SCOPE 27 - Climate Impact Assessment

7 Pastoralism

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7.1 INTRODUCTION

Pastoralism is understood in the present paper as the unsettled and non-commercial husbandry of domestic animals. Thus it differs from sedentary subsistence husbandry systems and profit-oriented transhumant operation and from commercial ranching, although the same term may be used to describe these other forms of animal rearing (such as pastoralism in Australia). Pastoralism thus described is a way of life and livelihood for an estimated 60–70 million people, mainly in Africa and in Asia.

Studying the impacts of climate on pastoralism is complicated by the fact that pastoralism is essentially —but not solely—a form of adaptation of human societies to hazards and hardships induced, and imposed on them, by climatic constraints. The wandering husbandry of domesticated animals as a response of rural societies to climatic variability or limitations for human subsistence is about as old as irrigated agriculture, which first developed in the Middle East and then in Egypt some 5000–10,000 years ago. Runoff farming also developed in the Middle East and then in North Africa 2500–3000 years ago. Evidence of the latter does not go further back than 4000–5000 years (Bonte *et al.*, 1981), while the first references to domesticated animals (which may not necessarily have been nomadic) date back to 8000–12,000 years ago for sheep and goats, 6000–8000 for cattle and 4000–5000 for camels (Zeuner,1963).

7.1.1 Pastoral Systems

The impacts of climate on pastoralism, as a managed ecosystem that evolved as an adaptation to climate, vary in important but often subtle ways by the type of pastoralism practiced and the various management techniques adopted. Pastoral types of animal production systems may take many forms based on the degree of nomadism, its regularity and the type of animals kept. (See Bernard and Lacroix, 1906; Capot-Rey, 1953; de Planhol and Cabouret, 1961-72; Bataillon,1963; Johnson, 1969; Monod,1973, 1975; Bonte *et al.*, 1981 for a thorough analysis of these forms.)

One may first distinguish (Monod, 1973, 1975) among true *nomad pastoralism* where the whole household moves with the herd or flock, *transhumant pastoralism* where only the herder moves with the stock, and *semi-pastoralism* where cultivation (usually of cereals) constitutes a significant segment of activity.* There are intermediate forms where the whole family may move with the herd or with a part of it for shorter or longer periods. The movements may also be *periodic*, pendulum-like (that is, linked to climatic seasonality), or *aperiodic* (that is, depending on random climatic vagaries in time and space). In addition, one can further differentiate systems according to the type of stock which is kept: cattle, one- or two-humped camels, sheep and goats, horses, reindeer and even yak or llama. These characteristics may be combined with various geographic situations. One may thus differentiate between transhumant pastoralists and periodic nomads, those who having their homeland in the mountains spend the cold seasons in the plains from those who having their homeland in the plains move to the mountain areas for the dry hot season.

* In oil-rich countries, new forms of `semi-pastoralism' have developed based on herds managed in a pastoral-like way by expatriate waged shepherds from similar cultural origin in low-income neighboring countries; this new type of

management, due to very high internal meat prices, employs costly management practices such as the trucking of water for stock and intensive supplementary feeding of grain and other subsidized concentrates. This type of husbandry is not included under the term of pastoralism described herein.

Within the various forms of nomadism, one may further distinguish among those who are almost sedentary like the Masai of Kenya and Tanzania; those who move over short distances within a few thousand square kilometers, such as the Tuareg of the bend of the Niger River in Mali, Niger and Upper Volta (Barral,1967,1977), and most East African pastoralists; from those who may move over very long distances (1000–2000 km), such as the Reguibat Lgouacem Moors of Mauritania (Cauneille, 1950; Bonnet-Dupeyron, 1951); the Kabbabish of the Republic of Sudan (Asad, 1970); or the Al Murrad of Saudi Arabia. There are also fundamental differences between those who are territorially based, such as the Moors and Tuaregs (Rodd, 1926; Nicolas, 1950; Nicolaisen, 1963; Bonte, 1973; Bernus, 1981), and those who have no permanent base, such as the nomadic Fulani, who consequently move over continental distances during the course of centuries and even within decades. The latter might be regarded as the true pastoralists since they are tied only to their herds and have had no real homeland throughout history (Stenning,1959; Dupire,1962,1970; Gallais,1967,1975,1977).

Finally, one can differentiate among those who have other significant means of subsistence (for example, hunting, fishing, cultivation, trading, caravaning, wage labor, raiding, handicraft industries, and/or religious activities) while practicing pastoralism as an important source of livelihood. There are even those who live as settled farmers, traders, shopkeepers or civil servants and own flocks or herds which are managed in a pastoral way by waged or share-owning shepherds, within a nomadic or transhumant production system. The latter case is no longer subsistence husbandry but it is not yet commercial husbandry, either.

7.1.2 Non-climate-related Pastoral Movement

At first sight it would seem that there is a clear linkage between pastoralism and climate, since most pastoral areas are subject to arid and semi-arid climates and therefore pastoralism would be the usual way to avoid the effects of seasonal drought on livestock in traditional societies. This is obviously grossly true, but there are, as ever, a number of exceptions.

First, pastoralism exists in a wide array of climatic conditions, from desert to subhumid, under temperate continental, mediterranean, tropical and equatorial climates (not to speak of the tundra); under various rainfall and temperature regimes in many regions of the world: central Asia, middle Asia, southwest Asia, northern Africa, the Sahelian and Sudanian zones of West Africa, arid and semi-arid East Africa, and southern Africa. It also used to exist (in the Middle Ages and until the beginning of the present century) under the temperate climates of western Europe (Braudel,1949).

Second, there are many areas within the arid zone where settled livestock husbandry is the rule, including traditional societies in Africa and Asia, not to mention the ranching system of production developed in America, Australia and southern Africa. Conversely, there are many semi-arid areas where pastoralism is not found either because of livestock health constraints such as trypanosomiasis or human health problems such as onchocerciasis (river blindness).

Third, nomadism, or transhumance, or herd movement, is not necessarily triggered by drought or climatic constraints. On the contrary, in some instances movement is initiated by floodings and the subsequent pullulation of flies, mosquitoes, ticks, worms and parasites of all kinds, affecting herds and herders alike. This is the case, for example, in the inner delta of the Niger River, the Sudd and the Bahr El Ghazal, and the lower Chad Basin, although in these cases there is an indirect linkage with climate on the catchment basins. In other cases movement may be caused by the search for more comfort, towards warmer winter or cooler summer areas (Barth,1961).

In most cases, however, movement is motivated either by the quest for better pastures, the exhaustion of the range, or the shortage of drinking water. The flocks of Provence in southeast France used to move for centuries to their summer lush `alpages' in the Alps Mountains (the word Alp, incidentally, means summer montane pasture in the local dialect), and come back to the Mediterranean shores with the first late summer frosts on the highlands and the first autumn rains in the lowlands. The same thing occurred between the Languedoc lowland garrigues and the Cevennes highlands. The Waled Nail and the Larbaa of Algeria spend the winter season in their home country on the steppic ranges of the northern fringe of the Sahara and move for the summer months to the stubble fields at the northern limit of the highlands, 300–400 km further north, thus travelling 600-800 km every year (Bernard and Lacroix, 1906; Sagne,1950; Capot-Rey,1953; Cauneille,1950,1968; Bataillon,1963). The migration of the Delta Fulani of Mali is regulated by the flooding of the Niger River and by the filling up of water ponds along the 250-km trail to the Nema of southeast Mauritania, where they move for the rainy season, while the return trip is governed only by the desiccation of the ponds along the trail (Gallais,1967,1975; Le Houérou and Wilson, 1978.)

Fourth, the degree of adaptation of ethnic groups of pastoralists to drought varies greatly. Thus in central Mali the Moors continue to utilize throughout most of the dry season ranges that have been abandoned by the Fulani at the end of the rainy season, and by the Tuareg a little later (Le Houérou and Wilson, 1978). In other words some pastoralists move only when they are compelled to, either by the lack of pasturage or the shortage of water, while others move long before the resources are exhausted in order to find better forage or cleaner water elsewhere, leaving the land to less demanding groups.

Thus `pastoralism' is not a simple system; there are virtually as many kinds of pastoralisms as there are ethnic groups practicing it. Even within the main ethnic groups in Africa, such as the Tuaregs, Fulani, Teda, Nilotic or Hamitic, there are very great differences in habitats, life styles, water, land and herd management practices, and social, cultural and religious values and beliefs. Strategies of adaptation to climatic variability and other hazards thus may be extremely different from one group to another, and therefore the impact of climate is necessarily quite variable according to the ecological conditions and the sociocultural adaptation strategies which are considered. The impact of climate should thus not be seen *per se*, in isolation, but within a sociocultural framework. This makes it extremely difficult to generalize and synthesize in a meaningful way as to the impact of climate at the societal level. Thus, I will limit myself to methods and findings related to primary and secondary resource bases from which pastoralism derives its mere existence—and, water, pasture, stock—which seem amenable to some valid generalization. In the ensuing sections I shall examine the link between climate variability and change and biological production in grazing lands, then the linkage between grazing land production and animals, and then I shall examine the many varied links between animals and human sustenance. In addition, I shall describe human modifications affecting each of these linkages, and conclude with some remarks on the future of pastoralism.

7.2 THE RELATIONSHIP BETWEEN CLIMATE AND THE PRIMARY PRODUCTION OF GRAZING LANDS

7.2.1 Climatic Factors

The climatic factors affecting primary production parameters are essentially rainfall (that is, water availability for plant growth) and energy flow (that is, temperature and potential rates of photosynthesis and transpiration). Temperature may strongly affect seasonal plant growth in temperate or montane climates, but it does not seem to affect greatly total annual production in pastoral zones except, of course, in truly cold climates such as in central Asia, the tundra, or high mountains. Plant production is usually affected when daily maximum temperatures drop to +10 °C, or below, for substantial periods of time, the zero growth being usually in the vicinity of +5 °C. In montane pastoral areas seasonal variations in temperature from year to year thus may strongly affect migration patterns in time and space, either in hastening or delaying migration as a result of early cold, mild winters, early or late springs, and the like.

There is a consensus among scientists that rainfall and evaporation are the overriding climatic factors that affect primary production in most pastoral zones; other climatic variables are often omitted in primary production predictive models (Rosenzweig,1968; Van Keulen,1975; De Vries *et al.*, 1978; Young and Wilson, 1978; Floret *et al.*, 1982). The predictive value of combining effective rains (that is, water that is actually infiltrated) and actual evapotranspiration is quite good. The only difficulty is then to determine how much rain has actually infiltrated and how much is being evapotranspired. This is, in principle, very simple to measure, but, in fact, is extremely difficult to integrate over large geographic areas, since it is strongly affected by many local factors (vegetation cover and structure, topography, soil characteristics and rainfall distribution in space and time). Since, for a given type of climate, yearly variations in evaporation are very small as compared to variations in rainfall, and since in arid and semi-arid zones annual evapotranspiration is always much higher than rainfall, annual rainfall is often used as the basic climate factor to relate to primary production over large areas.

7.2.2 Estimating Primary Production

There are three major methods for estimating the actual primary production of large geographic areas: ground appraisal at simple sites, aircraft and satellite remote sensing, and indirect appraisal through measurements of secondary livestock production.

There are many measurement systems employed in appraising the primary production of grazing lands. These include the use of biomass (gross, net or consumable), vegetation survey and mapping, range evaluation, and the like. These in turn are often presented as measures of carrying capacity for typical animals converted into an arbitrary standard animal unit, based on equivalents in metabolic weights (kg 0.75). For example:

300 kg Lwt zebu cow = 72.08 kg $^{0.75}$
30 kg Lwt goat =12.82 kg $^{0.75}$

Therefore one 300 kg Lwt cow = 72.08/12.82 = 5.47 times a 30 kg Lwt goat.

Because of the rarity of long-term series of measurements of both rainfall and range production, attempts have been made to mitigate the absence of ground data by using remote sensing. Low altitude systematic reconnaissance flights are routinely used for aerial livestock and wildlife censuses, for instance for the Ecological Monitoring of Rangelands in Kenya (KREMU) and Senegal (Inventory and Monitoring of Sahelian Pastoral Ecosystems); the same method has been used by private contractors for the governments of Sudan, Somalia, Kenya, Ethiopia, and others, either for livestock and wildlife censuses, or range appraisal, or both. They could thus help, in the course of each season, in the evaluation of annual production and better localization of productive and unproductive areas. The cost of this method is high and the extension to large pastoral areas in developing countries will certainly not expand in the foreseeable future because the benefit-cost ratio may be low and because of the `benign neglect' attitude of many governments towards their pastoralists and their range resource. Remote sensing of biomass and production, using airborne reflectivity sensors, is not reliable (IPAL, 1981); but such sensors may be used to measure `greenness' of vegetation, which is more tied to the feed quality of the range than to the amount of fodder available.

The use of satellite imagery would, in principle, make it possible to know the pasture production and its distribution over time and space at the end of each rainy season. This would be of great advantage in areas like the Sahelian zone where the rainy season lasts only 1─4 months, beginning and ending at fairly regular dates every year.

It would thus become possible to know in advance the forage availability in any given area for the 8─11 coming months of each dry season and so to plan range and stock management accordingly (Le Hourérou,1972), but this may remain in the domain of `range management fiction' for many years to come!

Experiments which lasted 4 years over a large zone in southern Tunisia (ARZOTU Project) showed, however, that satellite images, in order to be used in a reliable way for biomass assessment, need important and costly means of ground control (Long *et al.*, 1978), but further technical progress may improve the feasibility of this technique in the future.

Finally, methods of indirect assessment (deducing primary production from secondary production in fully stocked areas) are used in climatically comparable areas under ranching systems in America and Australia, but there are no similar statistical data available on range production in pastoral areas of Africa and Asia. There are no reliable statistical data on animal numbers and stocking rates either; the number of animals slaughtered or sold is not known; milk production is almost totally unknown. Thus there is no way of deducing primary production from secondary production.

7.2.3 Rainfall-Primary Production Relationships

Many authors have tried to relate rainfall and primary production or rainfall and carrying capacity (Lomasson, 1947; Walter and Volk, 1954; Coupland, 1958;.Le Houérou, 1958, 1962, 1963, 1964, 1965, 1969, 1971, 1975, 1977a, 1982, 1984a,b; Sneva and Hyder, 1962; Condon, 1968; Braun, 1973; Cassidy,1973; Tadmor *et al.*, 1974; Breman,1975; Philipson,1975; Bille,1977; Pratt and Gwynne, 1977; De Vries *et al.*, 1978; Floret and Pontanier, 1978, 1982; Cornet, 1981; Cornet and Rambal, 1981; Grouzis and Sicot, 1981; Floret *et al.*, 1982).

7.2.3.1 Annual Rainfall

When average annual rainfall is compared to average annual primary production in a given ecological and geographic zone, the correlations are quite satisfactory (`$r$' > 0.8, `P' < 0.01), especially in arid and semi-arid zones (Le Houérou, 1982, 1984a,b). But there are very great differences in productivity levels, as might be expected, depending on vegetation types and on the kind of management which is applied to them. The value of mean annual precipitation as a predictive indicator of average primary production is therefore limited to large geographic areas having identical climates, similar vegetation types, and comparable range management practices. This is, for instance, the case for broad ecological zones such as the Mediterranean arid and semi-arid zones of the Near East and North Africa, the Sahelian and Sudanian zones of northern Africa, the East African arid and semi-arid zones, and the Miombo of southern and eastern Africa, where climates, vegetation patterns and range management practices are rather homogenous—in their diversity—within each zone.

Mean annual precipitation or the actual amount of annual rain is of no value in predicting forage yield in a given site for a particular year. The latter depends more on actual rainfall distribution over the annual cycle than on the amount that falls, all other conditions being equal (Le Houérou and Hoste, 1977; Cornet and Rambal, 1981; Floret *et al.*, 1982; Le Houérou, 1982) as described in Section 7.2.3.3.

Accurate prediction (±10%) of actual yields in a given site for a particular growing season can be done only by knowing actually infiltrated rains and the rate of evapotranspiration, as shown by many scientists (Briggs and Shantz, 1913; De Witt,1958; Hanks *et al.*, 1969; Floret and Pontanier,1982). But this method can hardly be used for large geographic areas such as pastoral zones because it postulates the use of many data which are available only for a very small number of sites, such as: actual rainfall distribution in time and space, rainfall intensities, runoff rates, infiltration rates, evaporation from soil surface, fertility status of the soil, vegetation type, range condition. The integration of all these data over large geographic pastoral areas is an almost impossible task at the present time. As a matter of fact all predictive models and their validation are based on data from one site or a small number of sites, and cannot therefore be extended to large geographic areas having different characteristics.

At the present time the easiest, if not the best, assessment of range production in pastoral zones can be based on statistics of annual rainfall, which are available and fairly reliable, along with site experiments and surveys providing production figures (often excluding browse) that can be related to rainfall data. One can thus determine a rain use efficiency (RUE) factor which is the number of kilograms of above-ground dry matter produced per millimeter of annual rain over one hectare in one year (Le Houérou, 1982, 1984a). Calculated RUE values are shown in Table 7.1 and evidence good agreement between survey data and experimental findings, and rather amazing consistency across various ecological zones when large geographic areas are concerned.

Table 7.1 Rain use efficiency in arid and semi-arid grazing lands

No.	Zones	Average RUE (kg DM mm^{-1} ha^{-1} y^{-1})	Range
1	Mediterranean	2.8–3.8	1–10
2	Mediterranean	3.2	1– 6
3	Sahelo-Sudanian	2.6–3.6	1–10
4	Sahelo-Sudanian	3.3	–
5	Sahelo-Sudanian	3.0	2–11
6	Sahelo-Sudanian	3.5	2– 5
7	Sahelo-Sudanian	2.2	–
8	East Africa	6.0	3–12
9	East Africa	3.2	1.5– 5.0
10	N. Kenya	4.5	2.2– 9.6
11	USA	4.2	–
12	Australia	1.5	0.7- 3.3

[1] Detailed surveys over some 30 million hectares of rangelands in Tunisia, Algeria, Morocco, Libya, Syria, Israel, Egypt, Italy, Spain, France and Greece (Le Houérou, 1962-1982). Lower figure refers to southern Tunisia, higher figure from compilation of other surveys and experiments.

[2] Experimental data from seven range types of southern Tunisia over seven consecutive years, in range conditions somewhat better than the average of the area (Floret and Pontanier,1982).

[3] Compilation of a number of surveys over some 100 million hectares in Mauritania, Senegal, Mali, Upper Volta, Niger, Nigeria, Chad, Ivory Coast and the Republic of Sudan over a period of some 15 years. Lower figure excludes browse, higher figure includes it. (Le Houérou and Hoste,1977; Le Houérou, 1982.)

[4] Experimental work in three sites of northern Senegal over a decade, in good range condition (Cornet, 1981).

[5] Experimental data collected over 7 years in one site of northern Senegal in range conditions well above the average Sahelian situation (Bille, 1977).

[6] Experimental data from a dozen sites over a period of 4 years in central Mali in range condition above the average Sahel situation (Hiernaux *et al.,* 1980).

[7] Experimental data from many sites in northern Upper Volta over 4 years, in range condition below the average Sahelian situation (Grouzis and Sicot,1981).

[8] Experimental data gathered over a period of 2 years in the Serengeti National Park, Tanzania, under range conditions far above the average situation in East Africa (Braun, 1973).

[9] Integrated global estimation for the rangelands of East Africa (Pratt and Gwynne, 1977).

[10] Experimental and survey data from the arid zone of northern Kenya over 4 years (Lamprey and Yussuf, 1981).

[11] Synthesis of the data available on the arid and semi-arid zones of the United States. This figure does not refer to pastoral areas; it is given here for the sake of comparison (Szarec, 1979).

[12] Data shown are computed from a study by Condon (1968) on the carrying capacities of the rangelands of the southwest of New South Wales. The figures given show clearly the low fertility status of the Australian rangelands. RUE increases from 0.7 under 120 mm of rainfall to 3.3 under 500 mm. But the figures given by Condon are concerned with livestock density in range zones; they are therefore somewhat lower than if extracted from carrying capacities *strictu sensu.*

In the Mediterranean region and intertropical Africa, the overall order of magnitude of RUE is 3–4 kg DM mm^{-1} y^{-1} (Le Houérou, 1982). This figure, based on a large number of surveys over many million hectares, has been confirmed by long-term experimental data both in the Mediterranean zone and in the Sahel (De Vries *et al.*, 1978; Hiernaux *et al.*, 1980; Cornet, 1981; Grouzis and Sicot,1981; Floret and Pontanier, 1982). These estimates also accord well with figures for the United States and East Africa, with the exception of the Serengeti Plains. Indeed, the major exception is for Australia (with the above-mentioned reservations), and overall the figures from various ecological zones are amazingly consistent.

At the continental level, rainfall distribution over seasons, in different ecological zones, does not seem to influence total productivity greatly over the whole annual cycle, contrary to what might be expected. The RUE factor is almost similar under comparable management practices under the winter rains. regimes of North Africa and the Near East as under the tropical summer rains regimes of the Sahelian and Sudanian zones, as well as under the bimodal equatorial regime of East Africa.

But the quality of the production along the annual cycle is totally different in the three cases. The Mediterranean arid zone, having a much longer potential growing season, with fair probabilities of rain occurrence over 5–7 months per year, produces green forage for longer periods than under the monomodal tropical regime of the Sahel, where the growing season lasts 1–4 months only. The equatorial bimodal rainfall regime of East Africa allows for two growing seasons per year and green forage is thus available for 1–3 months twice each year. The protein content (that is, the feed value) of the forage is thus kept at desirable levels for much longer periods every year in the Mediterranean and in East Africa, as compared to the Sahel.

Range types and composition are also very different in the three cases. While dwarf shrubs are dominant in the Mediterranean and perennial grasses in East Africa, the Sahel ranges are dominated by annual grasses of very low feed value outside the growth period. Moreover, there may be compensation in the Mediterranean and East Africa between the annual growing seasons. If rains fail for one season they may be adequate 3-4 months later, whereas in the dry tropics such as the Sahelian or the Sudanian zone, seasonal rain failure means total drought for at least one year, since there are 8-11 months of continuous dry season.

Within a given rangeland type RUE may vary considerably with range condition, as we shall see in Section 7.3. Productivity may currently be decreased by a factor of 3 or even 5 to 1 or sometimes up to 10 to 1 for a given range type in a given site by mismanagement practices such as prolonged heavy overstocking. Conversely, RUE can often be increased by a factor of 3 to 5, using various techniques and heavy inputs such as water conservation techniques, fertilizers or reseeding. These are, however, usually not economically or socially feasible in the pastoral zone.

In general, RUE increases with the total biomass and plant cover present, as water losses from direct evaporation through soil surface are inversely related to these parameters. RUE also seems to increase with average rainfall up to an optimum and then decreases due to other limiting factors such as soil fertility or water-logging, as suggested by the research of Floret and Pontanier (1978) in Tunisia, Cornet (1981) in Senegal and De Vries *et al.* (1978) in Mali. Other experiments, however (Tadmor *et al.*, 1972a), suggest that RUE remains constant for a wide spectrum of water applications. The subject deserves further investigation.

7.2.3.2 Annual Variability

It is a well known fact that in all arid and semi-arid zones of the world, rainfall variability increases with aridity. South of the Sahara, for instance, the coefficient of variation* for annual rainfall varies from 0.40 at the edge of the desert to 0.15 in the rain forest, with values between 0.25 and 0.40 in the pastoral area (Le Houérou and Popov, 1981). In the Mediterranean North Africa it varies from 0.50 to 0.60 in the Northern Sahara, to 0.20 in the higher rainfall coastal zones (Le Houérou,1959).

It is less well known that variability in annual primary production is greater than variability in the amount of annual rains. If we compare the ratio of maximum to minimum recorded yields to the ratio of maximum to minimum rainfall (MY/my ÷ MR/mr) as published by several scientists for various and arid semi-arid zones, we shall find values similar to those shown in Table 7.2.

Table 7.2 Rainfall to yields variability ratios

Area	Max rain ratio min	Max yield ratio min	Yr Rr	No. of years	Reference
USA (various sites)	3.48	6.55	1.88	7–20	Cook and Sims, 1975
S. Tunisia	3.75	6.95	1.85	7	Floret and Pontanier, 1982
N. Senegal	13.6	21.3	1.57	7	Bille, 1977

* $V = \sigma/P$ where σ = standard deviation of annual rainfall and P = mean annual precipitation.

The use of maximum/minimum ratios as an indicator of variability is debatable. It surely is not, in theory, the best possible indicator. The ratio between coefficients of variation is a better indicator ($\sigma / \bar{x}$). A worldwide study of arid and semi-arid rangelands by the present writer (Le Houérou, 1984b) over 77 series of coupled data on annual primary production/annual rainfall totalling 835 years, i.e. an average 12 years per series (3–43), concluded as follows:

1. the ratio vY/vR averaged 1.50 (s.e. = 0.07);
2. the ratio MY/my ÷ MR/mr averaged 1.81;

where: vy = coefficient of variation of annual primary production ($\sigma / \bar{x}$);
vR = coefficient of variation of annual rainfall;
MY = maximum annual yield recorded within each series;
my = minimum annual yield recorded within each series;

MR = maximum annual precipitation recorded within each series;
mr = minimum annual precipitation recorded within each series.

The `variation in variability', however, is high. In some 10 percent of the cases variability in production is lower than in rainfall (depressions, water tables, higher rainfall areas 7600 mm). In the same 835 years over the same 77 sites RUE averaged 4.0 kg DM mm^{-1} ha^{-1} y^{-1}, again with large variations mainly due to range condition, that is, essentially as a result of management practices. The latter may totally hide the effect of climatic aridity. The study concluded that rain use efficiency depends more on management practices than on climatic aridity; the RUE factor is therefore a good criterion for evaluating ecosystem condition, health and productivity.

The consistency between the three sets of data in Table 7.2 is unexpectedly good and one may say that variability in annual production, as measured by maximum/minimum ratios, is expected to be 150–200 percent of the variability in annual precipitation. It would seem that a similar situation prevails in arid Australia; Young and Wilson (1978) wrote: `when the rainfall received in a particular year is half the median, forage growth may be reduced to one quarter.' This means a variability in production 50 percent greater than the variability in rainfall, as found in our study (Le Houérou,1984b).

7.2.3.3 Seasonal Distribution

Seasonality of rainfall does not seem to have a strong effect on total primary production when expressed in dry matter. The distribution of rain within the rainy season, on the contrary, has a very strong effect on production. It is a well known fact that the highest production is not necessarily the consequence of the highest rain. Moderate rains with regular distribution patterns and moderate intensities are the most efficient. Modelers have designed ideal distribution patterns (Van Keulen, 1975; De Vries *et al.*, 1978; Floret *et al.*, 1982) but, as the number of possible situations of rainfall events over a given rainy season is almost infinite, it is extremely difficult to quantify the effect of rain distribution on primary range production as has been done for crops. A simple and crude criterion used by several authors has been the number of rainy days. The use of this criterion does not improve the predictability of production as drawn from the amount of rain fallen. Several authors have also attempted to define `useful rain'; there are as many empirical and more or less arbitrary definitions of `useful rains' as the number of authors. The principle is to discard all precipitation beneath a certain amount per day or per week or per month. The subject is poorly documented as far as range production in pastoral areas in relation to `useful rains' is concerned.

In higher rainfall areas such as the southern Sudanian zone of West Africa, production is linked to the length of the rainy season rather than to the amount that falls (Boudet,1975). In otherwise similar regions, areas with 7 or 8 months of rainy season and, say, 1200 mm of precipitation, will have a higher production than areas' having 1500 mm falling in 5 or 6 months. But these are hardly pastoral zones.

7.3 MODIFICATION OF CLIMATE-PRIMARY PRODUCTION RELATIONSHIP BY MANAGEMENT PRACTICES

The effect of climate on pastoralism cannot be validly considered in isolation but should be examined within a socioeconomic framework. Many surveys and experimental studies have shown that vegetation response to climate depends as much on its status and condition as on climate variables.

7.3.1 Management Practices

It has been mentioned above that RUE may vary by more than 300 percent within a given plant community according to plant cover and biomass. The decrease of RUE with reduced plant cover as a result of overgrazing, wood-cutting, and inappropriate cultivation is one of the main mechanisms of desertization, as shown by many scientists (Le Houérou, 1959, 1962, 1968, 1971, 1975; Floret and Le Floch, 1979; Floret and Pontanier, 1982). All management practices which tend to reduce plant cover and biomass will therefore decrease RUE and, conversely, management practices tending to maintain plant cover and biomass will 'also increase the productivity of the ecosystem. The effect of different practices —no grazing, heavy grazing and overstocking—on plant cover, production and RUE for two North African plant communities is shown in Table 7.3.

The absence of grazing or undergrazing because of insecurity (as in northern Kenya, eastern and southern Ethiopia) or because of the lack of permanent water (as in many areas of the Sahel) can be a local problem. But underused areas probably represent less than 1 percent of the total pastoral zones of Africa and Asia and therefore, generally speaking, are not a relevant factor.

Table 7.3 Effect of management practices on plant cover, primary production and RUE

	No grazing				Heavy grazing			Overstocking		
Site	Rainfall	Plant cover (%)	Production (kg DM ha^{-1} y^{-1})	RUE (kg DM mm^{-1})	Plant cover (%)	Production (kg DM ha^{-1} y^{-1})	RUE (kg DM mm^{-1})	Plant cover (%)	Production (kg DM ha^{-1} y^{-1})	RUE cover (kg DM mm^{-1})
Hodna Basin, Algeria[1]	200	25	1044	5.22	5	425	2.13	3	257	1.29
Southern Tunisia [2]	314	25	1069	3.40	8	615	1.96	4	415	1.32

[1] *Salsola vermiculata-Anabasis oropediorum* community (silty gypsic soil, Hodna Basin, Algeria [Le Houérou, 1971]).

[2] *Rhantherium suaveolens-Stipa lagascae* community (coarse sandy soil, southern Tunisia [Bourges *et al.*, 1975]).

The presence of edible trees and shrubs increases considerably the stability of production in range ecosystems, thus buffering and damping out the effects of climatic variability. This fact is due to various characteristics of trees and shrubs, including the ability to draw water from many meters down into deep soil layers (up to 50–100 m in some cases, but routinely 10–30 m in arid zones) not accessible to the shallow root systems of grasses and herbs, and to make use of out-of-season rains. In addition, trees and shrubs can remain green throughout the dry season, and many species can carry their green leaves, phyllodes, or cladodes for 18–24 months, accumulating forage from two or more growing seasons. These leaves contain high contents of protein, carotene and minerals, whereas dried-out grasses are virtually void of digestible protein and carotene. Some trees, such as *Acacia* and *Prosopis*, also produce highly nutritive fruits that may be stored and marketed.

The value of shrubs and trees was particularly exemplified during the 1968–73 drought in the Sahel where browsers (camels and goats) managed to survive throughout the drought while grazers (sheep and cattle) perished of starvation in great numbers. The conservation and maintenance of multi-story range ecosystems thus extends the usable primary production. Unfortunately, in many pastoral areas, tree and shrub cover is in rather rapid regression due to overexploitation (browsing, lopping, wood-cutting), which in turn renders them more sensitive to the effects of drought. Additionally, bush fires are held responsible for the annual destruction of 80 million hectares of pastures in the semi-arid and subhumid savannas of Africa (Wickens,1968), thus diminishing the grazable acreage and increasing the pressure of livestock on the unburnt areas.

Overgrazing for long periods of time in arid and semi-arid zones may lead to sharp evolution in pastoral groups (Lamprey, 1983). The grazing lands of the Samburu in northern Kenya have thus become progressively unable to sustain cattle and Samburus are now shifting from their traditional cattle pastoralism to camels and small stock, mainly goats. Similar recent revolutions have been reported in other East African pastoralist groups (Dyson-Hudson, personal communication).

Thus conservation methods are essentially the continuous adaptation of stocking rates and kinds of livestock to carrying capacities and the nature of the range; the utilization of grazing systems compatible with the regeneration of vegetation; and, in some cases, improvement techniques such as ripping, subsoiling, scarifying, pitting, contour benching and water spreading, which all tend to increase the water intake of the soil and therefore of RUE. These may be combined with oversowing or planting of shrubs which, in addition, aim at improving the use of water by the utilization of more productive plant material.

All these practices, by increasing water intake by the soil, tend to smooth off the effects of irregular rainfall and increase rain efficiency.

7.3.2 Trends in Management

The impact of climate variability on rangeland ecosystems in pastoral areas may be enhanced or reduced by human actions (management practices). The trend in such practices unfortunately appears to be in the direction of exacerbating climate variability impacts. The sharp increase of livestock numbers in Africa since the 1950s, due mainly to efficient vaccination campaigns and the increase of the human population (be it sedentary or nomadic), continuously augments the pressure on ecosystems. It should be stressed that the increase in human pastoral populations is light as compared to the case of settled farmers, even when the farmers are former nomads such as the Buzu Tuaregs or the Farfaru Fulani, the rate of demographic increment being 1.0–1.5 percent versus 2.5–3.5 percent for the farmers in West Africa (Bernus, 1981). The surface of land under cereal cultivation has doubled in the Sahel of Africa for the past 20 years, at the expense of rangelands and of the pastoralists, as shown in several local surveys in Niger, Mali and Senegal; the same holds true for many parts of the pastoral zone of East Africa (ILCA,1978). Boreholes discharging great quantities of water without any control of stock numbers have contributed to attract large numbers of stock (15,000–20,000 tropical livestock units* around some boreholes ill the dry season in the pastoral zones of Niger [Bernus, 1971]), thus destroying all vegetation in a radius of 20–30 km. Wood-cutting affects large areas around cities and villages in the pastoral area; in some cases one has to go many kilometers from towns in search of firewood, and it may cost the town dweller as much to boil the pot as to fill it.

One of the conclusions of a detailed study of a Sahelian ecosystem in northern Senegal is that it would take two to three decades for the vegetation to return to its predrought conditions after the 1968–73 episode, in a situation of total protection (Bille,1978); in the present conditions of exploitation the impact of the Sahelian 1968–73 drought will never be cancelled or absorbed. It has also been concluded that the continuation of the present type of exploitation of the Sahel would render most of the pastoral area unfit for animal nutrition for 6–9 months of dry season every year within the next 50 years or so, owing to the elimination of the woody plants which at present supply most of the protein and carotene in stock diets during the dry season (Le Houérou,1980a).

The situation is less dramatic in East Africa, for the time being, but it is still worsening rather fast (Lamprey, 1983). In northern Africa, however, the situation is improving because supplementation with concentrate feeds is taking place. In many pastoral areas around 30 percent of animal nutrition needs presently are met in this way—a significant achievement considering that supplementary feeding was hardly known, let alone practiced, in these regions only 10 years ago (Le Houérou and Aly,1981).

* TLU = conventional mature head of zebu cattle weighing 250 kg = 5 sheep = 6 goats = 2 asses = 0.8 camel, metabolic weight equivalents.

The present impact of man in pastoral areas—overstocking, wood-cutting, bush fires, `wild' water development, expansion of inappropriate cultivation, and ever-increasing animal numbers—all intensify the pressure on grazed ecosystems. These, in turn, become less resilient and less able to `absorb' climatic droughts, which they used to do under the light exploitation conditions of past centuries. If this chaotic situation imposed onto the pastoralists persists—and there is unfortunately little doubt that it will—one can predict only a gloomy future for pastoralism. Range ecosystems will become more and more sensitive to periodic droughts (which are a constant characteristic of the arid and semi-arid pastoral zones). Pastoralism will either have to disappear quietly or evolve towards other systems of animal production, with increased reliance on supplementary feeding of grain and concentrates for longer and longer periods.

7.4 PASTORAL LIVESTOCK PRODUCTION

Secondary production from livestock in pastoral systems is very low by modern animal husbandry standards. Birth rates in pastoral cattle barely reach 60 percent (50–65), with 5–15 percent abortions and stillbirths; 40 percent of the calves (30–45) die in the first year and about 5 percent per year subsequently, save disease outbreaks or drought (Doutresoulle, 1947; Coulomb, 1971,1972; Wilson and Clarke,1975; SEDES,1975; ILCA,1978; OMBEVI, 1978; Republic of Niger, 1981; Diallo and Wagenaar, 1981; Wilson *et al.*, 1981; Wilson and Wagenaar,1983). In the East African pastoral zone, predation by carnivores (spotted hyenas, lions, jackals) may reach up to 10 percent (Kruuk,1980). Output (offtake and herd increment) is thus of the order of 8–12 percent in cattle, 20–25 percent in small stock, and 7–8 percent in camels.

Net annual body weight gain of African zebu cattle is usually around 50 kg, so that mature size is reached only at 5–6 years of age. In lambs and kids daily gains are 50–100 g up to 6 months and 100–300 g for camel calves (IPAL, 1981). These low performances are due to feed restriction, since milk is shared on about a 50 percent basis between the pastoralist and the calf, and to the fact that these breeds have been selected for centuries on the criterion of survival rather than on production. Production, in addition, is seriously hindered by parasitism and diseases. Conversely, modern productive stock could possibly not survive in the ecological conditions in which pastoral stock do. In spite of this, research has shown that such `local breeds' (such as Boran, Gobra, Azawak cattle, Awasi, Somali, Persian, Fat Tail Barbary, Karakul sheep) are amenable to considerable improvement in their performance when they are properly managed.

It should be kept in mind that meat production is not—with the exception of sheep—the primary objective of African pastoralists, but rather milk production, and, occasionally in East Africa, blood production. Milk production varies with ecological conditions and breeds. It is of the order of 300–600 liters per annum for cattle, 80–100 liters for goats, 50–70 liters for sheep, and 1500–2000 liters for camels; about half of these quantities are left for the calves, kids and lambs and the other half levied by the pastoralist (Dahl and Hjort,1976; ILCA,1978; IPAL,1981).

7.4.1Climate-Livestock Relationships

Livestock numbers are strongly influenced by climatic variability, but unlike primary production, they dampen rather than amplify climatic variability. Le Houérou (1962) showed that, over a period of 25 years (1936–60) in southern Tunisia, the ratio of maximum annual number over the minimum was 3.7 for sheep and goats while the ratio of maximum to minimum rainfall over the same period was 6.8, whereas camels' and donkeys' numbers were little affected by rainfall variations (±20 percent). The variabilities ratio was thus 6.8 ÷ 3.7 =1.84. In Agadez, Niger, the ratios for 1968–72 were the following: cattle, 4.6; sheep and goats, 3.0; and camels, 2.0; with rainfall, 4.0 (Bernus, 1981). Variability in stock numbers is thus 25–50 percent smaller than variability in rainfall, contrary to what happens for primary production.

In addition, there is a time lag of 1–2 years in the correlation between rainfall and stock numbers (Le Houérou, 1962); therefore a 1-year drought is no catastrophe. Serious problems arise when two or more dry years occur in succession, as happened in the Sahel in 1910–15,1940–44 and 1969–73 (Bernus and Savonnet,1973) and in the north of the Sahara in 1920–25,1944–48, and 1959–61(Le Houerou,1962, 1968, 1979).

During such a severe multiyear drought, 30–70 percent of the herds may die. It is reckoned that 50–70 percent of small stock died of starvation in the North African pastoral zone during the 1944–48 drought, while the overall losses in the Sahel during the 1968–73 drought are estimated at 30–50 percent for the whole region. (The low was in Senegal at 20 percent, and the high in Mauritania at 70–80 percent.)

The performance of the surviving livestock is also considerably reduced in terms of growth, of milk and meat production, and in terms of reproductive rate. The consequences of reduced nutrition and fertility in connection with drought or disease on the future performance of the herd has been studied for cattle by Dahl and Hjort (1976), via simulation modeling. Similar work remains to be done for small ruminants, but some data for sheep are available. According to Israeli workers it would seem that the reproductive performance of Awasi sheep is not affected until normal body weight is reduced by 30 percent or more (Tadmor, personal communication); our own results on Fat Tail Barbary sheep in Libya are in support of that statement (Le Houérou and Dumancic, unpublished).

A 50 percent reduction in pastoral production potential probably could be ascribed to the consequences of climatic variability, now that major disease outbreaks have been virtually curbed. It has been calculated in Tunisia that the interannual stabilization of the national flock, the variability of which formerly reached 55 percent (+29 to –26 percent of the mean), would increase its net productivity by 25 percent (Le Houérou and Froment, 1966). At the level of the pastoral zone, where the variability is over 110 percent (+50 to –60 percent of the mean), one would therefore expect the loss in productivity due to climatic variability to be more than 50 percent of the potential, all other management conditions (including health) remaining equal. This figure is confirmed when examining offtake from herds and flocks in the pastoral zone. These offtakes are hardly half of what they are known potentially to be under proper management (essentially feeding) conditions.

7.4.2 Modification of Climate-Livestock Relationships by Drought Adjustments

The high variability in primary production is effectively dampened by the drought-resistant breeds of livestock raised by pastoralists as described above, by the mix of livestock held, and by various sociocultural relationships in addition to the basic nomadic movement.

The strategy of keeping mixed herds—cattle and small ruminants or camels and small stock—is a drought insurance strategy, as herd build-up in small ruminants is much faster than in large stock; save disease or accident a couple of cows will produce 10 offspring in 5 years while two ewes will produce 32 and two goats 130, in the same time span (Lundholm, 1976). At the same time, keeping grazers (cattle and sheep) and browsers (camels and goats) increases the risk-sharing of drought.

Other strategies of general use among pastoralists in the African ecocultural environment include the complex system of leasing or borrowing-lending—gifts of animals among kinsfolk, relatives and friends-creating a complicated network of duties and rights, of gifts and claims, and of reciprocity. Intermarriages between ethnic groups occupying different ecological niches (such as the Samburu, Rendille and Turkana) and various political alliances, such as among the Coffs of North Africa, also tend to reduce the risks (drought and disease) by spreading the herds over as large an area as possible under as varied ecological conditions as possible. Under such expedients the possession of the larger number of animals—or the strategy of debtors and clients—are the best possible drought insurances.

Other tactics, such as range exclosures and deferred grazing, were practiced for centuries in some Bedouin pastoral societies in Arabia (Hema) and northern Africa (Gdal) as part of a drought-evading strategy. Some practices, such as the sophisticated and labor-intensive cattle-watering system of the Boran of South Ethiopia, in conjunction with a form of rotational-deferred grazing through the organized seasonal use of water resources, also tended (in addition to the age-class social structure) to keep stock and human numbers under control (Helland, personal communication).

Past methods also involved supplementary support and included the possession or control of oases and grain fields cultivated by slaves or dependent farmers for their pastoralist masters (Tuaregs, Moors). Other strategies were raiding and warfare, the major goal of which was sometimes the replacement of flocks or herds decimated by disease or drought and hence, word for word, a matter of life and death.

Today, pastoralist adaptation goes beyond the system itself and includes settlement as farmers of the pastoral population in excess of the carrying capacity, wage labor, village shop-keeping and trade, government employment (army, police), and emigration to cities.

7.5 LIVESTOCK AND HUMAN POPULATION RELATIONSHIPS

7.5.1 Livestock and Human Ratios

Large differences in the ratio of livestock to human beings occur in different pastoral systems. These are shown for various African systems in Table 7.4. They range between 3900 kg of live weight per person among the Masai to 400 kg for the Ifora Tuaregs. The groups of the lower part of Table 7.4, particularly the Ifora Tuaregs, are destitute pastoralists who managed to survive during the Sahel drought only because of food assistance; several thousand of this group sought refuge and assistance in Niamey and Tamanrasset; probably many died during the 1968–73 drought. Their near neighbors on the table experienced similar conditions in 1979–82. The Masai, on the contrary, appear as `rich' pastoralists, living as they do under the much better ecological conditions of semi-arid to subhumid climates with lush grass savannas (at least as compared to the conditions in which the Saharan pastoralists live).

The comparison of pastoralists keeping similar species in approximately similar proportions, may, however, be considered valid, for instance Masai, Samburu, Boran, Fulani, Karimojong, Baggara, who are primarily cattle pastoralists, as opposed to Somali, Rendille, Kabbabish, Tuaregs, Afar, Moors, Al

Murrah, who are primarily cameleers, and to Turkana, Middle Eastern and North African Bedouins, who are essentially small stock owners. Overall the limit of survival, in the absence of cereal cultivation, seems to be around 800–1000 kg of live weight per person (Brown, 1971; Lamprey, 1983).

Table 7.4 Livestock to human population ratios

Pastoral ethnic groups	kg Lwt of stock per person*	References
Kenya Masai	3900	Allan, 1965
Tanzania Masai	3500	Allan, 1965
Somali	1500	Allan, 1965
Turkana	1300	Allan, 1965
Baggara	1300	Allan, 1965
North African Bedouins	800–1500	Le Houérou, 1962
Bororo (woodabe) Fulani	1175	Dupire,1970
Kel Dinnik Tuaregs	1075	Bernus,1981
Rendille	1020	Lusigi,1981
Jie	880	Allan, 1965
Kel Air Tuaregs	625	Bernus,1981
Karimojong	600	Dyson-Hudson, 1966
Kel Ifora Tuaregs	400	Swift, 1975

* The amount of live weight per person has been calculated from various units: large stock units (500 kg), standard stock units (SSU = 450 kg), livestock units (200 kg), tropical livestock units (TLU = UBT = 250 kg), ovine units (40 kg small ruminants), as used by various authors. These ratios should be considered with caution as livestock equivalence factors are only approximate—more precise comparisons would emerge from the use of metabolic weights (wt 0.75)—and as their value in terms of survival strategy are quite different. But there is a zonation in the kinds and breeds of animals which are kept; this zonation is based on drought risk or, to put it in a different way, in rainfall belts or ecoclimatic zones (Le Houérou and Popov,1981).

Thus the meaning of the ratio may differ substantially with the terms of trade between grain and livestock products. Fewer and fewer pastoralists live on a purely animal products diet; more and more include grain in their food, particularly in the dry season. The Kel Dinnik Tuareg pastoralists of Niger, for example, depend on millet grain for 52 percent of their annual energy consumption (Bernus, 1981). Grain is either cultivated by the pastoralists themselves, or bought or bartered against livestock products. In the latter cases the terms of trade may depend considerably on year, season, region and country. The subsistence and survival ratios thus may vary substantially in time and space.

Sensitivity to climatic variability is inversely related to the livestock/humans ratio; this fact explains the constant trend of pastoralists to maximize stock numbers as a form of drought insurance. As stock productivity is related to amount of rain and thus inversely related to climatic variability, one would expect the ratio of livestock to humans to increase with aridity; it would seem rather that the reverse actually occurs. The reasons for this paradoxical situation remain nebulous to the author; the only explanation proffered is that overstocking, overpopulation and the increasing destitution of pastoralists in the drier zones has stretched the system to its limit of elasticity.

7.5.2 Economic Costs of Climate Variability

According to Food and Agriculture Organization (FAO) statistics, Africa had in 1979 some 526 million head of livestock (200 million FAO Standard Animal Units*), that is, an increase of 75 percent over the last 30 years. More than 400 million heads (or 150 million SAU) are still kept under more or less traditional pastoral or semi-pastoral production systems, in the author's estimation. Asia (without the USSR and China), on the other hand, harbors another 200 million heads (50 million FAO SAU) of pastoral stock. The world's number of pastoral stock is thus more than 600 million heads, or 20 percent of the total livestock population of the globe (pigs excepted).

Given the very low output and offtake rates and the poor individual production performances of pastoral stock, one may reckon that not more than one-third of its genetic production potential is able to manifest itself. The loss in production from the potential of pastoral stock thus may be grossly ascribed to climate hazards in conjunction with poor management of range and herds for about 50 percent, while the balance may be ascribed to diseases (in conjunction with poor nutrition), parasitism and predation.

If we accept the assumption that production † could, in principle, be tripled to meet genetic potential (and many experiments suggest such an assumption, indeed) the elimination of climatic hazards alone would increase production by some 100–150 percent in the 600 million heads of pastoral stock. If the pastoral stock of the world numbers about 200 million SAU with a market value of some $200 per unit, the global capital value is $40 billion; assuming an average actual output‡ of, say, 15 percent, we reach an annual production value of $6 billion against a potential of $18 billion; the loss in productivity due to climatically related causes would be of the order of $6 billion per annum. These figures are, naturally, nothing more than very crude orders of magnitude; they do, however, tend to show that the impact of climate variability on pastoralism is important.

The absolute variability in pastoral output, however, does not depend only on the absolute variability of rains or on the intensity of drought. It is still affected more by the duration of drought. A drought of 1-year duration is usually more or less well `absorbed' by the system. Catastrophes occur when two or more `dry years' occur in sequence.

* FAO's SAU = 1.1 camel = 1.0 horse, mule and buffalo, = 0.8 cattle and ass, = 0.1 sheep and goat.

† Production = animals slaughtered + herd increment + animal products and services (milk, blood, hides, hair, wool, draught power, transport, etc.)

‡ Average offtake ratios plus herd increment: camels 7 percent; cattle 10 percent; shoats 25 percent; equines 10 percent.

7.6 CONCLUSION

The linkage between climate and pastoral stock is, as we have seen, complex and affected by many variables which may be studied in various ways. This range of methods can be summarized by way of a simplified impacts analysis chain, in which a variable climate is reflected in the variation in primary productivity of biomass and edible plants. This in turn leads to fluctuation in livestock numbers, which in turn affects human numbers and wellbeing. A wide range of relatively standardized methods are available to study each element in the chain and the links between them, and some of these are shown in Table 7.5.

The impact of climate variability differs, of course, and is affected primarily by:

1. ecological conditions, in particular the nature of the vegetation, and the condition and trend of the rangeland;

2. adaptive strategies of the pastoralists to minimize the impact of drought.

In general, variability in primary production is much greater than variability in rainfall. Variability in stock numbers is somewhat smaller than variability in rainfall, but variability in secondary production is very poorly documented; it would seem to be of the same order of magnitude as the former. And the ratio of livestock to human beings is inverse to rainfall. Thus overall, variability in climate is amplified in primary production, but dampened in the production of livestock and in the sustenance of human beings. This is primarily due to various adaptive strategies.

Although these adaptive strategies are extremely diversified, they have a high cost in the long-term survival of pastoral systems. In pastoral systems the general tendency is to maximize stock numbers and their geographical distribution in order to reduce the risks. This strategy inflicts disastrous consequences on the environment.

Pastoral societies in past centuries were based on traditional land tenure systems which have been upset in the last few decades by sharp political and economic changes, whereby power has moved from the hands of the pastoralists to the settlers. The traditional systems, in which warfare and raiding were important components, were more or less in equilibrium with their fragile environment, but much lighter densities of both human and livestock populations prevailed in those times. Furthermore, both human and livestock populations were periodically swept out by disease outbreaks (the rinderpest epizootic of the 1880s in East Africa, for instance).

As human and stock populations increased as a result of imposed peace and of large prophylactic measures against human and animal diseases, the importance of climatic variability on pastoral production increased correlatively. The main constraint to pastoral husbandry thus shifted from disease outbreaks to periodic food and water shortages, and hence to climatic variability.

Table 7.5 Climate impact analysis of pastoralism

	Climate variability-------------------->		Primary production-------------->		Secondary production---------------->		Sustenance
Indicators	Rainfall, evapotranspiration		Production— biomass, edible plants		Production— livestock		Human wellbeing
Methods	1. Statistical analysis of rainfall records 2. Available moisture indication	Study of statistical relationships between rainfall and primary production and carrying capacity	1. Range survey 2. Measurement of primary production 3. Remote sensing 4. Low altitude reconnaissance	Analysis of livestock feeding patterns	1. Analysis of production parameters 2. Herd demography surveys 3. Livestock and wildlife censuses	1. Livestock/people numbers ratios 2. People/crop aggregate ratios 3. Land supporting capacity surveys (humans/livestock)	1. Population census, births, mortality data 2. Nutrition surveys 3. Migration estimates 4. Household economy surveys

	flights	4. Low altitude recon-naissance flights (animal numbers and seasonal distri-bution)

The impact of climatic variability in turn is intensified by the depletion of rangelands, which are less and less productive and less and less able to `absorb' prolonged drought events. The continuing expansion of cultivation in pastoral areas increases still more the stress on pure pastoralists. The usual response of pastoral societies is sedentarization and progressive shifting from pastoralism to agropastoralism and subsistence farming, a tendency generally encouraged—at least implicitly—by governments, since no serious large-scale integrated attempts to organize and modernize pastoralism have ever been made by any government in any country, to the author's knowledge.

There are, nevertheless, some islands of stability where pastoralists have more or less managed to keep their traditional system of control on human and stock populations through various sociocultural mechanisms and balanced water and land use systems; an outstanding example of this are the Boran of southern Ethiopia. How much longer will such systems last? Pastoralists themselves are evolving very fast, their values are changing, their expectations and needs increase as they become more and more aware of the outside world and of opportunities for easier conditions of life. One can only predict a point of rupture between decreasing resources, increasing populations, and the growing needs and expectations of pastoralists.

Indeed such a point may already have been reached. Table 7.6 shows the present situation as regards the population-supporting capacities in the arid and semi-arid zones of Africa. The study, made by a large multiorganizational, interdisciplinary team over several years, shows very clearly that arid (100–400 mm) and semi-arid (400–600 mm) zones of Africa already are supporting more

Table 7.6 Population-supporting capacities in arid and semi-arid zones of Africa

Ecoclimatic zone	Length of growing season (days)	Average present population density (person/km^{-2})	Potential population- supporting capacities	
			Under low inputs	Under intermediate inputs
Desert	0	0.03	0.01*	0.02†
Arid	1–74	0.06	0.03*	0.04†
Semi-arid	75–119	0.16	0.07*	0.20
Dry subhumid	120–179	0.20	0.32*	1.54

*Present-day intensity above potential under low input.

† Under intermediate input.

Source: Le Houérou and Popov (1981), computed from a study by Kassam and Higgins (1980).

people than they possibly could on a long-term sustained basis under low input conditions. Under intermediate inputs only the dry subhumid zone (600-800 mm) within the pastoral area could sustain more people—about seven times more than the present population. These prospects leave little future for the expansion of pastoralism.

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