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RANGE MANAGEMENT IN A CHANGING ENVIRONMENT: A SOUTH AFRICAN PERSPECTIVE

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ABSTRACT

We address a number of management principles pertaining to temporal and spatial changes in rangeland systems. Both plant community composition, and availability and quality of forage, are temporally variable. The process of community change, at least in southern Africa, appears to differ between humid and arid environments. In humid environments, change follows a relatively gradual and predictable pattern, with both over- and under-grazing resulting in decreased carrying capacity. Factors other than grazing also cause change. In arid environments, change is event-driven, providing the grazier with risks and opportunities to cause or prevent community change from one state to another.

Humid and arid rangelands also exhibit different patterns of inter- and intra-seasonal variation in forage availability and quality. In the former, changes, particularly in quality, are relatively predictable, allowing the grazier to match forage demand to supply, thus facilitating stable animal husbandry systems. In arid ranges, the profound change is inter-seasonal forage production, implying unpredictable carrying capacity. Flexibility in livestock numbers is therefore essential.

Spatial heterogeneity of rangelands results in patch utilization and localised deterioration of varying scale. In southern Africa, the traditional response has been fencing, an expensive and sometimes impracticable solution on an extensive scale. Fire and siting of artificial water points or mineral licks are alternative options for redistributing animals.

The interaction of spatial heterogeneity with temporal rainfall in arid rangelands provides pulses of productivity varying in space, time and magnitude. Settled pastoralism is perhaps unsuited to these environments.

Finally, in view of the complexity of rangeland systems, and the paucity of empirical predictions for graziers, we suggest that formalised adaptive management - decision-making from past mistakes and successes - is the most appropriate means for graziers to cope with a changing environment.

INTRODUCTION

Grazing management is the process whereby the grazier examines probable consequences of different management actions and selects that which, in his opinion, has the highest chance of attaining his objectives (adapted from Provenza, 1991). The role of the range scientist in this process is not to prescribe what the grazier's objectives should be, but rather to provide reliable predictions of the consequences of management actions. The various combinations of enterprises and management actions from which the grazier might choose are almost endless. Superimposed on this are socio-economic conditions which influence grazier objectives ranging from commercial to subsistence pastoralism (nowhere more evident than in the dichotomy of first world/third world pastoralism in southern Africa).

Clearly, the range scientist cannot hope to address all possible permutations of grazier objectives and management options through empirical experimentation, and is forced to develop conceptual models and hence management principles to assist in prediction. These will be based as far as possible on quantitative research, but will, of necessity, also rely heavily on conventional wisdom, observed successes and failures of graziers, untested hypotheses and intuition.

In this paper we address a few management principles pertaining specifically to a changing physical environment, emphasizing experience gained in southern Africa in a broader perspective. We accept that changes of circumstance affecting the grazier are not confined to the physical environment. Indeed, changing economic, social and political climates probably influence grazier decisions more than changes in physical conditions and resources.

We address the topic as follows: we describe what we consider to be the most important changes that are taking place, without entering into detail of the processes involved; we discuss some of the implications of these changes to pastoral systems and attempt to identify tactical management principles or responses, and, we indicate how graziers may formally implement flexible management in a changing environment.

Temporal Change

The temporal pattern of changes in plant abundance, composition, structure, productivity and quality are commonly recognized to be a response to both abiotic (e.g. rainfall) and biotic (e.g. grazing) influences. These patterns show marked spatial variation from the local to regional scale. For convenience, we separate changes in structure and composition of plant communities (community change) from changes in forage productivity and quality, although they are frequently interdependent.

Community Change

The nature of community compositional change has been the subject of considerable debate in recent years. The traditional paradigm of Clementsian succession for rangelands has been firmly challenged (e.g. Westoby *et al.*, 1989), with the latter emphasizing event-driven phenomena. A main issue has been whether or not communities progress gradually from coloniser to climax communities, whether or not grazing retrogression is the mirror image of progression, and the cause and predictability of these changes (Westoby, 1979; Walker, 1988; Danckwerts and Adams, *in press*). In southern Africa, the favoured philosophy has been that community change is gradual and predictable with retrogression occurring in response to herbivory - the Dyksterhuis (1958) increaser-decreaser approach (e.g. Foran *et al.*, 1978; Tainton, 1986; Bosch *et al.*, 1989). Perhaps this is because the work in southern Africa has been developed largely in humid rangelands where conditions and resources for growth are relatively predictable and constant between years. It is therefore expected that heavy grazing will result in an orderly increase in the proportion of plants with well-adapted defence or tolerance mechanisms to cope with herbivory. Conversely, an absence of grazing would favour tall lignified plants (Stuart-Hill and Mentis, 1982) with low forage value.

The increaser-decreaser model, with two categories of increasers (those that increase with either under- or over-grazing) is emphasised in grazed humid rangelands of southern Africa (e.g. Tainton, 1981) with the implication that carrying capacity would decline under both excessive- and under-utilization. The management paradigm for humid ranges has thus been that the grazier should strive for a level of grazing light enough to prevent an increase in unpalatable increasers adapted to grazing, but heavy enough to prevent an increase in plants adapted to no grazing, and that he should adapt grazing intensity on the basis of observed changes.

An important criticism of the increaser-decreaser model is the implicit assumption that grazing is the most important gradient rangeland species respond to, yet there is accumulating evidence that many species show a minor response to the grazing gradient (Mentis 1982; O'Connor 1985). As an example, *Themeda triandra* is generally considered to be the most important decreaser species in southern Africa. It is only moderately adapted to herbivory, yet also disappears in the absence of grazing in humid rangelands unless there is regular fire (Coughenour *et al.*, 1985; Danckwerts and Stuart-Hill, 1987). The classification of this species along a grazing gradient may be incidental.

The point we highlight here is that, while community change in humid rangelands might be a relatively orderly process, it is over-simplistic to explain change merely in terms of responses of species to grazing alone. Indeed, fire is an enormously important tool in the management of humid rangelands, at least in southern Africa (Trollope, 1989), and its impact might well be greater than that of grazing, at least within a reasonably practicable range of stocking rates (Danckwerts, 1990a; Danckwerts, 1990b).

In contrast, work in drier parts of southern Africa (e.g. O'Connor, 1985; Walker et *al.*, 1986; Danckwerts and Stuart-Hill, 1988) indicates that community change takes place largely in response to stochastic environmental events, that this change can be rapid and unpredictable, and that the interaction with management can be critical. This work concurs with conceptual models from other arid and semi-arid areas (e.g. Westoby, 1979; Noble, 1986; Walker, 1988; Westoby et *al.*, 1989). In particular, the state and transition model of Westoby et *al.* (1989) has been invoked to explain community change in a number of arid areas. Briefly, it describes a state as a stable assemblage of species occupying a site, and, for communities to move from one state to another, some external force is required to overcome this stability.

The implication is that long periods of system inertia are punctuated by unpredictable risks and opportunities for the manager to move the system from one state to another (Westoby et *al.*, 1989). The key issues are for the manager to be aware of what state or states have the greatest chance of fulfilling his objectives, and to be aware of what combination of event and management is required to cause or prevent movement from one state to another. As an example, Danckwerts and Stuart-Hill (1988) found that even moderate grazing after a severe drought in semi-arid savanna resulted in a sharp decline in the presence of *T. triandra* in the sward. In adjacent sites, ungrazed for one season after the drought, new *T. triandra* recruits replaced plants that died during the drought, retaining the range in its original state. The difference between the two treatments was still present three years later.

To summarise, the philosophy of gradual and predictable changes appears to have a reasonable utility for humid rangelands, and the event-driven approach in arid ranges. However, in southern Africa, many rangelands are transitional between the two, and both models may apply at the same sites, but on different time scales.

Structural Community Changes

Possibly the single most important change in community structure for grazing management is bush encroachment, often a result of overgrazing (e.g. Walker et *al.*, 1981). Because of a general decline in grass production with increasing tree biomass (Scanlan, 1992) pastoralists have generally responded by attempting to reduce the woody component through herbicides, mechanical clearing or fire (e.g. Dye and Spear, 1982; Trollope, 1989). These practices are, however, expensive and/or have relatively short-term effects (e.g. Scholes, 1990) while the increased animal performance rarely matches increased grass production (Teague and Smit, 1992).

As an alternative, Aucamp et *al.* (1983) suggested matching the animal species with the vegetation through the introduction of browsers, such as goats, into existing pastoral systems so as to utilize the available woody component. In conjunction with fire, such a system could control the woody species (Trollope, 1989) while animal production would exceed that achieved under traditional grazing systems (Aucamp et *al.*, 1984) because of complementary resource use by grazers and browsers, as well as the relatively high fecundity of the latter animals (Aucamp et *al.*, 1984).

Changes in Forage Productivity and Quality

An important aspect of temporal change is intra- and inter-seasonal change in the quantity and quality of available forage. Intra-seasonal changes are more predictable in humid rather than arid rangelands, because of the inherent predictability of climate in humid areas. In both areas, this typically involves an abundance of forage during the rainy seasons, with a decline in the dry season. In humid areas - termed 'sourveld' - this is commonly accompanied by a marked decline in forage quality as the dry season approaches, reaching sub-maintenance levels in winter (O'Reagain and Mentis, 1988). Forage intake and daily gain of a free ranging steer would thus vary considerably over the year (Fig. 1).

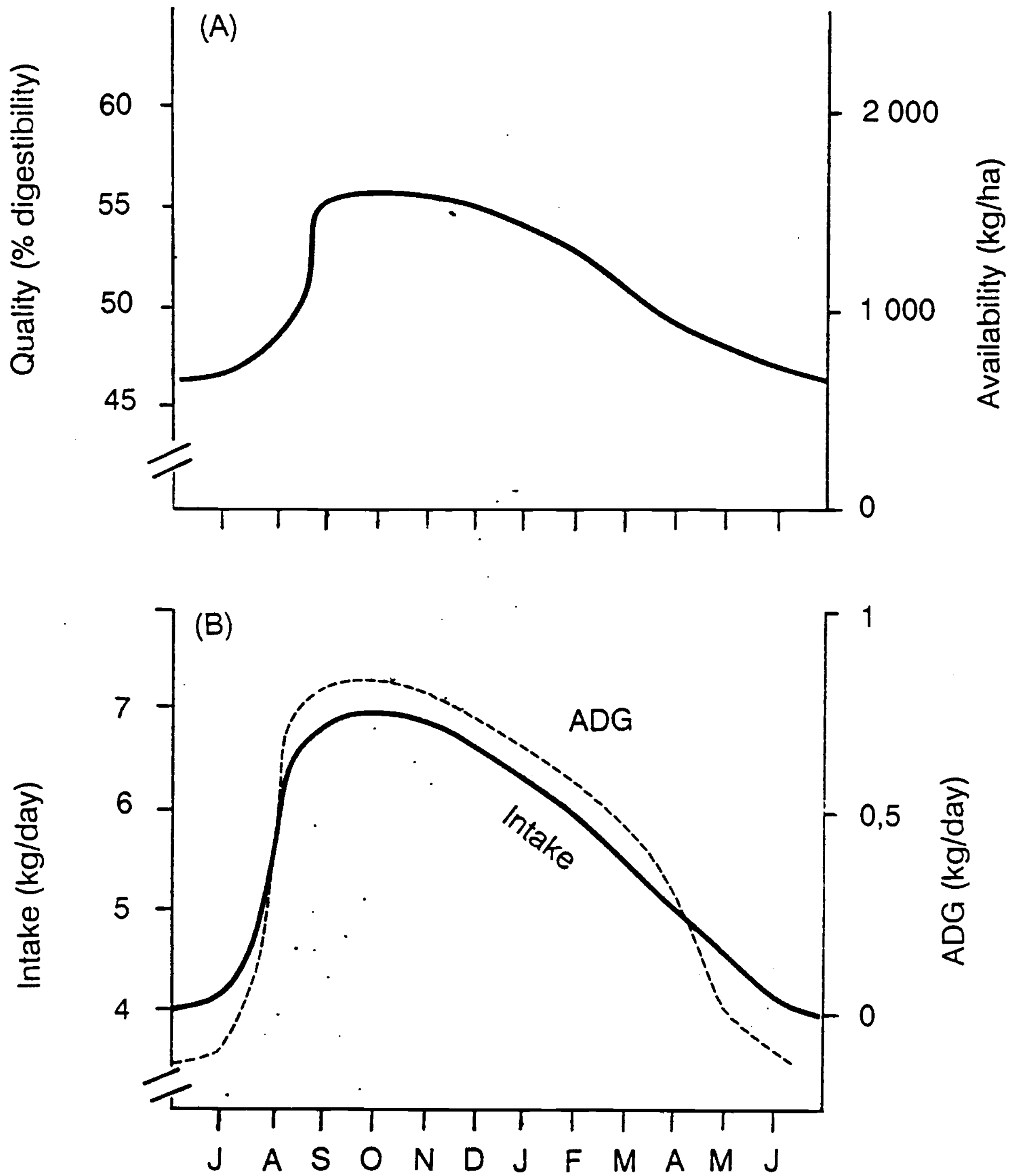

Figure 1. Trends in forage quality (A) and in daily intake and daily mass gain (ADG) per head (B) on humid sour grassveld where forage availability is never limiting (after Danckwerts, 1989*b*).

Without supplementation, the loss in mass during winter can be considerable, up to 80 kg/head (Preller, 1959). Clearly, graziers with reproducing animals would aim at lambing or calving during spring to take advantage of the high quality at this time, and would implement some form of supplementary feeding in winter.

The predictable intra-seasonal changes in forage availability and quality in humid rangelands renders the grazier in a position to practise fodder flow planning - matching forage demand to supply as far as possible, and providing supplementary forage where deficit still occurs. Further, inter-seasonal variation is relatively small, allowing stable production systems with relatively constant animal numbers. In drier areas of southern Africa - termed 'sweetveld' - forage quality remains relatively constant throughout the year and sufficient for animal requirements (e.g. Danckwerts, 1989a).

Turning to inter-seasonal variability, forage productivity is directly related to mean annual rainfall. In turn, in the summer rainfall region of southern Africa, mean annual rainfall is inversely correlated to its coefficient of variation. The CV ranges from 40 % for areas with a 400 mm mean to less than 10 % for a 700 mm mean (Tyson, 1986). As a consequence, inter-seasonal changes in forage production are marked in semi-arid rangelands. For example, a twelvefold difference in grass production was recorded between average and dry years in *Acacia* savanna in Zimbabwe (Dye and Spear, 1982). They may also be exacerbated by outbreaks of phytophagous insects such as the harvester termite (Barnes, 1982).

The overwhelming implication of these trends is that carrying capacity varies considerably from year to year. As an example, over a 10-year period in semi-arid savanna, grazing capacity varied from 0.026 to 0.2 large stock units per ha, a difference of over 700 % (Tainton and Danckwerts, 1989) (**Fig. 2A**).

Here, a grazier stocked at the long-term mean carrying capacity (0.09 large stock units per ha) during 1982/'83 season, would still have been 350 % overstocked. Under these circumstances, the concept of a long-term mean carrying capacity seems to have no practicable significance. Clearly, graziers in arid areas must somehow be able to react to this enormous fluctuation. Perhaps the simplest and traditional way of coping with this is through nomadism - an option still practised in some third world countries, although population pressures are making it increasingly impossible for nomadism to continue. In developed countries, the practice is generally precluded by land tenure systems. We assess a number of the possible alternative options under settled pastoralism.

1. The most obvious option is to maintain stocking rates at very low levels to ensure stable production in all but the driest years. The problem here is the lost opportunity cost of wasted forage and the cost of land precludes this option in most commercial systems. Further, problems of inadequate forage will still arise in the driest years.

2. The grazier may destock with the onset of drought and restock when sufficient forage has accumulated after rain. This option is limited by the relative inelasticity of the market for domestic livestock, making it unable to cope with fluctuations in supply and demand. Furthermore, droughts are often regional, making availability of livestock for restocking very limited and exorbitantly expensive.

   Adopting this approach would also require that the grazier recognize differences between dry spells and drought - in our experience graziers are often optimists, and delay destocking too late, resulting in poor condition and low prices for animals being disposed of.

3. The third option is a combination of the previous two, and involves setting the number of reproducing animals at a low but stable level and "filling" with readily disposable livestock. The advantage of this approach is that, provided adequate records of rainfall and productivity are available, the number of reproducing animals can be set according to a probability level selected by the grazier (e.g. Danckwerts, 1987a). The grazier can then react to dry spells or

drought by disposing of filler animals, and to wet cycles by either or both of purchasing fillers and retaining home-bred progeny. As with option one, however, problems of inadequate forage will still arise in the driest years.

4. Fodder banking is another obvious means of coping with forage shortage during drought. The size of the fodder bank needs to be in direct proportion with rainfall variability (Jones, 1983), and therefore increases with increasing aridity. The problem here is that arid regions are usually situated too far from fodder-producing areas to make this option financially viable on its own. An alternative method of fodder banking, widely advocated in southern Africa, is to withdraw a portion of a ranch from grazing for an extended period and on a rotational basis. It is generally recommended that ranchers in semi-arid areas withdraw at least a third of their range from grazing for the duration of each growing season (Tainton and Danckwerts, 1989). For this option to work, the rested range must remain palatable to livestock after the duration of the rest period. Although there will obviously be some loss of forage on the rested range through desiccation and consumption by wild herbivores, the option nevertheless has a significant buffering effect on inter-seasonal variation in carrying capacity. This is demonstrated by using the example for semi-arid savanna given earlier (Fig. 2A) to determine the carrying capacity of the same range assuming one third was rested each year (Fig. 2B). It is clear that resting would have had a major fodder flow advantage and, indeed, this option was practised with great success on the area in question (Danckwerts, 1987b). Nevertheless, while buffering inter-seasonal fluctuation, this option will by no means eliminate it (Fig. 2B) It also requires some means of controlling animal distribution.

None of the options listed above is likely to be entirely successful on its own. Above all, the pastoralist will need to strive for flexibility in livestock numbers, and this can probably be best achieved by some combination of the options listed above. For the settled pastoralist in arid areas, coping with inter-seasonal fluctuation in carrying capacity will be a major management challenge.

Spatial Variability

Rangeland systems exhibit spatial heterogeneity, varying from patch to landscape scale, in composition, structure and productivity. This is a consequence *inter alia* of aspect (e.g. Du Toit, 1967), catenal position (e.g. Walker, 1985) and geology (e.g. Ebersöhn, 1961) and localised phenomena such as fire. Superimposed on the physical environment may also be intra-seasonal patchiness in rainfall distribution associated with stochastic formation of convectional thunderstorm cells (Preston-Whyte and Tyson, 1988).

Sites therefore differ in the amount and quality of plant material produced and in value as a forage resource to the animal. Sites may also differ physically in terms of cover, proximity to water, exposure to weather and predation risk. Foraging value and habitat suitability are not constant but vary between animal species (e.g. Jarman and Sinclair, 1979) and both between and within seasons (e.g. Fabricius and Mentis, 1990).

The consequences of spatial heterogeneity for rangeland management are threefold. Firstly, animals select strongly for sites with a high resource value (area selective grazing), largely avoiding other areas (e.g. Downing, 1979). Excessive use of preferred sites may degrade the vegetation to a less productive community with a resultant increase in soil loss (e.g. Donaldson, 1986). Secondly, uneven animal distribution results in inefficient resource use with some areas being heavily impacted, while others are under-utilized. Consequently, the actual carrying capacity of the range may be substantially lower than its potential. Thirdly, different areas react differently to grazing and other driving variables, complicating range management. For example, in humid grassland, S and N aspects may respond differently to grazing in terms of species composition, herbage production and vigour (Du Toit, 1967).

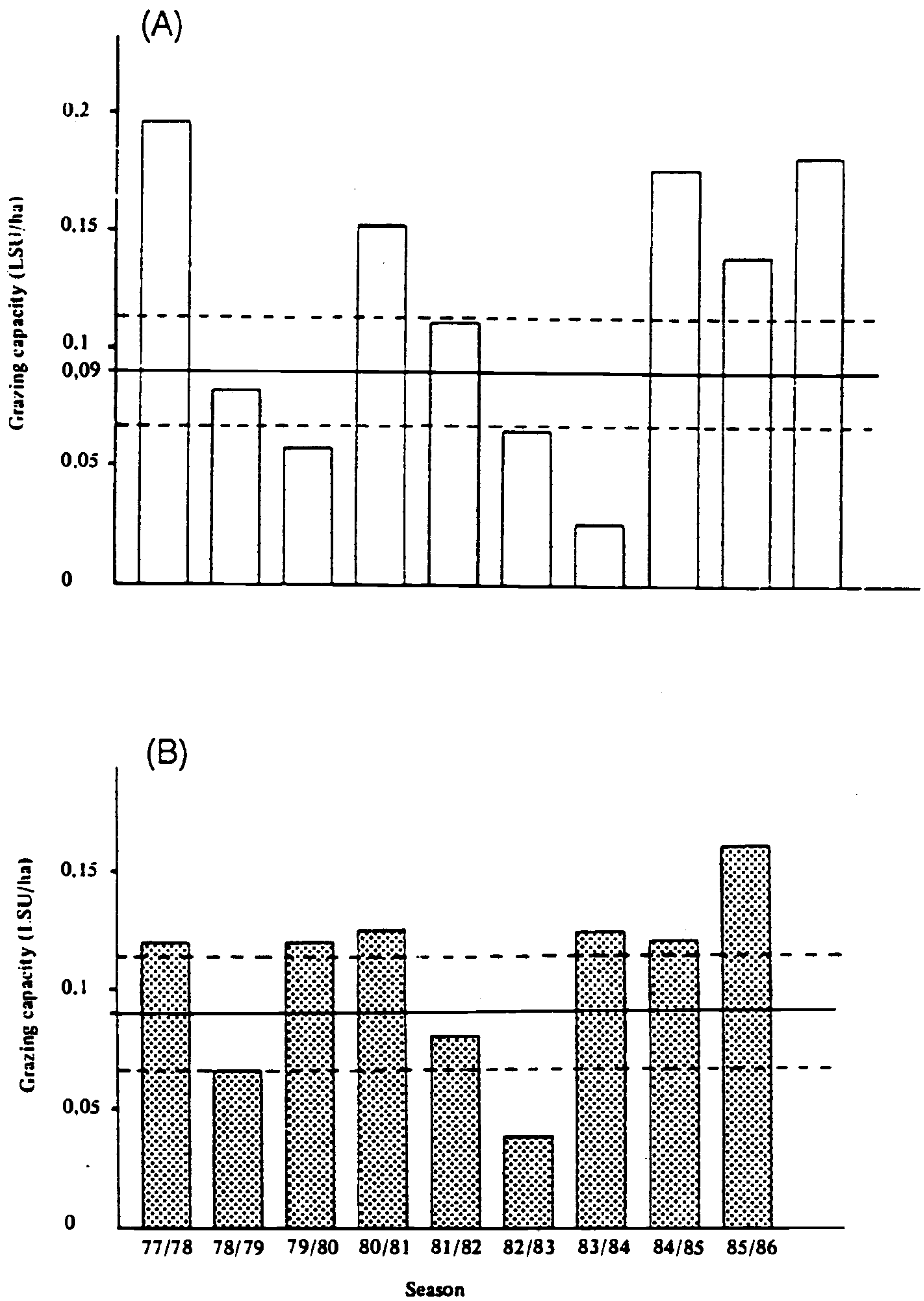

Figure 2. Seasonal grazing capacity at the Adelaide Research Station from 1976 to 1986 (A), and grazing capacity assuming one third of the range is rested each year (B). Bold lines represent long-term mean grazing capacity and broken lines represent a range 25% above and below the long-term mean (after Tainton and Danckwerts, 1989).

The significance of these effects varies according to the landscape position, sensitivity to degradation and extent of the impacted area. Where utilized areas are relatively small and do not occur in sensitive areas e.g. riparian zones, they may possibly be regarded as sacrifice zones. Conversely, if areas are large and/or occur in sensitive zones, degradation is usually considered unacceptable, necessitating management of animal distributions.

The simplest solution may be to stock the entire range at a level which the preferred areas can sustain (Edwards, 1981). Economically, this may be unacceptable due to inefficient resource utilization and the low animal production per unit area.

In southern Africa, fencing of different vegetation types (paddocking) along with some form of rotational grazing, has been widely recommended to ensure even, controlled use of rangeland (e.g. Anon., 1926; Roux, 1968; Booysen and Tainton, 1978). Areas are separated according to vegetation type, aspect, topography and soil with each group of animals rotationally grazing a recommended minimum of between four to eight camps (e.g. Booysen *et al.*, 1974; Barnes, 1982). Such systems allegedly maintain, or even improve, long-term range condition (*sensu* Foran *et al.*, 1978) while increasing animal production through maintenance of higher carrying capacities (e.g. Roux, 1968; Booysen and Tainton, 1978). While the alleged benefits of rotational grazing are debatable, camping *per se* appears to be important in preventing localised degradation and facilitating range management (O'Reagain and Turner, 1992). On the other hand, paddocking has a number of disadvantages. Firstly, capital expenditure is high and may only be financially justifiable if depreciated over periods which frequently exceed the planning horizon of most graziers (Mentis, 1991). Secondly, poorly sited fences (e.g. incorporating a relatively palatable into a larger, less preferred community) can result in degradation (e.g. Donaldson, 1986).

As an alternative to fencing, fire may be used under extensive conditions to shift animal pressures across different habitats. Varying fire frequency creates a mosaic of burnt, recently burnt and unburnt patches varying in attractiveness to the grazing animal (Van Wilgen *et al.*, 1990). Burnt areas are typically selected in preference to unburnt areas because of the high quality regrowth on the former (Mes, 1958; Grunow, 1979). As an example, large-scale movement of indigenous ungulates between habitats is a *de facto* consequence of patch burning in many conservation areas (Van Wilgen *et al.*, 1990). Nevertheless, there are a number of potential problems associated with burning. Firstly, where large differences exist in resource quality between sites, burning may be unsuccessful in attracting animals on to less preferred areas (e.g. Novellie, 1992). Secondly, residence time of animals on burnt patches may be less than required before they return to preferred habitats (Grunow, 1979). Lastly, in low rainfall areas burning may not be an option, either because of an unavailability of fuel, or because of the potential forage value of herbage in droughts.

Provision and siting of artificial waterpoints and mineral licks are further options for manipulating animal distributions, both at paddock and landscape scale (Mills and Retief, 1984; Knight *et al.*, 1988). For either method to be successful animals must be dependent on such sites for water or mineral intake (Knight *et al.*, 1988), and must be aware of the location of new sites. For example, in the arid Kalahari, the closure of waterpoints forced wildebeest out of affected areas but had no effect on springbok or gemsbuck distributions (Mills and Retief, 1984). Both methods may, however, lead to localised range degradation due to animal pressure around such sites. Also, as has happened in both wildlife and pastoral areas (Sinclair and Fryxell, 1985) animal numbers may explode in the new, previously unexploited habitat resulting in large-scale resource degradation.

Other less orthodox methods that might include heritable patterns of habitat or dietary selection, dietary learning, or the manipulation of social cues (Provenza, 1991) are potential options for manipulating animal distribution that have not yet been explored in southern Africa.

A Return to Transhumance?

Spatial heterogeneity interacts with temporal rainfall variability increasing rangeland complexity. In semi-arid areas this results in pulses in productivity which are stochastic and poorly predictable in time, space and magnitude (Ellis and Swift, 1988). Under such non-equilibrial conditions, the traditional response has been adoption of transhumance (Sinclair and Fryxel, 1985) tracking pulses in productivity (e.g. McNaughton, 1979). Because of the opportunity for spatial exploitation of the environment, nomadic systems can generally support a higher carrying capacity than sedentary systems (Barnes, 1979) and also appear to be less detrimental to the vegetation (Sinclair and Fryxell, 1985; Ellis and Swift 1988). Settled pastoralism, as is commonly practised in developed countries, thus seems an ill-adapted form of land use in arid rangelands. This is particularly the case in southern Africa where ranches are relatively small, even in dry areas, minimising the opportunity for exploitation of spatio-temporal heterogeneity in the environment. Western land tenure systems seem to preclude the ecologically more attractive option of communal Merino flocks tracking pulses of productivity through the South African Karoo or the Australian outback.

Adaptive Management - a Flexible Approach in a Changing Environment

In the preceding section, we discuss in detail a number of somewhat discrete management principles that graziers might use to cope with a changing environment. The grazier, however, is not confronted with decisions one-at-a-time, but must use a combination of conceptual models and principles to cope with his own unique set of circumstances. How does he do this? All graziers monitor, albeit in a subjective manner, both the performance of their animals and the condition of their range. They are constantly learning from their past successes and mistakes (and those of their neighbours), and from the recommendations of range scientists. They then adapt their management to incorporate what they have learnt. Essentially, what they practise is what is termed "adaptive management" - the system of making management decisions based on past mistakes and successes in situations where few facts are known, but where decisions cannot be delayed (Holling, 1978; Walker & Hilborn, 1978).

We propose that adaptive range management is perhaps the best means of coping with a changing environment. This system allows the grazier to make management decisions in a formal, yet holistic manner, and to modify his decisions as circumstances demand. Although he uses management principles developed elsewhere, his decisions are tailored for his own unique set of changing circumstances.

As an example of how adaptive management can be implemented, Stuart-Hill (1989) presented a decision-making algorithm for commercial ranches in southern Africa, assuming a dual grazier objective of economic viability and environmental sustainability (**Fig.** 3).

Implementing such a system depends directly on three important monitoring programmes:

1. recording performance of animals, and hence their economic performance;
2. measuring change in vegetation, and
3. recording the environmental conditions that occur and the management decisions being taken.

If the procedure (**Fig.** 3) continues for long enough, and is formalised, the grazier will develop a model specifically adapted to his ranch, without any research necessarily having been conducted under his own unique conditions.

In conclusion, the key to successful adaptive management is an adequate monitoring programme. Most graziers keep rainfall records, many keep records of their animal performance, some keep records of their management decisions, but few monitor their vegetation. Perhaps the greatest challenge for range advisers is to convince farmers to keep well-balanced records, and to use these in decision making.

CONCLUSION

We have attempted to identify the nature of environmental change and its implications for grazing management, essentially from the southern African experience. The paper takes a traditional ecological approach in assessing change and its implications, often ignoring changing economic environments and socio-political conditions as major driving variables of grazier management, and hence vegetation change.

Management decisions by graziers in southern Africa often bear little relationship to traditional ecological considerations with economics being the major driving force (e.g. Danckwerts and King, 1984; Danckwerts and Marais, 1989). Although the importance of economics may be taken to be self-evident, we consider that changing economic conditions should be formally integrated into conceptual ecological models of rangeland change. This is a major challenge for rangeland scientists in the future.

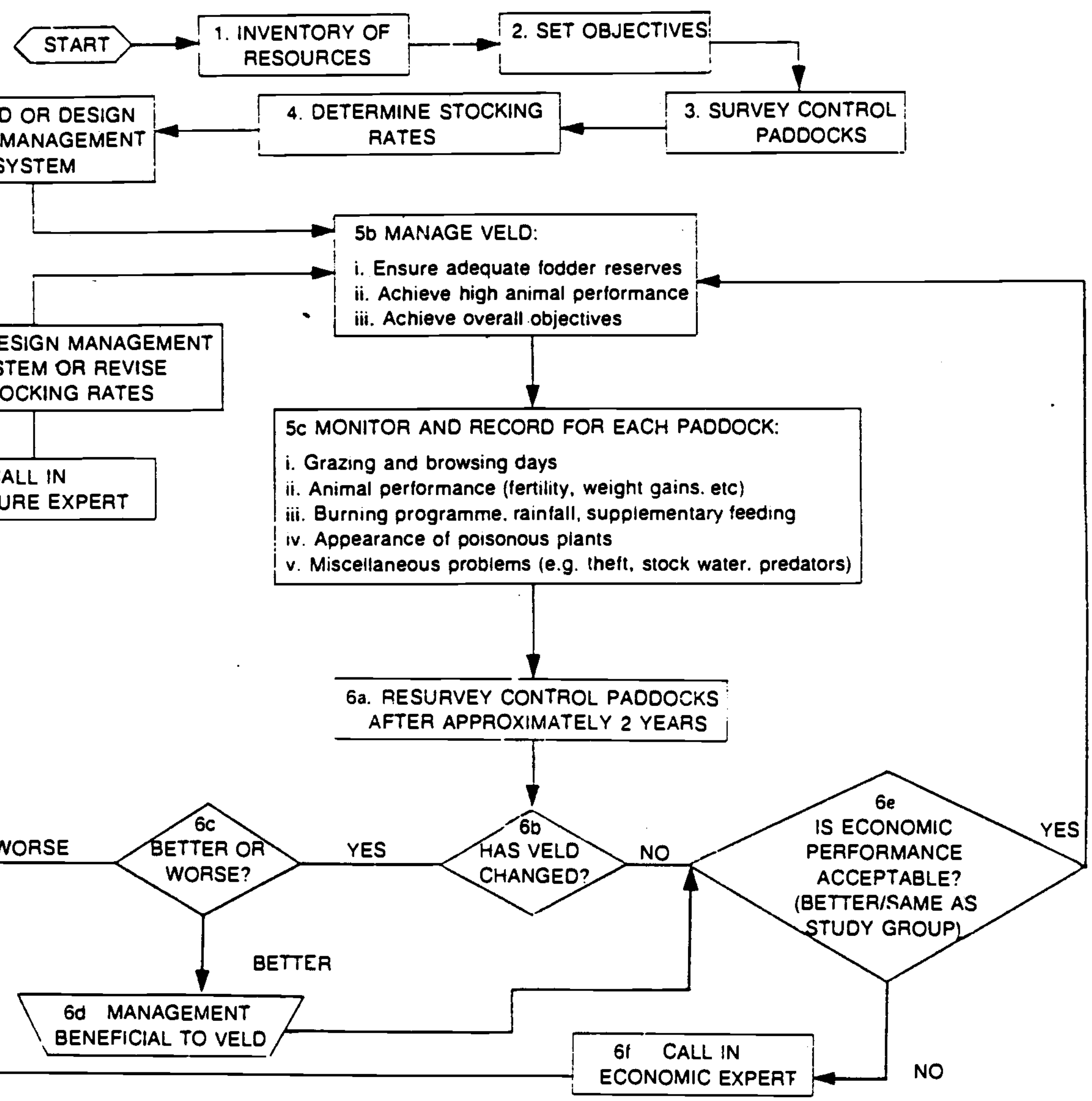

Figure 3. Procedure for adaptive range management (Stuart-Hill, 1989).

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