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WATERS AND THE PATTERNS OF ANIMAL USE.

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ABSTRACT

Most rangelands users are well aware of the crucial role played by the quality and location of waterpoints in pastoral paddocks. Research over recent years has helped us to quantify this role. Today we can predict the general patterns of long term grazing distribution in most paddocks, and use these predictions both to suggest general paddock planning principles and to help plan individual paddocks. For example, we can indicate what the minimum distances ought to be between waterpoints and fencelines. The distribution patterns have implications both for the productivity of stock, and for reducing the risk of land degradation in the rangelands.

INTRODUCTION

Grazing animals do not use their ranges evenly. Factors such as preferred vegetation types, wind directions and paddock design all combine to cause heavier grazing pressure in some areas than others (1). If this lack of evenness is too excessive, the areas of high use either risk degradation, or demand so low a stocking rate that most of the paddock is unused. As a consequence, there is a need for managers to try to even out the patterns of grazing impact. For this to be done sensibly, we need to know first what the quantitative effect of different paddock designs will be on evenness, and second what effect an altered paddock design is likely to have on economic costs and returns.

In this paper, I shall briefly review previous work on grazing distributions, and describe recently-developed methods of ascertaining the likely distribution of grazing pressure in a particular paddock design. I shall then develop a random-walk model to show that a considerable part of the impact of sheep distributions can be based on some very simple assumptions about sheep behaviour, and seek to use this model to derive some general principles for paddock design which may be widely useful. Finally, I shall mention how these principles might be applied to the individual paddocks with which managers must deal, and return to the need for economic interpretation.

HOW CAN WE PREDICT GRAZING DISTRIBUTIONS ?

Any observant manager knows that sheep and cattle grazing patterns are affected by many factors. Only a few of these factors are amenable to manipulation in attempts to improve the evenness of use. The natural features of the landscape - vegetation types, hills, natural waters, and so on - as well imposed climatic features - wind, rain and temperature - cannot usually be altered and must be managed for. Most animals need to water at least once a day during summer months in most parts of Australia; this need is intensified during drought times, when the palatable perennial component of the vegetation also comes under pressure. Consequently, the location of water is the single most important determinant of the distribution of grazing pressure (e.g. 2, 3). The quality of water, the location of fencelines, and other special attractions such as licks, can also usually be adjusted by management.

Whilst the observation that these features are important is useful, it does not provide any quantitative information about how to plan a particular paddock. There are powerful economic and practical reasons for placing waters in particular locations - on fences to water more than one paddock, in drainage lines to allow dams to fill, or in locations where bores have been successful. In the past, these practical factors have been paramount, and many waters have been poorly located from an ecological perspective. Today, the use of polythene piping allows flexibility in the exact location of a water trough (as opposed to the source from which it is derived). Additionally, in some areas, new fence developments, or the replacement of old decaying fences, allows managers to consider whether these are located sensibly.

Consequently, we need methods of objectively and quantitatively predicting the effects of different paddock layouts on grazing distributions. This section discusses the more technical aspects of how this can be done - some readers may wish to skip on to the next section.

Early models.

The earliest approaches to predicting animal distributions came as spin-offs from complex whole system models (4, 5, 6). This was a clumsy, expensive and inappropriate way of obtaining distributions, and alternative methods using regression models were soon developed (7, 1). I have previously reviewed these (1), but, in brief, they depend on obtaining information on sheep or cattle distributions for some paddock, modelling the pattern in terms of natural and artificial features in the paddock, and then transferring the model to other paddocks to predict the expected patterns there (Fig. 1). The original (and validation) distributions can be obtained from direct observation and mapping of animals (on the ground for sheep, and from the air for cattle), or by using dung surveys as pioneered by Lange (8). The models were usually derived by multiple regression using relatively simplified transformations of the descriptive paddock features (7, 1).

In Paddock 1:	Map animal usage
	Map paddock features
	Divide paddock into grid
	Use multiple regression techniques to predict activity level in each grid cell on the basis of paddock features
In Paddock 2:	Map paddock features
	Divide paddock into grid
	Predict pattern using model from paddock 1, and check correctness

Now use model to test alternative layouts, etc.

Fig. 1. The basic process of obtaining a generalisable model of animal distributions.

This approach is difficult to generalise for different wind conditions, salinities, and vegetation types, unless many paddocks from different areas are used for modelling; this has gradually been done. Also, some physiological understanding of how often animals must return to water was needed to improve the models (1). Despite these limitations, the method has helped identify factors of potential significance (Table 1), and highlight the most important.

Table 1. Factors shown to be potentially important in animal distributions - different factors are more important in different areas and for different animal species.

Location of:	water (in relation to other factors) fencelines (layout, paddock size,etc) shade night-time campsites preferred vegetation barriers like hills special attractions like licks
Quality of:	water (esp. salinity) vegetation (water content, salt, etc)
Climate, etc:	wind directions temperatures wool length (i.e. time of shearing)

Newer approaches.

In recent years, the simple approach has been improved. The data collection phase for animal distributions is being revolutionised by satellite information. Direct observations of dung surveys are labour intensive to carry out, and with large paddock, especially with the greater ranging ability of cattle, observations become statistically unreliable due to the small proportion of a paddock that can be surveyed. Satellite information is more limited in available time periods, but permits the comprehensive, fast coverage of a much larger area.

The approach was devised by Pickup and Chewings (9), and, in brief, involves obtaining a satellite image soon after a good rain, then another a few months later; the difference between the two images at any point represents the natural decay process on the landscape plus grazing effects. The change due to natural decay (including grazing by animals such as kangaroos which may be unrelated to distance to water) can be estimated for each vegetation type as the change far from water, so the remaining pattern is the change due to grazing. This must be assessed for each vegetation type separately, since each may have different response curves. The approach has been successfully used in central Australia for cattle, and is now being applied over a wide area of Western Australia to confirm its utility in sheep lands. Apart from problems common to all satellite data such sun angle corrections, the method's major limitation is the requirement for a simple rainfall-induced growth and grazing pulse where subsidiary rains do not introduce too much noise. However, this still provides ample opportunities for devising and validating distribution models.

The second stage of the prediction process - that of deriving models from the observed distributions - has also advanced. Pickup and Chewings (9) have used simple analog models to successfully capture the main distribution patterns for cattle. These are even less biologically-derived than the early regression models, but their parameters are amenable to some biological interpretation. The fact that a considerable component of the distributions can be explained so simply is taken up further in the next section of this paper.

The limitation of these analog models is that, because they lack biological derivation, they cannot easily be transferred to new situations since factors such water salinity and wind directions are not easily incorporated in them. There has therefore been considerable interest in trying to develop the links between such simple models (and the early regression models) and the detailed understanding of sheep behaviour represented by early process models. This has led to models which incorporate the recognition that the distance travelled over by sheep is dependent on the time that a single drink lasts; a simple model of sheep water balance can then give considerable insights into their response patterns (1). Additionally, a better understanding of the ways in which they move across the landscape and respond to vegetation density can help interpret how adequate the simple analog models really are (see next section). Finally, some new rule-based approaches based on classification trees and the CART methodology (10) are being assessed and look promising, but there are no results available from these as yet.

As with any scientific work, developing an understanding is only one part of the problem - the development of a method for delivering that understanding to managers is at least as important. Models are of little value to managers directly, and the **RANGEPACK** project (11) has been developing a paddock design tool called Paddock to help managers use these models. Although a prototype using the earlier models has been available for years, the more fully validated version is expected to be available early in 1991.

MODELLING SHEEP AS RANDOM WALKERS

As mentioned in the previous section, a surprisingly large amount of the long-term patterns of animal distributions can be accounted for by simple analog models based on distance from water. In this section, I examine why this is so by showing how many of the patterns we see in real life can be simulated using a random walk model. I focus on sheep in this section, but similar findings could be repeated for cattle. This does not necessarily imply that sheep are always walking randomly (despite their reputation for intelligence !), but it does show why it is not sensible to try to explain patterns with complex models when simple ones will largely suffice.

Methods.

I have simulated a notional square paddock which is broken up into a 200x200 set of grid cells. Each day the sheep are assumed to start from the waterpoint cell, the position of which can be altered; at each timestep, the sheep basically move at random to one of the 8 cells surrounding their present position. If the new position would be outside the 'fence', they move to the nearest cell which is inside the paddock. After 1,000 time units, they start again at the waterpoint, so I ignore the action of returning to the water. This process is repeated for 1,000 days, and the total number of times that they enter each cell is counted.

A basic random walk does not really require simulation, since it can be solved analytically for a distribution with respect to distance to water (d) of the form $activity = \exp(-d)$, if the effect of the closed fenceline is ignored. However, we know that at least two additional effects must be happening in the real landscape. First, sheep tend to walk in to the wind, and, second, they will spend less time in areas which have previously been grazed out.

The effect of wind.

The effect of wind is incorporated by assuming that, on moving from each cell, sheep are slightly more likely to move into the direction of the day's wind than away from it. On any given day, a wind direction is therefore randomly selected from the known wind rose, and then the probability distribution shown in Table 2(a) is applied relative to this direction; there is limited justification for this particular distribution but it has worked in previous process models (5, 6). Most of the examples shown below were simulated for an even wind rose (i.e.. 0.125 probability of each wind direction), but some use a wind rose which is biased to south (Table 2(b)) as a simplified ideal of reality in southern Australia.

Table 2. Probability distributions (a) for movement in relation to prevailing wind direction and (b) for a south-dominated wind rose used in some simulations.

(a)		(b)	
Back 3 octants	0.110	NW	0.05
Back 2 octants	0.110	N	0.05
Back 1 octant	0.125	NE	0.05
Into wind	0.200	E	0.10
Veer 1 octant	0.125	SE	0.15
Veer 2 octants	0.110	S	0.35
Veer 3 octants	0.110	SW	0.15
With wind	0.110	W	0.10

Feedback due to previous use

The effect of vegetation impact is incorporated by assuming that the more time units that sheep have spent in a given cell, the more likely it is that that cell has become less preferred to the sheep (either because this year's growth has been removed in the short term, or because long term vegetation changes have taken place). Previous work (6) has indicated that when they are carrying out at least a little grazing, sheep walk at speeds between 0.15 and 2.5 km/h; the same study found some evidence for the speed of movement being dependant on vegetation density. For the simulation, therefore, the speed of movement through a cell is assumed to be minimal until at least 25 visits, and then to increase linearly to a maximum at 200 visits, thereafter stabilising at the maximum speed. This is effectively saying that after 25 visits the quality of the pasture starts to deteriorate, but that after 200 visits, sheep cannot move through it any faster than some maximum speed. These speeds are adjusted in the simulation to suit the paddock size concerned.

The results of the simulations are reported in two ways. First, the pattern of use across the paddock over the 1,000 days can be said to represent a long term pattern of impact and therefore potential vegetation change in the paddock; the evenness of this is shown by a histogram of the number of cells in which there has been different levels of use (not included in this paper). Second, the pattern of use in days 800-1,000 is representative of the use by the sheep after the changes have taken place - i.e. simulates present day usage in an area where the total pattern has developed over a long time; again the evenness of this can be assessed from a histogram.

Results.

The results of the simulation are remarkably realistic. Fig.2 shows the long and short term patterns resulting for a centrally located water with southerly winds dominating; similar patterns can readily be found in real simple vegetation types, as illustrated by Fig.3 which compares the long term patterns observed around a real fenceline water from satellite on a area of the Nullarbor Plain in Western Australia with a simulated one. The substrate of the Nullarbor is bright limestone, so that relatively small changes in the cover of the normally dominant chenopod shrubs (primarily saltbush, *Atriplex vesicaria,* and bluebush, *Maireana sedifolia*) show up very clearly from satellite. The precise details of the two patterns are not identical (partly due to differences in the exact location of the real fencelines), but it is notable that the simulation produces apparent fingers of extra usage which are similar to those to be found in the real image. In the absence of the simulation, one would probably assume that resulted from special vegetation types, or other attractants, but the simulation generates them merely from random behaviour.

By themselves, these results do not constitute a proper validation of this simulation approach. However, they do illustrate the important point that too much effort in land-based interpretation of the animal distributions could be entirely counter-productive - a large proportion of the pattern in these cases is explained by this simple random walk model modified only by wind directions and vegetation density as measured by previous grazing activity. Although greater accuracy might be produced by understanding the vegetation selection better, the effort necessary might be out of all proportion to the improvement in predictive ability. Even this simple model can give us a way to make important management recommendations, as the next section now shows.

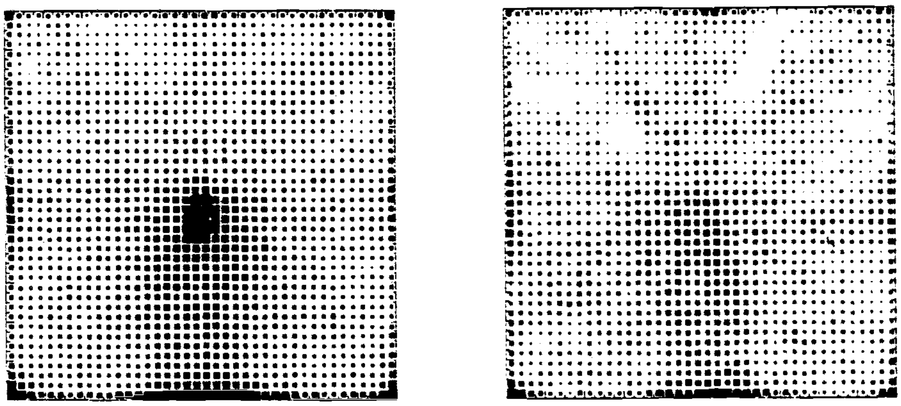

Fig.2. Predicted patterns of activity for (left) all 1,000 days, and (right) during the last 200 of these, for a random walk model from a centrally-located water in a uniform paddock subject to a southerly wind pattern (Table 2); the 200x200 cells in the paddock have been agglomerated into 40x40, and the area of the square in each resulting cell is proportional to the activity level predicted there.

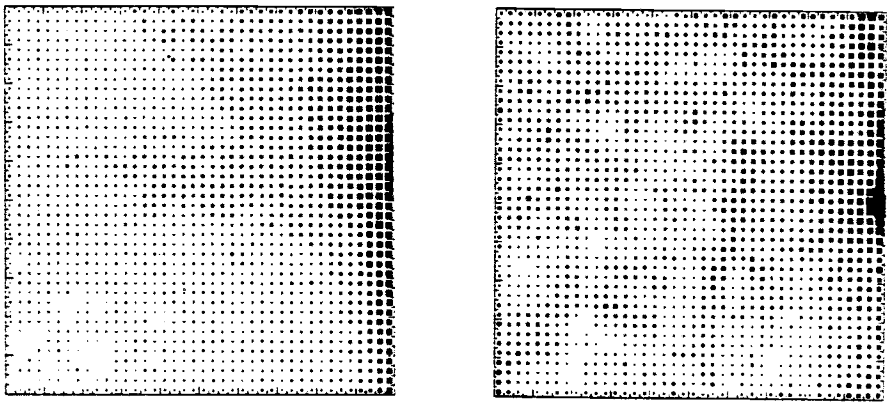

Fig.3. Patterns of activity as determined for a waterpoint on a western fence (left) from reflectance changes in Landsat imagery of an area on the Nullarbor Plain, and (right) from random walk simulations subject to a southerly wind pattern. See Fig.2 for method of display.

HOW FAR FROM FENCELINES AND CORNERS SHOULD WATERS BE ?

Despite the obvious simplicity of the random walk simulation model outlined in the previous section, it can be used to look quantitatively at the predicted patterns of grazing impact for different waterpoint locations. The issues revolve around the fact that it often appears cheaper to build water on fences to water two paddocks at once, or even in corners to water four; this has been a common paddock design historically, but many managers are having second thoughts about the obvious grazing pressure that this puts on the approaches to the waterpoint. They may now wish to use polythene piping to move the water away from the fence. The question is, though, what distance from the fence will achieve the best cost/benefit from the re-location ? This simulation model can assist by showing the expected pattern for different distances, although managers must still interpret this in terms of the salinity of their waters and vegetation, their particular paddock design, and their own economics. I shall examine only a couple of these issues here, but future work will look at these questions in more detail.

Methods.

The simulations described in the previous section were repeated using an even wind distribution with the waterpoint located at every 5th cell position between the middle of the western fence and the centre of the paddock, and at every 5th cell position between the northwest corner and the centre of the paddock (Fig.4). Note that these patterns cannot be solved analytically due to the fenceline effects. Although only a single 1,000 day simulation is used for each of these, the patterns were reasonably stabilised. A measure of the unevenness of usage is provided by the standard deviation of the activity levels in each cell - this tends to be greater as a larger proportion of cells are either unused or used very heavily, as occurs with waters close to the fence: for a paddock which was used perfectly evenly, this measure would be zero. This measure is shown plotted against the distance from the western fence (thus for the corner simulations, the plotted distance is 0.707 times shorter than the length of piping which would be needed to move the water from the corner itself).

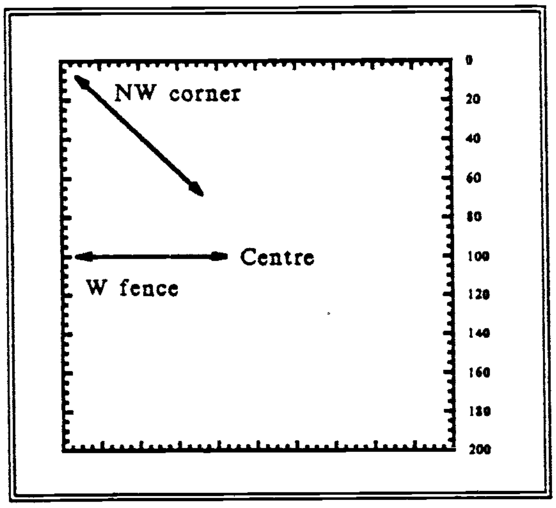

Figure 4. Schematic illustrating the waterpoint locations tested for Fig.5. An even wind distribution was used, so that the patterns would be less extreme for waterpoints which are on a fence or in a corner that is on the upwind side of the paddock, and more extreme for one on the downwind side.

Results and discussion.

As can be seen in Fig.5, the lack of evenness in the grazing distributions eventually falls off as the water is moved away from the fence or corner.

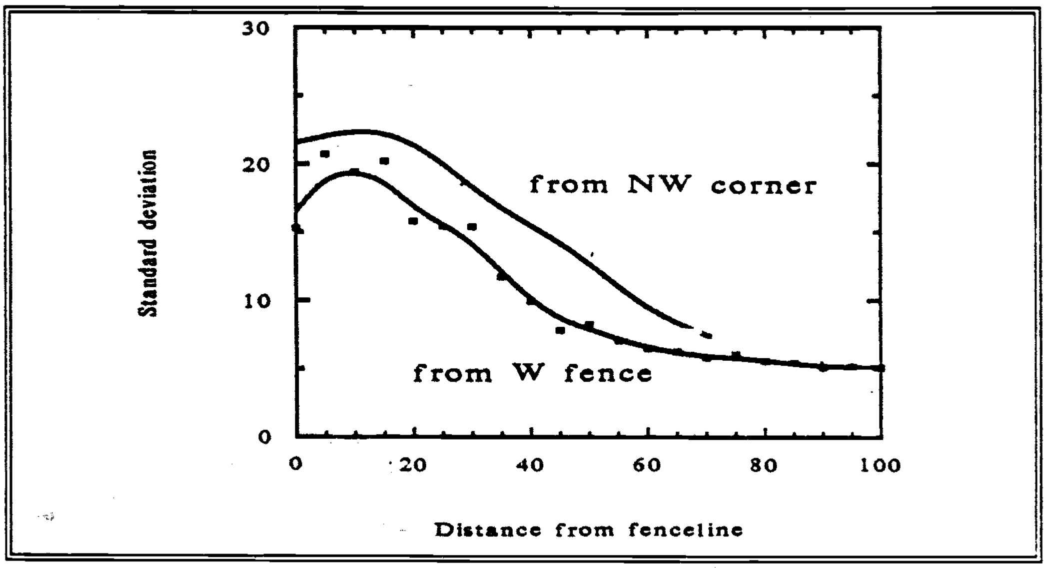

Fig.5. Predicted evenness of use of a paddock simulated with one waterpoint at various distances from its western fence, as measured by the standard deviation of total activity levels in all cells in the paddock; the 200x200 cell paddock was simulated for 1000 days with an even wind rose for each water location. The water locations are shown in Fig.4; distance from the fenceline is measured in cells (see text below for further discussion of real scale).

The absolute values shown mean little, but the relative values are important - they show that the standard deviation of cell use can be more than halved by moving waters about 40 cells into the paddock, for the assumptions used here. They indicate that it is much easier to improve the evenness of use for waters on straight fences than for waters in corners, and that the latter need to be moved out further for the same improvement. It is also notable that no real gain at all is to be made until the water has been moved at least 20 cells. Other measures of use are also important - for example, the proportion of cells which are used heavily, the proportion which are not used at all, and so on. All of these data are also available and generally show the same patterns and approximate magnitudes of improvement as the standard deviation.

So far, no mention has been made of what the absolute size of a cell is, and, therefore, just what 40 cells width of polythene piping might be. This was deliberate, since the absolute figure depends on factors such as the salinity of the water and fodder, and the total size of a paddock; the main purpose of this study was to show that moving waters away from a fence can easily have a major impact on distribution patterns. However, with low salinity levels in a simple paddock which is about 5km square, 40 cells represent about 1 km. For saline waters, the distance would be less because the effective 'grazing area' is less (see 3), but the area accessed is correspondingly less.

If the impact around water is evened out, pastoralists stand to gain in at least three ways. Areas of local degradation around the water (the so-called 'sacrifice zone') are made smaller; the animals have to walk less far to find some feed; and in drought times, feed is likely to persist longer. All of these could lead to improved animal production, as long as the gains are not destroyed by substantial increases in stocking rate. Furthermore, the reduction in the size of the degraded area around water has indirect values, such as reducing the problems of dirty wool. In summary, even small investments in polythene piping can have substantial effects on reducing degradation and improving production.

CONCLUSIONS

The random walk model used above is really too simple - it does not account for salinity, which effectively re-scales the simulated paddock, and it is not a very efficient way of assessing new layouts. Nonetheless, it delivers two important messages - to managers, that waters on fences and in corners are not a good idea, and that they can be improved by relatively small amounts of piping; and to scientists, that a large part of what appears to be very complex grazing patterns for sheep (and cattle) can be explained by simple models.

The challenge now is to identify the aspects of grazing distributions which really do need more detail than a simple model can provide. The effects of salinity have been previously mentioned and can be dealt with easily on a physiological basis. The effects of preferred vegetation types are undoubtedly another matter for concern, which can hopefully be addressed with satellite technology. An amalgam of the various models reviewed earlier in this paper should prove capable of meeting this challenge.

Equally important, however, is the need to turn these models into useful information for managers. Whilst the cost of putting in a kilometre of polythene piping is easily calculated, we also require a better understanding of the possible economic benefits of improved evenness of grazing. Managers need to start to keep production figures on a paddock by paddock basis on their properties so that they can start to develop this understanding. It is to be hoped that the second phase of the current WADA-CSIRO project will also help to obtain these records.

Finally, of course, the results must be made available to other managers. The RANGEPACK Paddock prototype paddock design module is on display elsewhere at this conference, and may be a useful vehicle for this endeavour.

ACKNOWLEDGEMENTS

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