CARRYING CAPACITY: UNDERSTANDING OUR BIOLOGICAL LIMITATIONS*

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ABSTRACT

The historical development of a time-dependent carrying capacity concept within the biological sciences is reviewed. It is demonstrated that sociological neglect of the time dimension alters the meaning of carrying capacity: instead of the maximum population that a given resource base can sustain *indefinitely*, sociologists have focused on the maximum that can be achieved in the short run. Such a shift in focus has led sociologists in the past to emphasize technology and organizational factors and to overlook environmental degradation by overuse. A new approach is suggested that will hopefully alert sociologists to the fateful ramifications of living by drawdown.

Social scientists used to be able to disregard most concepts from biology. In the present state of the world, we can no longer understand competitive human relations by restricting ourselves to a totally nonbiological vocabulary.

One important biological concept is carrying capacity, which refers to the clash between the biotic potential of a population (ability to reproduce geometrically) and environmental resistance (factors which check its growth). It means, simply, the maximum number of a species that a given unit of land can "carry" indefinitely (Whittaker, 1975:17). Populations of plants and animals, in the natural state, often "overshoot" their carrying capacity and die back before undergoing oscillations around the carrying capacity level (Whittaker, 1975:17-19). This concept provides a framework for understanding competition.

For an animal species in which one group is not enormously differentiated by culture from other groups of the same species, there is little enough variation in individual resource appetites so that a simple head count has served

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reasonably well as a measure of the ecological load imposed by a population upon the environment that supports it. Among humans, however, cultural differentiation has resulted in vast differences between the per capita resource appetites of one group and another. This has complicated issues pertaining to carrying capacity, which were easier to conceive and clarify among nonhuman populations. Accordingly, the first part of this paper looks at usage of the carrying capacity concept among ecologists, range scientists and wildlife managers. After showing that its greatest utility in these fields has depended upon explicit recognition of the time dimension, the paper discusses problems arising from neglect of that dimension in human ecologists' usage of the term.

Animal Populations: Natural and Managed

Deer population studies (Klein, 1968; Mech, 1966) indicate when predators or other controls are eliminated, as is the case when the species is introduced onto islands, the population increases rapidly, then crashes (dies off). Heady (1975:116) observes: "In these instances, the limiting factor seemed to be only one – the food supply. Control or crash was both sudden and severe."

Man's domestic animals can also suffer such consequences by overgrazing, and have done so. Range scientists have developed a concept which seeks to prevent such consequences. Grazing capacity or carrying capacity, as used by range scientists, is a management concept that recognizes the complex interaction between animal population and productivity on a given unit of land. The management goal is to maximize the number (or mass, for mixed populations) of animals carried indefinitely; hence the need to avoid degrading the range. Thus, in Range Science, carrying capacity refers to the size of a population which can be supported *indefinitely* on a given area of land.

Unfortunately, there has been some confusion created in the literature by those (Odum, 1971:183-85; Boughey, 1968:34-5) who view carrying capacity, K, as the upper population asympotote or "maximum population size possible." The implications of this subtle but profound difference in conceptualization of carrying capacity for unwary human ecologists cannot be overstated. It is imperative that we clarify the existing confusion lest human ecologists continue to imagine that man is set apart from other species so fully that organization and technology can always be depended upon to increase the carrying capacity of the land for mankind in the future (Hawley, 1950, 1968; Micklin, 1973:9; Schnore, 1958) as they have done in the past (Boughey, 1975:254).

I will argue that this is a dangerous conceptualization, that humanity may be achieving its increase in numbers and in material affluence at the expense of the environment (range). I believe that a new approach to human carrying capacity, one with a time dimension, is vital. Although this paper is exploratory, it will conclude by suggesting a new carrying capacity equation which, although tentative, may encourage further research.

Some ecologists tend to describe natural populations by the simple logistic model (Odum, 1971:183; Boughey, 1968:34, *ad passim*):

$$\frac{dN}{dt} = rN\frac{(K-N)}{K} \qquad \text{(Equation 1)}$$

where K, the upper asymptote, is the carrying capacity, N is the population and r is the "intrinsic rate of population increase," i.e., the biotic potential for growth if an environment were infinite. This model is found in Diagram 1.

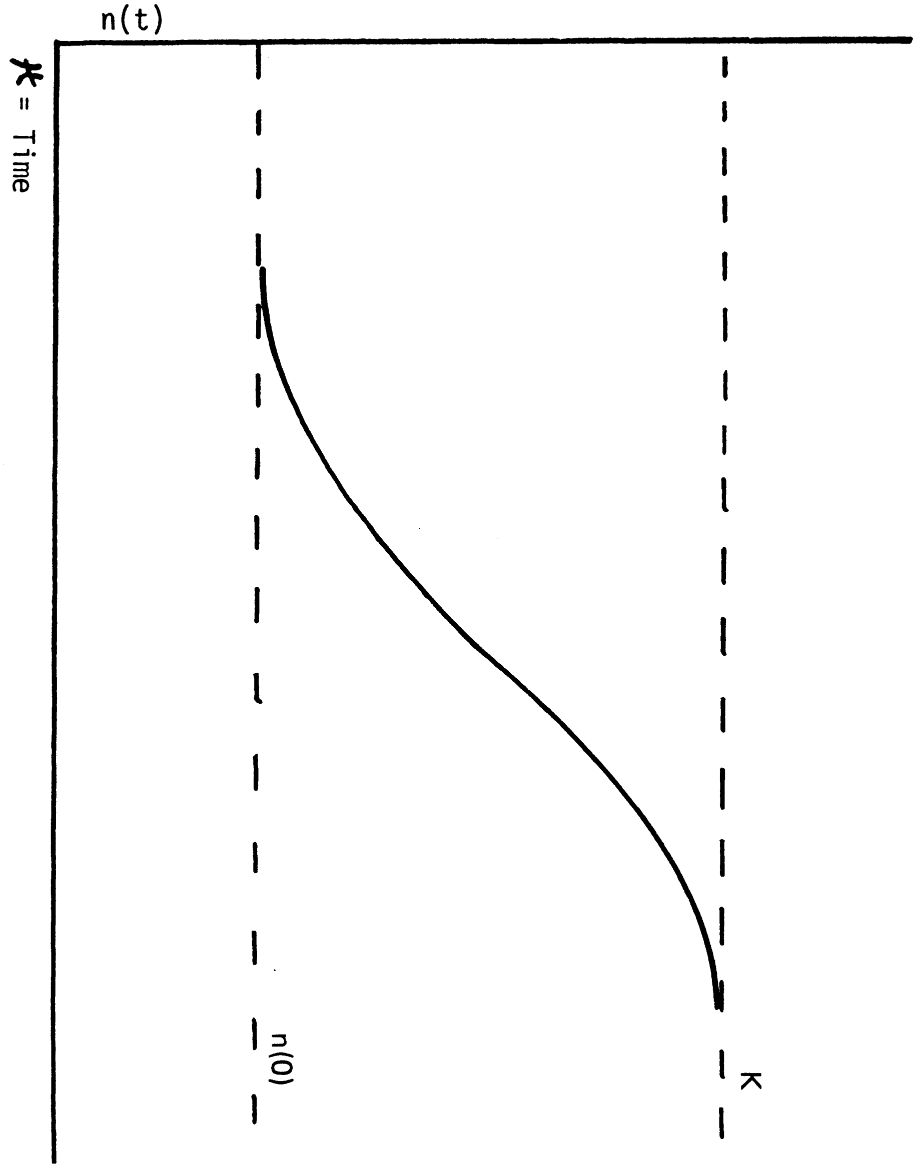
When considering this model, the reader may ask: How then is it possible to exceed the carrying capacity, as indicated by the deer population irruptions, when carrying capacity *is* the upper limit?

The confusion created by Odum in defining carrying capacity, K, as the "upper asymptote" forces him to write (1971:185): ". . . almost always the population overshoots the upper asymptote and undergoes oscillations before settling down at the carrying capacity level." We must ask what Odum really intended since, by the mathematical definition of an upper asymptote, overshoot would be a conceptual contradiction. I believe that this confusion could be eliminated by relabeling K as the maximum number that can be *carried indefinitely* by a given area. Obviously, the number of a population carried temporarily may sometimes exceed that which could be carried indefinitely. The tendency for natural population systems to overshoot and the subsequent oscillations may be explained in terms of these two levels.

By analogy, if a person is given an allotment of food sufficient to carry him for one month if properly budgeted, and then proceeds with a friend to gobble it up in two weeks, they will starve before the next allotment. The budgeted or managed food supply represents the "indefinite" carrying capacity whereas the period of gobbling represents a temporary overshoot. In short, a population can only exceed its (indefinite) carrying capacity by degrading its environment. This results in a *lower* subsequent carrying capacity and the sequel is population die-off (often exacerbated by the onset of winter in the case of the deer population studies). If a tract can provide 365 deer-days per year, it can carry one deer indefinitely. This means that, as a ratio, carrying capacity implicitly has a time factor, both in the numerator and in the denominator. But just to assume that time thus cancels out and is not relevant would be misleading. We shall examine later the consequences of such an assumption.

When food supply is the only limiting factor, a tendency for more severe

DIAGRAM 1



Population (Logistic) Growth Over Time

overshoots and oscillations prevails (Heady, 1975:116). But nature is not usually such a sloppy manager. For example, the average level of deer *with predation* in the often-quoted Kaibab deer study (Dasmann, 1976:219) was many times less than the number reached at the height of irruption and presumably could have been sustained perpetually.

The basic function of population management is to prevent environmental damage by intervening to prevent the population from overshooting carrying capacity. The prevention of environmental damage thus prevents reduction of carrying capacity. This relation between overuse and environmental damage is the essence of the carrying capacity concept as developed by range scientists.

Carrying Capacity: A Relational Concept in Range Management Literature

The concept of carrying capacity, as used by range scientists (and wildlife biologists), has varied over time, but it has usually emphasized the *interaction* between a population and its environment (see Edwards and Fowle, 1955; Heady, 1975). Hadwen and Palmer (1922:29) defined carrying capacity as: "... the number of stock which range will support for a definite period of grazing without injury to the range." Dasman (1948:400) considered carrying capacity:

> ... the maximum number of grazing animals of a given class that can be maintained in good flesh year after year on a grazing unit without injury to the range forage growing stock or to the basic soil resource.

Edwards and Fowle (1955) point out the importance of definitions such as Dasmann's as the basis for range management. Specifically, they state (1955:591):

> If a population is sufficiently large to deplete the food supply faster than it is being produced, or injures the environment in some way, the size of future populations will be affected. *This is an important concept in Dasmann's definition which is usually assumed in considering carrying capacity.* In theory, it is simple, recognizing that the animals should be in such numbers that they eat only the annual interest from food plants and none of the principal.

In addition, they note that his definition considers the quality of the animals and that, "... a unit of environment may support a large number of deer living at a minimum subsistence level, or a lesser number of healthier animals" (1955:591).

More recent definitions of carrying capacity also reflect the management function. The Range Term Glossary Committee (1964) defined carrying capacity as "the maximum number of individual animals that can survive the greatest period of stress (i.e., natural fluctuations such as drought) each year on a given land area." Sharkey (1970) broadened this definition to: "the total weight of animals that can be supported permanently."

In order to operationalize these management-oriented definitions, measurement concepts such as animal-unit-month, sheep-day, deer-day, cow-month and many related terms are employed in an attempt to quantify carrying capacity and are based on the characteristics of each species to graze the land. We need not be concerned here with the somewhat complex manner in which the range manager calculates range capacity, animal requirements or grazing pressure. The point lies rather in the basis for such estimation techniques: that proper use is "that maximum point of defoliation (use) which continues to maintain excellent range productivity" (Heady, 1975:123).

Range management has two purposes: (1) to protect or improve basic range resources and (2) to optimize production of goods and services. They are, to a degree, in conflict because as each animal grazes, "it reduces available herbage both in quantity and quality, thereby changing the habitat for itself and altering its future response. [Therefore] control of animal numbers is the most important single tool available to the rangeland manager" (Heady, 1975:113).

A demonstration of the *interactive process* between animals and their environment in which the sustainable carrying capacity principle was violated is presented by Dasmann (1976:197) in the following:

> This [1930's Forest Service] survey showed that the original capacity of the native range vegetation to support livestock had been cut in half during the few decades that the range had been grazed. The original capacity of the native vegetation was estimated at 22½ million animal units . . . . As a result of overstocking by livestock, the vegetation had deteriorated to the point where in 1930 the range capacity was only 10.8 million animal units. However, in 1930 the western range was still carrying 17.3 million animal units instead of the 10.8 million that it could have supported without further damage. The damage was therefore continuing. If stocking were reduced to a level below the range capacity, it would take approximately 100 years to restore the ranges to their original condition. In about 60 years of use, therefore, enough damage had been done to require a century to repair.

In ecological terms, overgrazing tends to set back succession[1]: plant species high on the successional scale are replaced by plants lower on the scale (Dasmann, 1976:200). Ecologists are trained to judge both the condition of the range and range trend. Condition refers to "the extent to which a range has departed from a climax (plant) stage toward successional stages as a result of grazing use" and range trend is a determination of whether the range is deteriorating further or returning toward a climax stage under existing conditions of usage (Dasmann, 1976:200). Obviously, overgrazing is to be avoided since it would mean lower carrying capacity of the range area as plant cover decreases and soil erosion increases. This process, unless checked, accelerates until the range becomes a virtual desert and the carrying capacity, at least for livestock, reaches zero. Man's role in the increasing desertification of the Sahara ecosystem, principally by overgrazing of domestic animals, is a recent example of this process (Hamblin, 1979).

Carrying Capacity and Human Ecology

Having witnessed the central place of carrying capacity within range science, we may now ask: Does it enjoy such a position with human ecology and, if not, why not? The answer appears to be a qualified no.

Hawley recognized (1950:149) carrying capacity as "unquestionably the most important issue confronting mankind." Why then has it not received more careful and concerted attention within human ecology?

The reason human ecology has not been able to use carrying capacity as successfully as range science, as either a unifying concept or as a superordinate management tool, lies in the way that human ecologists conceptualize carrying capacity. They have generally meant the largest number of persons that a given area can carry *at a given time.*[2]

The very heart of the range management model, *"for an indefinite period"* (hence avoiding degradation), is deleted. This leaves the concept nearly meaningless. We are then left with no reference as to *how long* a given load is supportable. Obviously, there can be enormous gains in the number of animals carried by a given area *at any one time,* but such gains occur at the expense of the environment and thus at the expense of future numbers. For example, in range terms, 5 hectares may carry 1 animal in a 5-pasture rotation plan for a short time, but 25 hectares would be necessary to carry the 1 animal for the complete season.[3] To confuse the two levels by calling the first one carrying capacity when that name should be reserved for the latter one is to think that 5 hectares are adequate when 25 are needed – an egregious error.

Why human ecologists have opted for the temporary version of carrying capacity is not so easily answered. But we can speculate that human ecologists, in their preoccupation with social organization and technology as factors which have made possible enormous increases in human populations, have not fully realized (Dunlap and Catton, 1979; Catton, 1978) that these increases may be temporary ones achieved by degrading ("overgrazing") the environment.

Hawley, attempting to extend the carrying capacity concept to human populations, wrote (1950:149): "Man is no different from other organisms in that at any given time the supply of available materials and the existing conditions will support only a limited number of individuals." Nevertheless, he undermined his own effort by demonstrating the effect of social organization (utilizing Wiechal's population density figures for differing types of economies) and by citing the impact of technology in extending the local resource base (Hawley, 1950:151-60). This led Hawley to a precarious position – that the resource factor ". . . plays little or no part in regulating the size of populations" (1950:162). Ironically, he was quite explicit in disregarding the time dimension of the carrying capacity concept:[4] "Yet, leaving the future out of account, the world at the moment has access to a superabundance of materials . . . That these may be exhausted someday is beside the point" (Hawley, 1950:162). Such analysis has confused the meaning of carrying capacity in human ecology.

So has the use of the logistic equation presented earlier.[5] Application of such an equation to human populations emphasizes growth of numbers and neglects environmental degradation. Accordingly, the upper asymptote, K, is likely to be taken as greater than the carrying capacity level actually sustainable. The adoption of this approach by some human ecologists has resulted in the emergent theory of "cultural succession" which has as its major tenet the ability of humans to *increase* their habitat's carrying capacity. Boughey (1975:254) proposes that:[6]

> Each cultural advance would raise the level of the human secondary productivity in the individual group territory, ***thus increasing its carrying capacity for erectus-sapiens*** individuals. As the ecosystems contained in the territory could not receive any greater input of energy, this increased size of ***erectus-sapiens*** population could only be achieved in one of two ways. It would be effected if there were a corresponding reduction in the biomass of competing species populations . . . or it could be achieved by 'mining' accumulated resources of the ecosystem . . . . Increases in human population size probably were achieved in both ways.

Boughey has allowed himself to use the term "carrying capacity" too loosely. Man has achieved *temporary* gains in productivity and population by displacing nonhuman biomass with human biomass and by mining accumulated reserves. Referring to the second method, mining reserves, as a gain in "carrying capacity" is misleading. To be more realistic, we must question how sustainable present human population levels are and what will happen when the reserves are depleted.

The New Approach

To summarize the comparison between a draw-down of temporary reserves and sustainable carrying capacity, I offer Diagram 2. Simply put, when the population is at a level below sustainable carrying capacity, it is living off the "interest," not irreparably damaging its environment, and can (barring some catastrophic unforeseen natural phenomenon) sustain this level indefinitely. At any level above the sustainable carrying capacity, however, it must depend upon the reserves or "principal" of its environment, thus causing deterioration and a lower sustainable carrying capacity.[7]

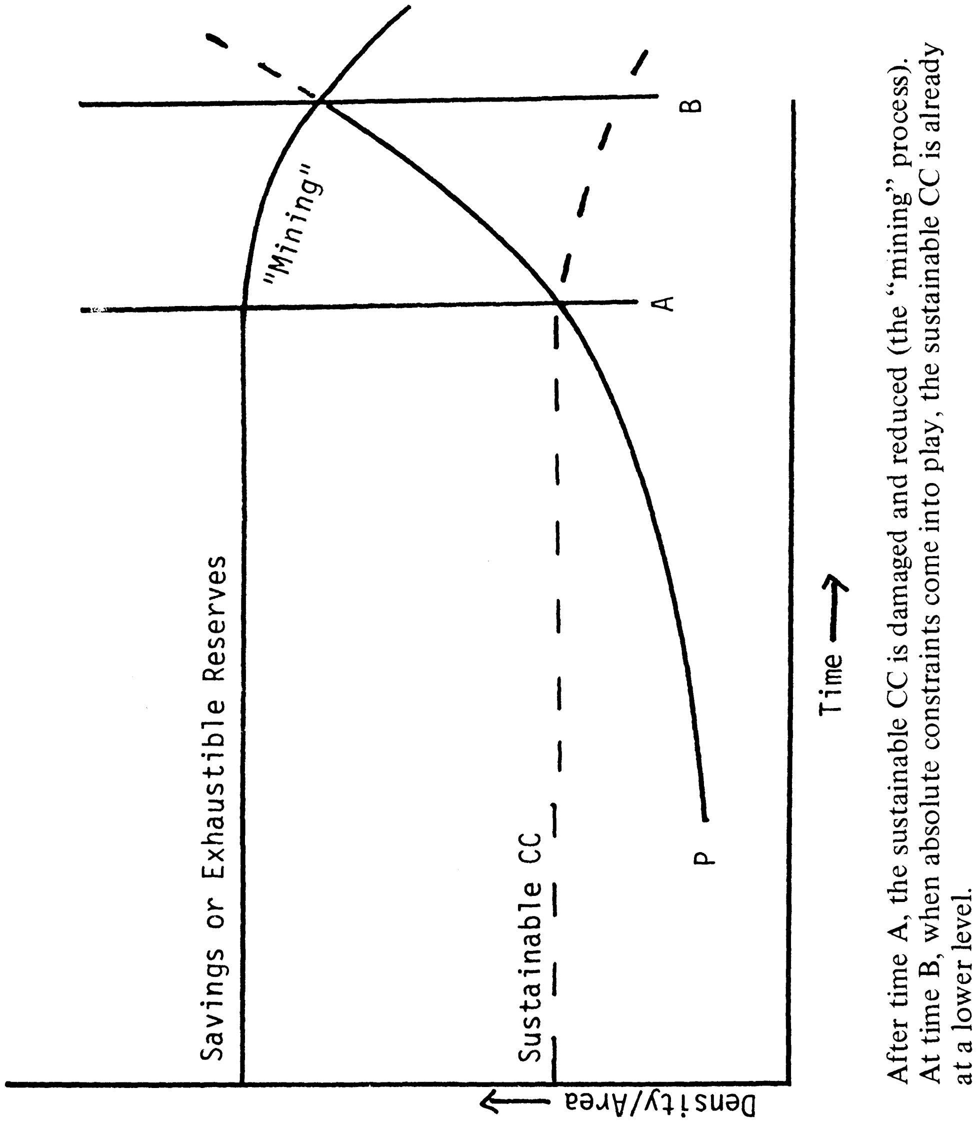
In past societies, this principal was probably directly applicable (Dasmann, 1976:91; Carter and Dale, 1974; and Hudson, 1971:21-4), and Brown (1978:67-8) makes the case that it is still so for certain countries. The issue has become complex, however, for as has been observed (Hawley, 1950:163-69; Catton, 1974; Geisler, 1977; Wisniewski, 1978), the community has transcended its locale: produce is imported or exported to distant places; cities are maintained by the hinterland. Further, the connection between humans and their food source is not readily observable. Ambitious attempts to use soil erosion as a measure of man's overuse, such as that of Allan (1965) are correctly critiqued by Street (1969) as being extremely difficult to apply.[8] The problem is that soil, upon which man's plant and animal food sources depend, will deteriorate relatively slowly and, therefore, does not lend itself to measures of short-term changes.

This difficulty in measurement accentuates an important aspect of the grazing model which may not be readily grasped at first. Namely, why is the crash portion of the irruption-crash curve, diagrammed below, so steep? That is, why does crash occur so rapidly? The answer is fairly simple. Once the population level goes beyond the sustainable carrying capacity level, the environmental reserves or "savings" are withdrawn at accelerating rates. In other words, the population is growing larger at the same time that the sustainable carrying capacity level is shrinking. Therefore, when ecological constraints come into play, the results are likely to be sudden and dramatic. Correct understanding of the carrying capacity concept is therefore an essential basis for foreseeing the disastrous consequences of living by draw-down.

To make this absolutely clear, let us reiterate two aspects of the grazing model: (1) carrying capacity is a function of time (e.g., sheep-days, not just sheep) and (2) carrying capacity may be diminished by excessive population pressure.

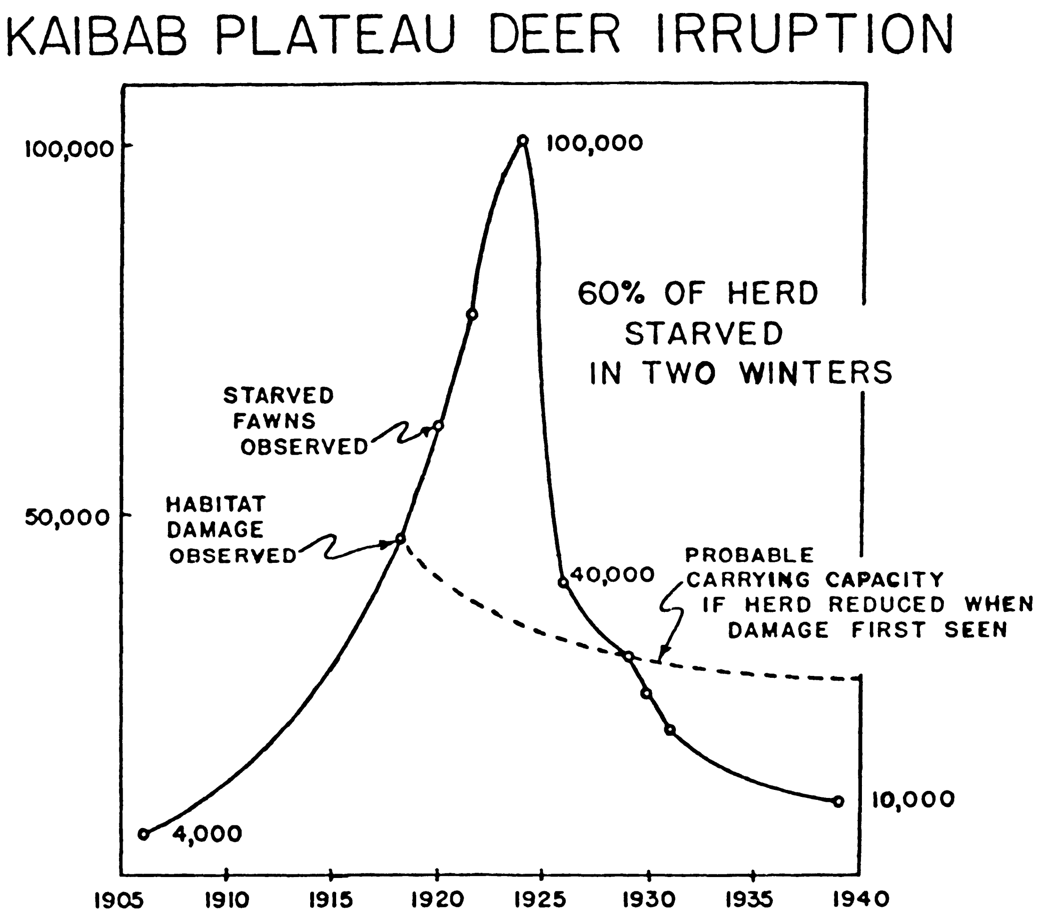
How then might we approach measurement of a human carrying capacity? In the range management literature, the carrying capacity concept tells us that demand for a resource can no more than temporarily exceed recurrent supply.

DIAGRAM 2



Comparison of Results of Living on Sustainable Carrying Capacity and Exhaustible Reserves

DIAGRAM 3



Adapted from Catton (1978).

In the long run, demand must be equal to or less than supply.

Letting P = population; R_t = renewal rate of limiting resource (amount produced in time interval t) and D_t = demand per capita (during time interval t) for limiting resource, then we can write:

$$PD_t \leqslant R_t \qquad \text{(Equation 2)}$$

R_t only takes on large positive values if t is a very long time span. On the demand side of the equation, however, PD_t can become very large even when t represents a short time span, either because P may become excessive or because per capita appetites may be increased. Going back then to the "deer-day" concept, we can see that if deer subsisted on a "nonrenewable" resource, the number of deer supportable by a given quantity of that resource could be very large only if the number of days that they expected to live were very small. The equation, of course, is at all times understood to refer to a given unit of land.

It is here suggested that this equation is fundamentally applicable to human beings. The issue becomes one of letting supply on a *sustainable* basis (instead of *total* stock, including "principal") regulate demand. For many renewable resources, we have the measurement capabilities (Watt, 1968) as Foin (1976:218) indicates for fisheries: ". . . the concept of sustained yield is a useful measure . . . fisheries science already has the sophistication in population ecology and mathematics to determine sustained yields" even though, for both economic and political reasons, we often indulge in over-fishing despite knowing better.

Although difficult to determine (Brown, 1978:67; Ophuls, 1977:130-34), the amount of population pressure that the earth can carry on a sustained basis is undoubtedly below the current level. Murdoch (1975:461-62), for example, states the argument thus:

> There is guarded optimism among agriculturalists that we can feed the 6 or 7 billion people who will be on earth at the turn of the century. But . . . there exists real doubt that the earth can sustain even 6 billion over long periods. Indeed, Hulett has estimated that, if we take account of all resources and of our effects on the environment, and if the population came to have the current U.S. standard of living, the total sustainable world population would be only 1 billion.

Murdoch explains that "to feed 6 or 7 billion people, we will have to do things to our food-producing ecosystems which are liable to impair their capacity to produce food in the future." Reflecting an awareness of the difference between living by draw-down and living with sustainable carrying capacity, his reference to Hulett also reflects the potential trade-off between standard of living and population level. This trade-off is possible since the "needs" of the human species (D_t) are so variable; however, the population pressure ($P \times D_t$) is *limited* by sustainable resource levels.

The implication of sustainable carrying capacity for those who advocate a "steady-state" (Daly, 1973; Renshaw, 1976) is that we must first pass through a reduction period, a very difficult task (Whittaker and Likens, 1973:367-68). This concept of carrying capacity should go a long way toward supplying the ecologically-prescribed limits that Daly seeks (1973:15, 155-56). On the other hand, if those who do not or cannot conceive of human carrying capacity in sustainable terms have their way, mankind will repeat the tragic failures of the past (Harris, 1977; Mulloy, 1974).

FOOTNOTES

[1] For an elaboration of why man needs to reverse the succession process, but not to the point of overgrazing, the interested reader is referred to Odum (1969) and Margalef (1968).

[2] Within the human ecological school, those with a biological orientation (Pianka, 1974; Emlen, 1973; Boughey, 1968; Odum, 1971, *ad passim*) indicate a strong preference for the logistic growth model presented in Equation 1, although several exceptions were found: Whittaker (1975), Ehrlich, Ehrlich and Holdren (1973) and Wagner, Bailey and Campbell (1973). For a historical discussion of the logistic curve in Ecology see Frank (1959).

Those with a social orientation either largely ignore the concept or define it in terms entirely relative to the level of technology (Brush, 1975; Hayden, 1975; Bayliss-Smith, 1974).

[3] This example is adapted from Heady (1975:119).

[4] The reader is invited to read this in context, Chapter 9, Hawley (1950). See also Hawley (1968:328-37).

[5] See E.P. Odum, *Fundamentals of Ecology,* 3rd Ed., pp. 183-88, for elaboration.

[6] See Lenski and Lenski, *Human Societies,* 1974, pp. 76-8, 103, for a more cautious appraisal. Also, Miller *Living in the Environment,* 1974, p. 107, note particularly the graph.

[7] Ehrlich, Ehrlich and Holdren (1973:70) remind us that "when accumulated stocks are large compared to annual consumption, as is true of forests or certain ocean fishes, consumption can sometimes exceed the sustainable yield for decades before the damage becomes

obvious."

[8]For a summary discussion of attempted analysis by anthropologists and others, see Bennett (1973), Netting (1974) and Hardesty (1977).

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