Blocks 15, 16 and 17 are rectangles which could be sampled by transects of fixed length. The advantage of so doing lay in the resultant estimate and its variance being largely free of statistical bias. Each transect comprised 25 segments and hence had an area of 50 km^2. N is estimated simply as A/a. Density per km^2 is given by:

$$\hat{D} = \Sigma y/(an),$$

with a standard error of:

$$\text{SE}(\hat{D}) = \sqrt{\{[(N - n)s^2]/(Ana)\}}.$$

Estimated numbers per block and its standard error are solved as:

$$\hat{Y} = (N\Sigma y)/n, \text{ and}$$

$$\text{SE}(\hat{Y}) = \sqrt{\{[N(N - n)s^2]/n\}}.$$

Note that the standard errors are calculated to reflect sampling without replacement, and that a in this analysis is constant (= 50).

Data from the remaining blocks called for a more elaborate analysis termed the Ratio Method. We first calculated what would be the width of a transect if, instead of being a series of spaced segments 400 m wide, it was a continuous strip with area equal to the summed segments. Since 94% of time on track was spent observing, the 'equivalent width' of a continuous strip would be 94% of 400 m, which is 376 m or 0·276 km. N is now estimated as the total north–south extent of a block in kilometres, divided by 0·376. Block 1, for example, has a north–south extent of 137 km and so the number of east–west 'equivalent' transects that could be fitted into it is: $N = 137/0\cdot376 = 364$ transects.

In contrast to the previous analysis, a, the area of a transect, is now a variable whose value is specific to each transect. First we estimate density per square kilometre as:

$$\hat{D} = \Sigma y/\Sigma a,$$

and then a supplementary variable, G:

$$G = \Sigma y^2 + \hat{D}^2\Sigma a^2 - 2\hat{D}\Sigma ay.$$

From these:

$$\mathrm{SE}(\hat{D}) = \sqrt{\{[N(N-n)G]/[A^2n(n-1)]\}},$$

$$\hat{Y} = A\hat{D}, \text{ and}$$

$$\mathrm{SE}(\hat{Y}) = \sqrt{\{[N(N-n)G]/[n(n-1)]\}}.$$

Table 2. Estimated densities and numbers of red kangaroos in 1978 and 1979

Values are given ± standard errors

Block	1978		1979	
	Density per km²	Numbers	Density per km²	Numbers
1	2·11±0·31	38600±5800	2·50±0·58	45900±10700
2	2·14±1·16	29500±16000	4·44±1·12	61400±15400
3	2·23±0·95	16300±7000	3·21±0·93	23400±6700
4	2·08±0·76	15400±5500	4·52±1·28	33400±9400
5	1·24±0·11	20000±1700	2·76±0·91	44600±14600
6	0·08±0·04	1300±700	0·70±0·36	12100±6200
7	2·85±0·82	45500±13100	4·87±0·74	77800±11700
8	3·41±1·06	47100±14600	2·40±0·57	33200±7900
9	7·89±1·10	121000±16800	10·46±2·43	160400±37300
10	10·22±1·05	93600±9600	8·44±1·87	77200±17100
11	2·99±1·22	25900±10500	6·28±1·10	54300±9500
12	8·60±3·16	53700±19800	6·07±2·58	37900±16100
13	8·66±1·33	53600±8200	9·82±0·54	60800±3300
14	14·36±2·81	188700±36900	11·59±2·60	152300±34200
15	8·67±1·01	134400±15600	7·02±0·96	108800±14800
16	1·84±0·82	28300±12800	1·11±0·30	17100±4700
17	0·00	0	0·00	0
Total	4·41±0·28	912800±58900	4·83±0·32	1000600±66300

Depending on the strength of correlation between y and a, and the trend of variance along the regression of y on a, estimates by the ratio method may be statistically biassed, particularly if n is low. This problem was investigated by use of Cochran's (1963) formula 6.14 to estimate relative bias for the 1978 survey. Estimated bias, averaged over 14 blocks, was $-1\cdot53\% \pm 0\cdot93\%$ for red kangaroos, and $-2\cdot35\% \pm 1\cdot23\%$ over nine blocks for grey kangaroos. Since neither differs significantly from zero we are satisfied that statistical bias generated by the ratio method is so slight as to be inconsequential.

Differences in density between years and between blocks were tested separately for each species by analysis of variance. An unweighted-means analysis was used because the number of transects varied by block. There were three factors: blocks, years, and lines within blocks. The first two factors are fixed, the third being ran-

Table 3. Summary of analysis of variance comparing red kangaroo densities by blocks and by years

Source	Sum of squares	Degrees of freedom	Mean squares	Variance
Between lines		68		
Blocks	1729·592	15	119·506	9·61***
Lines within blocks	659·452	53	12·442	
Within lines		69		
Years	24·014	1	23·014	2·75 NS
Years × blocks	85·266	15	5·684	0·68 NS
Years × lines within blocks	444·320	53	8·383	

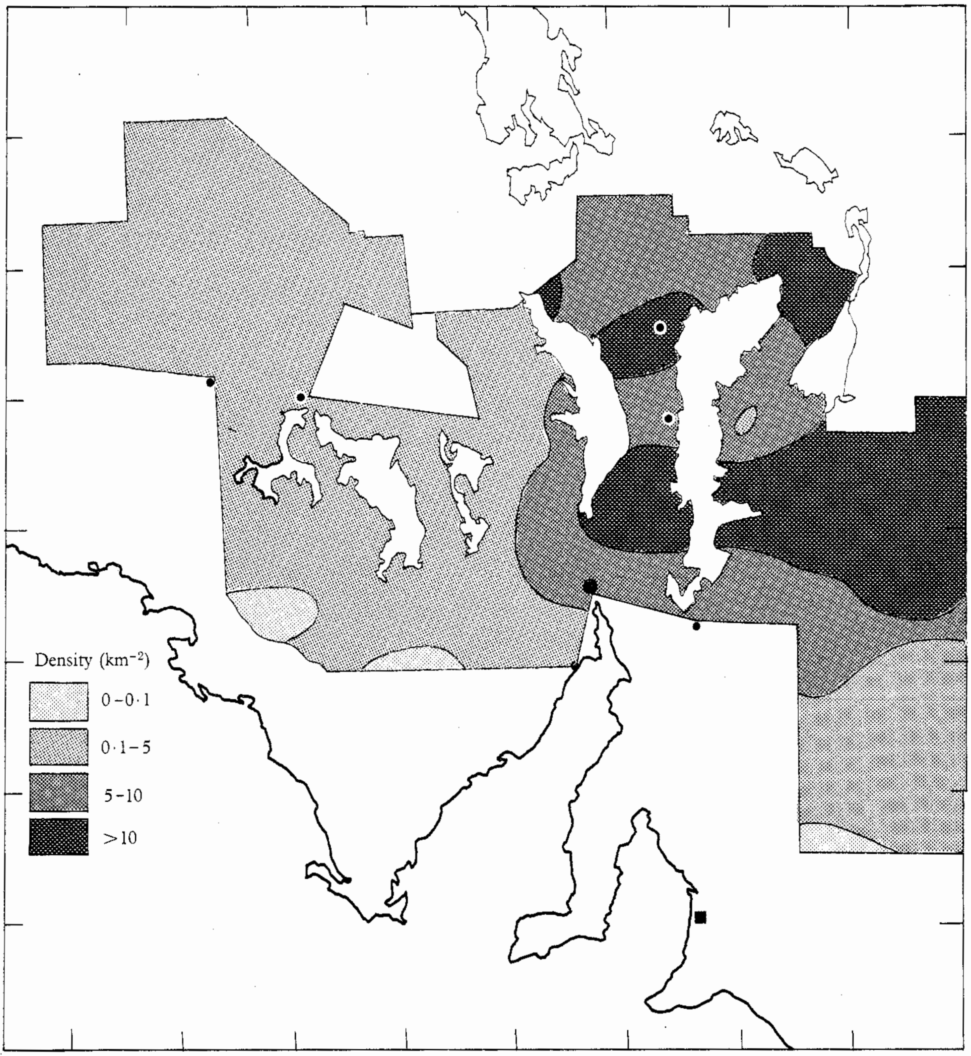

Fig. 3. The distribution of red kangaroo density in the survey area.

dom with repeated measurements on its levels. The model is detailed by Winer (1971, p. 602).

The analysis of red kangaroo densities included all blocks other than block 17; that for greys was restricted to blocks 5, 6, 8, 11, 15, 16 and 17. Input data were densities per square kilometre corrected for visibility bias, each line within a block contributing a single density in each of the two years.

Results

Red Kangaroos

Table 2 gives estimates of density and numbers of red kangaroos in each block in 1978, together with the standard errors of these estimates. They sum to an estimate of 913,000 ± 59,000 for the pastoral zone at an overall density of 4·41 ± 0·28 km^{-2}.

Table 4. Estimated densities and numbers of grey kangaroos in 1978 and 1979

Values are given ± standard errors

Block	1978		1979	
	Density per km^2	Numbers	Density per km^2	Numbers
1	0·00	0	0·00	0
2	0·13±0.02	400±300	0·00	0
3	0·00	0	0·00	0
4	0·00	0	0·06±0·06	400±400
5	0·47±0·19	7600±3000	0·53±0·28	8600±4400
6	5·58±1·44	96800±25000	3·79±0·67	65800±11600
7	0·45±0·30	7200±4700	0·62±0·37	9900±6000
8	3·27±0·13	45200±1800	3·37±0·80	46600±11000
9	0·00	0	0·00	0
10	0·10±0·08	900±700	0·00	0
11	0·96±0·25	8300±2100	0·96±0·27	8300±2400
12	0·07±0·06	400±300	0.00	0
13	0·00	0	0·00	0
14	0·03±0·01	400±200	0·04±0·03	500±400
15	1·13±0·28	17400±4300	1·00±0·33	15500±5100
16	6·27±1·47	96600±22600	3·74±1·37	57600±21000
17	1·17±0·82	8700±6100	0·39±0·15	2900±1100
Total	1·40±0·17	289800±35100	1·04±0·14	216100±28100

The equivalent estimates for 1979 sum to 1,000,000 ± 66,000 (Table 2). The difference was tested for significance by analysis of variance (Table 3) which showed that densities differed significantly between blocks but not between years. Neither did years and blocks interact.

Fig. 3 is a smoothed density distribution map compiled from the 1978 data. The highest densities (>10 km^{-2}) were restricted to the east of the area, on both sides of the Flinders Range. Medium densities (5–10 km^{-2}) generally border on or interdigitate with the zone of high density. Very low density or absence (<0·01 km^{-2}) were recorded only in the south-east and south-west corners of the pastoral zone.

Table 5. Summary of analysis of variance comparing grey kangaroo densities by blocks and by years

Source	Sum of squares	Degrees of freedom	Mean squares	Variance
Between lines		24		
Blocks	157·207	6	26·201	6·25**
Lines within blocks	75·422	18	4·190	
Within lines		25		
Years	5·126	1	5·126	3·74 NS
Years × blocks	2·210	6	0·368	0·27 NS
Years × lines within blocks	24·668	18	1·370	

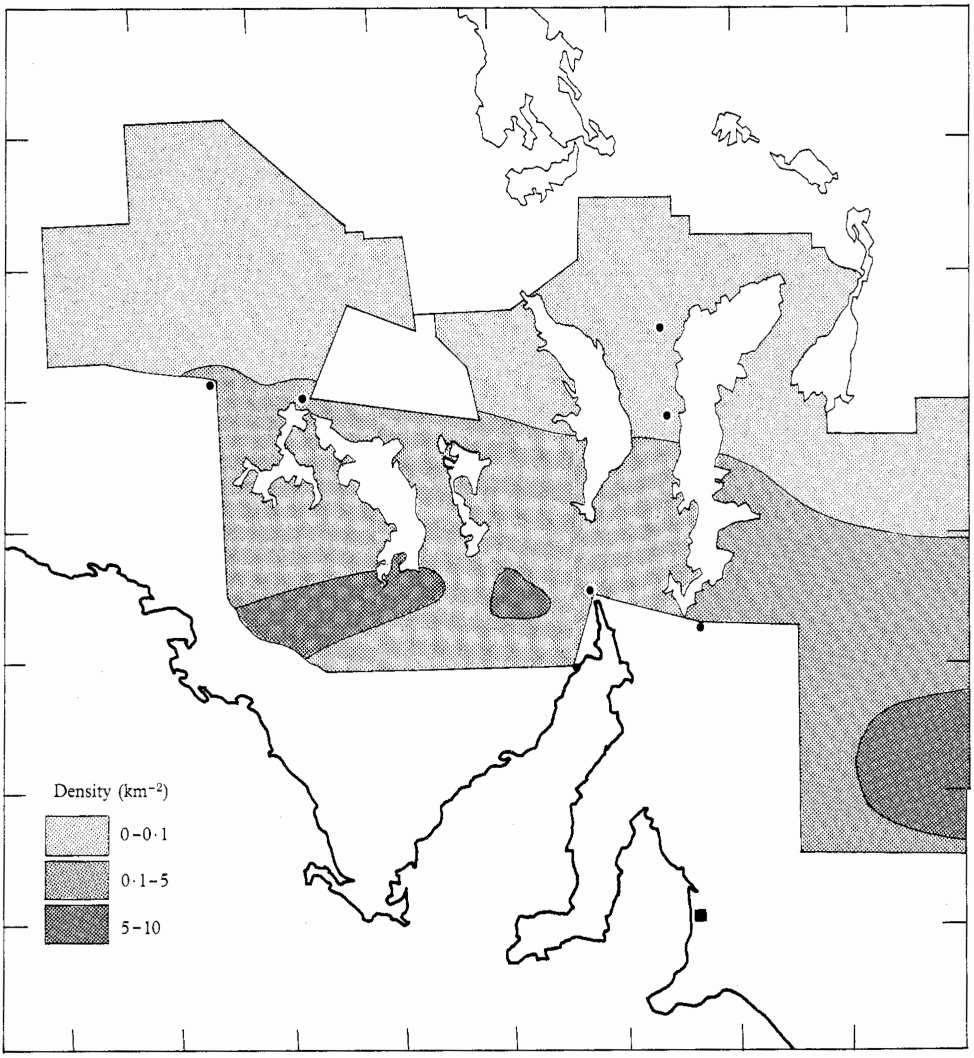

Fig. 4. The distribution of grey kangaroo density in the survey area.

Grey Kangaroos

There is no record of eastern grey kangaroos, *Macropus giganteus*, in the pastoral zone of South Australia although they occur in a small part of the state south of that zone and also in adjacent parts of New South Wales (Poole 1977). A ground survey was mounted in February 1979 to check for eastern grey kangaroos along the South Australian side of the South Australia–New South Wales border, but none were found in the pastoral zone as here defined, although Poole (personal communication) took a specimen north of it in 1977. We assume therefore that all grey kangaroos counted by us were western greys, *M. fuliginosus*.

Table 4 gives estimates by blocks for 1978 and 1979. An estimated total of 290,000 in 1978 was reduced to 216,000 in 1979, but the difference just failed to reach significance at the 5% level of probability (Table 5).

The density distribution map of Fig. 4 shows that grey kangaroos were not seen in the north of the pastoral zone. Note that the 'effective boundary' of distribution is set at the isopleth of 0·1 kangaroos per square kilometre. This map of distribution is very similar to that given by South Australian National Parks and Wildlife Service (1974) but both differ from Poole's (1977) map. The anomaly reflects only the source of Poole's data: the localities recorded for museum specimens taken in South Australia.

Logistics and Costing

The survey was broken into a set of sessions flown from centres where an airstrip, fuel and accommodation were available. We used Waikerie, Broken Hill, Leigh Creek, Parachilna, Port Augusta, Coober Pedy and Kingoonya. Fuel was readily available at all these other than Parachilna and Kingoonya, where we arranged prior delivery of drum fuel.

The Cessna 182 used on these surveys had an endurance of 360 min, allowing sessions airborne of up to 5 h. Placement flights to and from survey areas and between transects were flown at 120 knots while the transects were flown at 100 knots.

The time required to complete a survey averaged 102 h in the air. Of this, 20 h were spent travelling twice between Sydney and South Australia on each survey, 44 h were expended on placement flights within South Australia, and 38 h were spent on the transects. Hence the actual surveying accounted for less than half of the hours in the air required to complete a survey, a fact that is germane to costing future surveys of this kind. Total flying time should be calculated as about 0·0004 h per square kilometre of survey area, for each 1% of sampling intensity applied.

Costing is calculated on the basis of a chartered aircraft flown by a commercial pilot. Two operational observers and a trainee observer complete the team. Overheads such as the cost of administration, office facilities and additional insurance are not included. Overtime is not paid. We assume that the pilot does not exceed his legal limit of flying hours, and that rest days for observers and time lost to adverse weather are absorbed entirely by the pilot's legally enforced proportion of time on the ground. The survey would then take 21 days.

At 1979 prices, the approximate costs are as follows:

Survey	$	
Charter of Cessna 182 and cost of fuel: 102 flying hours at $54	5508	
Pilot: 21 days at $100	2100	
Biologist: 21 days at $110	2310	
Experimental officer: 21 days at $70	1470	
Technical officer: 21 days at $50	1050	
Living allowance: 4 × 21 days at $35	2940	
Charts, data forms, etc.	130	
Fuel depot opening fees	210	
Travel on ground	190	
Telephone calls	150	
Total for survey		16,058
Analysis and report preparation		
Biologist: 6 days at $110	660	
Computing	200	
Total for analysis		860
Total		16,918

This costing should be broadly applicable to similar extensive surveys in the arid and semiarid zones. Enough detail is given to allow modification of this list according to local and special circumstances in other parts of Australia. One major difference is the proportion of unsurveyed areas within the study area in South Australia (high ranges, large lakes and restricted military zones), greater than in most other states. We have costed the survey as if it were a single block of 207,000 km^2, but in reality that area is discontinuous within a larger area of 242,000 km^2. The unsurveyed areas add to the costs because they must be flown over or around to get at the surveyed areas.

The cost of an aerial survey of the pastoral zone of South Australia can be summarized as 102 flying hours at $165 per hour, or as 6655 km of transect at $2.50 per kilometre, or more meaningfully as 207,000 km^2 of area surveyed at a cost of 6c per square kilometre for each 1% of sampling intensity.

Discussion

The density of red kangaroos was estimated as 4·41 km^{-2} in 1978 and 4·83 in 1979, to give an average of 4·62 km^{-2}, a figure comparable with the density of 4·18 estimated by similar methods on the western plains of New South Wales in 1975 (Caughley *et al.* 1977). The two estimates from South Australia each have a coefficient of variation of around 7%, a precision more than adequate for monitoring the effect on numbers of the drought cycle and commercial harvesting.

The density of grey kangaroos was estimated as 1·40 km^{-2} in 1978 and 1·04 in 1979 in the pastoral zone as a whole, but they were restricted to the southern half of the area (Fig. 4). Coefficients of variation for these estimates were around 13%.

The logistical problems anticipated in the survey of a large and remote area such as this did not, in fact, eventuate. We attribute this to careful planning before the survey, to the use of long-range tanks, and to a smattering of luck.

At a sampling intensity of 1·3% the aerial surveys cost $0·08 per km^2. We would be astonished if any alternative method approached that economy. This study indicates that extensive aerial survey is a feasible, cheap and precise means of monitoring kangaroo populations in remote areas.

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