Quantitative Assessment of Grazing Behaviour of Sheep in Arid Areas[1]

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Highlight

Five indices are suggested to quantify components of spatial distribution of grazing sheep which were observed by aerial photography. Indices based on sheep numbers were more sensitive to environmental changes than those based on distances between sheep. It is suggested that the adjustment takes place by a change in the numbers within independently grazing flocks, while social contact between sheep, as reflected by various nearest-neighbour distances, remains unaltered.

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There is little knowledge of social organisation in husbanded sheep, except that when a number of sheep of the same age, breed, and sex are introduced to a paddock, they may split up into a number of groups. The members of groups are constantly changing (Arnold and Pahl, 1967). Reasons for the split up are varied: age, sex, and breed on the one hand, topography and feed supply on the other, together with the interactions of animal, environmental, and management factors. It is apparent that there is contact between individuals within the groups and between groups, the latter being distance-dependent. What is not known is how contact is maintained and over what distance, (a) between individuals, (b) between groups. There is no experimental evidence to define the distances over which the senses can be used for discrimination. However, from observation, smell is used at close hand for recognition, and hearing over quite long distances (< 800 yards) (Arnold, unpublished). The distance over which sheep can see and discriminate appears to be fairly short, but from 'sight height' i.e. 1 to 2 ft above ground distance will be limited by topography.

This paper attempts to relate the spatial distribution of sheep within paddocks in arid areas to the general condition of the range in north-west

Table 1. Kayrunnera, May 1967 survey.

Paddock	Size (acres)	Type of sheep	Number of sheep	Weather condition and mean time of sampling							
				May 9				May 10			
				AM		PM		AM		PM	
				Time	Temp (°F)	Time	Temp (°F)	Time	Temp (°F)	Time	Temp (°F)
Hilton	10,000	Ewes and Lambs	350	9:25		3:40		9:20		3:35	
Ocean Dam	10,000	Ewes and Lambs	350	9:15		3:35		9:15		3:35	
					60		75[1]		60		80[1]
Woolshed	12,000	Weaner Ewes	600	9:15		3:25		9:15		3:35	
Gilbys	10,000	Ewes and Lambs	420	8:45		3:30		8:45		3:35	

[1] Sunny, slight wind.

New South Wales. Due to the large size of paddocks (about 10,000 acres) and low stocking rates (between 30 and 40 sheep/mile^2), the most suitable method of sampling the experimental areas was considered to be aerial photography. It was established by means of pre-survey flights that from the altitude of 700 ft: sheep were not disturbed by the aircraft noise; all members of the aggregates defined as flocks were covered by a single photograph; on most occasions when one flock was sighted no other flocks were seen; on rare occasions, when more than one flock could be sighted simultaneously, they were separated by a considerable distance. Therefore individual photographic records were regarded as independent sampling units for the purpose of statistical analysis. For each photograph, indices, based on the number of sheep and the distances between sheep on the photograph, were computed, which quantified components of the spatial distribution of sheep.

Methods and Materials

A review of Dudziński and Arnold (1967) is necessary to achieve a full understanding of this paper, thus some parts of the 1967 paper are summarised in sufficient detail to render the present paper self-contained.

The main aims of the 1967 paper were to establish the advantages of studying behaviour patterns of grazing animals by aerial photography, and to detail the methods of sampling and the subsequent processing of the data. The method of photographic sampling of a paddock consisted of (1) searching a quarter of the paddock for a flock of sheep, (2) on spotting a flock, taking a vertical photograph at 700 ft altitude, (3) then proceeding to another quarter of the paddock before searching for another flock, thus further ensuring that individual photographs could be regarded as independent units. The method of processing the photographic information was to enlarge photographs to 10 × 10 inches, superimpose a grid with 0.25-inch spacings (i.e. 40 × 40 grid), and record, on Hollerith punch cards, the coordinates of the positions of each sheep. Values of the following indices were then obtained for each photograph: (1) the number of sheep per photograph = flock, (2) the mean number of sheep per occupied cell of the grid (theoretically 12.1 × 12.1 ft), and (3) the index of 'spread' (SD of the inter-sheep distances divided by the square root of flock). For details of the effects of (a) type of sheep (sex), (b) time of day (am vs pm), (c) time of survey (August vs November), and (d) different paddocks (within each of three localities, Kayrunnera, Mt. Murchison, and Mulberrygong, all in New South Wales) on the indices and further details concerning the data, see Dudziński and Arnold (1967).

Experimental Data.—The data used in this paper is the Kayrunnera data of Dudziński and Arnold (1967), together with data from further survey conducted at Kayrunnera in May 1967. Reference will be made to the data cited in Dudziński and Arnold (1967) without further explanation or comment. The details of the May 1967 survey are listed in Table 1. Whilst the same four paddocks were used as in previous surveys, some of the sheep previously at Gilby's were now at Hilton. It is of considerable importance to later discussion that the last survey was conducted after appreciable rains, whereas the previous surveys were conducted under extreme drought conditions (Fig. 1).

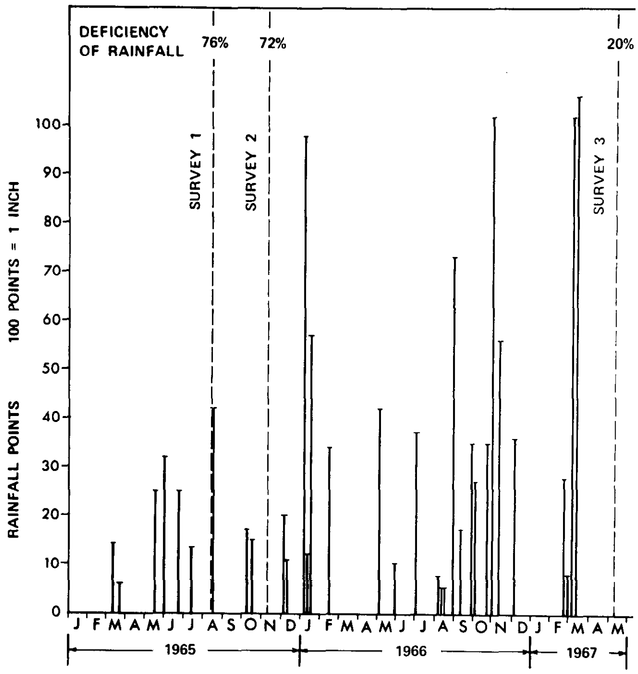

FIG. 1. Rainfall pattern for sampled site (Kayrunnera) with survey dates and corresponding rainfall deficits.

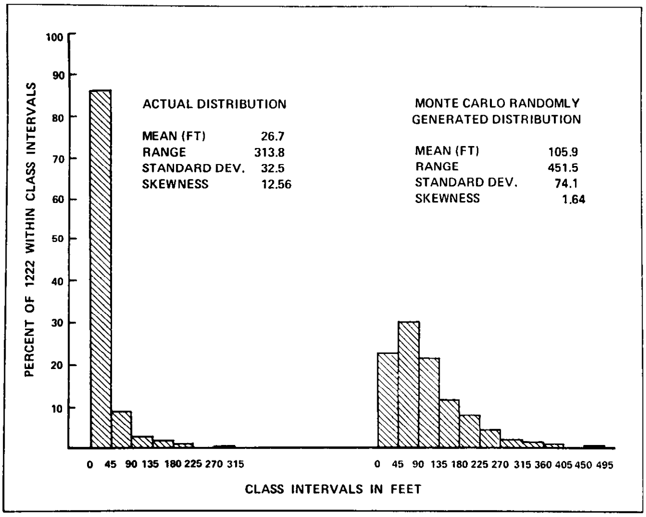

FIG. 2. Frequency distributions of nearest-neighbour distances of 1,222 sheep with basic parameters.

Spatial Distribution of Sheep.—The aim of this paper is to investigate changes in the spatial distribution of sheep in relation to changes in the general condition of the range. It is therefore necessary to quantify spatial distribution of sheep. Attention was concentrated in the previous paper on the development of the aerial photography technique. In this paper a set of indices, based on the number of sheep and the distances between sheep on each photograph, are defined, which quantify components of spatial distribution in a much more comprehensive and complete manner than the set described in the previous paper.

The 'Group' Concept.—Some of the indices to be defined involve the concept of a *group* of sheep in association with each other. Before proceeding to a definition of a *group*, it was necessary to verify whether sheep could be regarded as locating themselves independently and at random within the area photographed—if so, there would be little purpose in carrying the study any further. The contrary was, in fact, established as follows:

(1) The entire 1,222 nearest-neighbour distances for all sheep (over all surveys, and paddocks), were assembled in a frequency distribution.

(2) Corresponding to each photographic record, a simulated record was derived by using a Monte Carlo technique to assign random positions, one for each sheep. The simulation was obtained by the RANF subroutine (Webb et al., 1967). Both frequency distributions are given in Fig. 2.

If sheep were locating themselves at random within the areas photographed, it could be expected that the frequency distributions of Fig. 2 would closely conform. However, it is apparent that the shapes of the two distrubutions are widely discrepant, especially in the class (0–45 ft), where 86.5% of distances actually lie, as compared with only 22.2% for the simulated distribution. The difference in shape can be assessed by examining coefficients of skewness which are 12.6 and 1.6 respectively.

Due to the large preponderence of nearest-neighbour distances in the class (0–45 ft), it seemed reasonable to define a *group* as a collection of sheep, in which each sheep in the collection is at most 45 ft from at least one other sheep of the collection. In order to examine it in more detail the cumulative frequencies of the distribution in Fig. 2, expressed as percentages, of distances less than particular value are given in Table 2. While the increase in cumulative percentage is quite substantial for values less than 45, the increase in cumulative percentage is rather less for values greater than 45. Thus it is considered that 45 ft represents a reasonable estimate of the distance between nearest neighbours grazing in a cluster defined here as *group*.

Table 2. Percentage of 1,222 nearest-neighbour distances in increasing class intervals.

Class interval (ft)	0–25	0–30	0–35	0–40	0–45	0–50	0–55	0–60
% of 1,222	63.8	77.3	79.2	84.2	86.5	87.3	89.8	89.8

Indices of Spatial Distribution.—By comparing (a) paddocks (representing different habitats or contain different types of sheep), (b) three surveys (representing changes in range condition), (c) interactions of paddocks with surveys (representing interaction of habitats with range condition) the effect of weather and habitat is assessed. In order to study the effect of these environmental changes on spatial distribution, five indices are introduced, for each of which a value could be obtained from a single photographic record. Because of the assumed independence of photographic records it is contended that sheep of a particular photograph have no obvious contact with other sheep in the paddock, but are in association with themselves.

The actual indices fall into two categories:

(I) Three indices which are related to the number of sheep on the photograph, viz.
  (1) the total number of sheep on a photograph, denoted FLOCK (as in the 1967 paper)
  (2) the number of groups of sheep on the photograph, denoted NGROUPS
  (3) the average number of sheep per group on the photograph, denoted AVGROUP
  (clearly these three indices are functionally related by AVGROUP = FLOCK/NGROUPS)

(II) Two indices, which are related to distances between sheep on a photograph, viz.
  (4) the average nearest-neighbour distance of sheep, over all sheep which are contained in groups of size two or more within the flock, is denoted by ANNDW $= \Sigma d/$(FLOCK–S), where d is a *sheep* nearest-neighbour distance, and S is the number of groups with single sheep
  (5) the average nearest-neighbour distance of groups within a *flock*, over all groups, is denoted by ANNDB $= \Sigma D/$NGROUPS, where D is a *group* nearest-neighbour distance.

The applications of these indices are illustrated in Fig. 3a and 3b. Clearly, ANNDW is not relevant when there are no groups of size 2 or more (i.e. when no sheep on the photograph have a nearest-neighbour distance of less than 45 ft), and ANNDB is not relevant when all sheep are within one group (i.e. no sheep have a nearest-neighbour distance greater than 45 ft). This accounts for the lower number of observations for ANNDW and ANNDB in Table 3. Both ANNDW and ANNDB were computed from the hierarchical system computer program CLASS of Lance

Table 3. Actual and transform means of five indices of grazing behaviour with numbers of observations in brackets with significance levels and error variance (Kayrunnera, all surveys).

Paddock	FLOCK			NGROUPS			AVGROUP			ANNDW			ANNDB		
	Aug 65	Nov 65	May 67	Aug 65	Nov 65	May 67	Aug 65	Nov 65	May 67	Aug 65	Nov 65	May 67	Aug 65	Nov 65	May 67
Hilton	6.3	4.4	3.5	2.1	2.5	2.3	3.9	2.1	2.1	16.5	19.1	17.2	84.7	108.2	98.2
	(16)	(12)	(18)	(16)	(12)	(18)	(16)	(12)	(18)	(16)	(10)	(13)	(8)	(10)	(12)
Ocean Dam	5.5	4.2	5.8	2.2	2.5	2.4	3.7	2.8	3.0	17.2	19.8	17.8	83.4	106.9	96.9
	(16)	(10)	(20)	(16)	(10)	(20)	(16)	(10)	(20)	(15)	(9)	(19)	(9)	(6)	(12)
Woolshed	5.2	3.7	6.8	2.3	2.6	2.4	2.7	1.8	3.7	17.6	20.0	18.2	92.3	115.7	105.8
	(16)	(12)	(16)	(16)	(12)	(16)	(16)	(12)	(16)	(15)	(10)	(16)	(13)	(10)	(12)
Gilbys	6.4	7.2	12.5	2.4	2.7	2.6	3.1	3.0	8.9	15.8	18.5	16.5	88.4	111.8	101.9
	(15)	(10)	(17)	(15)	(10)	(17)	(15)	(10)	(17)	(14)	(10)	(17)	(12)	(8)	(10)
Grand Mean			5.7			2.4			3.5			17.9			99.5
Transform Mean			.756			.321			.443			1.241			1.957
Error Variance	.049 (160 df)			.059 (165 df)			.057 (160 df)			.028 (146 df)			.033 (117 df)		
Significant Source	Survey × Paddock Interaction ***			—			Survey × Paddock Interaction ***			—			—		

*** $P < .001$.

and Williams (1967). Given co-ordinates of individual sheep on a photograph, program CLASS prints out nearest-neighbour distances of pairs of sheep, then distances between pairs, groups of pairs, etc. Hence nearest-neighbour distances between individuals and any arbitarily defined groups can be easily read from the computer printout. The program prints out the squares of the distances.

It was found that the values of the indices defined above required logarithmic transformation in order to remove heterogeneity in the error variance, and to provide normal approximation to the underlying distributions of the indices. In case of ANNDW and ANNDB the transformation was Log + 1. A bias occurred due to the method of measuring distances between sheep, see Dudziński and Arnold (1967). Distances were computed by superimposing a rectangular grid on the photographs, with each unit of the grid representing an area 12.1 × 12.1 ft. If two or more sheep were present in the same cell of the grid, they were given the same co-ordinates, and hence these sheep would have been considered to be zero distance apart from each other. In fact, due to the size of each unit of the grid, sheep within the same cell, may be from 0 to 17 ft apart—thus to regard these sheep as being zero distance apart biases the distances. As an approximate correction for this bias, 0.5-grid units were added to the zero distances before using the program of Lance and Williams (1967). (0.5-grid units = approximately 8 ft.)

Results

The analyses of variance on the five indices, and a tabulation of the means of the indices tabulated by paddock and survey are given in Table 3. Mean squares in the analyses of variance are in transformed units, whilst the figures in the tables of means have been back-transformed to the original units. Since the second-order interaction (survey × paddock × time of day) was not significant, it has been pooled with the residual variation after removing all treatment effects.

There was a highly significant interaction ($P < 0.001$), between paddocks and surveys, for FLOCK and AVGROUP. There were no significant mean squares for NGROUPS, ANNDW and ANNDB.

Discussion:

The only available information on the condition of the range at the site under study was:

(a) the opinion of management of the station, and

(b) rainfall records.

As rainfall records are of a quantitative nature, it would seem reasonable to attempt an explanation of the results in the light of the information in them. The rainfall records for the period of study are given in Fig. 1, together with the percentage deficit of rain for the year at the time the surveys were conducted. The August 1965 and November 1965 surveys were conducted in a period of severe drought. The May 1967 survey at Kayrunnera was conducted after a reasonable recovery from the drought. As stocking rates in these areas are rarely changed, rainfall is the most important factor in determining the condition of the range.

The high survey by paddock interaction for FLOCK and AVGROUP could be attributed to the following:

(1) Hilton, the paddock usually in poorest condition, failed to recover from the severe drought occurring at the time of the first two surveys, and hence there was no significant change in the values of FLOCK and AVGROUP between November '65 and May '67.

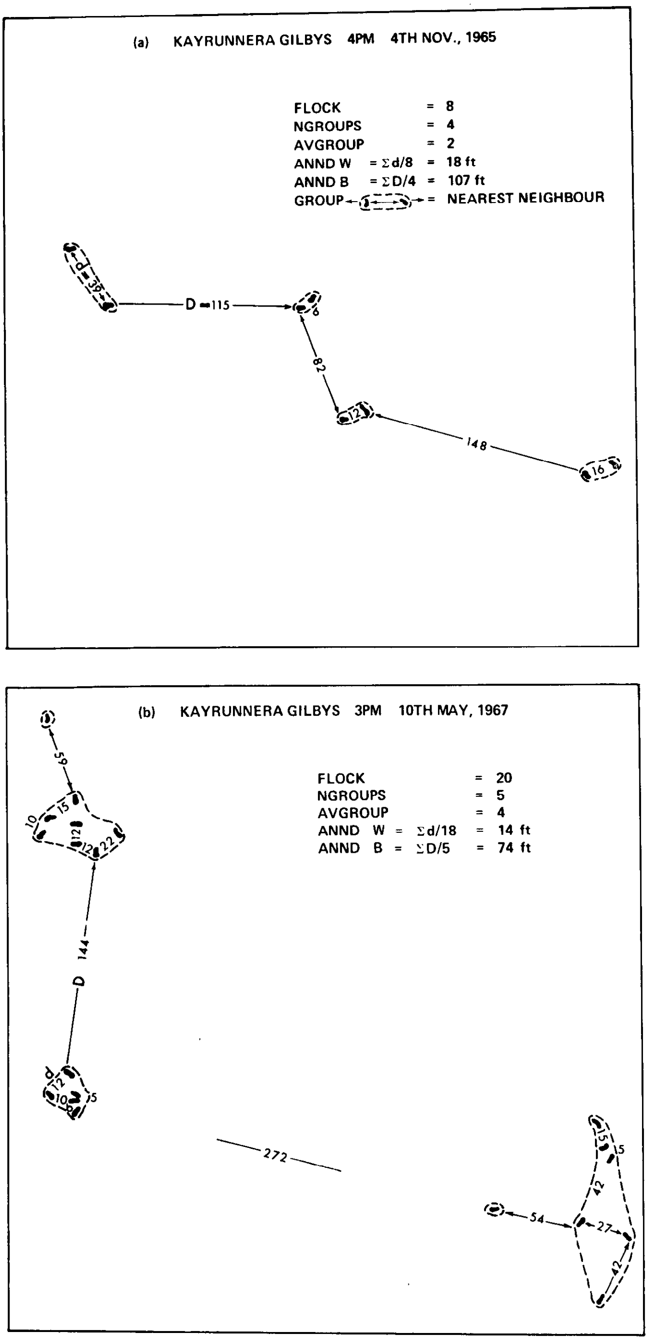

FIG. 3. Aerial view of the grazing patterns with five indices indicated. (a) Drought pattern, (b) Partial recovery from drought.

(2) Gilbys, the paddock usually in best condition, had sufficient reserve of feed available to leave sheep dispersion relatively unaffected during the drought period. Hence, Gilbys was the only paddock for which no drop occurred in FLOCK and AVGROUP between August '65 and November '65. In addition, the relieving rains before the third survey brought about a substantial increase in FLOCK and AVGROUP by May '67.

A general point of interest is which of the five indices vary between environments as reflected by different paddocks and successive surveys. It is assumed that where changes occur, the parameter is one that reflects adjustment to changes in the environment. A parameter that does not, probably reflects basic componet of social behaviour. The indices FLOCK and AVGROUP varied in different environments, whilst NGROUPS, ANNDW and ANNDB did not change. The fact that FLOCK and AVGROUP change whilst NGROUPS does not, indicates that as environmental stresses are relieved, the flock sizes (i.e. FLOCK) increases, accompanied by an increase in group sizes (AVGROUP) within flocks, but with the number of group (NGROUPS) within flocks remaining unchanged. This latter point is somewhat surprising since a negative relation would logically be expected. The maintenance of constant ANNDW and ANNDB would indicate (a) deliberate contact between groups (ANNDB), and (b) a basic distance is preserved between individuals within groups (ANNDW). These changes are illustrated in Fig. 3a and 3b. However, the reasons given for the changes must be regarded as speculative, until more detailed knowledge of the system is available and experimental controls are imposed. Our field observations indicate that FLOCK is a basic social unit. Transac photography is required to justify this assumption and to check for biases due to failure to observe animals, or failure for FLOCK aggregates to account for the majority of the animals in the paddock. Work is currently underway to improve the validity of the suggested conclusions.

Conclusions

Because Kayrunnera is a marginal habitat for Merino sheep (8 in. rainfall), it was expected that sheep would be sensitive to changes in range condition (Watt, 1968). The techniques introduced in this paper and in Dudziński and Arnold (1967) are thus probably best applicable to a change in range conditions in marginal areas.

This paper is an attempt to introduce some quantitative indices of grazing behaviour. The previous paper (Dudziński and Arnold, 1967) aimed at establishing the technique of aerial photography. The index of 'spread' of that paper was introduced mainly as an illustration of the statistical and computational potential of the technique. The five indices discussed in this paper, as a set give a more complete picture of the dynamics of sheep movements as influenced by enviromental factors. Thus, the set of indices of this paper replace the set introduced in Dudziński and Arnold (1967), with the exception of the index, FLOCK, which is retained.

In conclusion, it may be said that the quantitative indices of grazing patterns introduced are useful joint parameters for analysis of the interactions between environmental stresses and social habits of grazing animals in marginal habitats.

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