Dryland Networks Programme

ISSUES PAPER

Rethinking Range Ecology:
Implications for Rangeland Management in Africa

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IIED
INTERNATIONAL INSTITUTE FOR ENVIRONMENT AND DEVELOPMENT

Paper No. 33
March
1992

odi
Overseas Development Institute

Rethinking Range Ecology: Implications for Rangeland Management in Africa

Overview of Paper Presentations
and Discussions at the
Commonwealth Secretariat Technical Meeting
on Savanna Development and Pasture Production,
19-21 November 1990, Woburn, UK

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This paper is an overview of themes emerging from the papers presented at a technical workshop on range ecology convened by the Commonwealth Secretariat at Woburn, UK in November 1990. Twenty-five scientists attended, all of whom had worked extensively in Africa. Funding for the workshop and for writing and publication of this paper came from the Commonwealth Secretariat, the World Bank and the International Institute for Environment and Development (IIED). Roy Behnke is the coordinator of the Pastoral Development Network at the Overseas Development Institute in London and Ian Scoones is a Research Associate with the Drylands Programme at IIED.

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Introduction[1]

Few range management projects in dry Africa have had a discernible, positive, and permanent impact on the way communal rangeland is used. Most have failed to enlist the active cooperation of the pastoral communities they were supposed to serve. These failures reflect a variable combination of social, institutional and technical deficiencies in project and programme design. This paper examines one aspect of this complex problem: the limited appropriateness and validity of conventional range management theory in the African situation.

The third edition of Stoddart, Smith and Box's standard textbook *Range Management* opens with the observation that:

> In the more than 30 years since the appearance of the first edition of *Range Management*, there have been many changes... . Nevertheless, no new conceptual framework differentiates the field of range management now from then (1975:ix).

While this statement may have been true in 1975, it no longer holds. What were once anomalous individual field cases are now increasingly linked into an internally consistent, alternative theory of the functioning of savanna rangelands (Frost *et al.* 1986). In many instances this work calls into question conventional range management techniques and the theoretical assumptions which underpin these techniques.

The policy implications of the new ecological theories for Africa's predominately communal rangelands, managed by pastoralists, have been raised but only tentatively explored (Ellis and Swift 1988). Likewise, the basic biological research which should inform policy making often is not readily accessible to the other parties interested in applied rangeland management, including administrators, social scientists and economists. The papers examined in this report therefore review recent biological research on African rangelands and highlight its management implications for future donor and national government policy.

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[1] Acknowledgements: The authors would like to thank Wolfgang Bayer, Hank Breman, Layne Coppock, John English, Peter Frost, James Gambiza, Cees de Haan, Dennis Herlocker, Brian Kerr, Ben Norton, Gregory Perrier, Stephen Sandford, Martin Upton and Richard White for a close and critical reading of previous drafts of this report. We would especially like to thank Carol Kerven who commented upon the manuscript at every stage in its preparation. The views expressed here are those of the authors alone, as will be immediately apparent to a number of our commentators who raised substantial issues which we were not able to address within the confines of this report.

The preeminent management problem on communal African rangeland has been perceived for some considerable time, both by the public at large and by many rangeland professionals, as the control of rangeland degradation through the control of excessive livestock numbers. The scientific basis for this concern has been the concept of rangeland carrying capacity, defined and measured according to assumptions about the impact of herbivores on plant succession. This concept has provided the standard against which African rangelands are judged to be overstocked, inefficiently used, and ultimately degraded (Sandford 1983).

The papers reviewed here pose a number of difficult questions regarding the precision with which carrying capacity can be estimated, current definitions of the concept and its relevance to certain dry African environments. They also critically examine the concept of rangeland degradation and propose techniques for its more appropriate assessment. Finally, these papers contribute empirically to the debate by providing new data on the present condition of rangelands and livestock in a number of African countries.

In sum, it is argued here that the mainstream view of range science is fundamentally flawed in its application to certain rangeland ecologies and forms of pastoral production. If range management is to be of any use in these settings, conventional theories and recommended management practices require not minor adjustment but a thorough re-examination. The papers reviewed here provide an opportunity for just such a reassessment.

Carrying Capacity and Succession Theory: the Mainstream Approach

The conventional notion of carrying capacity in range management rests on theories of plant succession, defined as the orderly and directional process whereby one association or community of plant species replaces another (Stoddart *et al.* 1975:156). Succession theory was initially developed at the turn of the century to explain variation in vegetation types in North America (Cowles 1899, Clements 1916). Research in range science from the 1920s to the 1940s transformed this theory into a practical, applied technique for the management of natural forage and grazing animals, that is, range management (Sampson 1923).

Both succession theory and range management practice assumed that a single, persistent and characteristic vegetation, the climax, would dominate a particular site, depending on the soil and climate of that site. If this climax vegetation was disturbed, the vegetation could nonetheless return through a successional sequence to climax. An obvious example of disturbance and subsequent succession back to climax is provided by the clearing of a forest area for agriculture, the abandonment of the area, and the eventual reestablishment of forest through a predictable sequence of intermediate vegetational stages.

Range management adapted these ideas to grazing systems. It was assumed that the effects on vegetation of grazing paralleled, in a less dramatic way, the effects of clearing fields for crop agriculture. That is, grazing pushed the successional sequence back to some form of sub-climax. The task for the range manager was to balance grazing pressure against the natural regenerative power of the plants, thereby maintaining a stable sub-climax which yielded a steady and profitable flow of animal products. The concept of carrying capacity was *important because it marked the stocking density at which this balance could be* achieved.

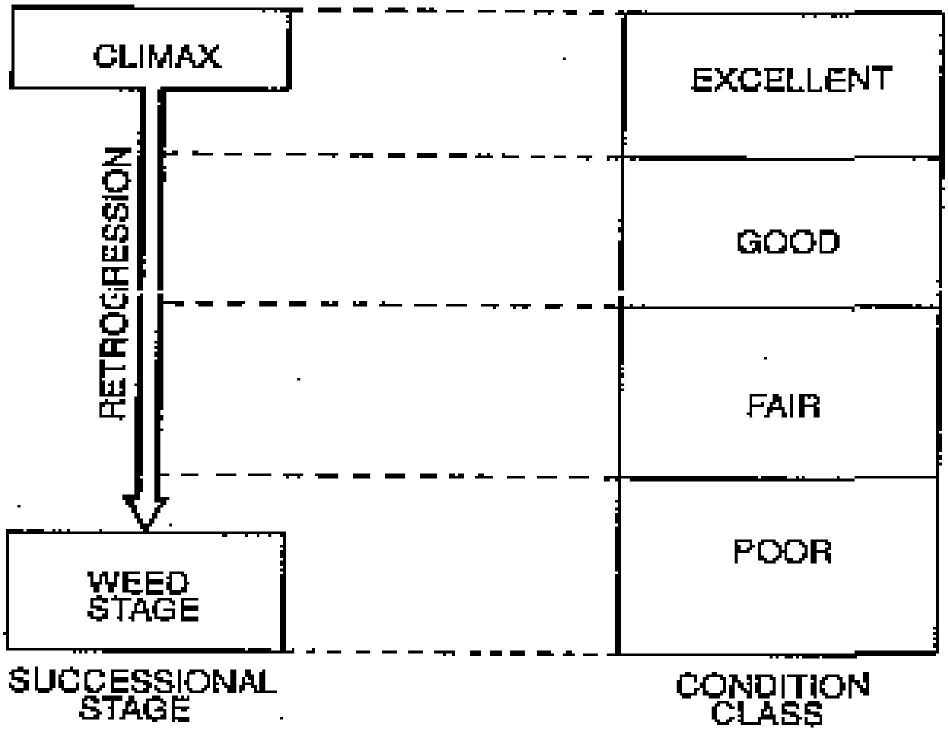
Pushed beyond the threshold of carrying capacity, the balance between grazing pressure and the inherent regenerative powers of the range was destroyed, and the condition of the range progressively deteriorated. This deterioration was reflected in a process of regression back through the successional sequence. The theoretical relation between poor range condition and an early stage in a successional sequence is diagrammatically expressed in Figure 1.

In practical terms, experienced range managers found that they were often able to estimate range condition by reference to plant species which were particularly sensitive to the effects of grazing. These indicator species either increased, decreased or invaded a range depending on the intensity of grazing pressure, and thereby provided a convenient measure of the extent to which grazing had altered and was continuing to alter the climax vegetation. This botanical approach to the assessment of range deterioration was defended on the grounds that vegetation change preceded both reduced livestock production and increased levels of soil loss, and therefore served as a valuable 'early warning' of declines *in other parts of the rangeland system (Stoddart et al. 1975:267).*

Carrying Capacity: Ecological or Economic

A different approach to the definition of carrying capacity has been developed by wildlife population biologists, in response to the practical problems of managing parks, their vegetation and their wild herbivore populations. Range ecologists have much to learn from these allied professions in developing a definition of carrying capacity which is appropriate to the management of

Figure 1: **Relationship between Range Condition and Degree of Retrogression from Climax Conditions**

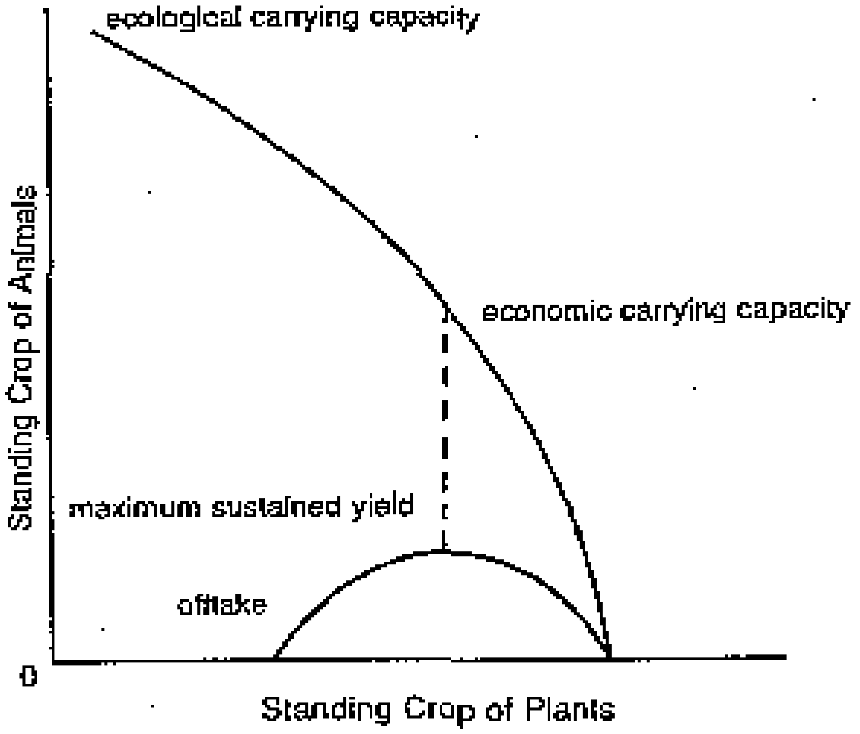


Source: Modified from Stoddart, Smith and Box 1975

communal rangelands used by African pastoralists. If extended to include the study of pastoral production on communal ranges, this approach to carrying capacity also demands a fundamental reassessment of the extent to which heavy stocking rates in pastoral areas constitute overgrazing.

Figure 2, originally presented by Caughley (1979) and elaborated by Bell (1985), provides a schematic overview of the relationship between plant and wild herbivore populations at alternative stocking densities. The top curve in Figure 2, called the zero isocline of vegetation, marks all technically feasible combinations of plant and animal densities in a hypothetical grazing system. At the far right end of the horizontal axis, the curve depicts the situation which prevails when there is a small animal population and a large standing crop of plants. As the animal population increases, the edible plant biomass declines.

Figure 2: The Relationship between Plant and Animal Populations in a Grazing System



Source: Adapted from Caughley 1979 and Bell 1985

In an undisturbed grazing system, the increase in animal numbers will eventually be checked by the declining availability of natural forage. This will occur when the production of forage equals the rate of its consumption by animals, and the livestock population ceases to grow because limited feed supplies produce death rates equal to birth rates. At this point there is no surplus production either of individuals or biomass. This point of equilibrium, routinely designated 'K' in the ecological literature, is termed ecological carrying capacity in Figure 2. At ecological carrying capacity, livestock may be plentiful but they will not be in particularly good condition; neither will the vegetation be as dense nor will the plant communities necessarily be composed of the same species as they would be in the absence of animals (Caughley 1979, Bell 1985).

If managers want denser vegetation or healthier animals, then they must maintain fewer animals. This can be done either by hunting, in the case of wild herbivores, or by culling, in the case of domestic stock. The offtake curve in Figure 2 indicates the different offtake levels managers must maintain in order to support combinations of plant and animal densities other than those occurring at ecological carrying capacity. Initially the offtake curve rises from zero at very low stocking rates and increases with the increasing size of the herbivore population. The sustainable offtake rate—determined by multiplying the total animal population by the excess of the birth over the death rate—is highest at the stocking density at which the animal population is growing most rapidly. This point of maximum sustained yield usually lies at about half to two thirds of the stocking density at ecological carrying capacity, a stocking density which Caughley has termed 'economic carrying capacity' (1979). As the animal population grows beyond economic carrying capacity the offtake rate begins to fall and ultimately returns to zero as increasingly high rates of mortality and falling birthrates obviate both the need and opportunity for offtake to maintain stable animal populations.

Depending on the economic and aesthetic environment in which they are operating, wildlife managers have been called upon to maintain many of the different combinations of plant and animal densities illustrated in Figure 2. Through their control over hunting quotas, they frequently have had the capacity to do so.

As an illustration of the management options open to wildlife ecologists, let us consider a park which is financially sustained by a tourist industry based on game viewing. In this case the manager will require a relatively dense population of animals which will increase the probability that the individual tourist will actually confront the animals he has come to see. In this instance the park manager may desire a high animal population well above economic carrying capacity, a density which might be termed 'camera carrying capacity'. An unavoidable, but potentially attractive, by-product of these high stocking rates might be a thinning of the vegetative cover which could interfere with the sighting of game. On the other hand, a park might be operated to produce maximum kilograms of game meat for sale. In this instance the manager will require that density of animals which provides the maximum sustained yield in terms of meat output, or economic carrying capacity as defined by Caughley. An unavoidable by-product of this management system will be fewer animals and more vegetation, relative to a park managed for game viewing. Still other animal-plant population balances might be required in parks managed to produce trophy specimens, or to preserve particular plant communities sensitive to grazing pressure.

And which of these three park management systems is the correct one? All are technically feasible and all are economically profitable, under certain conditions. And each is associated with a distinctive density of animals. From the vantage point of wildlife management all three management systems are ecologically and scientifically defensible, although their relative financial and aesthetic merits might be hotly contested. Implied in this position is the conclusion that there is no single biologically optimal carrying capacity which can be defined independently of the different management objectives associated *with different forms of animal exploitation.*

> We conclude, therefore, that the only embracing definition of carrying capacity is: 'That density of animals and plants that allows the manager to get what he wants out of the system'. Thus, any specific definition of carrying capacity must be expressed in relation to a particular objective, and it must be defined very precisely since there are no 'natural' stability points in such interactive systems that act as foci for self-defining concepts (Bell 1985:153).

Given this perspective, it makes little sense to speak about overgrazing or understocking unless managers also specify the kind of management system they wish to institute and frame their assessment in terms of the appropriate stocking density for that system. Contrary to the presumptions of mainstream range science, there exist for wildlife managers no 'objective' biological criteria which will permit the specification of carrying capacity without prior reference to the goals and objectives of managers.

And if carrying capacity must be defined relative to economic objectives for wildlife management, why should the concept be treated any differently when applied to alternative forms of domestic livestock production on natural forage? In the pastoral as in the wildlife setting, there would appear to be different stocking densities associated with and appropriate to different forms of pastoral production. For example, if there exists consumer demand for high-grade meat, some ranchers may find it profitable to sell relatively few animals in excellent condition raised on a relatively abundant forage supply. These ranchers will need to hold their stocking densities well below economic carrying capacity as defined by Caughley, and will have to accept slaughter offtake rates below maximum sustainable yield expressed in terms of kilograms of harvested meat.

Alternatively, ranchers may be producing for a market in which meat is sold ungraded by weight, as is presently the case in Kenya. Ranchers operating in this marketing environment will, like their counterparts producing game meat sold by weight, seek to maintain stocking densities close to Caughley's economic carrying capacity[2].

Finally, there is the case of subsistence-oriented pastoralism as well as other forms of livestock husbandry (commercial dairy and fibre production) which seek to harvest animal output in the form of live-animal products such as milk, blood, traction power and transport. Offtake for these producers does not require animal slaughter and they can, therefore, profitably exploit a large standing crop of animals (Payne 1990). At some cost in terms of the output, health and viability of individual animals, these producers may be capable of maintaining high levels of aggregate output at stocking densities approaching ecological carrying capacity. Natural mortality in such heavily stocked systems may be high, but for the pastoralist it is not the unmitigated disaster it would be for commercial ranchers since animals can be slaughtered in anticipation of death and, in some cases, a certain percentage of carcasses may be retrieved and consumed after death.

The relationships depicted in Figure 2 are simplified and cannot predict real plant and animal interactions in most grazing systems. Subsequent sections of this report elaborate on many of the additional factors which must be considered in evaluating the effects of grazing pressure on rangeland resources in different situations. What Figure 2 does provide is a logical structure for distinguishing between the ecological and economic aspects of rangeland assessment.

Mainstream range management has sought to develop the biological science of rangeland use in order to address the practical needs of producers. Due to the historical association of range management with producers on beef ranches, many of the standard botanical indicators used to assess 'carrying capacity' (increasers, decreasers, perennial:annual ratios, bush 'encroachment' etc) have actually been implicitly derived in order to assess *economic* carrying capacity levels for beef ranching systems. Here we have one explanation of how livestock numbers in some parts of Africa have continued to grow, in some instances for four or five decades, beyond the purported limits of 'carrying

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[2] Because there are significant variable costs associated with holding domesticated stock, economically optimal stocking densities for commercial ranchers will always lie below the stocking density which produces maximum sustainable yield per hectare (Workman 1986, Wilson and Macleod 1991, Jarvis 1984, Carew 1976.)

capacity'. What was being estimated by the techniques of range management, it would appear, were not ecological but economic carrying capacity levels, and moreover, economic carrying capacity levels for kinds of production systems which did not exist in the areas being assessed. In Zimbabwe, for example, official recommended stocking rates relate to 'economic' carrying capacity for commercial beef production, and are a half to a third of estimated ecological carrying capacity and well below long-term stocking densities (Scoones 1990b).

Grazing Systems Not at Equilibrium

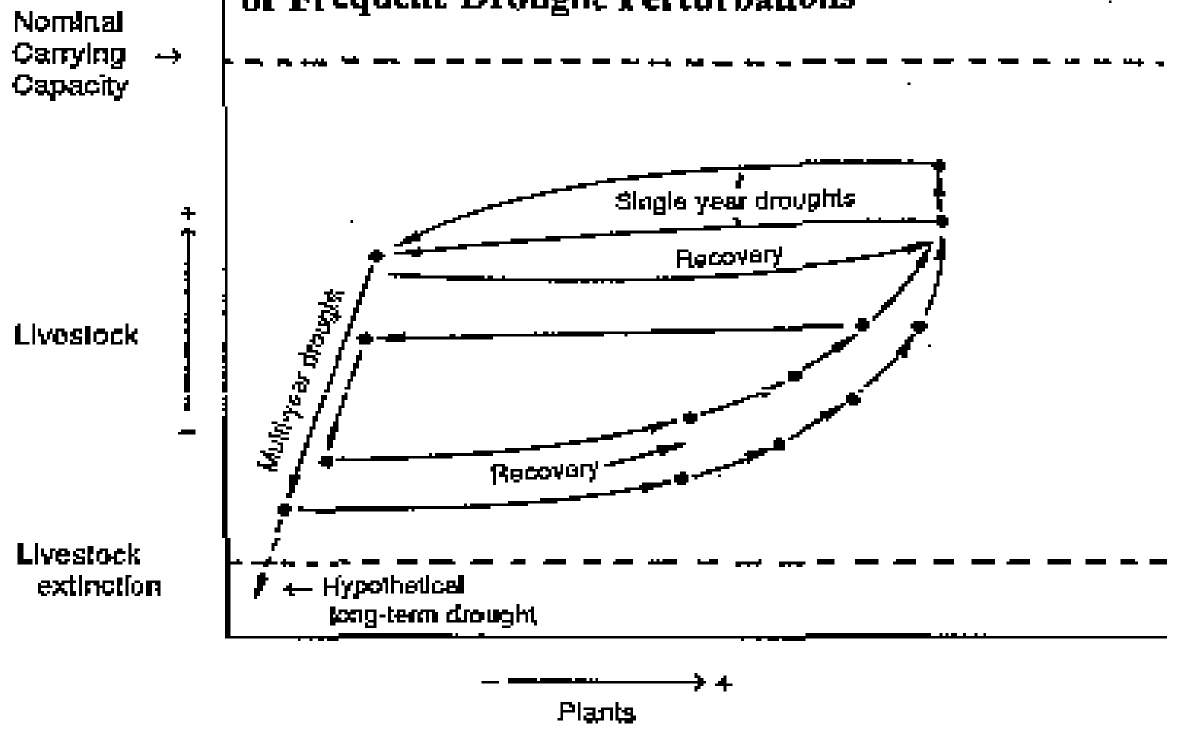
The erratic and variable rainfall in many pastoral areas of Africa poses a further fundamental challenge to standard conceptions of carrying capacity. Any notion of carrying capacity—be it ecological or economic—is predicated on the notion that herbivore numbers are controlled through the availability of forage and that the availability of forage is controlled by animal numbers, a pattern of negative feedback which eventually produces a stable equilibrium between animal and plant populations.

This pattern of interaction between plants and herbivores presumes, in turn, that conditions for plant growth are relatively constant. If physical factors such as rainfall and temperature fluctuate widely, it is likely that these non-biological variables will have a greater impact on plant growth than marginal changes in grazing pressure caused by different stocking densities. Moreover, unavailability of forage in bad years may depress livestock populations to the point where the impact of their grazing on the vegetation is minimal in most years. Thus, in these fluctuating climates, rainfall, not forage availability, may ultimately be the variable which limits herbivore population growth.

If disturbances are intermittent, it may be useful to analyze a grazing system as if it were at equilibrium, and to treat outside perturbations as 'noise' which confuses and obscures an underlying equilibrium pattern. On the other hand, if disturbance is frequent, random 'noise' so dominates events that it is more useful to think of the 'noise' itself as the system. Noisy or event-driven grazing systems require a different approach to and understanding of carrying capacity, which we must now examine.

Figure 3, based on Ellis and Swift (1988), illustrates plant-livestock interactions under the influence of frequent drought perturbations in a fluctuating climate—that of Turkana, Kenya. The axis labels in Figure 3 are identical to those in Figure 2. What has changed is the presumed level of stability in the

Figure 3: **Turkana Plant-Livestock Interactions under the Influence of Frequent Drought Perturbations**

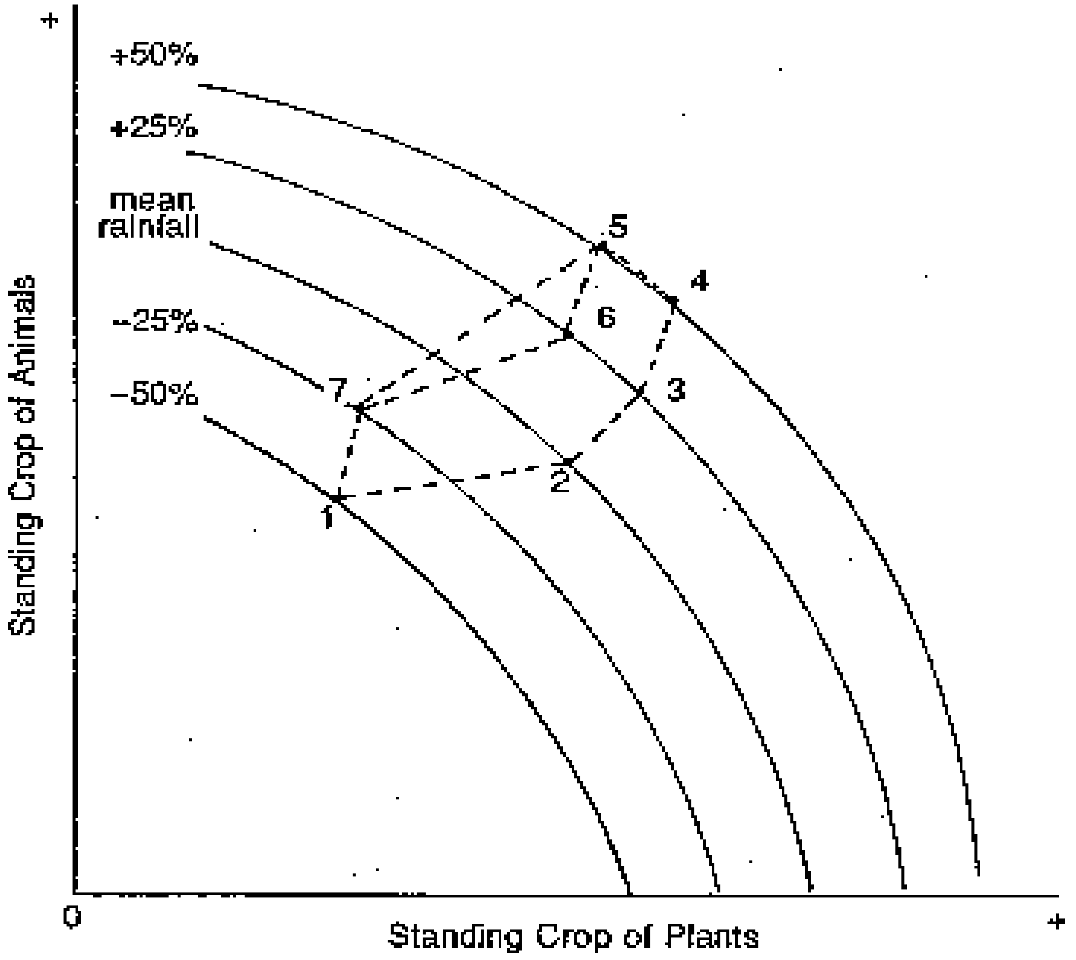


grazing system. As a result, the inverse relationship between plant and animal populations which characterized Figure 2 has been replaced by a more complicated pattern.

The points on the far right of Figure 3 chart a process of both plant and animal population expansion under favourable rainfall conditions for that particular environment. The points to the left of the figure represent the contraction of both populations under drought conditions of varying degrees of severity. Single year droughts constitute a minor and very temporary setback for the animal population, and a somewhat greater but nonetheless temporary setback for the plants, while multi-year droughts precipitate population crashes of both plants and animals. In this system, livestock populations may decline because of a lack of fodder, but fodder is scarce because there is too little rain rather than too many animals. Moreover, major droughts are frequent enough and herd recovery is slow enough that livestock numbers are never given an opportunity to approach ecological carrying capacity. In sum, the condition of this grazing system at any particular time is determined more by the chance occurrence of non-biological events than by interaction between the biological components of the system itself (Ellis and Swift 1988).

Why this should be so is illustrated in Figure 4, which summarizes the differences and underlying similarities between equilibrium and non-equilibrium grazing systems. In contrast to Figure 2 (the equilibrium situation), Figure 4 is based on a series of alternative vegetation isoclines corresponding to different annual rainfall levels, rather than one such level. The plant and animal populations which could theoretically be supported during an extended period of mean rainfall are presented in the middle curve. On either side of the mean isocline are additional curves depicting potential plant and animal populations in periods of above or below average rainfall. These additional curves reflect the diminished importance of mean rainfall and mean production values for an

Figure 4: Schematic Representation of Plant-Livestock Interactions under the Influence of Frequent Drought Perturbations



understanding of a system dominated by variability. For illustrative simplicity, only four additional curves are given, corresponding to a percent deviation from mean rainfall of -50%, -25%, +25% or +50%. In reality, variable amounts and timing of rainfall generate an almost limitless number of such additional curves.

Superimposed upon this series of isoclines are seven data points which, in much simplified form, depict the pattern of livestock and plant population response to variable rainfall in Turkana. As in Ellis and Swift's initial diagram (Figure 3), movement along the pathway 5—7—1 represents the onset of a major multi-year drought; pathway 1—2—3—4—5 represents recovery from such a drought; and the circuit 5—7—6—5 depicts the impact of and recovery from a single year drought. These alternative 'pathways' (or sequential combinations of plant and animal populations) are not confined to movement along one isocline, as they would be in the equilibrium situation. They instead reflect movement across a number of hypothetical isoclines, as plant and animal populations respond differently to short or long periods of deviation from mean rainfall levels, and respond at different rates.

Figures 2, 3 and 4 summarize quite different approaches to the understanding of rangeland ecology. In equilibrium grazing systems of the kind depicted in Figure 2, the physical conditions supporting plant growth are relatively unvarying, consumption by herbivores controls plant biomass, and the availability of feed ultimately regulates the growth of the herbivore population. In Figures 3 and 4 depicting non-equilibrium grazing systems, the physical conditions supporting plant growth vary widely and consumption by herbivores does not control plant biomass because the animal population is itself held in check by the same physical factors which control the vegetation. Grazing pressure may cause changes in vegetation, but the effects are complex and intermittent, as is discussed below.

Vegetation Change in an Episodic Environment

Thus far the discussion has focused on the relationship between plant and animal biomass in a grazing system. But range managers are not interested solely in the quantity of forage available for livestock, but in its quality and, hence, in the species composition of that forage. Grazing systems not at equilibrium present peculiar problems for the analysis and management of compositional changes in rangeland vegetation.

Irreversible, sudden or unpredictable changes in vegetation are difficult to reconcile with conventional notions of range succession as an incremental response to grazing pressure (Bartolome 1984). Citing extensive evidence of such anomalies, Westoby *et al.* have argued that standard successional models cannot account for observed patterns of vegetation change in rangelands not at equilibrium, and have offered an alternative 'state-and-transition' model to account for these changes.

In this model, no attempt is made to array various vegetation states along a single successional pathway. Instead, the vegetation in a particular area is described 'by means of catalogues of alternative states and catalogues of possible transitions between states' (Westoby *et al.* 1989:266). A range may move from one state into a number of different states, or return to its original state along a transitional pathway, and due to factors different from those which caused the initial change.

Different combinations of factors, of which grazing pressure is but one element, may be required to cause an alteration in state, and the effects of a particular stocking density will be unpredictable unless all these factors are known. Because other factors vary widely, effectively managing arid rangelands is not a matter of adhering to a single, conservative stocking rate which will apply in all circumstances. Rangeland management is, instead, a game of calculating probabilities 'the object of which is to seize opportunities and to evade hazards, so far as possible', what Westoby *et al.* (1988:266) call 'opportunistic management'.

The implications of opportunistic management for formal livestock development policy in dry Africa will be discussed in the closing section of this report. Opportunism is not, however, new to Africa's pastoralists; it provides the rationale behind one of the most characteristic of their husbandry techniques—migratory stock keeping.

The Ecological Determinants of Livestock Movements

Livestock movement is likely to play a very different role in equilibrium and non-equilibrium grazing systems. If a herd is confined to one place, livestock numbers, viability and productivity are limited by the scarcest resource in the scarcest season in that place. These limits to settled livestock husbandry will apply, both in an equilibrium grazing system of the kind depicted in Figure 2 or in a non-equilibrium system of the sort depicted in Figures 3 and 4. But the costs of immobility will be slight in equilibrium systems where conditions are constant, and high in non-equilibrium systems where one particularly unfavourable period can limit production irrespective of the abundance of resources in other periods.

Mainstream range management techniques are ideally suited to addressing the needs of settled forms of animal husbandry operating under equilibrium conditions (exemplified by fenced ranches in temperate climates). Essentially, these techniques attempt to dampen seasonal and inter-annual resource fluctuations within a delimited rangeland area. Conservative stocking rates, for example, are designed to provide a prudent rancher with a 'buffer' of surplus forage in unusually poor years; fencing or the placement of water points is used to promote uniform patterns of grazing and efficient forage consumption, while cultivated pastures are intended to offset insufficient forage production on natural pastures in certain seasons, etc. These techniques are useful in equilibrium grazing systems in which range productivity is both reliable and susceptible to some degree of management control.

Non-equilibrium grazing systems present a different kind of management problem. The costs of a sedentary production strategy are likely to be much higher in non-equilibrium settings because of the wide, unpredictable, and largely uncontrollable swings in productivity which characterize these environments. Here effective management is more a process of responding flexibly to stress rather than preventing it, and movement provides a means of circumventing stress under certain ecological conditions.

The advantages of herd mobility are illustrated schematically in Table 1 which depicts a mixed settled and migratory grazing system consisting of three ecological zones used over three seasons. The values in the table represent the potential number of livestock which could be sustained in each zone by season, assuming wide seasonal variation in zonal carrying capacities. In this hypothetical system, the number of sedentary livestock which can be maintained permanently in any ecological zone is 100, the carrying capacity of each of the zones during their seasonal period of most restricted resource availability. The total sedentary livestock population which can be supported within the region is 300, the sum of the lowest carrying capacities of the three ecological zones.

Mobile livestock production would increase the total regional livestock carrying capacity to 1,000. Permutations of eight different migratory regimes could be employed by individual herders to sustain this increase (moving sequentially

Table 1: Settled and Migratory Stock Levels in a Seasonally Variable Environment

Regional ecological zones	Seasons			Settled stock numbers
	Wet	Transitional	Dry	
A	1,000	100	200	100
B	200	1,000	100	100
C	100	200	700	100
Totals			1,000[1]	300[2]

[1] Total regional livestock population including migratory and settled stock
[2] Total regional sedentary livestock population

through the wet, transitional and dry seasons, these regimes are ABC, ACB, ABA, ACC, BCA, BBA, BBC, BCC). A simple migratory pattern combining two such regimes is illustrated in the table. Assuming 100 permanently settled animals in each zone, 600 additional migrant animals could be sustained on the migratory cycle A (wet) → B (transitional) → C (dry) → A (wet), indicated by the solid arrow. A further 100 migrant animals could be sustained by a B (wet) → C (transitional) → D (dry) → B (wet) pattern of movement, indicated by the broken arrow. These increases are possible because migratory stock numbers are determined by the scarcest resource period in the region as a whole (the dry season in our hypothetical example), rather than the sum of each such period for individual ecological zones.

Although not intended to illustrate any concrete situation, Table 1 suggests a transhumant pattern of cyclical herd movement based on predictable environmental fluctuations. Although rigidly simplified for illustrative purposes, this case involves eight distinct migratory regimes which could be variously recombined depending on the number of animals following each regime. Field studies of pastoral transhumant cycles confirm the potential complexity of these systems (Fry and McCabe 1986, Dyson-Hudson 1972, Behnke and Kerven 1984).

This complexity is magnified by the effect of fortuitous environmental fluctuations,

analyzed by Sandford (1983:33-36). The logic of Sandford's analysis is similar to that in Table 1, but is based on annual rather than seasonal carrying capacity figures for grazing areas within a region. A simplified version of Sandford's analysis is recalculated in Table 2.

In Table 2, area A is a relatively high production zone, B is medium, and C is a relatively unproductive zone, measured in terms of each area's three-year mean and single-year maximum and minimum carrying capacity. What matters in this case, however, are not the permanent ecological differences among the areas, but transient differences in forage production resulting from the erratic distribution of rainfall in particular years.

If livestock populations must be held in each area separately, the total sustainable regional livestock population over the three-year period is 700 head, the sum of the carrying capacities for all areas in their worst year. On the other hand, if we presume that animals can move freely between areas in response to exceptionally high or low rainfall, a total regional livestock population of 1,300 can be maintained. This higher value reflects the combined total carrying capacity of all three areas in the worst rainfall year for the region as a whole, year two.

Table 2 and Sandford's more detailed calculations illustrate the benefits of opportunistic stock movement in response to unpredictable rainfall fluctuations which are spatially and temporally random, and are suggestive of contemporary patterns of herd movement in the communal areas of Botswana and Zimbabwe, or Kenyan Maasailand. In these cases long-distance livestock movement is predominantly a contingent response to unpredictable but localized rainfall deficits, disease outbreaks, borehole breakdowns or range fires. In contrast to pastoralists engaged in seasonal transhumant movement, herders in these areas do not follow regular migratory routes. They instead maintain access rights to safe havens or fallback areas which will carry their herds through temporary crises in their home area.

Whether movement is regular and seasonal, contingent, or a combination of contingency and regularity, the producer's strategy within non-equilibrium systems is to move livestock sequentially across a series of environments each of which reaches peak carrying capacity in a different time period. Mobile herds can then move from zone to zone, region to region, avoiding resource-scarce periods and exploiting optimal periods in each area they use. In this way

Table 2: Settled and Migratory Stock Levels in an Unpredictably Variable Environment

Regional ecological zones	Three year mean carrying capacity	Years 1	2	3	Settled stock numbers
A	633	1,000	400	500	400
B	433	300	200	800	200
C	333	100	700	200	100
Totals	1,400[1]		1,300[2]		700[3]

[1] Regional mean carrying capacity
[2] Total regional livestock population including migratory and settled stock
[3] Total regional sedentary livestock population

mobile livestock producers can maintain within a wide geographic region a total livestock population and levels of productivity in excess of that which could be sustained, all else being equal, by several separate herds confined to their individual areas. The prevalence of herd mobility as a husbandry strategy is symptomatic of the general approach to livestock management in non-equilibrium environments. Herd management must aim at responding to alternate periods of high and low productivity, with an emphasis on exploiting environmental heterogeneity rather than attempting to manipulate the environment to maximize stability and uniformity. The closing sections of this document will discuss the implications of this 'opportunistic' style of herd management for the design of formal livestock development projects and programmes.

Responses to Spatial and Temporal Variation: Three Cases from Pastoral Africa

Three papers presented at the 1990 Technical Meeting—which described pastoral systems in Kenya, Ethiopia and Zimbabwe—explored the distinction between equilibrium and non-equilibrium grazing systems. Each of these papers also emphasized the role of opportunistic movement—on a daily, seasonal, yearly and generational scale—in the maintenance of these grazing systems. Probably the most exhaustively studied non-equilibrium or 'event-driven' grazing system in pastoral Africa is that of the Turkana of northwestern Kenya, described by J Ellis and his co-workers (reference to this work can be found in Coughenour *et al.* 1985, Coppock *et al.* 1986, Ellis *et al.* 1987, and Ellis and Swift 1990). Ellis and his colleagues found that in central Turkana, rainfall levels affected all aspects of the production system, and were highly erratic. Drought had occurred about 13 times in the last 50 years, and serious multi-year drought had occurred four times over this time period (Ellis *et al.* 1987). Livestock losses due to drought could cut herd sizes in half, but there was little evidence that rates of loss were closely related to stocking rates. Basically, animals begin to starve, or at best hold their own, during the dry season. If the dry season was prolonged by drought, termites and the loss of vegetation to wind, sun and decomposition removed dry forage even if it was not consumed by livestock. With the exception of certain localities which sustained very high stocking densities, how many animals made it through a drought was determined more by the length of the dry period than by the number of animals which existed before the dry period began.

Ellis and Swift (1990) broaden the scope of this analysis to include arid grazing systems outside Turkana. They examine long-term rainfall patterns from a number of arid regions in Africa and argue that many of these environments experience massive and unpredictable fluctuations in rainfall similar to those in Turkana. Given these climatic patterns, non-equilibrium, event-driven grazing systems may prevail on many of the most arid rangelands of the continent.

These conclusions are qualified in Coppock's study of the Borana rangelands of southern Ethiopia (1990). Rainfall is higher and more reliable in Borana than in Turkana, and severe droughts occur at less frequent, 20-year intervals. Coppock argues that in this more stable environment, pastoralists and their livestock are important agents of vegetation change. Periodic droughts may make interpretation of the situation more difficult, but the fundamental pattern is one of equilibrium, and equilibrium concepts such as carrying capacity are therefore analytically useful in the context of these environments.

In Borana, however, the pattern of grazing-induced vegetation change is complex both spatially and over the long-term. Elaborating on the work of J C Billé and others, Coppock hypothesizes a process of bush encroachment under heavy grazing pressure which depletes soil nutrients and increases the competitive advantage of shrubs over perennial grasses. The replacement of grasses by woody shrubs is followed by the abandonment of the site by pastoralists. In the absence of heavy grazing pressure, few new shrubs are established, while those which already exist grow to maturity. Soil nutrients are slowly replenished by leaf litter, and grasses are gradually reestablished as fires thin out the trees. In a cycle that can take from 60 to 100 years to complete, the pastoralists recolonize the site which once again has a fertile soil and supports a mixed grass and tree savanna.

Although the composition of the vegetation at any particular site is unstable, the overall grazing system in Borana may be remarkably persistent, as pastoralists cycle through a number of different sites. This pattern of land use raises both theoretical questions regarding the nature of degradation and practical questions regarding the appropriateness of measures to control it in Borana. Within mainstream rangeland management, bush encroachment, the loss of soil and soil nutrients, and declining livestock productivity indicated by the abandonment of sites by pastoralists would qualify unequivocally as rangeland degradation. But as described for the Borana case, bush encroachment is part of a potentially sustainable pattern of rangeland use built around spatial flexibility by pastoral producers. Efforts to control bush encroachment and stabilize productivity at a particular site would forestall the very processes which eventually rejuvenate site productivity and provide the basis for continued rangeland productivity on a regional scale. What is critical to the maintenance of the larger system are human and livestock populations which are low enough to permit sufficient 'fallowing' between the reoccupation of individual sites.

Like Coppock, Scoones (1990b) is concerned with disentangling the relative importance of equilibrium and non-equilibrium factors in shaping a grazing system, in this case a communal area in Zimbabwe. Unlike Coppock, Scoones focuses his analysis on the dynamics of the livestock populations rather than the state of the vegetation. He does this by asking what controls the growth of the livestock population—particular historical and episodic events such as droughts, or continuous, systemic factors such as the size of the cattle herd itself.

Using sixty years of livestock population data from southern Zimbabwe, Scoones concludes that in a run of relatively good rainfall years cattle populations do approach a ceiling set by ecological carrying capacity. As stocking densities increase, birth rates decline and death rates rise, but the two rates never attain equilibrium and thus the cattle population never reaches the limits of its growth. The maximum stocking densities determined by ecological carrying capacity are never attained because of the random intervention of exceptionally stressful years. At these times cattle die in unusual numbers and do so at rates which cannot be predicted on the basis of stocking density. In the long run, therefore, non-equilibrium factors tend to be the major influence on cattle population numbers, resulting in populations below potential 'equilibrium' density. However, equilibrium processes are significant during intervening years when cattle populations are high and may be important in the regulation of the cattle population. Over a long time perspective, the semi-arid conditions of southern Zimbabwe apparently result in both non-equilibrium and equilibrium conditions at different times.

As in both Turkana and Borana, the maintenance of livestock in Zimbabwe is contingent upon their mobility and their capacity to exploit variations in the environment. Although not normally characterized as a migratory system of production, cattle in Zimbabwe's communal areas routinely exploit the 'patchy' nature of local vegetation which changes in response to soil differences along drainage systems. In addition to regular, seasonal movements, herds may also engage in long-distance migration out of their home areas in years of exceptional stress.

The common pattern which emerges from the Kenyan, Ethiopian and Zimbabwean case studies is heterogeneity—spatial and temporal variability and its exploitation by pastoral herds and their owners. Discussion thus far has focused on the importance of variability for our understanding of the concept of carrying capacity. We now turn to an examination of the practical problems which this variability poses for the measurement of carrying capacity in the field.

Short-Term Livestock Feed Supply and Demand

In many instances, attempts to determine carrying capacity are essentially attempts to estimate the levels of livestock output which could be expected from different production systems at different stocking densities. These 'carrying capacity' calculations may be more precisely labelled 'calculations of short-term livestock feed supply and demand', since the focus of analytical interest is not on long term degradation but on the capacity of the system to meet immediate production goals at alternative stocking densities.

In practice, these calculations involve estimating the total edible vegetation produced annually from a specified area and comparing this estimate to the forage consumption requirements of the resident livestock. Two alternative methods for assessing feed supply-demand levels are routinely employed (and a comprehensive review of these methods is provided by de Leeuw and Tothill 1990).

The simplest of these methods is based on estimates of the total edible plant biomass which is produced annually in a rangeland area, routinely expressed in tonnes of dry matter per hectare. Total production is then adjusted by a 'proper use' factor—which routinely varies from about 30% to 45%—representing that proportion of the vegetation which is available for consumption and which the analysts presume can safely be consumed without causing rangeland deterioration in subsequent years. (The issue of how range deterioration is defined and measured is addressed in the next section.) The adjusted production figure is then divided by the feed requirements of an individual animal, and the result expressed in terms of the number of animals which can be sustained per unit of rangeland, an approach employed by de Leeuw *et al.* (1990).

Calculations of livestock sustainability based on tonnes of dry matter produced per hectare ignore the variable quality of forage as animal feed, a shortcoming which can be redressed by assessing vegetative production in terms of fodder quality rather than quantity. This elaboration of the more standard methods of calculation is applied to Sahelian rangeland productivity in the paper by de Ridder and Bremen (1990). This paper forcefully emphasizes the depth of research and the understanding of underlying biological processes that must underpin these apparently straightforward attempts at estimation.

Both the precision and utility of evaluating feed supply-demand are, however, open to doubt. With respect to the precision with which estimates can be derived, there is opportunity for significant error at almost every step in the calculation:

- The 'proper use factor' is little more than an educated guess, since little is known about the carryover effects of grazing between years; estimated carrying capacities are, moreover, extremely sensitive to alterations in these estimated rates of use. As Bartels *et al.* note (1990), the decision to apply a use factor of 45% rather than 30% can increase estimated carrying capacity by half.
- Rainfall-based estimates of biomass production rarely take into account landscape heterogeneity and variability in productivity. For instance, the regression estimator developed by Le Houérou and Hoste (1977) for the Sahel failed to include data points representing the low lying 'bas fonds' areas, where high grass production is found.

- Carrying capacity assessments assume fixed boundaries, but mobility of stock means that these assessments are artificial; on the other hand, it is in practice very difficult to assess 'carrying capacity' in systems where spatially disparate resources are used at different stages of a flexible transhumant cycle.

- Estimation of the amount and kind of forage needed by an animal is not straightforward, especially when several herd species with different feeding habits use the same rangelands, when herd owners pursue different economic objectives, or when livestock feed requirements are derived from research station animals which may not be physiologically or genetically adapted to nutritional stress (Payne 1965, Western and Finch 1986).

- Compensatory regrowth of grazed and browsed plants, resulting in higher quality and, occasionally, in higher production, is frequently ignored.

These difficulties have occasionally led to estimates which are so obviously wrong as to be embarrassing. Bartels *et al.* (1990) cite the example of carrying capacity estimates from Somalia which estimate that certain rangelands are chronically overstocked at rates 8 times in excess of their capacity, a situation which is biologically impossible.

Conceptual ambiguity, argue Bartels *et al.* (1990), is compounded by measurement error to the point where carrying capacity estimates do not serve as a reliable tool for planning purposes:

> We have concluded that the CC (carrying capacity) concept is of questionable validity in livestock production systems in Africa, that it is virtually impossible to accurately estimate CC, and that the concept can not be meaningfully applied in pastoral systems. The enormous expense devoted to estimating CC in Sub-Saharan Africa has contributed little to livestock development and has diverted resources from other priorities. Let us admit the problems with the CC concept, and stop trying to apply it.

And finally, there is the issue of how feed supply-demand estimates might be used. The papers by de Leeuw *et al.* 1990 and de Ridder and Bremen (1990) clearly demonstrate the analytical importance of these estimates in attempts to understand the functioning of Sahelian grazing systems. These estimates also colour our perception of African pastoralism, its current condition and development potential. Recent advances in field techniques may diminish the degree of error in these calculations and enhance their accuracy (see especially Bremen and de Ridder 1991). But analysis is one thing and enforcement is another. As Bartels *et al.* (1990) note,

> Though there have been numerous attempts, we know of no case in which a government has successfully persuaded pastoral households, or a pastoral group, in Africa to voluntarily limit livestock numbers to an estimated CC.

Until administrators devise some mechanism for implementing recommended stocking densities, these estimates may provide the background for administrative decision making, but they do not constitute realistic management objectives.

The Definition and Measurement of Rangeland Degradation

Range degradation, like the more popular but allied term 'desertification', has been defined in a multitude of contradictory ways (as discussed in ODI 1977, Sandford 1983, and Warren and Agnew 1988). Clear definition is important, both because the issue of rangeland degradation is emotionally charged, and because the meaning which is ascribed to the term largely determines the choice of the diagnostic criteria which are used to measure its occurrence.

In this report we equate rangeland degradation with the long-lasting or permanent loss of an economic good, in this case an irreversible decline in livestock production. A formal definition of rangeland degradation consistent with this point of view has been provided by Abel and Blaikie (1989:113), as follows:

> Range degradation is an effectively permanent decline in the rate at which land yields livestock products under a given system of management. 'Effectively' means that natural processes will not rehabilitate the land within a timescale relevant to humans, and that capital or labour invested in rehabilitation are not justified... . This definition excludes *reversible* vegetation changes even if these lead to temporary declines in secondary productivity. It includes effectively irreversible changes in both soils and vegetation.

The phrase 'under a given system of management' merits some elaboration. Different land use systems utilize different components of the natural environment and must maintain those components if they are to be sustainable. To take an obvious example, conservationists will be concerned to maintain the diversity of species present in an area, while commercial wildlife operators may require not species diversity but a plentiful supply of the large game animals upon which they are financially dependent. Degradation assessment, as defined here, does not attempt to determine which of these land use systems is 'best'. It does attempt to assess the capacity of a given management system to maintain those features of the natural environment which are essential for its continued wellbeing.

Potential biological and physical indicators of range degradation have been proposed, including changes in soil, vegetation and livestock condition and output (see Table 3). What must now be examined is the extent to which these indicators can identify permanent losses in livestock output which are of genuine concern to pastoral producers. Conventional range management has relied on vegetation indicators to assess range degradation. Whether these

Table 3: Biophysical Indicators of Degradation

Soil changes
- Decreased fertility
- Decreased water holding capacity
- Decreased infiltration
- Soil loss significantly in excess of soil formation

Vegetation changes
- Changes in vegetation productivity over time, unrelated to rainfall patterns
- Changes in vegetation cover
- Changes of plant species composition of use to animals
- Shifts between vegetation transition states that result in decreased fodder (eg. severe bush encroachment)

Livestock production
- Condition scoring of animals
- Calving rates and death rates (population models)
- Milk yields

Source: Workshop discussions

relied on vegetation indicators to assess range degradation. Whether these indicators are also reliable measures of permanent declines in economic output from Africa's rangelands is, however, open to doubt.

The initial problem is to decide what we want to measure: declining productivity or vegetation change. Given the essentially economic definition of degradation employed here, vegetation change is of no intrinsic interest unless it also provides reliable evidence of changes in livestock productivity. The high stocking rates which are maintained by some pastoralists will, almost certainly, alter 'pristine' or 'climax' vegetation, in equilibrium grazing systems or in areas of stock concentration around water points or settlements (Coppock 1990, de Leeuw *et al.* 1990, Grouzis 1990). These ranges will tend to be in poor condition, if range condition is successionally defined, but, as Wilson and Tupper have observed, 'agriculture in general is based on the modification or replacement of natural vegetation, and rangeland, although only partially modified, must be assessed on the same basis' (1982:689). Very few agriculturalists would conclude that an English sheep paddock or a Javanese rice paddy were 'degraded' solely because, several centuries previously, they had replaced a temperate or a tropical forest. A more important question is whether any of these agricultural systems, including pastoral systems of range exploitation and the man-made environments they have created, are sustainable in the long run.

Direct examination of rangeland vegetation does not provide a simple answer to this question. Large fluctuations in species composition, plant biomass and cover are characteristic of arid and semi-arid rangelands subjected to erratic rainfall. Because the vegetation in these areas is continuously disturbed, it has adapted to disturbance and possesses an enhanced capacity to recover from disturbance (Walker *et al.* 1981). The productivity and composition of such rangelands may be unstable in the short run, but resilient over the long term (Holling 1973).

In such an environment, degradation could be said to occur only when the vegetation had crossed, or was at risk of crossing, critical thresholds which prevent or severely inhibit its subsequent return to a more productive state. In practice, the problem is to distinguish between drought induced fluctuations and permanent changes in vegetation states (Grouzis 1990). Current knowledge of the dynamics of savanna ecosystems frequently does not permit this distinction to be made with confidence, although future research may eventually clarify the issue (Friedel 1991, Laycock 1991). As a result, it has, thus far, proved very difficult to differentiate between permanent human-induced 'degradation', as opposed to temporary rainfall-induced vegetation change (Alchrona 1989, Warren and Agnew 1989, Tucker *et al.* 1991).

Rates of soil loss and other deleterious changes in soil chemistry and physical properties may prove to be more reliable than vegetation change as an indicator of irreversible rangeland degradation. The challenge, in this case, is to develop techniques for measuring and modelling soil loss (Biot 1990), and to relate these measures to economically significant changes in livestock output (Abel 1990).

Biot (1990) presents a soil loss model for a portion of the hard veld rangelands of eastern Botswana. In this eroding landscape, as in much of arid and semi-arid Africa, rates of soil loss are greater than rates of soil formation, even with zero use. While human use might accelerate ongoing processes, stopping environmental change is not an option. Biot uses the concept of 'soil life' or 'residual soil suitability' to express the length of time a given level of output from the land can be maintained under different intensities of grazing. His estimation techniques provide an unexpectedly optimistic picture of soil loss on Botswana's communal rangelands. At the stocking densities prevailing at the time of his study, he estimates the residual soil life in his study area to be over 400 years. Environmental change is certainly taking place in Botswana, but not at the catastrophic rates routinely depicted (Cook 1983).

Biot's results are not generalizable; they pertain to only one landscape and one management system. What may be generalizable are his modelling techniques. In his paper he explores the potential of these techniques by comparing rates of soil loss for hypothetical rangeland systems in the semi-arid, wet and dry tropics. As might be expected, this comparison demonstrates that landscapes respond very differently to grazing pressure depending on factors such as rainfall, slope, soil texture, and vegetative cover. While Biot's conclusions are at this stage only indicative, they suggest that additional field work may make it possible to quantify both the risk and rate of soil loss from rangelands under different environmental and management conditions.

Abel (1990) builds on Biot's analysis of erosion in eastern Botswana in an attempt to further specify what might be an 'economically acceptable' rate of degradation. Abel compares the economic costs to Botswana herd owners of maintaining current levels of soil loss versus reducing those levels. He bases his comparison on a model which predicts the immediate and long-term effects of two different stocking rates, the current stocking rate in the communal areas of eastern Botswana versus the lower, government-recommended stocking rate for these areas.

Based on earlier estimations of herd productivity at these two stocking densities, Abel concludes that the lower, recommended density would significantly reduce the aggregate productivity of the communal herd and do so at considerable collective cost to herd owners. He also shows that the current (high) and recommended (low) stocking densities produced virtually identical levels of soil loss between 1978 and 1988, given the pattern of rainfall in that period. Put simply, the immediate costs to producers of destocking would be heavy, while the long-term gains in reduced range degradation would be slight. In eastern Botswana, destocking is not worth it.

In a topographically complex landscape, soil lost from eroding areas, such as slopes, may be transported and subsequently redeposited elsewhere within the landscape, resulting in a relocation rather than an absolute decline in soil resources, plant growth and grazing activity. Abel and Biot's models are restricted to an estimation of slope erosion. Net soil loss from the hardveld landscape in eastern Botswana is a fraction, possibly only 20% to 25%, of the slope erosion estimated by Biot (Abel and Stocking 1987, Biot 1990).

Stafford Smith and Pickup (1990) present techniques for the analysis of such processes of soil and productivity relocation. Their material is drawn from ranching areas of arid Australia, areas which experience climatic fluctuations similar to arid Africa and where ranches are large enough replicate some of the land use patterns characteristic of Africa's open rangelands.

They begin with the simple observation that soil is not only eroded, but also transported and deposited. Soil loss in one site may mean soil accumulation in another, and degradation assessments that are insensitive to the inter-dependence between points on the landscape may provide little insight.

If grazing pressure increases, around a water point for example, the removal of vegetative cover may alter both rates and patterns of soil movement in the vicinity of the water point. How these localized changes affect the total landscape will depend not only on the extent of grazing pressure but on spatial variables such as the position of the water point relative to preexisting drainage and erosional systems. Complex spatial patterns may, therefore, confound attempts to detect environmental change.

Stafford Smith and Pickup provide techniques for incorporating spatial variables into rangeland assessment. Given the mobility of both human and animal populations in Africa, and the capacity of mobile populations to exploit spatial heterogeneity, these techniques would seem to be essential for an understanding of both environment change and the response of African pastoralists to change.

A Classification of Rangeland Types: Implications for Management

The distinction between equilibrium and non-equilibrium grazing systems calls for a rethinking of rangeland classification. In practice, range managers need to be able to distinguish between those types of rangeland in which non-equilibrium models are appropriate and those in which conventional successional interpretations, and concepts like carrying capacity, are still relevant.

Many different classifications have been used to distinguish African savanna types. Grassland ecologists have differentiated savannas according to species composition (Acocks 1953, Rattray 1957, Pratt and Gwynne 1977); others have classified savannas in relation to topographical variations in the landscape (Milne 1947, Morison *et al.* 1948). Only recently have more analytical classifications, based on models of savanna functioning, emerged (Frost *et al.* 1986, Solbrig 1991). These models ascribe overriding importance to soil fertility and moisture in the genesis of different forms of savanna vegetation.

In general, primary production and animal density in a savanna are positively correlated with mean annual rainfall (Coe *et al.* 1976, Le Houérou and Hoste 1977, Rutherford 1978, Deshmukh 1984). The simple relationship between high animal density, high levels of primary production and high rainfall is complicated, however, by a third variable—soil type as influenced by base geology. Bell has provided empirical evidence that, at comparable rainfall levels, savannas with nutrient-rich or poor soils support different types of vegetation, and variable densities and kinds of herbivores (Bell 1982, 1984).

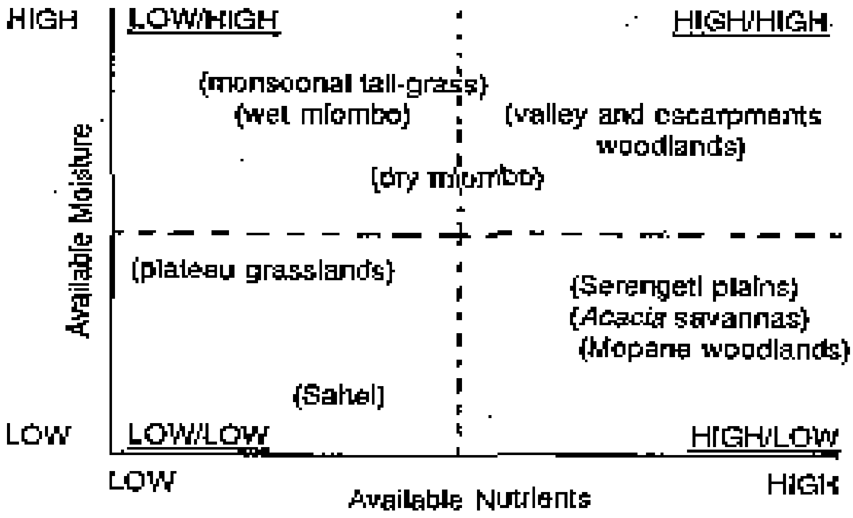
Implicit in Bell's analysis is a functional classification of savanna types based on various permutations of available soil moisture and soil nutrients (Frost *et al.* 1986). This classification is presented in Figure 5. Soil nutrient availability, the horizontal axis in Figure 5, is influenced by parent geology, and by nutrient transport from weathering and water movement. The availability of moisture for plant growth, the vertical axis, is determined by total rainfall levels and distribution, soil physical properties (particularly infiltration rates) and topography. Various combinations in plant available moisture and nutrients create the major vegetation types noted in Figure 5.

The following section discusses the implications of this savanna classification for the management of African pastoral areas. We ask what the classification system tells us about the likelihood of equilibrium or non-equilibrium dynamics, expected patterns of degradation for different rangeland types and the implications for feed resource management.

Degradation in Equilibrium and Non-Equilibrium Environments

As rainfall becomes low and erratic (vertical axis on Figure 5), both primary productivity and livestock populations will fluctuate widely and non-equilibrium dynamics will predominate (Ellis and Swift 1990). Conversely, relatively wet savanna areas with stable rainfall regimes may be able to sustain livestock densities which have a significant impact on plant biomass and species composition, the classic equilibrium situation (Coppock 1990). In areas where

Figure 5: Hypothetical Distribution of Savanna Types in Relation to the Main Determinants of Savannas



both wet and dry periods occur, there may be a shift between equilibrium and non-equilibrium dynamics over time (Scoones 1990b).

The instability inherent in certain climatic regimes may, however, be exacerbated, or dampened, according to soil type (horizontal axis on Figure 5).

On fertile clay soils, levels of primary production are closely correlated with, and as variable as, annual rainfall levels. This instability results from a combination of adequate soil fertility, which induces high levels of plant growth when water is sufficient, combined with the poor water infiltration and retention capacity of clay, which severely limits plant growth when water is insufficient. Coarse but nutrient deficient soils show the opposite pattern—relatively stable plant growth constrained, during periods of good rainfall, by the availability of nutrients, but maintained, at low rainfall levels, by the capacity of the soil to admit and hold water (Dye and Spear 1982).

Soil physical and chemical properties may *also influence the way in which* different range types respond to grazing pressure. Grazing pressure on heavy textured soils has a significant effect on infiltration through soil capping, compacting of soil structure, removing of litter, and decreasing the density of perennial grass tufts (eg. Kelly and Walker 1976, O'Connor 1985). Under heavy grazing pressure, increased run-off and decreased infiltration can result in undesirable changes in vegetation states leading to the creation of poor quality open grassland or encroached woodland (Walker *et al.* 1981, Grouzis 1990). By contrast, sandy nutrient-poor savanna soils, and the vegetation they support, appear to be more resilient to herbivore impact (see Barnes 1965 for Zimbabwe). *As a result of higher infiltration in sandy soil, the grass layer tends* to be insufficient to out-compete the woody component, and, with the exception of extremely low rainfall areas, a woody-grass vegetation is relatively stable.

Finally, the positive correlation between soil fertility and plant palatability may also influence the stability of the grazing system. Except in very low rainfall areas (as in the northern Sahel), poor soils support a vegetation characterized by woodland and grassland of low nutritional value from grazing animals. Relatively low densities of herbivores are able to survive in this environment and their grazing may have only a marginal impact on plant biomass and the *relative balance of woody and herbaceous species. By contrast,* savannas with higher quality soils support a higher density (and a greater diversity of wild herbivore species) because of the better quality feed resource. Under these conditions, stocking densities may be sufficiently high to suppress the standing crop of herbaceous material and/or suppress woodland and encourage grassland (Bell 1982, 1984).

In sum, climatic instability, manifested in low annual rainfall levels and high coefficients of rainfall variation (Caughley *et al.* 1987), is the probably the most reliable single indicator of the shift from equilibrium to non-equilibrium grazing systems. Soil factors may nonetheless suppress or exaggerate the effects of an erratic climate. Sandy, nutrient-poor soils produce vegetation which is relatively stable in its productivity, unpalatable, and resistant to herbivore grazing pressure. Range types on these soils may be relatively less exposed to degradation, when low and erratic rainfall suppresses livestock numbers (the low/low quadrant in Figure 5) or when high rainfall levels produce unpalatable vegetation and low stock densities relative to biomass production (the low/high quadrant in Figure 5). Savanna types on fertile clay soils exhibit the opposite characteristics: instability in biomass production (under fluctuating rainfall), high feed palatability and high but potentially variable stock densities. Because the soils are prone to competition, both soils and associated vegetation may be susceptible to degradation if rainfall is reliable enough to sustain high stock densities (the high/high quadrant in Figure 5).

Feed Resource Management

Fodder palatability (quality) and biomass (quantity) both vary with changes in available plant moisture and nutrients. With respect to grasses, there is generally an inverse relationship between biomass production and palatability. Palatability tends to increase with improved soil fertility and/or reduced soil moisture. Under very dry conditions, annuals are dominant. The production of fodder biomass shows an opposite trend, with higher biomass production found in wetter rangeland areas where perennial grasses dominate.

The relative balance of trees and grasses also depends on soil properties, and the abundance of water. In heavy soils, the upper soil layer may retain a significant proportion of incoming water, allowing the growth of a vigourous grass layer which can inhibit the regeneration of trees. At similar rainfall levels but on lighter soils, most water penetrates to the sub-soil and the vegetation may be dominated by trees, which have roots which are deep enough to utilize this source of water (Walter 1971, Walker *et al.* 1981, Knoop and Walker 1985, Coppock 1990).

Feed resource management will vary according to fodder quality and quantity in different range types. For instance, the use of the tree layer as a fodder resource will reflect the availability and quality of alternative feed sources. In nutrient poor grasslands, browse resources may be important in supplying high quality feed to livestock at particular times of the year. Alternatively, in nutrient rich arid areas, grass biomass production may be highly variable and feed quantity may be an important seasonal constraint. In these situations browse may provide bulk feed when grass biomass is insufficient.

The nature of the fodder resource also affects the way animals are managed within and moved between different range types. African rangelands are ecologically heterogenous at a variety of different spatial scales. Local variability is important because it occurs over distances which livestock can walk. It would appear that animal movements—seasonal, annual and daily, local and long-distance, by both wild and domestic herbivores—systematically exploit the environmental discontinuities summarized in Figure 5 (Scoones 1989, Breman and de Wit 1983, McNaughton 1985, McNaughton and Georgiadis 1986). Different parts of the landscape may be critical in offsetting particular constraints. In the Sahel, for example, livestock are moved from low quality, high biomass range types in the dry season, to high quality, low biomass range types in the wet season (Breman and de Wit 1982). In Turkana a heterogeneous rangeland resource is partitioned among a number of different domestic herd species, which follow distinctive seasonal patterns of movement and resource utilization (Coppock *et al.* 1986). In semi-arid Zimbabwe, movement to relatively small but critical areas of high production, along rivers, streams or drainage lines, can be critical in sustaining livestock populations in the dry season, while top lands are grazed following the rains (Scoones 1989).

In all these cases, a vital step in understanding and possibly improving rangeland management strategies is the identification of key resources areas which redress critical constraints for livestock production for a particular range type. Analysis of constraints according to the interactions outlined in Figure 5, will assist in identifying key resources for different range types.

Opportunistic Management

International development agencies and African governments have devoted considerable effort to the suppression of pastoral techniques of land and livestock management. These programmes were undertaken on the presumption that pastoralism was inherently unproductive and ecologically destructive and, hence, required radical reform. Current empirical research supports none of these presumptions.

With respect to herd productivity, comparative studies of ranch and pastoral herd output in West Africa (Breman and de Wit 1983), Southern Africa (de Ridder and Wagenaar 1986, Abel 1990) and East Africa (Cossins 1985, Western 1982) demonstrate that pastoralism either equals or exceeds the productivity per unit land area of commercial ranching in comparable ecological environments. Any attempt to improve on the productivity of African pastoralism can, at best, aim to marginally increase already high levels of output.

The work reviewed here makes much the same point with respect to pastoral methods of range management. This report documents a convergence between pastoral techniques of range exploitation and recent developments in scientific range ecology. This convergence does not constitute a blanket endorsement of the positive ecological impact of African pastoralism. It is now clear, however, that pastoral land use practices are an effective response to the exigencies of a difficult natural environment, and that the development of livestock production in dry Africa requires the refinement and adjustment of these practices to changing circumstances, not their outright elimination.

Not confined to an arbitrarily demarcated ranch and with limited access to industrial inputs, African pastoralists have had little capacity or imperative to control localized fluctuations in rangeland productivity. They have, instead, adapted to instability. This attempt to exploit environmental instability and contingent events may be characterized as 'opportunistic management' (Sandford 1983, Westoby *et al.* 1989). High but fluctuating stocking rates and migratory patterns of forage exploitation are recurrent features of pastoral opportunism. Any systematic attempt to build upon pastoral husbandry practices and incorporate them into formal development programmes must examine the utility, and the limitations, of these management techniques.

With respect to specific management and policy issues in particular local settings, the papers presented at the workshop offered several suggestions. The discussion of rangeland classification in this report has specified the kinds of natural environments which are suited to conventional or opportunistic management approaches. A revised assessment of the merits of opportunism will, however, affect almost all aspects of pastoral development policy in dry Africa. In this closing section, we briefly explore some of the wider implications of opportunistic rangeland management for the redesign of these policies.

Sandford's analysis of the relative advantages of conservative or opportunistic stocking strategies provides a useful point of departure. Briefly, Sandford distinguishes between a conservative stocking strategy in which a 'constant number of livestock graze an area through good and bad years alike' versus an opportunistic strategy 'in which the number of livestock grazing is continuously adjusted according to the current availability of forage' (1983:38).

Because the intention is to hold animal numbers constant, conservative stocking rates are determined by the number of animals which can be maintained during periods of low forage availability. Conservatism is a matter of degree, but a conservative stocking rate always carries a cost—the forage which cannot be consumed and the livestock production which is thereby foregone in good years because livestock numbers are insufficient to consume all available feed. As Sandford has shown, this cost increases as the variability of rainfall increases and to the extent that managers adopt safer, more conservative stocking rates.

Opportunistic or variable stocking rates reduce the problem of unconsumed, and thereby surplus, forage in good years, but present potential problems of surplus stock in poor years. Livestock development programmes based on opportunism would not attempt to suppress these fluctuations in livestock numbers, but to exploit them by developing mechanisms to promptly and profitably remove stock when it does not rain, what Sandford (1983) has characterized as *efficient* opportunism. In this framework, livestock development policy would not be judged by its success in preventing periodic crashes in livestock numbers, which are inevitable, but by the appropriateness of its response to these crashes. At least three aspects of pastoral development policy would require revision in light of this changed objective.

Livestock Marketing Livestock sales are one obvious means to achieve rapid destocking, and livestock marketing would play an important role in an opportunistic policy towards rangeland management, as it has done in conventional livestock development programmes. However, the futile attempt to maintain constant levels of stock sales in order to prevent herd growth would be de-emphasized, and attention would shift instead to the design of marketing systems which can accommodate massive and unpredictable shifts in levels of throughput. A detailed examination of how this kind of marketing system might operate lies well beyond the scope of the present discussion, but it is clear that the organization, infrastructural requirements, performance criteria and financing of these systems would depart considerably from past attempts to improve livestock marketing.

Herd Movement and Land Tenure Livestock movement is a second means to adjust local imbalances in stock numbers and forage availability. Opportunistic management would seek to maintain mobility as a production strategy and to adapt this characteristic feature of pastoral nomadism to changing economic and institutional conditions. A new approach to pastoral land tenure would need to be a critical component of this effort.

Previous attempts to reform pastoral tenure rights have concentrated on delimiting bounded areas and restricting livestock to those areas. Since it was assumed that pastoralists would eventually settle on something like a ranch, little official effort was devoted to the question of maintaining pastoral tenure rights to key land resources which were intermittently used and not continuously occupied. To the extent that they are based on the use of force, customary pastoral techniques for maintaining these rights are incompatible with civil administration. The result has been the widespread deterioration of pastoral rights to scattered but highly productive categories of rangeland throughout dry Africa.

Any official attempt to foster opportunism by maintaining livestock mobility would require the development of legal formats capable of providing security of tenure while permitting flexibility of use patterns. This will be no easy task. Models for this kind of tenure system are not readily available from pastoral areas of industrialized countries, which have themselves had a chequered record with respect to the promulgation of appropriate pastoral tenure legislation.

Pastoral Administration Finally, there is the question of who manages an opportunistic management system. Conventional range management in dry Africa has been highly interventionist. It has generated much bureaucracy, but little effective action. The non-equilibrium view of range ecology suggests an alternative management model which relies on limited but focused interventions coinciding with key events, interspersed with long periods of minimal administrative interference. This suggests less rather than more centralized regulation, the devolution of control over local resources to producers and producer groups, and a shift in emphasis from enforcement to monitoring critical developments and servicing local needs (Swift 1990).

By definition, there can be no set blueprint for opportunism. Any attempt to systematically develop opportunism would require development programmes specifically tailored to particular settings. Pastoral communities are uniquely qualified to undertake these local adjustments and refinements; scientific recognition of the competence of these communities as land managers is a first step in this direction.

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