

Carrying capacity: outdated concept or useful livestock management tool?

Introduction

Carrying capacity (CC), in its most basic definition, determines the maximum livestock or wildlife population that a habitat or ecosystem can support on a sustainable basis. In livestock production, the concept has been applied mainly to the management of the arid and semi-arid rangeland regions of the world and especially to pastoral systems in Africa where livestock are primarily dependent on grazing resources for feed supply. The CC concept, more than in other disciplines, has provided a planning and management tool which has formed the basis of many proposed development interventions designed to ensure the continued sustainable exploitation of these rangeland ecosystems (Stoddard *et al.*, 1975). Pastoral systems in other regions, such as intensive dairy or beef production in Western Europe, are highly dependent, and can produce economically, on outside feed resources. It is, hence, hypothesised that the CC concept has not been applied to any great extent in these systems, as potential livestock production is not restricted by the available land and its primary productivity.

Theoretical background and definitions

The CC concept has been used by range managers since the start of this century, and rests on the theory of plant succession developed in North America. The theory assumes that a climax vegetation, which is dependent on the soil and climate, potentially occurs at a particular site (Heady, 1975). In livestock grazing systems, population density affects vegetation production and condition which reduces the vegetation to a sub-climax. It is the range manager's task to balance the regeneration of the plants and the grazing pressure of the livestock. CC marks the stocking rate at which this sustainable grazing pressure is achieved.

Different objectives

Livestock CC is based on the idea of 'ecological carrying capacity', under which populations grow until restricted feed supplies reduce birth rates and raise death rates. This point is defined as 'K', the asymptote of the populations growth curve based on the available resources. Commercial management of livestock aims to obtain off-take from the population for human consumption (milk, meat, sales), therefore, the population must be managed at a density below 'K', so that birth rates are greater than death rates. Figure 1 shows the hypothetical interrelationship between livestock populations and vegetation. It indicates the different off-take levels managers must maintain in order to support combinations of plant and animal densities other than those occurring at 'ecological carrying capacity'. Initially the off-take curve rises from zero at very low stocking rates and increases with the increasing size of the herbivore population. The sustainable off-take rate is determined by multiplying the total animal population by the excess of birth over the death rate and 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 and has been termed the 'economic carrying capacity'. As the animal population grows beyond economic CC, the off-take rate begins to fall and ultimately returns to zero as increasingly high rates of mortality and falling birth rates obviate the need and opportunity for off-take to maintain stable animal populations (Behnke and Scoones, 1993).

Figure 1: The relationship between plant and animal populations in a grazing system.

(Adapted from Caughley, 1979 and Bell, 1985)

The conclusion from this model is that CC can not be defined independently from livestock production and range management objectives. Therefore, the actual population density providing useful off-take varies with the type of production and management objectives (e.g. milk vs. beef), and the economic CC for a commercial beef ranch producing prime cuts, may be completely different from that of pastoralists on communal areas, where the value of the livestock is determined by a range of outputs including its use for draught, manure and milk. It makes little sense, therefore, to talk about overgrazing or under-stocking without specifying the management system (Bell, 1985).

The variability in the definitions of CC is mainly concerned with stability in space and time, and the precise meaning of both ecological and economic CC. The acceptable CC is normally determined by a

combination that satisfies both livestock production and vegetation condition objectives, which has important implications for the management. Nevertheless, various all embracing definitions have been proposed which range from the vague 'the density of animals and plants that allow the manager to get what he wants out of the system' (Bell, 1985), to the very specific 'the user-specified quality biomass of a particular species, under the influence of social or behavioural constraints, for which a particular area, having user-specified objectives, will supply all energetic and physiological requirements over a long (but specified) period' (Giles, 1978).

Equilibrium and non-equilibrium environments

Relatively stable environments, with predictable primary production, little inter-annual variation and with regular predictable seasonality, allow the adoption of a stable CC. Vegetation productivity and condition in these environments may be mainly dependent on stocking density. Unstable environments have unpredictable and large inter-annual variation and greater spatial heterogeneity in primary production, requiring seasonal or inter-annual movement of livestock or variation in livestock numbers. These environments require choices between alternative stocking/grazing strategies, i.e. conservative or opportunistic with varying stocking densities (Scoones, 1994). The dominant range model based on the CC concept developed in North America assumes that pastoralists in the arid and semi-arid regions occupy potentially equilibrating grazing systems (Figure 1). Destabilisation of these systems is caused by overstocking by pastoralists. In accordance with this stereotype, the objective for the development interventions has been to restore the equilibrating conditions by the promotion of a conservative stocking strategy or CC which allows animals to survive the lowest primary production (Bartels *et al.*, 1990).

During the past two decades, however, new understanding has supported an alternative view which argues that the opportunistic CC, allowing stocking densities to vary over time to make maximum use of vegetation without damaging range resources and accepting the periodic need to destock or suffer losses, of pastoralists are appropriate in highly variable environments. Pastoralist systems, in these regions, essentially operate as non-equilibrium, but persistent, ecosystems dominated by random abiotic events (Behnke and Scoones, 1993). This proposed livestock and vegetation interaction, illustrated in Figure 2, has identical axis to Figure 1, but the presumed level of stability has changed and the inverse relationship between plant and animals characteristic of Figure 1 has been replaced by a more complicated pattern.

Figure 2: Turkana plant-livestock interactions under the influence of frequent drought perturbations.

(Ellis and Swift, 1988)

Increased understanding of the 'how' and 'why' of intervention failures which have used the ranch model, have shown that non-equilibrium ecosystems are better exploited by the flexibility and opportunism

'Nine years of research among pastoral nomads in northern Kenya has given us a very different view of the dynamical behaviour of pastoral ecosystems to that portrayed in the equilibrating paradigm. It has also caused us to question the appropriateness of development procedures which are based on the paradigm's assumptions. The results of our work in Ngisonyoka Turkana, reveal anything but an equilibrating ecosystem. Here in the arid Northwest corner of Kenya, pastoralists are locked in a constant battle against the vagaries of nature and the depredations of neighbouring tribesmen. Droughts and raids are ongoing stresses; drought induced livestock mortality

practised by African pastoralists, rather than the conservative strategies associated with North American range management practices. Whereas these techniques may be ideally suited to fenced ranches in temperate climates, in non-equilibrium grazing systems, due to their random productivity, a management strategy which responds flexibly to stress, rather than tries to prevent it, is much more effective. The rejection of the ranch model has not taken place in Africa only. In similar ecosystems in

Australia and North and South America, droughts have also brought home the realisation that the succession theory might not be applicable in a highly unstable, dry tropical ecosystems. Planned development intervention should, hence, facilitate observed pastoral drought strategies such as the expansion of the grazing area and the compensation for productivity losses by product substitution and reduction in demand. Facilitation of these management strategies is essential to pastoralists' success and

persistence and the continued efficient exploitation of the non-equilibrial environments they inhabit (Scoones, 1994).

Calculating carrying capacity

CC is calculated from an estimation of annual production of consumable vegetation, linked to animal requirements for feed and nutrients. Annual primary production can be estimated by the measurement of standing biomass (normally at the end of the growing season) or by remote sensing (NDVI), or predicted using empirical relationships of primary productivity to rainfall or from more complex relationships between soils, soil water, fertility and rainfall. These estimates are normally corrected for the available or useful biomass, which is the proportion of the vegetation actually useable by livestock (grazing efficiency), the maximum utilisation of vegetation that still allows sustainable long-term range condition and primary productivity (proper use), and, occasionally, the available crop residues and other feeds (Bartels *et al.*, 1993).

Animal numbers are generally expressed in some substitution unit, such as tropical livestock units, which all use distinct substitution ratios for the different classes of livestock. Feed requirements for livestock are estimated on the basis of feed intake in dry matter (DM) as a % of liveweight, which are sometimes corrected for feed quality to estimate protein and energy requirements for specific maintenance and productive functions (de Leeuw and Tothill, 1990).

Problems of calculation

Large amounts of money, effort and time are devoted to produce modelled relationships between soil, water and vegetation to improve the estimates made for primary and secondary (livestock) production of rangelands. Apart from the obvious technical difficulties in the calculation of CC, an intrinsic problem is that it supplies a static assessment only, whereas in practice there is large variability in space and time. The concept further assumes that one class of livestock are kept within a certain area, under one form of management which is an exception rather than the rule. In addition, niche resources such as river banks, drainage lines or 'bas fonds', and the use of by-products or bought foodstuff, are frequently ignored. There are three main reasons why the determination of CC, as described in the previous section, can lead to inaccurate estimates. Firstly, the assumption that animals are able to ingest a prescribed amount of dry matter per day does not take into account the influence of sward density, time spent foraging, seasonal variability in feed availability and intakes, accepted seasonal variations in liveweight and different and multiple production objectives. Secondly, basing CC on estimates of peak plant biomass production ignores the influence of grazing. Thirdly, and probably most importantly, the choice of the 'proper use' multiplier, which is normally set between 30 and 45 % of the total DM production of the biomass, is often, at best, an educated guess. The decision to use 45 or 30 %, however, will double or half the calculated CC

'Field (1980) made careful calculations of actual stocking rate and carrying capacity (in terms of Standard Stock Units of 450 kg) for each region in Somalia, based on estimates of populations of camels, cattle, sheep and goats, their age-class distributions and estimated liveweights by age-class; the proportion of diet for each livestock type coming from herbaceous and browse resources; the dry matter feed requirements of each livestock type; estimated production of herbaceous and browse material; and a proper use factor of 50%. He concluded that actual stocking rates were more than twice the carrying capacity for 13 of the 16 regions, averaging three times the carrying capacity overall. At the extreme, Bari region stocking rate

(Bartels *et al.*, 1993). Moreover, 'proper use' will vary according to growing conditions, species composition, time of defoliation, the type of herbivore, and the availability and distribution of drinking points for the animals. An issue which has been given less consideration is the use of substitution factors for livestock.

Different types of livestock have different dietary preference, and grazing behaviour and efficiency. Simple weight ratio substitutions do not take these peculiarities into account. Moreover, whatever the ratio used, none of them consider the population structure which is normally closely related to specific management objectives, or the differences in the age structure and composition of the liveweight biomass of the population which makes substitution meaningless.

Reflecting on the above, it is not surprising that measurement of the same resources have led to very diverse estimates for CC. In addition, it is a common practical observation that the theoretical CC is exceeded many fold in communal rangeland areas, and that these situations are apparently sustainable over long periods (Scoones, 1989).

Carrying capacity as a management and planning tool

In spite of the above problems, CC remains a commonly used parameter on which management and planning decisions are based. Commercial ranches in Africa and Australia have used the concept to plan appropriate stocking densities, and both colonial and current African government have made destocking interventions supported by CC calculations (Scoones, 1992). In addition, ranch settlements and development of infrastructure in pastoral areas, such as slaughterhouses and numerous other development

'The most important aspect of livestock production which is occupying the mind of Government is the accumulated and continuing deleterious effects of overstocking and overgrazing in communal lands which are causing severe and potentially irreversible ecological degradation...A comprehensive national programme that focuses on these problems will be implemented... Such a programme will include stock control, better land management and destocking where necessary'.

interventions in pastoral societies such as recent efforts to plan the resettlement of refugees in the Horn of Africa, have been planned using estimated CCs (Unruh, 1993). Most of these development interventions have been based on, and judged by, the output of a single commodity. In

most pastoral communities, however, livestock fulfil a wide range of objectives. Single households on communal areas are also more likely to view labour and livestock as scarce commodities, rather than land. Furthermore, the variability in use by other households of the same resource, and the fact that livestock, in the absence of alternatives remains the most lucrative form of investment in rural Africa, make the application of CC as a planning and management tool in these societies ambiguous. The UN desertification control programme, however, states that 'estimating the sustainable CC of rangeland is fundamental to any long-term effort to help the environment to recover' (Pearce, 1992). In addition, studies of allowable numbers of livestock in newly inhabited areas, as well as ex-ante economic evaluations for commercial ranch and rangeland interventions, routinely use the concept (Kreuter and Workman, 1994a; 1994b).

Perception or reality

Following decades of failed interventions into pastoral societies, the image of desert sands engulfing African villages, combined with reports of livestock causing devastation to the rainforest, has led to a popular belief that livestock are responsible for world-wide environmental destruction. The CC concept has been used as the scientific standard against which rangelands are judged to be overgrazed, and to prove that pastoralism, as practised in the majority of the world's rangelands, is inherently inefficient and environmentally destructive (Hardin, 1968; Lamprey, 1983). Research has shown, however, that severe droughts are an integral part of the long-term dynamics in Africa. Some evidence indicates a climate induced movement of the Saharan vegetation belts, but there is no evidence to substantiate the claims that grazing livestock are a major causal agent. Frequently, areas perceived as degraded due to the over exploitation by pastoralists, quickly recover as soon as the rains return. The portrayal of pastoralists as instigators rather than victims, and the assumption of livestock induced desertification and rangeland degradation as a basis for research, however, has made policy makers and international organisations move away from pastoralists rangeland development issues (Sandford, 1983).

New directions for pastoral development

The recent rethinking of range ecology can be summarised under three main headings. Firstly, African pastoral production systems are influenced by a range of differentiated livelihood objectives. Interventions which fail to address these, are not likely to succeed. Secondly, the productivity of African rangelands is heterogeneous in space and variable over time, which makes flexible movement and stocking crucial. Thirdly, external factors such as droughts determine livestock numbers and vegetation status in many arid and semi-arid non-equilibrium grazing systems (Behnke and Scoones, 1993). In these circumstances it is thought that grazing has a limited effect on long-term production of grass only, and opportunistic or tracking strategies are most efficient in the use of available feed and environmentally benign (Ellis *et al.*, 1993).

Managing change

The recognition of this variability has also led to the exploration for various new rangeland management strategies, which can all be classified under *adaptive planning*. Fundamental to this type of planning and

management is the notion that no matter how much information might be available, events remain essentially unpredictable and random. It therefore uses guidelines and principles in a continuous iterative process, instead of prescriptions. This does not, however, imply that the notion of CC has been completely rejected. Monitoring of livestock productivity and range condition and productivity, learning lessons from experience and practice, for different types and combinations of secondary productivity and similar activities could provide the framework and develop the plans that allow an appropriate response in a wide variety of circumstances. To enable this permanent monitoring programmes with special attention to niche grazing resources, which develop databases capable of distinction between annual variability and long-term trends in primary and secondary production as well as economic impact, need to be introduced. When this monitoring detects grazing induced declines in production or increases in soil erosion, measures conserving the resources must be taken.

Carrying capacity: Can we still use it?

It has become apparent that, even if it was technically feasible to accurately estimate CC for livestock production systems in non-equilibrial environments, the concept can not be meaningful applied to the prevailing pastoral systems in these regions. The questionable utility of CC in these areas has prompted several authors to reject the use of the concept, as it has diverted resources from other priorities and in many cases obscured the real problems. Some of the principles and measurements involved, however, might still be of value in the management and monitoring of key resources, which normally resemble equilibrium situations more closely. It might, in addition, still be of use in the iterative processes of adaptive management, to develop pre-defined contingency plans that allow responses to a variety of circumstances. Permanent degradation due to overgrazing is still rare in Africa, and livestock densities promoting it are normally the direct result of some form of government intervention such as fencing (Behnke and Scoones, 1993). This is not to imply, however, that there is room for complacency. Further development and promotion of local management systems, which regulate the use of niche resources in relation to local stocking rates, seasonal primary production levels, and the availability of alternative rangeland grazing, is urgently needed. These management systems are more likely to be sustainable than the current practices of imposed grazing restrictions and destocking based on a theoretical CC.

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