DYNAMIC CARRYING CAPACITY ANALYSIS AS TOOL FOR CONCEPTUALISING AND PLANNING RANGE MANAGEMENT IMPROVEMENTS, WITH A CASE STUDY FROM INDIA.

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ABSTRACT

The paper begins with a literature review of the basic theories which underpin range science. Two major approaches for determining carrying capacity (CC) are described, animal or plant oriented. The inherent problems with each approach are discussed in the light of a recent, wider debate, questioning the validity of CC as a range management tool.

Methodological approaches for determination of CC, with inherent problems, are discussed. A brief description is given of a study from Rajasthan, India, illustrating seasonal changes in dry matter (DM) production from a complex mosaic of fodder resources. Utilization is also complex and dynamic, with fodder imports and exports being realized either directly or through animal movements.

It is argued that despite its weaknesses, CC is a useful concept for planning range improvement projects. A redefined, dynamic CC is recommended, based on local technical knowledge. The authors conclude that until a more user-friendly alternative is presented, in a practical, rather than conceptual framework, CC will remain the best practical tool available to planners. They stress the need to fully involve range users (herders) in all aspects of project planning and implementation, if sustainable productivity increases are to be achieved.

It is suggested that a flexible stocking rate (SR), dependent on seasonal and annual variation in feed availability, must be a key element in any improved range and livestock management strategy. Traditional herders probably already practice this strategy on intuitive information.

INTRODUCTION

Carrying capacity defined

Carrying capacity (CC) is defined as the maximum number of animals, usually expressed as a standardised ‘Livestock Unit’ of 250 kg, that an area of land can support on a sustainable basis. It can be expressed numerically as a stocking rate (SR). The notion that there is a ‘correct’ CC embodying land productivity and climate variables for a particular range is fundamantal to conventional range science. In the light of recent research on African rangelands this notion has become the subject of some debate, which this paper discusses from the perspective of experience of range management problems in India.

A dominant factor influencing range management policies and practice tends to be land tenure. In industrialized countries (with a few notable exceptions), tenure of rangelands is usually private or, if public, private leases are often in force for its use. In much of the developing world on the African and Asian continents, and to some extent also in Latin America, large tracts of rangeland are common property resources (CPRs); sometimes with open, uncontrolled access. This condition makes range management more complicated, but not immune from rational approaches.

The nature of range management problems on CPR's

It must be stressed at this point that the problems facing rangeland development programmes on India's CPR's are mainly social, not technical. A lot is known about how productivity can be managed through such instruments as soil and water conservation, soil fertility management, and plant species manipulation. This is standard practice on commercial ranches worldwide, where a high degree of management control is possible. The highly specific nature of rangeland ecosystems techniques means, however, that techniques found to improve prouctivity in one region may not be applicable in another.

CPR's are those lands without any exclusive individual ownership or rights of tenure, to which many social groups, sedentary and migratory, claim access. Entitlement may be under intricate and complex management systems, or it may be open to all comers. Between such groups, a wide social and economic differential often exists, vis-a-vis access and entitlements to range resources. Some groups, such as those without any private land or fodder resources, are more vulnerable than others, especially during droughts. A thorough pre-project assessment of the likely impact of any intervention on the weaker groups is essential. Without a high degree of social organisation and commitment among user groups, technical interventions will not be sustainable and may widen existing differentials.

Insufficient emphasis by planners on the social and institutional constraints to rangeland development has resulted in widespread failure to have a positive impact on the way the range is used. Most projects in Africa, for example, have failed to engage the active cooperation of the range users, the very people they were designed to serve (Behnke, 1990). The establishment of social structures for improved range management must be a pre-requisite to any form of technical intervention.

This paper reviews the origins of range science, leading to a consideration of CC as a concept and in its various applications. A case study from Rajasthan, India, is introduced, in which CPRs form a part of the rangeland. While this paper was in the last stages of preparation, the review by Behnke & Scoones (1992) came to hand and it was found to ancitipate, from the African experience, many of the conclusions in the present paper.

LITERATURE REVIEW

Traditional range science

Range science and the theories upon which it is based originated in the USA at the end of last century and was developed primarily on the commercial cattle ranches of North America, Australia and Southern Africa. Pioneering works on the subject include that of Sampson (1923). More recent works embracing these same concepts include those by Stoddart, Smith and Box (1975), Pratt and Gwynne (1977), and Heady and Heady (1982).

The main theories which underpin range science are concerned with changes in plant species composition and how this is affected by various stocking rates; the so-called succession theory. This assumes a transition in either direction between a pioneer plant community colonising bare ground and a climax one representing the most diverse mix of plant species which the climate and soil can support (Abel, 1990). Degradation is the process of moving down to a lower successional level; in this case through overgrazing. If the grazing animals are then removed progression towards the climax resumes. The management goal is to maintain a balance between stock numbers and feed resources as close to the climax state as possible while using the land to maximize economic gain (Abel, 1990). Under low or erratic rainfall conditions this can be done by:

a) adjusting stocking rate
b) mixing livestock species (grazers and browsers)
c) ajdusting the timing, frequency and intensity of range use in response to seasonal weather and to indicators of range trend
d) strategic burning.

Range ecology, a systems approach to management

Range management is applied ecology, as it involves managing the environment in which plants and animals live in a way that provides the most favourable habitat for production. Plants and animals are not viewed separately, as each is a vital part of the other's environment; they are interdependent. Each must be looked upon as component parts of a larger, intricately related system. A change in one part (for example an increase in stocking rate) will change the relationships among all the other system components (Stoddart, Box and Smith, 1975). Add to these biological complexities the socio-cultural and institutional constraints mentioned earlier, and the need for a holistic, multi-disciplinary approach to rangeland development programmes becomes apparent.

The rationale behind CC studies

Most documented CC studies are from Africa, largely as a result of a familiar scenario: population increases on sub-saharan rangelands led to an increase in livestock numbers and consequently in stocking rates. A simultaneous decline in CPR's due to enclosure for cropping, ranching or disease control led to increased pressure on range resources, a recurrent pattern also in India. These studies resulted in perceptions of widespread overgrazing and desertification, based mainly on the theories of Hardin (1968). African governments increased funding for rangeland research out of which came many proposals for controlled grazing based on estimated CC. Prolonged droughts, substantial losses of animals, and reports of increasing degradation have lent a new urgency to solving the CPR problem.

Determination of CC

A basic technique for determining CC is to calculate the total amount of forage at the end of the growing season, multiply this by a correction factor (see below), and then divide by the average yearly feed requirements of a livestock unit. CC is usually expressed as a stocking rate in hectares per livestock unit (ha/LU). A general assumption is that livestock require a daily dry matter (DM) intake of about 2.5% of their bodyweight. Thus for a livestock unit of 250 kg, 2.3 tonnes of dry feed is required per year (De Leeuw and Tothill, 1990).

When calculating forage supply it must be remembered that, unlike conserved fodders (eg hay), not all range forage can be used by livestock. Some is not accessible to the animals and some is unpalatable. Further losses occur due to senescence and by trampling or fouling by the animals. Most importantly, after the harvestable portion of forage has been taken by grazing or browsing animals a residue should be left if the range is to continue producing on a sustainable basis. This is known as proper use. Three correction factors are thus needed to adjust for:

a) grazing inefficiency
b) losses
c) proper use.

With little or no research substantiating these correction factors, estimates remain subjective. Most studies use a single multiplier that combines corrections for all three. Le Houérou and Hoste (1977) assume that total dry matter (TDM) in a sahelian study contains 40% of edible forage, while in southern Ethiopia Cossins and Upton (1987) use a figure of 30%. Van Wijngaarden (1985) proposes a proper use of 45% of TDM during the dry season, finding a reduction in grass cover in the subsequent season at higher levels of utilisation. As a result of differences in the multiplier used, CC estimates vary. De Leeuw and Tothill (1990) report carrying capacity estimates by different authors of 4.4, 5.2 and 7 ha/LU for similar rainfall areas in the African Sahel.

Examples of CC methodologies

In some studies, estimates of CC have been plant orientated. The most basic of these have attempted to correlate annual rainfall with consumable fodder and hence CC, arguing that in areas with annual rainfall below 700mm, rainfall alone is a reasonable indicator of herbage production and thus SR. An example is given in Table 1 below.

Table 1. Utilizable primary production and CC on dry rangeland in tropical Africa

Annual Rainfall (mm)	Consumable Fodder * (DM Kg/ha)	Carrying Capacity + (ha/LU)
100	-----	----
200	150	15.2
300	225	10.1
400	300	7.6
500	375	6.1
600	450	5.1

** Assumes utilisation of 30%; + LU = 250Kg. Source: ILCA, Anon.*

A similar approach taking account of rainfall and vegetation has been developed in Tanzania. Much depends on a clear definition of the various vegetation types, as shown in Table 2 below.

When using rainfall data it is important to take into account not just the ammount of rainfall but also variation from year to year. For planning purposes, any serious attempt to predict primary range production using rainfall data should consider probability: how sure can we be of getting X amount of rain? Probability figures are shown in Table 3. The mean rainfall in this study area is 410 mm/yr. However, due to a high degree of inter-annual variation, CC estimates range from 6.7 to 4.1 ha/LU at 90% and 10% probability respectively (de Leeuw and Tothill, 1990).

Table 2. Carrying capacity (ha/Lu) of Tanzanian rangeland according to rainfall and vegetation

	Rainfall (mm)				
	375-600	600-750	750-875	875-1000	over 1000
Vegetation Type					
Grassland	5 - 7	4 - 6	3 - 4	2.5 - 3	2 - 2.5
Wooded Grassland	6 - 7	5 - 6.5	3 - 5	2.5 - 3.5	2.5 - 3.5
Woodland	-	5 - 8	4 - 5	3 - 4	3 - 4
Bush Land	10	6 - 8	5 - 6	4 - 5	3.5 - 5
Bush Thicket	30	18 - 24	15 - 18	-	-

Source: CTVM (1990)

Table 3. Probability of rainfall, biomass and CC in Northern Burkina Faso

Probability %	90%	50%	10%
Rainfall (mm)	295	410	575
Biomass (t DM/ha)	0.77	1.02	1.38
CC, ha/LU	6.7	5.6	4.1

Source: de Leeuw and Tothill (1990)

When rainfall unimodal (as in Rajasthan) variability year to year can still be high. In the study area (see later in this paper) the departures from average exceeded 2 s.d. in 60% of years. Where rainfall has a bimodal distribution variability between years is greater. In order to conceptualise the effect this has on CC, a frequency distribution of annual DM yield can be compiled from a regression equation of seasonal rainfall on total DM. An example is given in Table 4. A static estimate of CC based on the mean yield of 3.1 t DM/ha would risk serious overgrazing in every fourth year, with a similar chance of significant wastage or underutilisation in the other three years (de Leeuw and Tothill, 1990).

Table 4. Frequency distribution of annual grass DM yield in semi-arid Eastern Kenya

Yield class t DM/ha	**% of years**	**Yield**	
		mean	SD
<1	4	0.4	0.3
1-1.9	20	1.6	0.3
2-2.9	29	1.6	0.3
3-3.9	25	3.6	0.3
4-4.9	12	4.4	0.2
>4.9	10	6.4	0.8
Mean (n = 73)		3.1	1.5

Source: de Leeuw and Tothill (1990)

Other studies have demonstrated that soil factors may be an equal or greater constraint to production than rainfall. For example, from a detailed four year study in the African Sahel, Penning de Vries and Djitèye (1982) report that while on ranges receiving less than 250 mm/yr of rainfall available water is the main factor limiting production, where rainfall is more than 250 mm/yr a deficiency of soil nitrogen (N) becomes the key constraint.

The availability of water in the soil, known as the water balance, depends on several factors related to the site. The most important are the infiltration rate, water holding capacity of the soil, and the rate and extent of losses due to run-off and evaporation. These in turn are influenced by the degree of slope, and the percentage and nature of surface plant cover. Generally, heavier soils with a high proportion of clay retain more water and other nutrients than light sandy soils. Soils with perennial grass cover similarly retain more of the rain than soils with annual grass cover. Even in regions receiving similar rainfall, differences in soil type account for wide variation in forage production, and hence CC. This is illustrated in Table 5.

Table 5. Estimation of total DM production from annual or seasonal rainfall (tonnes DM/ha)

Rainfall (mm)	200	400	600	800
West Africa	0.6	1.1	1.7	2.2
Zimbabwe (WC:100mm)	0.5	1.7	2.2	2.5
Zimbabwe (WC:200mm)	0.7	2.6	3.2	3.7
Kenya	1.1	2.3	3.6	---

WC = water holding capacity

Source: de Leeuw and Tothill (1990).

In any evaluation of rangeland potential, the quantity of available forage is the primary consideration. However, basing an estimate of CC solely on forage quantity has rightly been criticised for ignoring the quality and hence value of that forage for animal nutrition. This criticism has led to use of animal oriented CC estimates, rather than plant oriented. The nutritive value of the (consumable) forage is assessed in terms of meeting specific livestock production objectives. Forage quality is determined by many factors, primarily those related to the site, climate, season, and the vegetation.

From a rangeland perspective, feeding value depends mainly on the amount of energy and nitrogen (N) available from the forage, although phosphorus (P) and vitamin A levels are also important. The energy value depends on the digestibility of the plant cells, which is determined by the amount of fibre in cell walls and the degree of lignification. The N availability, greatly influenced by soil N and rainfall, is most accurately assessed in terms of metabolisable protein through digestibility trials. A rough guide more commonly used in the field is the percentage of crude protein (CP = N x 6.25). Nutritive values of grasses change throughout the growing season, with N levels, digestibility, (and consequently intake) declining steadily after ear emergence. There is generally a negative correlation between quantity and quality as shown in Fig 1.

Figure 1. Generalised changes in the nutritive value of herbage with time

Source: CTVM (1990)

A minimum CP content of around 7% in the diet is considered necessary for maintenance of ruminant animal condition (Butterworth, 1985). During the dry season when grass has a low CP content with a low, often zero, digestibility, animal weight loss is likely even if a sufficient quantity of grass is available. At this time, browse, with a higher and relatively consistent N content throughout the year, is a valuable supplement providing protein,
energy and vitamin A (Mattick, 1990). Fig 2 illustrates the fluctuation in herbage quantity and protein content over a fourteen month period in Mali, West Africa. CP levels fluctuate between 4 and 20% and are highest early in the rainy season.

In the light of the above, Blair Rains, de Leeuw and Billé (1979) suggest that estimates of potential CC should be based on the amount of protein in the forage, and not on the yield of DM. This is supported by Ketelaars (1983) who presents evidence that food intake and production of cattle on natural feeds is almost always protein-limited. The same author gives an example of how differences between ranges in forage quality affects livestock production. In a study of the Sudano-Sahelian region he attempted to predict the magnitude of variation of liveweight gain due to such differences. Cumulative liveweight gain of cattle was estimated for four ecological zones representing a wide rainfall gradient. The author concluded that a ten-fold difference in weight increase is likely, due to variation in forage quality.

Figure 2. **The availability of forage and the fluctuation of its protein content (as a percentage of DM) during 14 months of transhumance for a Diafarabé herd, Mali**

Source: Reproduced from Penning de Vries and Djitèye (1982)

Feed quality *per se* is a relative notion. To have real meaning it must be related to the production objectives, which determine the desired plane of nutrition. For example, minimum feed quality requirements will be higher for a profitable level of production on a commercial beef ranch than for a pastoral community with a mixed species herd whose production goals are oriented to continuous milk production. When determining the CC of a range the production objectives of the herders must therefore be a prime consideration.

Recently, more detailed CC studies have combined both animal and plant approaches. In its widest sense, determination of CC becomes almost a full land evaluation exercise. Consideration is given to a large number of factors influencing range productivity. An example of this type of classification is given by Thalen (1979):

$$Ga = [(Ph \times ph \times nh) + (Pb \times pb \times nb) \times F1 \times F2 \times ....Fn] / Ra$$

Where:

Ga	=	unknown CC for animal type (a) for a land mapping unit, expressed as an animal units/unit area
Ph	=	production of forage in herbaceous layer in land mapping unit
ph	=	proper use factor for herbaceous layer
nh	=	correction factor for nutritive value in herbaceous layer
Pb	=	production of forage as browse
pb	=	proper use factor for browse
nb	=	correction factor for nutritive value of browse
Ra	=	forage requirements for animal type (a)
F1,F2...Fn	=	multipliers for relevant land qualities

Perhaps the most complete approach to evaluating primary and secondary productivity of rangelands is that of de Ridder and Breman (1991) from research in the African Sahel. This approach also combines plant- and animal-based methods, although the evaluation of range (primary) productivity is based not on vegetation but on landscape characteristics (geomorphology, relief, soil texture and depth) and rainfall, which determine water availability. Two equations are used (depending on whether available water is above or below 250 mm/yr) to estimate N availability in the vegetation, N content and grass biomass. Browse production and its N content are estimated in relation to water availability and tree cover, and grass biomass in average rainfall years is calculated for 5 different landscape types in 4 rainfall zones.

The calculated biomass, together with its N content is then used to determine livestock secondary productivity using an intake model which estimates feed intake according to N content and digestibility. The model is also reversible: where production objectives are defined (milk, meat, etc.) it is possible to estimate the intake level, N content and digestibility needed to meet these goals. De Ridder and Breman's technique can be used to estimate a standard CC as in Fig 3, expressed as animal biomass in tonnes/km2.

Figure 3. A comparison of estimated CC and actual SR's from three West African countries, expressed as animal biomass, t/km^2

Source: Reproduced from de Ridder and Breman (1991)

The solid line on the graph takes into account the quality criterion of N content not less than 7.5 g/kg. The points on the graph represent the actual SR's in the three sampled countries for 1982. More usefully, the technique can be employed to relate CC to the production goals and systems of the herders as in Table 6, which estimates the CC for two production goals and three production systems and compares this with actual stocking rates.

Table 6. Estimated CC (ha/LU) of three regions in Southern Mali, supposing three different systems and two production levels, compared to SR observed in 1986

Livestock system	**Production goal**	**Carrying Capacity**		
	(growth, kg/yr)	**Kadiolo**	**Sikasso**	**Koutiala**
grazing natural	25	7	11	14

pasture. (1)	50	8	14	17
grazing crop	25	6	7	7
residues. (2)	50	8	9	8
1 & 2 + agric	25	6	6	5
by-products	50	7	8	7
stocking rates		10	6	4

Source: de Ridder and Breman (1991)

The wider debate: conventional CC concept under challenge

With scientific advancement has come a greater understanding of range biology. Resource evaluation techniques have become more sophisticated. Satellite imagery, aerial photography, and ground sampling of soil and vegetation enable compilation of vegetation maps of large areas of rangeland. Satellite images are now routinely used to monitor range trend under various stocking rates. The use of computer models to simulate rangeland systems is increasing.

These deeper investigations have sparked a debate over the utility of the concept of CC in developing countries, partly fueled by the widespread failure of pastoral development programmes in Africa. Issues under debate include:

a) the validity of the concept itself
b) problems related to measurement of CC
c) problems related to application of CC.

CC: A valid concept for developing countries?

Until recently it was assumed that range management methodologies were transferable between countries. Techniques that worked in North America, where the original theories were developed, were considered also applicable in Africa, Asia or anywhere else.

However, recent reports based on African experience have questioned whether such ‘packages’ really are neutral as regards the context in which production takes place. The theories that underlie conventional range science were developed on commercial ranches of the USA. They are based on the management of single livestock species, usually within an enclosed area, where the main objectives are to produce high quality meat and maximise productivity per animal and per unit of labour. North American range management methods were later transferred to Africa where, by contrast, the majority of range users are not ranchers nor are they restricted to a specific area of land. They are mainly nomadic or transhumant pastoralists running mixed species herds, whose production goals are oriented towards milk and maximising productivity per hectare.

It is argued that failure to understand the rationale behind such systems leads to inappropriate government policies based primarily on considerations of environmental degradation, which invariably call for reduced SR's. These policies never succeed because they are at odds with the economic and socio-cultural objectives of the pastoralists, as a reduced SR also reduces productivity per hectare (Fig 4). Bartels, Norton and Gregory (1990) illustrate the policy dilemma, concluding, '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 Carrying Capacity'.

Figure 4. The influence of SR on production per animal and per hectare

Source: CTVM (1990)

African range research also suggests that some of the theories on which conventional range science is based may be flawed. In question are those relating to the stability and resilience of rangelands (see Holling, 1973 and Walker and Noy-Meir, 1982), the relative impact of climate and livestock on range condition, and the effects of reduced stocking rates on range condition (Abel, 1990). It is argued that semi-arid ranges are less stable as a result of variable rainfall, but are far more resilient to heavy grazing pressure than was originally thought. Moreover, management strategies based on the theory of grassland succession do not work; the theory itself is wrong (Westoby et al, 1989; Abel, 1990). Because of climatic variability, range productivity may be more a function of climate than of SR (Ellis and Swift, 1988).

In such a dynamic system the notion of a single 'correct' CC is unduly restrictive to range management. The maintenance of a stable balance between stock numbers and feed resources is not an optimal objective for range users. The policy implication of this is a move towards more flexible and short-term responses to environmental variation (Abel 1990). Such short-term management regards CC as a dynamic concept requiring active monitoring and rapid adjustments of SR.

Problems related to the measurement of CC

Can CC be adequately measured? Bartels et al (1990) argue that it cannot be estimated with sufficient accuracy for planning purposes. Other critics suggest that estimates of CC based on measures of seasonal forage production and livestock intake suffer from variability, subjectivity and error. For example:

* It assumes that livestock are capable of consuming their alloted daily amount of dry matter. In practice, accessibility problems and time spent searching for food on sparse ranges often limits intake.

* Estimates of available forage are usually too high, based as they are on peak plant biomass.

* Determination of the proper use factor is usually an educated guess as the relationship between uneaten forage in one year and re-growth in the next is not well understood (Mace 1991). The choice of a proper use value has a profound effect on the estimate of CC. Applying a proper use figure of 45% rather than 30% increases the estimated CC by half (Bartels et al, 1990).

* The determination of CC during planning for most range development projects in the past has assumed that the grazers would be cattle for beef production. Such CC estimates are lower than the actual SR on CPR's where mixed livestock species are being managed for multiple use (Payne, 1990).

These are examples of the types of error which have led researchers like Field (1980) to conclude that stocking rates on Somalian rangelands are three times the calculated CC over the whole study area and up to eight times in one particular region; this is a biological impossibility (Mace, 1991).

Biot's (1990) critique of CC is that though much is written emphasising sustainability, little mention is made of how this can be measured. For Biot, the most commonly used definition of CC is the stocking rate which can be sustained forever. From research on a communally grazed area in Botswana (Biot 1988) he has derived computer models to determine the long-term productivity of grass dominated rangeland as affected by irreversible processes of land degradation. Fig. 5 illustrates how the length of time over which a given SR can be sustained varies.

Figure. 5 Estimation of the CC of a 60 cm deep soil for a sustainability horizon of 100 years (theoretical)

Source: Reproduced from Biot, (1990)

Problems related to the application of CC

One of the main arguments advanced against CC as it is conventionally understood is that, even if it could be accurately estimated, it cannot be meaningfully applied on communally grazed rangelands. The conventional concept of CC assumes that a unique population of animals is associated with a defined grazing area and that the manager has full control of the grazing rights. On CPR's this is often not the case. Migration of animals in and out of the area throughout the year, as occurs in the extreme in Rajasthan, can greatly alter the livestock demand on a given grazing site (Bartels et al, 1990). This, along with the influence of other complex and inter-related socio-economic factors, complicates the application of CC in these situations.

Mace (1991) echoes other critics of CC who bemoan the enormous waste of time, money and resources devoted over the years to CC studies. Livestock development has benefited little, they say, and resources and attention have been diverted from other high priority work.

Generally, however, these same people acknowledge that there is a finite limit to increased production per hectare with rising stocking rates on all rangeland (point B in Fig 4). This indicates acceptance of the underlying principles on which the CC concept is based.

In sum, the real disagreements revolve around how to determine the optimum SR and then how to achieve it.

Practical implications of the critique of CC

What are the practical alternatives to CC for planning sustainable land use programmes? At the policy level more flexibility is called for, to facilitate the rehabilitation of traditional opportunistic management strategies and thus prevent further degradation of rangelands. In this light, Abel and Blaikie (1990) propose a 'tracking strategy' as an alternative to the CC concept, where stocking rates are encouraged to follow variation in rainfall more closely than at present, thereby optimising resource use. Such a strategy may require changes in land tenure to give specific groups exclusive grazing rights to clearly defined areas. It would also require a high degree of social organisation and the resolution of institutional constraints such as changes to pricing and marketing structures.

Abel (1990) and Scoones (1990) review African research, which stresses the ecological instability and intrinsic resilience of rangelands dependent on variable rainfall. The greater the variation, the greater the benefits of these so-called 'opportunistic stocking strategies' over more conservative ones (Sandford, 1983). They say that communal range management policies in Zimbabwe and Botswana, which recommend de-stocking to prevent land degradation, are based on conventional theory with incorrect technical assumptions and do not, except in the long-term, lead to a greater output of livestock products. The authors agree that in the long-term, soil erosion and land degradation increases with stocking rate but they do not discuss the effect of this on livestock productivity.

Unfortunately, apart from clarifying some misconceptions regarding the utility of the CC concept, contributors to the wider debate offer little in the way of a working alternative. Biot's predictive models deserve recognition for the thoroughness of the studies on which they are based. But the necessary data inputs, subjective assumptions and extrapolations on which they are based raise questions about the accuracy of any CC estimation based upon them. Furthermore the models are area-specific and static. While the models may prove useful on the rangelands of Botswana, they could not be effectively applied in India due to the ecological, social and economic differences between the two production systems.

Carrying capacity in the Indian context

Perrier (1990) highlights the importance of the context within which range management theory is being put into practice. Theories and methodologies developed for North American ranches are generally agreed to be of limited use in the African context. Rangeland management in the Rajasthan context is different again.

A pilot rangeland evaluation study here derived a dynamic estimate of CC (Hocking *et al*. 1992). The topography of the case study area (Bhat watershed) is very hilly, unlike the flat or gently sloping American plains or African savannas. The area of assessment is small (500 ha) and the villagers can to some extent limit access to it. The range users in the present case study are not nomadic or transhumant people, but are sedentary livestock keepers. Many families also grow food crops whenever possible. Unlike African pastoralists, herders willingly sell their animals, particularly when prices are high and/or feed stocks low. Generally, this is a rangeland production system over which the range users have a reasonable degree of control.

Abel (1990) draws attention to the importance of consulting the range users, whose technical knowledge of their own production environment surpasses that of the scientist. This participatory approach is fundamental to the present study. Although Abel and Blaikie's 'tracking strategy' paper refers to semi-nomadic African pastoralists, the Rajasthan study had the same objective: to maximise productivity through optimal use of forage. The main difference between the two systems was that, to match livestock density to feed supply, Rajasthan herders would buy and sell animals rather than move to better watered areas or accept high mortality in drought years.

Scoones (1990) makes the important distinction between ecological and economic CC. The former is determined by environmental factors. The latter is the SR offering maximum economic return, depending on the economic objectives of range users, according to their own productivity criteria. The lesson here is that range CC estimates based on environmental conservation policies are invariably at odds with the economic objectives of the range users and will therefore fail. The present study takes full account of the production goals of the herders and attempts to develop a strategy to ensure economic viability with ecological sustainability.

THE RAJASTHAN CASE STUDY

On the semi-arid communally used rangelands of Rajasthan where arable cropping is difficult or impossible, many people depend on the productivity of their livestock and on the lands on which these animals feed for meeting their daily needs. Over many years livestock keepers have evolved sophisticated systems for exploiting the range resource for optimum economic gain in the face of an uncertain climate.

Land reforms in the 1950's disrupted traditional arrangements that protected and regulated the use of CPR's. Much of the best grazing land was privatised for cropping (Jodha, 1986). There was a concurrent sharp rise in human and livestock numbers: the population of goats increased from 5.61 million in 1951 to 15.4 million in 1983. This significantly increased pressure on range resources. Ever-growing demand for fodder, fuelwood and other range products led to large scale deforestation, an increase in soil erosion, and declining fodder availability. There appears to be a 'classic' case of range degradation set into motion which, unless checked, may result in desertification of many districts east of the Aravalli range of hills.

So what is to be done? Various agencies are engaged in making attempts to re-afforest small patches of land, but few are tackling the basic causes. The most obvious solution is to remove livestock and enclose the worst affected areas until natural or managed forage regeneration is considered adequate to re-allow access, ideally on a restricted basis. Another option, which permits continued range use, is for herders to adjust their stocking rates (SR) to the carrying capacity (CC) of the range.

This concept of CC is seen as dynamic, varying spatially and temporally according to site quality, seasonal rainfall, and the production objectives of the herders. The Indo-Swiss Goat Development and Fodder Production Project (ISGP) examined these factors in a limited environment in Bhat watershed (Hocking *et al.* 1992).

The main objective of farmers whose animals graze and browse the extensive areas of wastelands and CPR's in Rajasthan is economic, to maximise their income from this activity. However, data collected in a study for ISGP by Ahuja and Rathore (1987) indicates that goat keepers are also aware of ecological considerations. Growth in goat populations has not been linear but is characterised by fluctuations related to seasonal variation in rainfall and hence fodder availability. This indicates that goat keepers are familiar with the concept of carrying capacity and are able and willing to adjust animal numbers to the available feed supply.

Productivity of fodder biomass is from a complex mosaic of fields, hills, pastures, and forest land; covered by resident livestock of various types and regularly grazed by trespass or migratory herds belonging to outside people. Sophisticated resource-based approaches as described in the literature were not practical in the ISGP study, which instead was confined to determination of total DM from various component sources in the area, and the numbers of animals using the resource in the annual cycle. The following paragraphs summarize the work, which is reported in full in the Proceedings of the Fifth International Conference on Goats.

Methods

A general survey determined the following parameters:

a) private cropping land area
b) private grazing land area
c) community grazing land of various productivity classes
d) livestock population: resident and migratory
e) other Government land areas.

All crop fields in the watershed were measured and the area calculated for respective crop combinations. Detailed productivity surveys were done on a sub-sample during three cropping seasons, accommodating topographic variables as follows:

a) low-lying fields with flat land (< 10% slope)
b) sloping fields (> 10% slope; average 40 %)
c) hilltop: flat fields on higher land (more stony, drier)
d) valley fields with alluvial soils.

Fodder storage practices of farmers were surveyed and the period of storage and rate of utilization determined. Post-harvest losses of fodder from all causes, including rejection, were assumed to total 40% at a flat rate of 5% per month for the eight months that most farmers kept some stored crop residues for fodder.

The total pasture land was classified into the same four categories used for crop land and grass yields estimated from three protected sample plots in each productivity class, using three clipping regimes throughout the rainy season to simulate different levels of grazing intensity:

a) the same plot, clipped every 2 weeks at 2.5 cm height
b) the same plot, clipped every 2 weeks at 7.5 cm height
c) different plots, each clipped every 2 weeks at 2.5 cm height.

Trees occur sporadically on all pasture land in Bhat and are heavily used for fodder by lopping the leaves and pods in suitable seasons. The three dominant tree species of Bhat are:

a) *Dhak, Butea monosperma* (consumed by buffaloes only)
b) *Bordi, Ziziphus nummularia* (consumed by goats only)

c) *Orinja*, *Acacia leucophloea* (consumed by all livestock).

Numbers of trees were counted and stem circumference measured at 1.3 height, on three 0.5 ha sample plots in each of the four land productivity classes. Productivity of trees was determined in 10 sample trees in each of three size classes of each species categorised on the basis of circumference. Sample trees were lopped by local practice and the loppings weighed before feeding to buffaloes or goats. The woody material refused was weighed again and the weight difference is considered as fodder.

All livestock within the watershed were counted every second month during one full year and classified in three categories:

a) residents belonging to the sample of 25 farmers
b) 'foreign' (trespass or migratory) moving into Bhat
c) residents temporarily grazing outside Bhat.

Data from all the sources described above were used to estimate total DM production during a sixteen month period covering two rainy seasons. Applying suitable correction factors and assumptions about consumption rates allowed the calculation of a dynamic monthly carrying capacity.

Results

Rainfall in the two seasons was about 700 and 900 mm, concentrated in July, August and September.

Average size of private land holdings is 2.2 ha of which an average of 0.8 ha is utilised for crops and 1.4 ha for grazing and cutting of grass. Cropping takes place in the low-lying areas and foothills. More sloping and higher areas are used as pasture land. During the monsoon season, maize is the dominant crop, grown in more than 70% of the crop fields often in mixed cropping. Paddy is the second most frequent crop. Total availability of crop residues was extrapolated from the sampled fields. Productivity of grass was likewise estimated from the sample plots on the different topographic classes. As an indication of change in quality of the grass, crude protein and fibre were analysed. From August to October there was a decline in CP from 6-8% to 3-4%; crude fibre content of the grass increased from 21-26% to 33-35%.

Total tree fodder production was calculated from an estimate of total trees made by extrapolating from the sample plots in each land productivity class, and per-tree production using average circumferences and the linear regression of yields, shown below: Linear regression of leaf yields and tree circumference.

Species	r	Linear Regression
Dhak	0.99	Yield = 0.197 * Circ - 4.59
Bordi	0.96	Yield = 0.154 * Circ - 1.78
Orinja	0.95	Yield = 0.139 * Circ - 2.71

Figure 6 shows that large surpluses of grass (pasture) are available in Bhat during August to February. Supplemented with crop residues and tree fodders, the fodder stock is sufficient up to March or April. The beginning of the critical period depends on the arrival of the monsoon rains, which in 1990 came in August making the period May to July critical for fodder shortage. The comparable scarcity period in 1991 was June and July.

Figure 6. Total fodder availability

Thus, standing crop of grass in the pasture land tends to be underutilized, or utilized by 'foreign' livestock. Harvesting of monsoon crops normally starts in December, so there appears to be a period of two to three months when labour could be available for grass harvesting and hay making.

Economic herd adjustments require good access to markets and a reasonable control over cash flow, both of which are difficult for Bhat residents on the margin of sufficiency. The alternative strategy, adopted in this situation, is to capture fodder resources external to their own supply.

Figure 7. Grazing pressure in Bhat village by resident and foreign herds

Figure 7 illustrates the seasonal herd movements inside (above the zero line) and outside (below the zero line) for Bhat livestock. Greatest movements outside occur in the season of greatest fodder scarcity, although restrictions of 'foreign' livestock begin a little earlier.

Net average influx of 'foreign' livestock into Bhat is about 50-60 livestock units per day. Exclusion of this foreign use of their grazing area could give the households of Bhat additional grazing capacity and save the efforts of moving to the forests. But the Bhat villagers are unable to prevent this entirely. Villagers informed us that it was a decision of the local administration (Panchayat), of which Bhat is a part, that Bhat should allow grazing of herds of other villages. There is no record that they receive any compensation in return for this use of their fodder resource. It appears to be the price they must pay in order to keep on good terms with their neighbours.

Nearby villages experience fodder shortages at a similar time to when they are experienced in Bhat, so tend to push their livestock into Bhat -- where the villagers are not able to prevent such invasions completely, although they can reduce them when the pressure is not so great. Meanwhile, Bhat resident livestock are sent to graze in the forest land below, where there is no resistance from resident villagers.

Carrying capacity

The ultimate synthesis of the information from Bhat is presented in Figure 8, showing monthly carrying capacity in AU/ha. The dynamic nature and seasonal changes are dramatically visible. Actual stocking rate (SR) in animal units is portrayed against this background, and shows that Bhat villagers can and do make marginal adjustments to SR in response to seasonal CC.

Figure 8. Carrying capacity vs stocking rate

Nevertheless, Figure 8 demonstrates that there remains a five-month period when in average years SR exceeds CC. During this period, livestock tend to lose weight and the range tends to become overgrazed. It illustrates the stark dilemma faced by Bhat pastoralists: how to make maximum use of fodder resources when abundant without being forced into over-utilization in seasons of scarcity?

In the situation of Bhat, it is difficult to increase the magnitude of adjustments to SR. One could conceive of strategies to improve their access to markets or to credit. But these become complex and probably beyond the scope of Bhat. Attempts to improve control over ‘foreign’ livestock could generate tension with neighbours. More promising could be a strategy based on better harvesting of fodder resources (especially pasture grass) when it is abundant, and improvements in storage for utilization during the lean season.

General conclusions

While livestock keepers have no control over climate they are able to influence primary and secondary productivity by their choice of animal species, the number, sex and age composition of their herds, and the distribution of animals spatially and temporally across their specific grazing area. In Bhat, they do this in response to their perceptions of a dynamic CC.

The importance of monitoring changes in range quality and livestock production over time is repeatedly stressed in the literature. It must be realised that all technological measures suffer from variability, error and subjectivity and that calculated carrying capacity figures must be looked on as a management guide, not as a hard and fast rule.

While range management specialists strive to improve their understanding and methodologies, traditional pastoralists tend to manage their herds in response to apparently intuitive knowledge of the ranges that they occupy. Stocking rates tend to maximise their ability to extract subsistence from the range despite changes in seasonal weather. Acute problems appear to arise only in years of extreme drought, when a degree of overgrazing occurs that appears often to be soon corrected with a return to ‘normal’ weather. Lasting problems come when their degree of control suffers from social or political perturbations.

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