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RANGE MANAGEMENT: OPTIMIZING FORAGE PRODUCTION AND QUALITY

J.E. Danckwerts[1] & N.M. Tainton[2,3]
[1] Department of Plant Sciences, University of Fort Hare, Private Bag X1314, Alice, South Africa
[2] Department of Grassland Science, University of Natal, P. O. Box 375, Pietermaritzburg, South Africa

Abstract

Range management involves optimizing forage production and quality, both in the short-term and in the long-term. In the short-term, forage production and quality is strongly influenced, *inter alia* by temporal climatic variability, stocking rate, grazing system, fire, animal type and spatial variability. On the other hand, long-term optimization requires prevention of range deterioration. The nature of this process seems to be profoundly different between humid and arid rangelands. In the former, changes are relatively predictable, with overgrazing resulting in gradual deterioration. In the latter, change is event driven, providing the grazier with long periods of system inertia interspersed randomly by risks and opportunities to cause or prevent community change from one state to another. Management for long-term sustainability often requires sacrifice of short-term welfare. The benefits of such management may even be beyond the planning horizon of the grazier. Implementing conservation thus requires altruism on the part of the grazier - an unlikely option. If society requires such conservation, it may need to amend its values, and either provide the grazier with an incentive, or outlaw overgrazing.

Keywords
Management, production, quality, range, short-term, sustainability

Introduction

Range management is the process whereby graziers examine the probable consequences of different management actions, and select those which, in their opinion, have the highest chance of attaining their objectives (adapted from Provenza 1991). Grazier objectives are driven largely by socio-economic conditions. Since these are diverse (nowhere more evident than in the first world/third world dichotomy of southern Africa), management actions will vary, even where conditions and resources for plant growth are similar.

Despite the diversity of grazier objectives, under domestic pastoralism, they usually relate directly to some aspect of animal performance, and only indirectly to range performance. Range management actions would thus be taken only in so far as they affect animal performance. Such performance would be a function of the quantity and quality of forage consumed by animals. Range management thus translates, essentially, to optimizing productivity and quality of forage, both in the short- and long-term, the optimum being determined by grazier objectives.

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 other management actions from which the grazier might choose are almost endless. Clearly, the range scientist cannot hope to address all possible permutations through empirical experimentation, and is forced to develop conceptual models, and hence management principles, to assist in prediction. These will rely as far as possible on quantitative research, but will, of necessity, also draw heavily on conventional wisdom, observed successes and failures of graziers, untested hypotheses and intuition.

In this paper we address a few range management principles that affect the quantity and quality of forage production, and consequently animal performance. We draw largely on southern African experience, but attempt to evaluate this in a broader perspective.

Short-term and long-term objectives

Differentiation between short- and long-term grazier objectives is arbitrary. The former refer essentially to the current- and near future welfare of the grazier, while the latter refer to welfare at a later stage, which may, or may not, require some sacrifice of short-term welfare. The comparison, on a time scale, is relative rather than absolute. In both instances they must fall within the planning horizon of the individual grazier. Management actions aimed beyond this horizon would be society goals and not grazier objectives.

Short-term welfare must be complied with, at least to a critical minimum level, before long-term welfare can be addressed. This applies to both subsistence and commercial pastoralism. In the former, short-term welfare must at least exceed that required for healthy physical existence, and in the latter, the grazier must be able to maintain financial liquidity. Below these "critical" levels, pastoral operations would fail before long-term objectives could be attained. Above these critical levels, graziers are in a position to consider long-term options that may not, but very often do, require investment or sacrifice of at least some short-term welfare.

In the ensuing discussion we differentiate between

[3]Present address: 3 Kew Gardens, Town Bush Valley Road, Pietermaritzburg, 3201

management principles aimed at optimizing forage production and quality in the short -term, and those with long-term objectives.

Optimizing short-term forage production & quality

Temporal variability and forage budgeting

Rangelands are temporally variable, and this results in major intra- and inter-seasonal changes in the quantity and quality of available forage. The character of this variability is, in broad terms, profoundly different between humid and arid rangelands. We structure this discussion by distinguishing between these two functional groups of rangelands, although we accept that there is a continuum between the two, and the comparison is, as with that between short- and long-term, relative rather than absolute.

Intra-seasonal changes are generally 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 season, with a decline in the dry season. In humid areas this is commonly accompanied by a marked decline in forage quality as the dry season, or winter, approaches, reaching submaintenance levels in winter (O'Reagain and Mentis 1988). Forage intake and daily gain of, for example, a free ranging steer would thus vary considerably over the year (Figure 1).

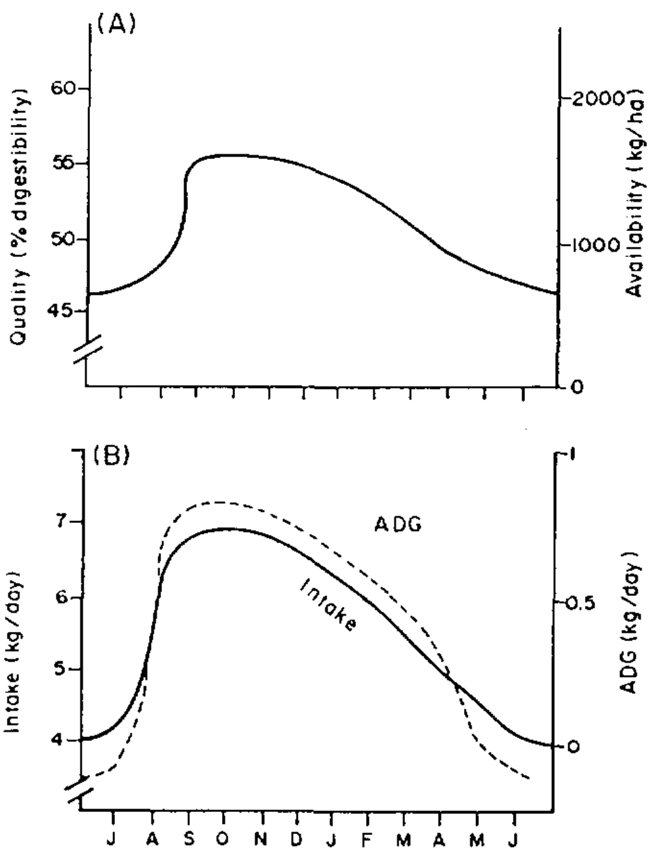

Figure 1 Trends in forage quality (A) and in daily intake and daily mass gain (ADG) perhead (B) on humid sour grassveld where forage availability is never limiting (after Danckwerts, 1989b).

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 render the grazier in a position to practice fodder budgeting - 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, forage quality often 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 mean annual rainfall is inversely correlated to its coefficient of variation. For example, in the summer rainfall region of South Africa 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 arid and semi-arid rangelands. A twelve fold difference in grass production was recorded between average and dry seasons in *Acacia* savanna in Zimbabwe (Dye & Spear 1982). Variable production 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 a semi-arid savanna system, grazing capacity varied from 0.026 to 0.2 large stock units per ha, a difference of over 700% (Tainton & Danckwerts 1989) (Figure 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 practiced 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 forage and the cost of land preclude 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.

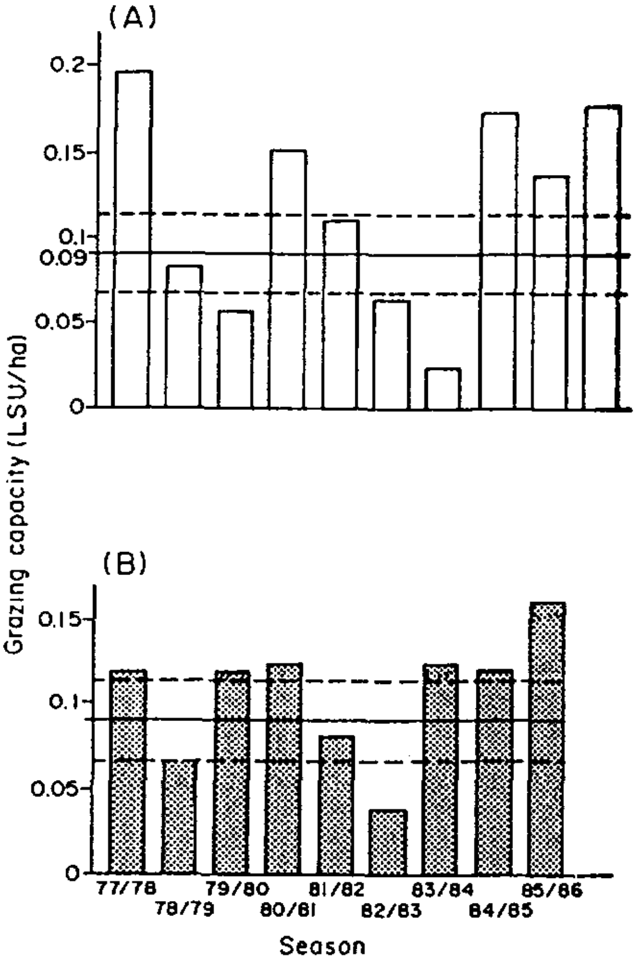

Figure 2 Seasonal grazing capacity at the Adelaide Research Station from 1976 to 1986(A), and grazing capacity assuming one third of the range is rested each year (B). Bold line represents long-term mean grazing capacity and broken lines represent a range 25% above and below the long-term mean (after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

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 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 is to withdraw a portion of a ranch from grazing for an extended period an on a rotational basis. In South Africa, we generally recommend that ranchers in semi-arid areas withdraw at least a third of their range from grazing for the duration of each growing season (Tainton & 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 (Figure 2A) to determine the carrying capacity of the same range assuming one third was rested each year (Figure 2B). It is clear that resting would have had a major fodder flow advantage and, indeed, this option was practiced with great success on the area in question (Danckwerts 1987b). Nevertheless, while buffering inter-seasonal fluctuation, this option will by no means eliminate it (Figure 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 the inter-seasonal fluctuation in carrying capacity will be a major management challenge.

Stocking Rate

The effect of stocking rate on animal production has been well documented (e.g. Jones & Sandland 1974), and it is not our intention to review this in detail. Stocking rate may affect animal performance in two ways - by affecting the amount of forage available for consumption per head, and also by possibly affecting the quality of forage on offer. In general, however, one expects animal performance to be relatively unaffected at light stocking rates, but that it should drop sharply as soon as forage availability becomes limiting.

Quantitative models of the effect of stocking rate on animal performance allow graziers to select that stocking rate which best suits their animal production objective. For example, Danckwerts & King (1984) used the model of Jones & Sandland (1974) to describe the effect of stocking rate on animal performance in a semi-arid southern African savanna. Economic analysis of this relationship (Figure 3) showed that the most profitable stocking rate was below that where maximum production per ha occurred, and this would almost always be the case provided there are costs of production associated with holding additional animals (Danckwerts & King 1984). In contrast, communal pastoralism might not have a profit incentive, and traditional values may, for example, dictate heavier optimal stocking rates than under commercial pastoralism (Danckwerts & van Rooyen 1979). Both the situations discussed above relate to short-term welfare. These optima may well conflict with long term objectives - we discuss this later.

Grazing systems

Most animal production goals would translate, in range management terms, to provision of adequate amounts of high quality forage to their animals. At any instant of time this can best be achieved by allowing animals to select freely from as large an area of range as possible, implying that animals that are continuously grazed (i.e. not rotated between paddocks) should, in the short-term, perform better per head than those that are confined to only a portion of the range in rotational or deferred system. Research has frequently shown this to be so, at least in southern Africa (reviewed by O'Reagain & Turner 1992).

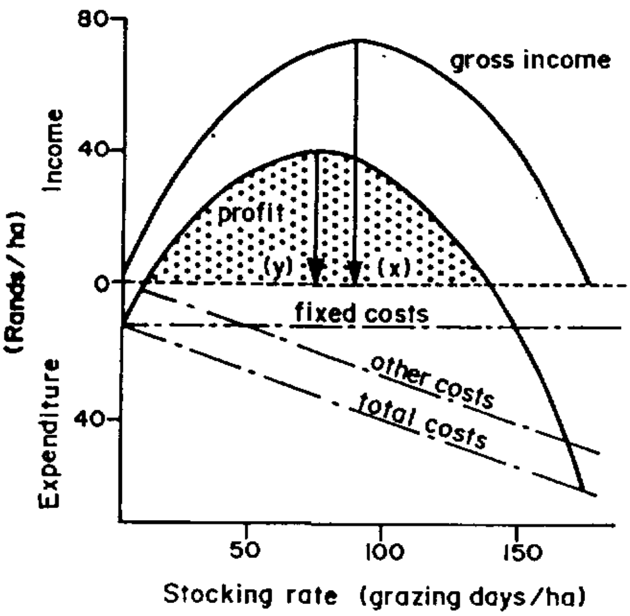

Figure 3 The effect of stocking rate on gross income per ha, costs of production per haand profit per ha. (X) and (Y) are stocking rates where maximum income and maximum profit occur respectively (after Danckwerts and King, 1984).

Rotational grazing systems may, however, be useful, even in the short-term, despite a depressing effect on animal performance. Firstly they can be used indirectly, in order to ration forage by withdrawing part of the range from grazing. This has already been discussed, and it is a form of rotational grazing, even though it may take place on an inter-seasonal time scale. Secondly, rotational grazing can be used to allow for differential quantity and quality of forage to be reserved for animals requiring different levels of nutrition. For example, steers could be used to remove old, relatively unpalatable herbage, and then removed. The new flush, could, after a suitable regrowth period, be reserved for reproducing or growing animals. Clearly, in order to implement this type of strategy, paddocking is necessary.

Despite these two situations, in general, we would argue that rotational grazing systems depress animal production in the short-term. Also, the capital expenditure involved in paddocking is high and may only be financially justified if depreciated over periods which exceed the planning horizon of most graziers (Mentis 1991).

Fire

Fire is an extremely useful tool for manipulating forage quality and availability. Its use for bush control has been well published in the international literature. Where inedible brush can be removed by fire, this practice will clearly be considered favourable in the short-term by graziers whose objective is to maximize production, or numbers of grazing animals.

Another, less well published short-term use of fire, is to improve the quality of the forage itself. This practice has been taking place in southern Africa for many years, and as early as 1807, the Xhosa, a nation of pastoralists, were reported to be burning range on an extensive scale to produce nutritious grazing for their livestock (Alberti 1807). Burnt rangeland is typically selected in preference to unburnt areas because of the high quality regrowth of the former (Mess 1958; Tainton *et al.* 1977; Grunow 1979). Fire does often, however, reduce, even if only temporarily, the production of forage (Tainton *et al.* 1977). This may be a crucial factor in systems where animal numbers are considered more important that animal performance. Fire, as a tool to produce nutritious grazing, will be of relevance only where rangeland becomes unpalatable with age. In southern Africa, this would apply essentially to humid rangelands, since arid ranges generally retain their quality when mature.

Animal type

While fire can sometimes be used as a management tool to manipulate vegetation to suit animal requirements, as an alternative, the grazier may be able to adapt animal species to suit the vegetation. This is not always possible since, in general, a plant species that is preferred by one type of animal tends to be preferred by other types of animals as well (Mentis 1981). However, a good example of adapting animals to suit the vegetation would be introduction of browsers into ranges encroached by woody plants. For instance, in southern Africa's Acacia savannas, production of both herbage and browse is strongly influenced by the density of trees. Introduction of goats, which are browsers, results in complementary resource use which potentially could greatly exceed animal production where only grazers are present (Aucamp *et al* 1983) (Figure 4).

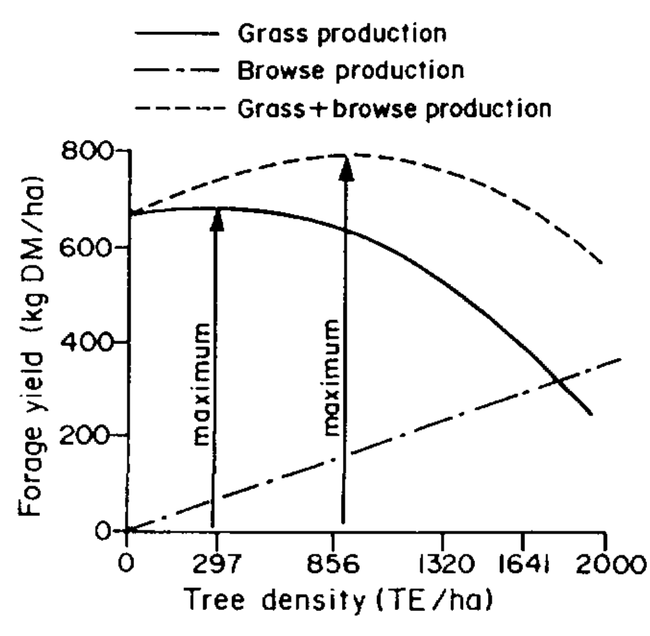

Figure 4 The influence of Acacia karoo density on grass, browse and total forage production (after Aucamp, et. al., 1983).

Spatial variability

Rangelands are spatially heterogeneous, ranging 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) geology (e.g. Ebersöhn 1961) and localized phenomena such as fire. Superimposed on the physical environment may also be intra-seasonal patchiness in rainfall distribution associated with stochastic formation of conventional thunderstorm cells (Preston-Whyte & 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 & Sinclair 1979) and both between and within seasons (e.g. Fabricius & Mentis 1990).

Animals select strongly for sites with high resource value (area selective grazing), largely avoiding other areas (e.g. Downing 1979). Such 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 range may be substantially lower that its potential. In southern Africa, fencing of different vegetation types (paddocking) has been widely recommended to allow even, controlled use of rangeland, and thus improved animal production (e.g. Anon 1926; Roux 1968). The high capital cost of fencing, referred to earlier, might, however preclude paddocking.

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). 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 water points and mineral licks are further options for manipulating animal distributions, both at paddock and landscape scale (Mills & 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.

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 sufficiently.

Management for sustained forage production and quality

If we accept evolutionary theory, then herbivory, will, in the long term, select for plants that can withstand the attentions of herbivores (Stuart-Hill & Mentis 1982). They do this through the presence of anti-herbivore characteristics which reduce their attractiveness as a feed. An increase in the abundance of plants with anti-herbivore characteristics is therefore viewed by graziers as range deterioration. This means that management for sustained forage production and quality will aim at preventing the increase, or reducing the abundance of these plants. Since it involves reversing the process of natural selection, the task of the range manager is a daunting one.

Indeed, the world's rangelands are allegedly degrading at an alarming rate, and overgrazing is frequently invoked as the cause. Yet, "overgrazing" is a loose term, and is certainly not consistently definable. Broadly, it represents the sum of those management actions that determine the extent to which anti-herbivore characteristics are selected for in plant communities. These actions might include, inter alia, stocking rate, animal type and species mix, grazing system and the interaction between fire and herbivory.

Commonly, the level of the various management actions required to ensure sustainablility will require sacrifice of short-term welfare on the part of the grazier. It generally pays to overstock in the short term, both in communal and commercial pastoral systems (Mentis 1986). Sustainablility may even require sacrifice of long term welfare - i.e. the benefits of the management actions required may only be attained beyond the planning horizon of the grazier, as for example with paddocking required for rotational grazing (Mentis 1991). Such management actions require altruism, and little wonder our rangelands are degrading.
A detailed review of the impact of various management actions on rangeland dynamics is beyond the scope of this paper - the interactions are almost endless. Instead, we will concern ourselves with the nature of rangeland deterioration (change), and how management actions might be taken to prevent unfavourable, or trigger favorable changes.

Temporal change

The nature of temporal compositional change has recently been the subject of considerable debate. The traditional paradigm of Clementsian succession has been favoured by rangeland scientists for many years. It argues that communities, if undisturbed, progress gradually and predictably from the colonizer to climax (or sub-climax) states which are ideal for grazing, and they are stable under "good" management. Further, overgrazing or mismanagement, causes retrogression which is the mirror image of progression. Southern Africa is an example where Clementsian philosophy has been favored, i.e. 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 much of 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 may therefore be 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 & Mentis 1982) with low forage value.

The increaser-decreaser model, with two categories of increasers (those that increase with either under- or over-grazing) has been emphasized for 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.

In recent years, the Clementsian paradigm has been firmly challenged (e.g. Westoby 1979; Mentis 1986; Walker 1988; Westoby *et al.* 1989), with the latter emphasizing the importance of event driven phenomena, especially in arid rangelands.

Even in humid rangelands, the traditional paradigm is open to criticism. For instance, an implicit assumption of the increaser-decreaser model is that grazing is the most important gradient rangeland species respond to. Yet, there is accumulating evidence that many species show only 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 & 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 term of responses of species to grazing alone. Indeed, fire is an enormously important tool in the management of humid rangelands, (Trollope 1989), 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 & Stuart-Hill 1987) 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 & Stuart-Hill (1987) found that even moderate grazing after 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 change appears to have reasonable utility for humid rangelands, and the event-driven approach in arid ranges. However, many rangelands are transitional between the two, and both models may apply at the same site, but on different time scales.

Spatial patterns of deterioration

The short-term implications of spatial heterogeneity in rangelands have already been discussed. In the long-term, excessive use of preferred sites generally degrades the vegetation to a less productive community with a resultant increase in soil loss (e.g. Donaldson 1986). Also, 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).

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 & Tainton 1978) areas are separated according to vegetation type, aspect, topography and soil with each group of animals rotationally grazing in 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 & Tainton 1978). While the alleged benefits of rotational grazing are debatable, camping *per se* appears to be important in preventing localized degradation and facilitating range management (O'Reagain & Turner 1992). On the other hand, paddocking has a number of disadvantages. Firstly, the cost - this has already been discussed. Secondly, poorly sited fences (e.g. incorporating a relatively palatable into a larger, less preferred community) can result in degradation (e.g. Donaldson 1986). Other methods of shifting livestock such as fire and provision of surface water would be equally relevant for avoiding degradation as they are for improving short term efficiency of rangeland use (discussed previously).

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 & Swift 1988). Under such non-equilibrium conditions, the traditional response has been adoption of transhumance (Sinclair & Fryxell 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 & Fryxell 1985; Ellis & Swift 1988). Settled pastoralism, as is commonly practiced 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.

Conclusion

A recurring theme in this paper is that range management for sustainable production often requires sacrifice of short term welfare. Range management may therefore be considered a compromise between short-term and long-term objectives. Even where a grazier is in a position to maximise personal longterm objectives, this does not necessarily mean sustainable pastoralism - gradual run-down may still be taking place and the management actions required to avoid this may yield results beyond the planning horizon of the grazier.

Society often requires that resource use should be sustainable, and this conservation philosophy is currently gaining increasing momentum. The reason is that if conservation practices are not applied, net revenue (be it financial of otherwise) will gradually decline. In contrast, if conservation practices are applied, net revenue would ultimately exceed that where conservation is not practiced, despite initial sacrifices (Figure 5).

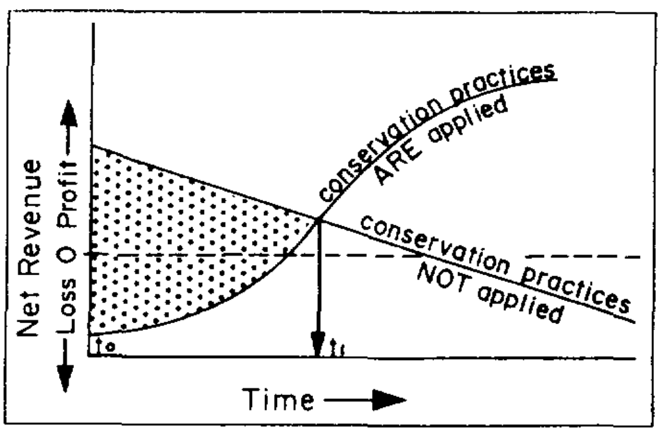

Figure 5 Hypothetical change in net revenue of a system when conservation practices are not and where they are applied (after Barlowe, 1982).

The grazier's adoption of conservation practices has two requirements. Firstly, initial net revenue under conservation management must exceed his immediate welfare requirements. Secondly the time t0 - t1 (Figure 5) must be shorter than his planning horizon. Non-compliance with one, or both, of these would require altruism from the grazier to adopt conservation management, and this is generally unlikely. Therefore, where society requires such conservation to be practiced, the grazier must be provided with an incentive, for example, by subsidisation or legislation. We thus conclude that to ensure sustainable range use, society might need to alter current values regarding the rights of range users.

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GRAZING CAPACITY AND LARGE STOCK UNIT EQUIVALENTS: ARE THEY COMPATIBLE?

M. B. Hardy
Cedara Agricultural Development Institute, Private Bag X9059, Pietermaritzburg 3200

Introduction

The purpose of this paper is to present a summary of a data set and some thoughts concerning the application of the concept of Large Stock Units (LSU) in setting grazing capacity estimates for cattle and sheep production systems on veld.

Mixed- or multi-species grazing are terms commonly used to describe the practice of grazing more than one species of livestock on the same resource. Mixed-species grazing is commonly practised by graziers and ranchers in livestock systems throughout Africa. By mixing different livestock species the available fodder is more efficiently utilized, the output of animal products may be increased, and the potential grazing capacity of the resource may be realized (Nolan & Connoly 1989).

However, there are numerous references to the negative effects that livestock production systems have had on natural grazing lands in South Africa (Anon. 1923; Scott 1952; King & Bembridge 1988). There was a concerted effort during the 1980s to address this problem with grazing capacity norms being determined for the whole country and the implementation of a National Grazing Strategy (Anon. 1985; Hayward 1986). The grazing capacity norms were established to provide guidelines on the environmental potential of an area to carry animals without degrading the resource. Grazing capacity was defined as the area of natural vegetation (ha) required to carry a single **Large Stock Unit (LSU)** for the normal grazeable period **without deterioration of the grazing or the soil** (Edwards 1981). By implication, graziers who stocked their farms with the 'correct' number of LSUs would expect to maintain condition of their veld (Tainton, *et al.* 1980) and to achieve an acceptable level of production per animal i.e. maintain a sustainable livestock production system.

Practical experience in livestock production systems has, however, suggested that there are problems associated with applying the LSU concept when setting grazing capacity norms. In cattle and sheep production systems the main questions which arise are: 1) will the grazing impact on veld due to sheep as compared with cattle be the same given the equivalent number of LSUs of each animal type, and 2) what differences in livestock production should be expected at equivalent stocking rates (LSU ha^{-1}) of cattle and sheep? The same questions may be asked for any multi-species livestock and/or wild herbivore grazing/browsing system.

The Large Stock Unit (LSU)

The sustainable use of veld for livestock production depends on a knowledge of the fodder requirements (for a specified level of production) of each class and type of animal using the fodder resource. In South Africa estimates of fodder requirements for animals of the same species but of different mass, or for different animal species are generally based on the detailed tables of Meissner *et al.* (1983) or the rough, but practical, conversion: $mass^{0.75}$ (Mentis 1981). While both these methods are based on intake of metabolizable energy (MJ ME kg^{-1} DM), the conversion tables of Meissner *et al.* (1983) have a sound theoretical base which also considers the species, maturity type, and physiological and reproductive state of each animal. Grazing preference is also considered in that it is recognized, for example, that, given the same pasture, sheep will generally select a diet of higher quality than will cattle.

Meissner *et al.* (1983) define the LSU as the **equivalent** of a head of cattle with a mass of 450kg which gains 500g per day in mass on a grass pasture with a mean DE of 55%. To achieve this the LSU requires 75 MJ ME d^{-1}. This implies that any other class, type or species of animal may be equated to an LSU by calculating their expected intake of ME.

Based on these conversion tables then, and given that each farming unit has a defined grazing capacity, a farmer may decide on how many of what class or species of animal could be stocked in each situation and expect a particular level of animal performance without deterioration of the resource. Not considered when applying the LSU concept in stocking veld according to the estimated grazing capacity are the grazing habits of different species and classes of animals. For example, sheep, being concentrate feeders (Mentis 1981), actively select for high quality forage which is normally found in the leaves of new regrowth and avoid old, rank herbage. The earlier sheep are provided access to new plant growth in spring the better is their performance (Barnes & Dempsey 1992). Furthermore, small herbivores such as sheep are anatomically and physiologically adapted to graze more selectively and closely than cattle (Heinemann 1970; Mentis 1980) and therefore have greater potential to degrade the vegetation than do cattle. Sheep therefore tend to concentrate their grazing on areas (or patches) of short, leafy, green herbage. The patches become over-grazed and trampled with consequent change in species composition and forage production potential. Cattle, being bulk grazers (Mentis 1981), can adequately provide for their nutritional requirements when presented with older herbage. Cattle therefore tend to spread their grazing over a wider area than sheep and do not concentrate on patches to the same extent as do sheep.

Grazing management recommendations are designed to take animal grazing habit into consideration. Hence the recommendation that sheep should be grazed together with cattle, at a ratio which favours cattle, to minimise the negative impacts of grazing on the veld by sheep.

However, much of the understanding of the effects of grazing habits of different animal species, and the incorporation of such understanding into grazing systems, is based on theoretical considerations. A trial was therefore established to examine the effects of grazing at a range of cattle to sheep ratios and stocking rates on animal performance and grazing impact. Animal performance and grazing impact data were then applied in evaluating the implications of defining grazing capacity in terms of LSU.

Grazing trial

The study was conducted at the Kokstad Agricultural Research Station (30°31'S, 29°25'E; altitude - 1341m) which is situated in Highland Sourveld (Acocks 1988). The trial comprised 15 grazing treatments viz. five cattle to sheep ratios (1:0, 3:1, 1:1, 1:3 & 0:1) each at three stocking rates (0.5 LSU ha^{-1}, 0.71 LSU ha^{-1} & 1.0 LSU ha^{-1}). Cattle to sheep ratios were balanced at the start of each grazing season in terms of LSUs according to the recommendations of Meissner *et al.* (1983). Each stocking rate/ratio treatment was managed as a four-paddock rotational grazing system with one of the paddocks in each treatment being rested for the whole season. The remaining paddocks were grazed in a 42 day cycle (14 days occupation and 28 day absence).

Animal performance

Animal performance data from each of the five ratios, at a single stocking rate were analysed and compared. Performance during the grazing season was expressed in terms of mass and average daily gain per animal. These data, together with estimates of the quality of intake, were used to calculate the changes in the number of LSU ha^{-1} for each ratio treatment through the grazing season applying the recommendations of Meissner *et al.* (1983). The number of LSU at any one time in the season provided an index of the grazing impact of each animal species at that time.

Grazing impact data

One paddock from each treatment was selected for sampling, these paddocks having the same occupation dates within each grazing cycle. A systematic point-sampling procedure was applied to ensure an even distribution of observations within each paddock. At each of 100 point positions the nearest individual of each of three target species (*Themeda triandra*, *Tristachya leucothrix* and *Alloteropsis semialata*) was observed and placed into one of five defoliation categories. The categories were: not grazed (U), grazed leniently but partially (LP), grazed leniently and uniformly (L), grazed severely but partially (SP), and grazed severely and uniformly (S). Tufts were considered to be uniformly grazed if, by visual estimation, less than one third of the tillers remained ungrazed. Partial defoliation was differentiated from uniform defoliation as both defoliation categories are commonly observed in grazed veld. Samples were taken at the end of each grazing season.

Results

Animal performance

Changes in LSU for each species of animal through the season are presentedin Figures 1a to 1d. Clearly, where the cattle and sheep

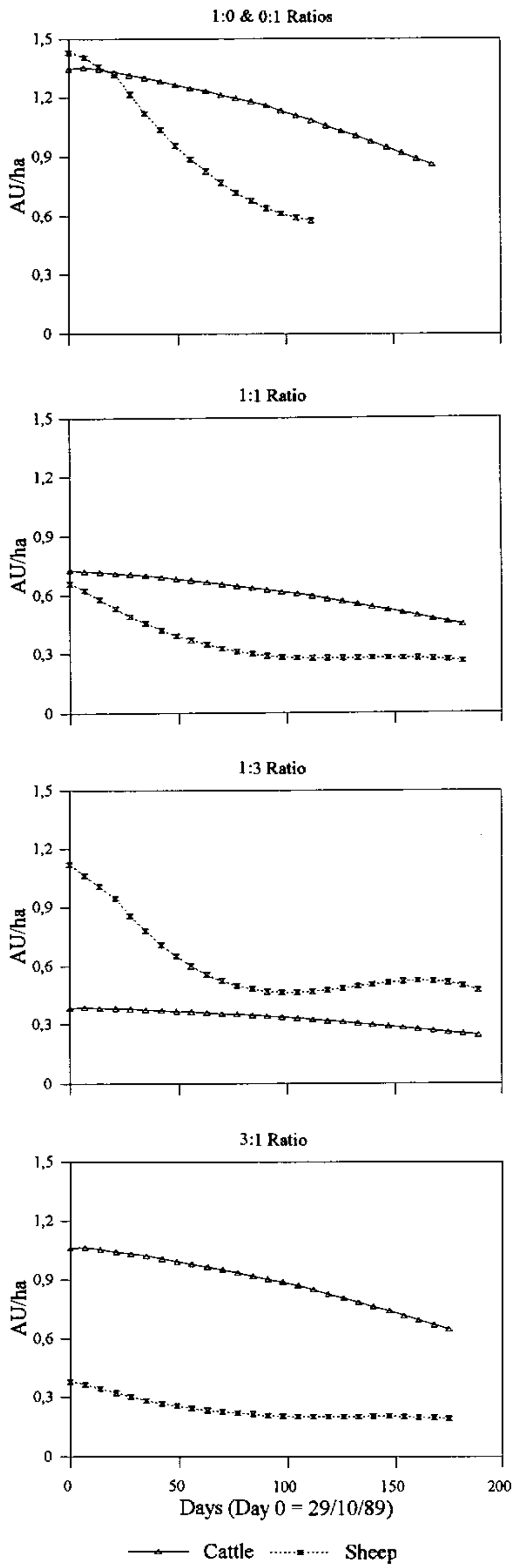

Figure 1 Seasonal trends in LSU ha^{-1} of cattle and sheep in each cattle:sheep ratio treatment (1:0, 3:1, 1:1, 1:3 and 0:1). presented in Figures 1a to 1d.

started at the same number of LSU ha^{-1} at the start of the season (Figures 1a and 1b), or where sheep where in higher proportion to cattle (Figure 1c), changes in LSU ha^{-1} through the season were quite different. This difference indicates a difference in grazing impact. Only the 3:1 ratio treatment showed some consistency in the proportion of cattle to sheep through the grazing season (Figure 1d). On the basis of LSUs therefore it could be assumed that the two animal species would have had a similar relative intake and, therefore, a similar impact on the veld when stocked at the 3:1 ratio at the start of a grazing season.

Grazing impact on individual grass plants

The impact of grazing due to the cattle-only (1:0 ratio) and sheep-only (0:1 ratio) grazing treatments on *T. triandra* and *T. leucothrix*, at a range of stocking rates (LSU ha^{-1}), is summarised in Figure 2. In Figure 2 the Y-axis represents the percentage plants of each species recorded in the severely grazed category (<2.5cm stubble height). There is a clear distinction between cattle and sheep in their impact on individual plants. For example, at a stocking rate of approximately 1.0 LSU ha^{-1}, 70% of the *T. leucothrix* plants were in the severely grazed category due to sheep grazing whilst only 30% of the plants had been grazed into the same category by the cattle stocked at the same rate (Figure 2b).

Cattle stocking rate was increased by a factor of 0.6 (to 1.6 LSU ha^{-1}) before approximately 70% of the *T. leucothrix* plants were severely grazed (Figure 2b). A similar result was obtained for *T. triandra* (Figure 2a).

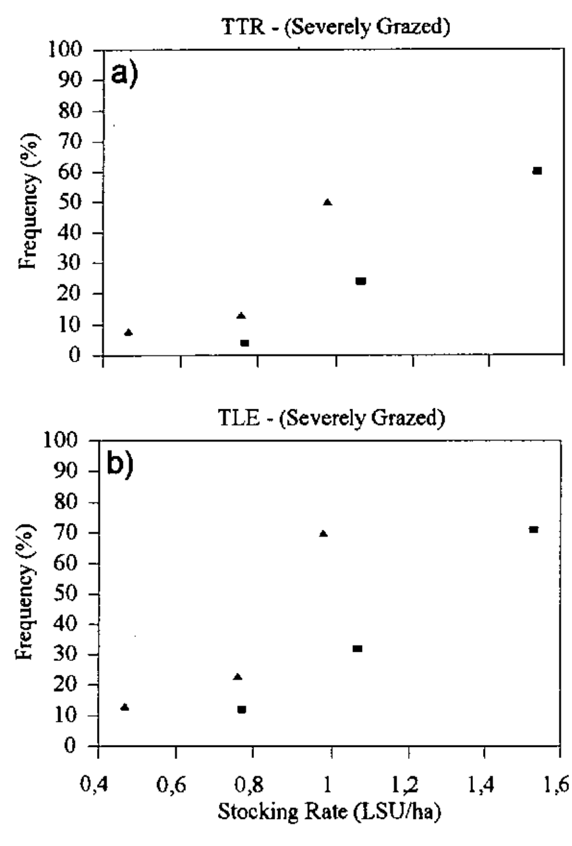

Figure 2 Proportion (%) of plants in the severely grazed category for a range in stocking rate (LSU ha^{-1}) of cattle-only and sheep-only grazing for a) *Themeda triandra* and b) *Tristachya leucothrix*

Discussion and conclusions

The severity of defoliation on individual plants in the cattle-only treatments clearly differs from that of the sheep-only treatments (Fig 2). This observation has important implications for the management of veld. As discussed above, grazing capacity estimates are based on the idea that, in the long term, the productivity of the veld will be maintained if it is stocked at the 'correct' rate. When different classes of cattle, or different species of livestock e.g. sheep, form important components of the livestock production enterprise, the number of cattle or sheep which may be carried per hectare is usually determined as a function or their estimated LSU equivalents and the grazing capacity of the veld type. However, the present data set corroborates the contention that it is not only the number of LSU ha^{-1} that is important, but also the animal types that are used in making up those LSUs. What the current study clearly demonstrates is that 1 LSU sheep will not have the same impact on the veld as 1 LSU cattle and that one cannot simply use the calculations to adjust from one type of animal to another. For sheep production systems, therefore, the grazing capacity estimates are misleading.

How then do these result add to our knowledge base relating to sustainable cattle and sheep production from Highland Sourveld? Sustainability relates to the maintenance or improvement of the forage production potential of the sward. Peddie (1994) conducted a research programme within the current trial which investigated i) the utility of a full growing season's rest for restoring the vigour of plants which were either severely (<4cm) or leniently (>4cm) grazed relative to ungrazed plants and ii) patterns of grazing on *T. triandra* and *T. leucothrix*. It was concluded that a full growing season's rest was sufficient time for the severely grazed *T. triandra* to regain vigour to the same level as plants which were leniently or ungrazed but that this was not necessarily true for *T. leucothrix*. In the second study, tufts of *T. triandra* and *T. leucothrix*, marked as having been severely grazed at the end of the first grazing season, continued to be severely grazed in the second and third grazing seasons. Thirty and 14 per cent of the marked *T. triandra* plants died in the sheep-only and the 1:1 ratio treatment respectively whilst none of the marked *T. triandra* plants died in the cattle-only treatment. A similar trend occurred with the *T. leucothrix* plants although the levels of mortality were not as high as the levels observed for *T. triandra*. Plants which died were replaced by less desirable plants with low forage production potential (Peddie 1994). Interestingly, for the severe grazing category, the mean height to which *T. triandra* plants had been defoliated after three years of grazing were 10.8mm, 13.3mm and 24.5mm for the sheep-only (0:1), 1:1 and cattle-only (1:0) ratio treatments respectively. Grazing heights for the same category of *T. leucothrix* plants were 7.3mm, 11.3mm and 23.5mm for the sheep-only (0:1), 1:1 and cattle-only (1:0) ratio treatments respectively. The results of these detailed studies corroborate the general patterns of defoliation presented in Figure 2.

It appears that, within a four-paddock rotational grazing system which includes sheep, plants which were severely grazed during the first season after a burn will continue to be grazed in following seasons and that such grazing may result in a relatively high mortality of these plants. While a full growing season's rest may have allowed for the recovery of vigour of plants which were severely grazed in previous seasons, a slow run-down of the system seems inevitable when sheep form part of the production enterprise. Run-down, or loss of production potential of the sward is likely to be slow at low stocking rates of sheep and more rapid at higher stocking rates.

It is suggested here, therefore, that in the long-term, a four paddock rotational grazing system which includes sheep as an integral component of the production enterprise, would not be sustainable. Further testing of the consequences of severe grazing by sheep on individual plants is necessary to provide corroborative evidence of plant mortalities under such circumstances. In the interim, empirical data acquired from the present trial provides strong indications that, in the long-term, the current recommendations of grazing cattle together with sheep order to **prevent** the degradation or loss of veld condition, which has been observed to occur in sheep-only production systems, will not succeed.

If we are serious about the maintenance or improvement of veld condition in the sourveld regions of South Africa, an alternative method for defining and applying grazing capacity estimates should be sought. Livestock production in the Highland Sourveld and similar Veld Types essentially involves cattle and sheep production enterprises. It is suggested, therefore, that it would be relatively simple (and acceptable in the farming communities) to define grazing capacity in terms of the species of livestock involved. The currently recommended grazing capacity for Highland Sourveld appears to be well suited to cattle production enterprises and the use of a four-paddock rotational grazing system. It is clearly not suited to livestock production enterprises which include sheep in a conventional four-paddock grazing system. Grazing management should therefore also be used as a qualifier in defining the grazing capacity of a particular area.

While the present study was not designed to investigate alternative methods of defining grazing capacity, results from this trial, together with the results of experiments involving sheep in similar Veld Types, provide guidelines which would assist in formulating such a definition.

It has already been stated that for cattle stocked at the appropriate stocking rate, a four-paddock rotational grazing system appears to have the potential to maintain the forage production potential of the veld. Where sheep are included in the system either together with cattle or on their own, an alternative management strategy is required. The severity of grazing and the consequences of maintaining such grazing on individual plants indicates that sheep should be prevented from grazing in areas of the farm which were grazed by sheep in the previous season. Severely grazed plants would then be given the opportunity to regain their vigour, even if cattle are allocated to these areas (since the cattle are not likely to graze individual plants to <2.5cm). Furthermore, since sheep require, green, leafy grass which is free of dead herbage to maximise their performance (Barnes & Dempsey 1992), the sheep should be allocated to paddocks which were burnt prior to the start of the grazing season (in the early spring). In the simplest form, therefore, it is suggested that for sustainable sheep production in Highland Sourveld, the sheep should graze only those paddocks which were burnt in early spring at a stocking rate suited to the forage production potential of the area. Sheep performance will be enhanced within these areas if the sheep graze together with cattle at a ratio which favours cattle. Paddocks grazed by sheep in one season could be rested in the following season or grazed by cattle.

Whereas the definition of grazing capacity for cattle assumes some form of multipaddock grazing system, the definition of grazing capacity for sheep production enterprises should also assume a management system which addresses the impact of grazing by sheep on the sward on animal performance.

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ANIMAL-RELATED INFORMATION REQUIRED AND A MORE COMPREHENSIVE APPROACH TO IMPROVE ESTIMATES OF CARRYING CAPACITY

H. H. Meissner

Department of Animal and Wildlife Sciences, University of Pretoria, Pretoria 0002

Introduction

The term *carrying capacity* has different meanings for different people. This is one reason why veld management programmes have not always proved successful. Danckwerts (1989) defined carrying capacity *as the area of land required to maintain an animal unit in order to achieve maximum profit in the short-term, while maintaining the condition of the vegetation and soil in such a way as to be able to fulfil the needs and aspirations of future land users.* This definition emphasizes an objective of profit which indicates to a particular animal production level required to produce a product. In communal land tenure systems the profit incentive is not a priority, but "wealth in numbers" is (Trollope 1985). Also, it is not relevant to game reserves where preservation of biodiversity is the primary objective. This points to the fact that carrying capacity should be defined with a particular objective in mind. However, *sustainability* must always be foremost and therefore improved estimates of carrying capacity are central to ensuring sustainable management and utilisation of ecosystems. The question addressed here is what animal-related information is required to fine-tune current estimates of carrying capacity.

The Animal Unit Concept

Many veld ecologists are of the opinion that the AU concept did not achieve what it was intended for and should therefore be replaced by something else. The question is also posed in this symposium (Hardy 1994). I am of the opinion that the concept is still relevant but that the application needs adjustment. To advance my argument, it is probably necessary to recall the initial intent. The AU as a norm or authoritative standard to estimate carrying capacity, was developed in an effort to *synchronize the requirements or intake of animals with the supply of fodder from the veld to the mutual benefit of both.* This has always been the prime objective. From the outset it was argued that the norm should be scientifically justifiable because it would have to be used in sound planning of farms or reserves, in determining the market value of farms, in acting as a point of reference/departure in aid schemes or property disputes, or in evaluating production systems (Meissner *et al.* 1983). *The norm was also not intended to predict production responses.* Whether the AU falls short as a relevant norm for estimating carrying capacity, the concept remains sound and there is sufficient evidence that the South African approach has been more acceptable than almost any other approach elsewhere. Therefore, I am of the opinion that the basis of the argument should be addressed towards the failure of the AU to effectively *simulate* carrying capacity, rather than the concept *per se*. The question is then, why has it failed? One reason is rigid application and recommendations by officials without taking into consideration veld condition, rainfall, animal species involved, management procedures and objectives. Carrying capacity is an *on-farm concern* and not a district or area concern. In game reserves, objectives are different and more factors come into play such as competition and spatial requirements. Marketing is only a secondary objective. Therefore, carrying capacity estimates in AU's for game reserves will almost always be lower than for livestock farming.

The second reason, which is the one that is addressed here, is the lack of research data which can describe/predict the *impact of the grazing animal on the vegetation and vice versa.* The impact on the animal follows from the argument that its performance reflects the balance between the *potential performance*, i.e. nutrient requirements, and the nutrients it is able to consume from the veld. This statement relates to the arguments of Meissner *et al.* (1983) in the AU development document, which I quote: "*Further, it was argued that the classification of animals should be done in two ways, namely in terms of requirements of different production functions and in terms of voluntary feed intake. The latter is the more practical in terms of pasture management and planning of production systems, because any particular pasture would not necessarily meet the requirements of the animal. The specific voluntary intake of pasture realized would eventually determine the production of the animal on that pasture. On the other hand, when animals are classified according to their requirements, provision is made for any particular production situation which might arise*", unquote.

The authors of the AU development document listed above expected voluntary intakes for different qualities of veld (Tables 4.4 to 4.15), but these have not been popular in estimating carrying capacity. Also, the predicted voluntary intakes are not expected to be accurate because the quality of the veld is ultimately determined by the selection pattern of the animal and the plant composition on offer, and not by the simple analysis of a hand-harvested sample. If the quality of the veld can be described in terms of what the animal selects, the estimates of carrying capacity will go a long way in making provision for the fact that the impact on the vegetation of one AU of species A is different from the impact of one AU of species B.

An example will illustrate: From the available South African results the following prediction equation has been calculated to estimate the quality of what cattle and sheep will select:

(1) $DOM_O(\%) = 66.5 - 0.85\ IVDOM_H(\%) + 0.013\ (IVDOM_H)^2(\%)$
$R^2 = 0.79$
where, DOM_O = Digestible OM of oesophageal sample
$IVDOM_H$ = *In vitro* digestibility of OM of hand-harvested sample

The average difference in estimate between cattle and sheep in DOM_O is 10%, i.e. the estimate for cattle is 5% less and the estimate for sheep 5% more than the calculated DOM_O.

Two other prediction equations have been developed from veld and pasture quality and intake data:

(2) $NDF(\%) = 48.7 + 1.46\ DOM(\%) - 0.019\ (DOM)^2(\%)$
$R^2 = 0.80$
where, NDF = neutral detergent fibre

(3) $OMI\ (g/kg\ W^{0.9}/day) = 70 - 97_e^{-0.975(DOM:NDF)}$ (Meissner & Paulsmeier, 1994)
$R^2 = 0.67$
where, OMI = voluntary intake of any ruminant species
DOM:NDF = ratio between DOM and NDF
$W^{0.9}$ = weight of the animal raised to the power of 0.9.

Example: If $IVDOM_H$ = 50%, DOM_O for cattle will be 53.5% and DOM_O for sheep 59.5%. NDF for cattle will be 72.5% and for sheep 68.5% (all figures rounded to 0.5). The ratio DOM:NDF for cattle will be 0.74 and for sheep 0.87 and the OMI respectively 23 g and 28.5 g/kg $W^{0.9}$/day. The OMI equates to 5.6 kg for a 450 kg ox and 0.88 kg for a 45 kg wether which represents a ratio of one 450 kg ox to 6.4 (45 kg) wethers.

If the difference in selection pattern was not taken into account, the ratio would have been one 450 kg ox to 7.9 (45 kg) wethers.

Thus, by taking into account the difference in selection pattern of cattle and sheep, the difference in stocking rate and therefore the impact on the vegetation is about 20%. Similar adjustments can be made to stocking rates of other bulk grazers and selective feeders with further modifications relating to spatial requirements and habitat overlapping. In this regard, considerable progress has been made with grazing systems of cattle and sheep and/or goats in the Eastern Cape (Danckwerts & Teague 1989; Trollope *et al.* 1992) and to some extent also in the Karoo and Free State Regions. However, much more information is required and the research effort needs to be multi-disciplinary.

Information required

We need data where different animal species graze together. This is of particular importance where there is competition for the feed resource or where the habitat overlaps. See the contribution by Novelli (1994) in this symposium. The usual approach in estimating carrying capacity has been to assume that the effect of the species is additive, which is wrong. For example, the ratio of cattle to sheep in the Eastern Cape on sourveld has been shown to be 1 LSU: 6 SSU (where LSU = Large Stock Unit and SSU = Small Stock Unit) and on sweetveld 1 LSU: 3 SSU (Trollope *et al.* 1992), i.e. *the impact of sheep on the vegetation is more severe than the impact of cattle.* One would expect this to be the case for selective feeders vs bulk grazers in general.

Large scale grazing experiments of this nature are however time-consuming and costly, and therefore mostly limited to experimental farms with the necessary infrastructure. For the remainder, researchers need to resort to simulation which requires specific inputs to improve estimates of carrying capacity. To that effect we need more information in three key areas:

(a) The requirements of animal species should be defined in terms of the *herbage on offer.* This necessitates measurements of the *amount* and *quality* of the herbage consumed by the grazing animal. It also requires identification of the *species composition* of the diet selected. Some progress in this regard has been made with livestock at Döhne, Glen, Grootfontein and Upington and with game at Timbavati (Meissner *et al.* 1990; Pietersen *et al.* 1993). Recently, exciting results have been reported by Ford (1994) at Roodeplaat. She found no difference between Simmentalers, Ngunis and Afrikaners in their selection of a preferred species (*Setaria sphacelata*) and an intermediate species (*Heteropogon contortus*), but the Simmentalers selected less of an unpreferred species (*Aristida congesta*) than the Ngunis and Afrikaners. The results suggest that indigenous stock may utilize the veld more uniformly which has far-reaching implications for estimates of carrying capacity and veld management.

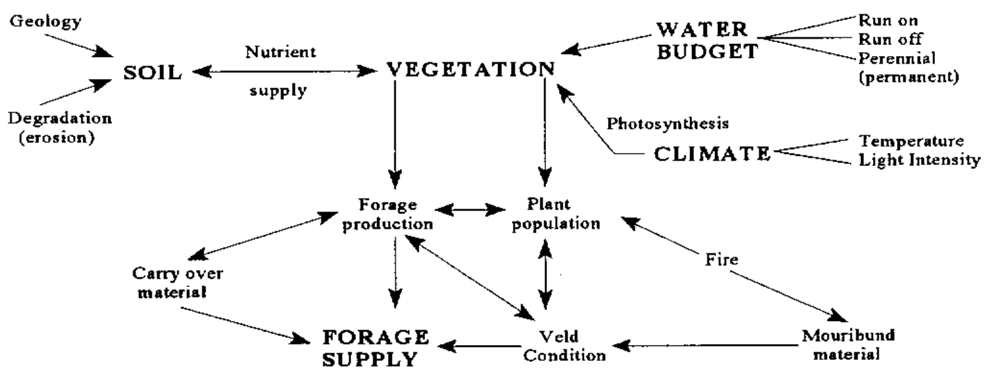
(b) The *critical period(s)* in food supply - quality and quantity - should be determined. Critical periods have a profound effect on animal production and stocking rate. Results in this area would also enable more economical supplementation and utilization of fodder reserves to the benefit of the veld.

(c) The ***nutritive status*** of animal species (e.g. mineral status) should be studied and monitored. The need for such information is maybe more important in the less studied game species than in livestock, but it would provide valuable input to refine carrying capacity and to establish critical periods. Monitoring nutritive status in the Kruger National Park has proved useful in aiding veld management decisions (Grant *et al.* 1994).

The information discussed should be integrated with veld condition score and other plant-based norms to develop suitable prediction models of carrying capacity. I am of the opinion that to make headway with carrying capacity we need to resort to sophisticated *mathematical models*. Carrying capacity is at best a dynamic equilibrium because it changes with season and is influenced by a magnitude of variables. Multi-variable models have become possible with the development of geographic information systems (GIS) which can be linked with process information mathematical prediction models (Coughenour 1993; Stewart 1993), whereby a framework is provided for organizing the central data base (to predict carrying capacity) with interacting data bases (submodels of influencing factors).

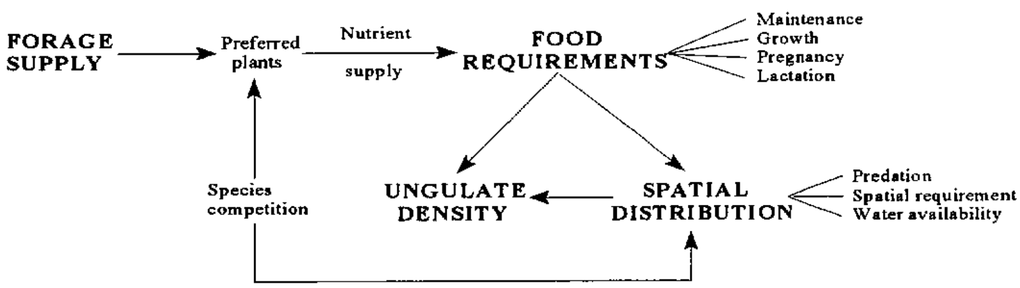
We have commenced developing a GIS-process driven model to estimate ungulate carrying capacity in the Kruger National Park. The following is a summarized account of the basic reasoning and elements considered, and which may be of value to other model builders.

Carrying capacity is simplistically defined as the dynamic equilibrium between forage supply and ungulate requirements (herbivory). Both elements have characteristics which modify the input-output relationship or have influencing or associative factors that do not contribute directly to the equilibrium. Forage supply is determined by forage production which is a function of climate, soil, water, fire and vegetation composition. Ungulate herbivory is a function of nutrient and energy requirements, and of food preference and availability. Ungulate herbivory is, however, modified by ungulate density which is only partially explained by food requirements. Other factors that contribute to ungulate density are water point distribution, perdition, spatial requirements and population dynamics (inter- and intra-species interaction). These factors would modify the simplistically defined equilibrium resulting more often in lower carrying capacities than anticipated, but rarely also higher carrying capacities (e.g. ungulates grazing new growth on burnt areas). The modifying influences should be addressed in submodels that can interlink to determine the dynamic equilibrium (carrying capacity).



Submodel 1: Forage supply

The essential elements which require modelling to different degrees themselves are soil, climate, water budget and vegetation.



Submodel 2: Ungulate density

The essential elements are forage supply, food requirements and spatial distribution.

By linking Submodel 1 with Submodel 2 it is envisaged that optimum densities (equate to carrying capacity) can be calculated for individual ungulate species in different areas and seasons.

The reliability of the prediction model will depend on the extent and accuracy of the data sets. These should be regularly updated by monitoring, literature surveys and fundamental research where information is lacking.

Closing remarks

The AU concept remains a useful point of reference and it is a unit that the farmer can associate with. Therefore, I do not think that we should abandon the concept at this stage. There is, however, considerable scope for improving its application in estimates of carrying capacity, but this would require *multi-disciplinary research* and development of *sophisticated prediction models*.

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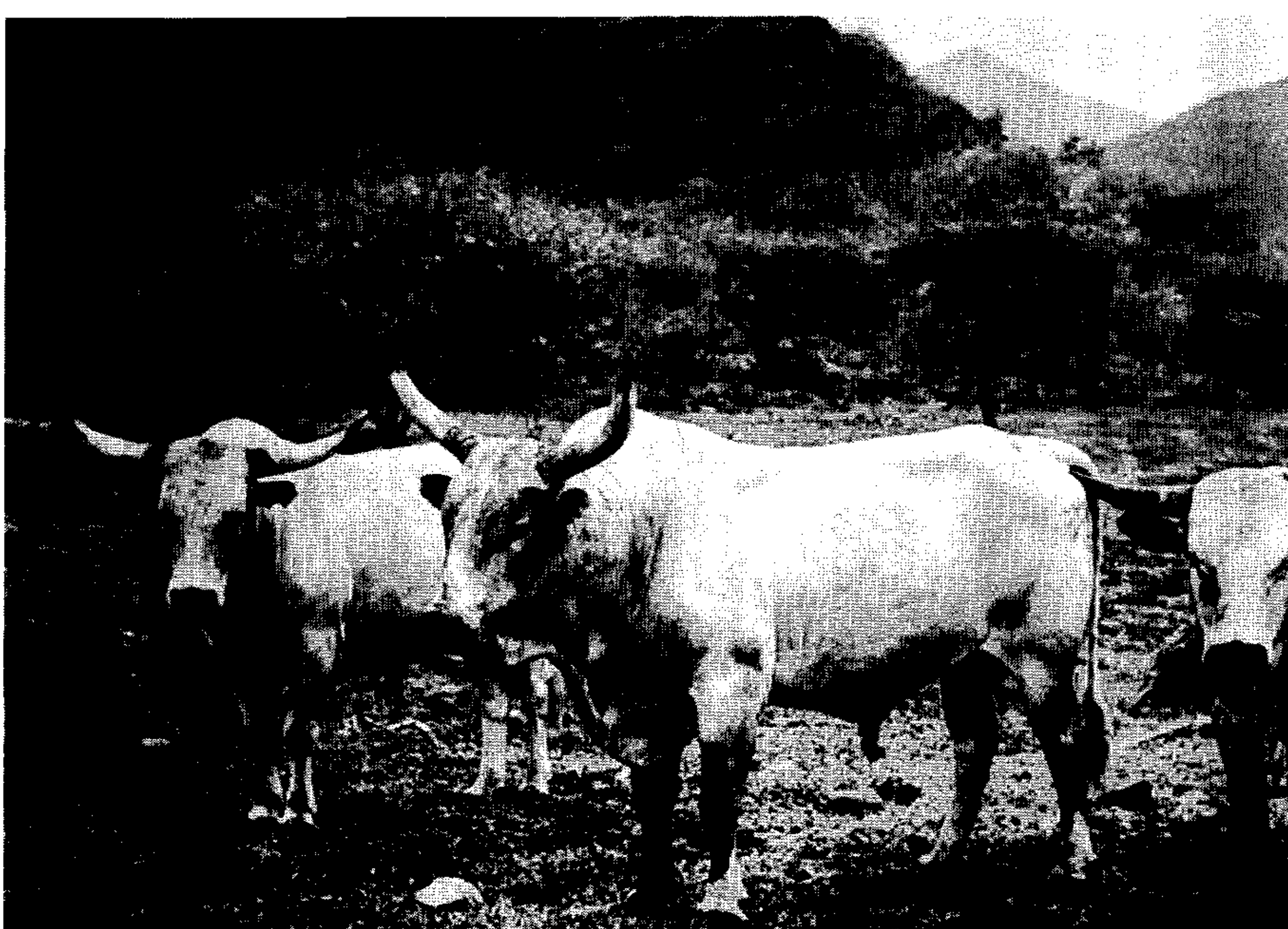

Preferences and diet quality of livestock indigenous to dry areas are some of the topics covered in these proceedings. Here, Zebu cattle are shown as examples of the cattle indigenous to central and east Africa (photo WSW Trollope).