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Rainfall, agriculture, livestock and human density in the dry regions of Kenya

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Models based on empirical data are produced to predict the human carrying capacity of semi-arid and arid Kenyan districts from rainfall and the resulting crop and livestock yields. These models predict a carrying capacity ranging from 1–2 persons/km^2, depending on livestock in the driest districts, to about 200 persons/km^2 depending on maize and beans at the upper limit (76 cm) of the semi-arid zone, based on the assumption that the average long-term rainfall is received every year. If the long-term carrying capacity is defined by the smallest annual rainfall received over a 10 year period the predicted human populations is lowered to about 70 persons/km^2 for areas receiving a long-term average of 76 cm of rainfall per year. Below 38 cm average annual rainfall, the population must depend totally on livestock production, which is less sensitive to rainfall but permits only low human populations. In semi-arid crop growing areas the maximum human populations observed are at or below the carrying capacity predicted from the average annual rainfall but are at or above the carrying capacity based on a one in ten year low annual rainfall level. The lack of detailed empirical data is noted, and important topics for research are suggested.

Introduction

The development of human populations is subject to many of the same environmental limitations experienced by population of other animals. For example, the amount of rain falling on the semi-arid zones of Kenya and neighbouring countries determines the crop and livestock yields (Pratt & Gwynne, 1977) which in turn determines the human carrying capacity of these dry regions (Morgan & Shaffer, 1966). Predictions of crop and livestock yields for the semi-arid and arid zones are, therefore, of primary importance in planning new settlements and for predicting human food needs in these zones. The purpose of this paper is to assemble data on food production and to produce models to predict the human carrying capacities of these lands and to compare these predictions with recent census data on human densities. By doing this, we hope to produce preliminary predictions of allowable human population levels, examine some factors which may influence these populations, and point out areas where research is needed to improve the accuracy of these forecasts.

Models predicting human carrying capacity must rely upon published relationships between food yield and rainfall. Our confidence in such models is influenced by the abundance and quality of available data. Although much good agricultural research has

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been done in Kenya, most studies have been carried out at government research stations and probably do not reflect actual yields obtained by small farmers and pastoralists. Furthermore, the severity and variability of post-harvest losses of grains to vermin or disease (Schönherr & Mbugua, 1976) will result in inaccurate predictions from models based on agricultural station data. Because year to year rainfall rates are very variable in the dry regions (Wernstedt, 1965–1978), the crop yields also vary widely. Consequently, models such as those that we develop here should not be used for management until the explicitly stated assumptions made in their development have been verified. The present equations are a first step and will hopefully stimulate others to collect the field data to strengthen the predictive powers of the models developed.

Development of the crop-yield model

Rural populations in the semi-arid regions of Kenya are supported by a variety of food sources, but maize (*Zea mays*) and beans (primarily *Phaseolus* spp.) make up much of the diet (Bullock, 1971). Because of this, computations of food yields based on these two crops will provide a reasonable estimate of food availability from agricultural sources. As little meat is eaten by these populations (Bullock, 1971), we do not here consider the secondary use of crops as feed for livestock. To predict human carrying capacity, yields of maize and beans under various rainfall regimes are needed. Glover (1957) collected maize yield data over an 11 year period for Kenyan Upland areas subject to European style farming and found that the areal yield (Y_M; kg dry wt/km^2/yr), associated with rainfalls up to about 80

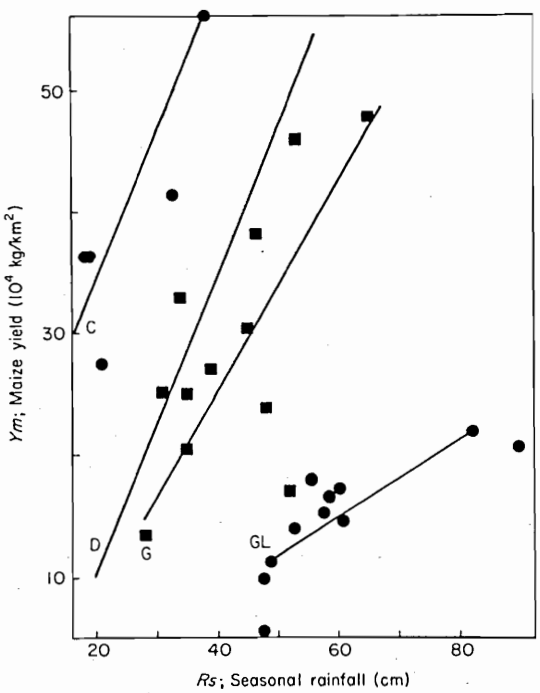

Figure 1. The relationship of seasonal yield of maize (kg km^2 × 10^4) to growing season rainfall (cm). Data and relationships are taken from Dowker (1963) (D, regression equation only) and Glover (1957) (GL) working in Kenya, Carreker, Adams *et al.* (1972) (C) in the U.S.A., and Garlipp (1976) (G) in South Africa.

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cm, was a linear function of rainfall over a 153 day growing season (R_s; cm). Very much higher yields were obtained by Dowker (1963) on an agricultural station (Fig. 1), where management appears to be greatly superior to that found on the commercial farms. We consequently used Glover's data for our equation:

$$Y_M = -35,718 + 3106\,R_s \tag{1}$$

Unfortunately, there has been no parallel work published on rainfall dependence of Kenyan bean yields although this has been found in other areas (Arruda, Tubelis *et al.*, 1980). Using the 1972/73 Kenya Ministry of Agriculture guidelines for expected yield (Schönherr & Mbugua, 1976) at annual rainfall rates (*National Atlas of Kenya*, 1970) for concomitant areas in the study region, we have produced an equation to predict annual bean yields (Y_B; kg dry wt/km^2) from mean annual rainfall (R; cm):

$$Y_B = -140,143 + 3088\,R\ (r = 1{\cdot}00;\ P < 0{\cdot}05)\ \text{(Fig. 2)} \tag{2}$$

Because maize yields are predicted from the growing season rainfall rate (equation 1), some correction must be made, such that both maize and bean yields can be predicted from the more widely available annual rainfall data. We determined the relationships between rainfall during the 120 days of highest rainfall (R_s) and annual rainfall (R; cm/yr) for desert, semi-desert, and highland stations (*National Atlas of Kenya*, 1970):

$$R_s = 1{\cdot}824 + 0{\cdot}4974\,R\ (r = 0{\cdot}972;\ P < 0{\cdot}05) \tag{3}$$

Combining equations (1) and (3) provides a prediction of annual maize yield (Y_M) from annual rainfall (R):

$$Y_M = -30{,}053 + 1545\,R \tag{4}$$

Assuming that the proportions of arable land planted in beans (A) and maize (1−A) add to one, we can use the two yield equations [equations (2) and (4)] to predict the mass of food that can be grown on each km^2 of arable land during each year (W; kg/km^2):

$$W = AY_B + (1-\mathrm{A})\,Y_M \tag{5}$$

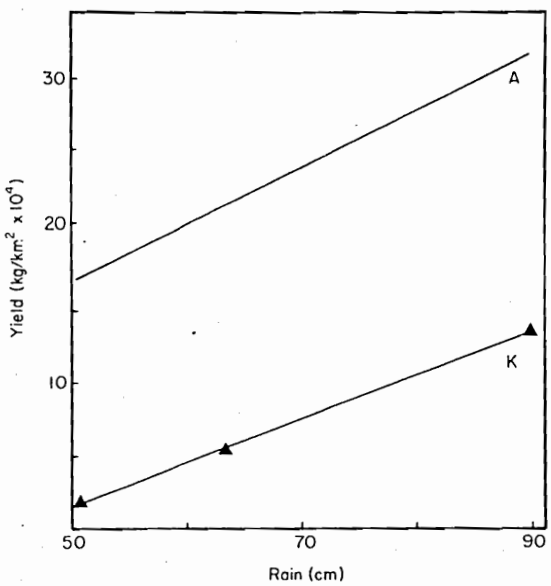

Figure 2. The relationship of annual yield (kg/km^2 × 10^4) of beans (*Phaseolus vulgaris*) in Kenya (K) and Brazil (Arruda, Tubelis *et al.* (1980)) (A) to mean annual rainfall rates. Data for Kenya are taken from the 1972/73 Kenya Ministry of Agriculture guidelines for expected yield (Schönherr & Mbugua, 1976).

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Because equations 2 and 4 are linear equations, low values of R may result in negative predictions of Y_B and Y_M. Care should be taken that all negative yield predictions are set to zero in this and all subsequent equations. Dry matter production can be calculated from equation (5) assuming that the moisture content of dry beans and maize averages 15% and 12% respectively (Fisher, 1977).

The human carrying capacity is not determined by the production of food bulk, but rather by the production of useable protein and energy. The total protein content of beans and maize is 0·221 and 0·095 kg/kg dry weight, respectively (FAO/WHO, 1973), but bean and maize amino acids are not supplied in the ratios required by man. Because about 66% of bean protein and 42% of maize protein is complete regarding essential amino acid content (FAO/WHO, 1965), the real production of useable protein (P, kg/km^2) is:

$$P = (0{\cdot}85)\,(0{\cdot}66)\,(0{\cdot}221)\,AY_B + (0{\cdot}88)\,(0{\cdot}42)\,(0{\cdot}095)\,(1-A)\,Y_M \qquad (6)$$

ignoring the fraction of protein made available through synergisms of maize and bean amino acid profiles (FAO/WHO, 1965). In addition, because beans and maize contain 3390 and 3630 kcal/kg dry wt. respectively (Platt, 1962), the actual calorie production (C; kcal/km^2) can be calculated:

$$C = 3390\,(0{\cdot}85)\,AY_B + 3630\,(0{\cdot}88)\,(1-A)\,Y_M \qquad (7)$$

Because human useable protein and calorie requirements are about 33 g dry wt/day and 2400 kcal/day respectively (FAO/WHO, 1973), the human carrying capacity permitted by areal protein (L_p, number of adults km^2/yr) and calorie production (L_C number of adults km^2/yr) can be calculated:

$$L_P = P/12{\cdot}05 \qquad (8)$$

$$L_C = C/8{\cdot}76 \times 10^5 \qquad (9)$$

The above calculations assume only one growing season (they are therefore not applicable to higher rainfall areas), no food spoilage or loss to vermin, and apply only to arable land. A study of bean production in Kenya's Central and Eastern provinces (Schönherr & Mbugua, 1976) reported that many small farmers experience severe losses during storage. When figures become available on storage efficiency (S_B and S_M; proportion of stored grain retained for human consumption) the needed corrections can be made to equations (6) and (7), expressing corrected protein (P') and calorie (C') production as:

$$P' = S_B\,(0{\cdot}85)\,(0{\cdot}66)\,(0{\cdot}221)\,AY_B + (0{\cdot}88)\,(0{\cdot}42)\,(0{\cdot}095)\,(1-A)\,Y_M \qquad (10)$$

$$C' = S_B\,(3390)\,(0{\cdot}85)\,AY_B + S_M\,3630\,(0{\cdot}088)\,(1-A)\,Y_M \qquad (11)$$

The equations (10) and (11) are identical to equations (6) and (7) but are corrected for storage loss. The resulting protein and calorie based carrying capacities can be calculated by substituting equations (1), (4), (10), (11) into equations (8) and (9):

$$L_P = [S_B\,(0{\cdot}85)\,(0{\cdot}66)\,(0{\cdot}221)\,A\,(-140143 + 3088\,R) + S_M\,(0.88)\,(0.42)\,(0.095)\,(1-\mathrm{A})\,(-30,053 + 1545R)]/12{\cdot}05 \qquad (12)$$

$$L_C = [S_B\,(3390)\,(0.85)\,\mathrm{A}\,(-140143 + 3088\,R) + S_M\,3630\,(0{\cdot}88)\,(1-\mathrm{A})\,(-30,053 + 1545R)]/8{\cdot}76 \times 10^5 \qquad (13)$$

where Y_B and Y_M are $\geqslant 0$.

It is evident from these equations that the human carrying capacity by protein (L_p; adults km^2/yr) and calorie (L_C; adults km^2/yr) production rates per unit arable land are functions not only of rainfall, but also of the proportion of land planted in maize and beans, and the storage efficiency. The ultimate human carrying capacity (L) is the lesser of L_P or L_C, unless the deficient component is supplied from outside sources. The population age

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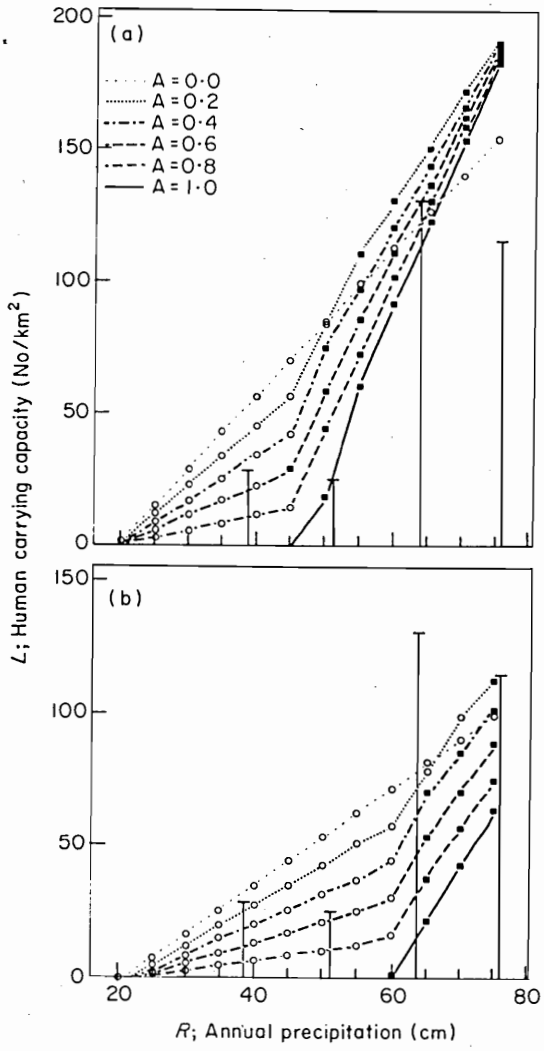

Figure 3. (a) Predicted human carrying capacity (No. persons/km^2) of arable lands as a function of mean annual rainfall (cm/yr) and different ratios of maize and beans planted [equations (12) and (13)] and assuming a 50% loss rate to vermin and spoilage. A is the fraction of arable land planted in beans and the fraction planted in maize is (1–A). Adult equivalent carrying capacities are converted to actual population carrying capacities through multiplication by 1·23 (see text). Open circles indicate that the population is limited by protein production and closed squares indicate calorie limitation. (b) Predicted human carrying capacity (No. persons/km^2 of arable land) as a function of R', where 10% of all annual rainfall levels lie at or below R'. Ranges of observed 1979 population levels for sublocations > 10 km^2 (Machakos, Kitui, Nakuru, and Nyandarhua Districts) are plotted as vertical bars (Kenya Government, 1980). All symbols are as in 3a.

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distribution for Kenya as a whole (Kenya Government, 1980) indicates that the adult equivalents multiplied by 1·23 provide a measure of the human carrying capacity (No. persons/km^2). Both here and in equations (12) and (13), the tacit assumption is made that food is neither sold nor traded. Any such trading will decrease the predicted human carrying capacities.

With some reservations, equations (12) and (13) can be used both to predict the theoretical limits to human populations per unit arable land in semi-arid regions of Kenya, and to examine the effects of variations in the proportion of beans and maize planted. Schönherr & Mbugua (1976) reported that 63% of bean fields are seriously infected with pests or diseases, and that 66–82% of farmers surveyed reported 'severe damage' to crops during storage. Actual storage losses must, therefore, total at least 50% of the yield obtained at agricultural stations or modern farms. That this is not an overestimate is indicated by postharvest storage losses averaging 50% for legumes in Tanzania and 90–100% for maize in Zambia over a 12 month period (Hall, 1970).

The human carrying capacity per km^2 of arable land, assuming crop losses of 50% (S_B and S_M = 0·5), is shown to rise almost linearly with increased rainfall (Fig. 3a). At the lowest rainfalls, where bean yields are negligible, both the energy and protein requirements are obtained from maize, with further growth of the population limited by protein production. Above 45 cm annual rainfall, the contribution of beans to the protein pool allows a rapid rise in human carrying capacity. The model suggests that using a small fraction of the land for bean production (e.g. A = 0·2) allows the maximum carrying capacity of people, all having a balanced diet. Theoretically, denser populations could be sustained by the growth of maize alone (A = 0·0) but to obtain all the required protein from this crop would require the ingestion of nearly 1 kg/person/day. This appears to be an unrealistic bulk quantity because Peters (1978) estimated that a 60 kg person should ingest about 550 g dry wt/day. Alternatively, larger populations are possible under conditions of chronic protein deficiency. However, regardless of planting regime, the carrying capacity declines to zero at 20 cm average annual rainfall.

Caution is required in interpretation, because equations (12) and (13) make only *average* predictions of human carrying capacity and do not account for years of abnormally high or low rainfall. For example, our model predicts significant human carrying capacities between the annual rainfall levels of 20 and 50 cm, while the Kenya Government (1962) suggests only nomadic herding in these areas. The discrepancy is largely attributable to the uncertainty of farming at annual rainfall rates so close to crop failure levels. It should be remembered that rainfall varies from year to year and that most annual rainfall levels are either above or below the long-term average rate. If grain storage was efficient, then one year's surplus could be used to offset another year's shortfall. Because storage is difficult, the true carrying capacity is the population that can be sustained indefinitely, without starvation. As a consequence, Fig. 3a overestimates the carrying capacity because it lacks the margin of safety needed to sustain the population in dry years. The size of this safety margin can be approached probabilistically by deciding how often a shortfall in food production can be tolerated biologically, sociologically, psychologically and politically.

The frequency at which crop failures can be accepted is beyond the scope of this endeavour. We can, however, examine the effect of one arbitrary safety margin upon the carrying capacity of Kenyan lands. Let us assume that a major shortfall can be tolerated once every 10 years. In this case the carrying capacity of various regions is not that predicted by R, but by (R'), the position of the lower 10% tail of the distribution of the R_i (where the i's are years). We determined the value of R' by examining the rainfall distributions over 13 years at six Kenyan weather stations (Wernstedt, 1965–1978). Annual rainfall at each station was found to be log normally distributed (χ^2 test; Conover 1971). R′ was determined as the upper boundary of the lower 10% tail of distribution of the R_i's by applying the t-distribution after logarithmic transformation. Although the data are not evenly distributed over the range of R, the R' were found to be significantly correlated

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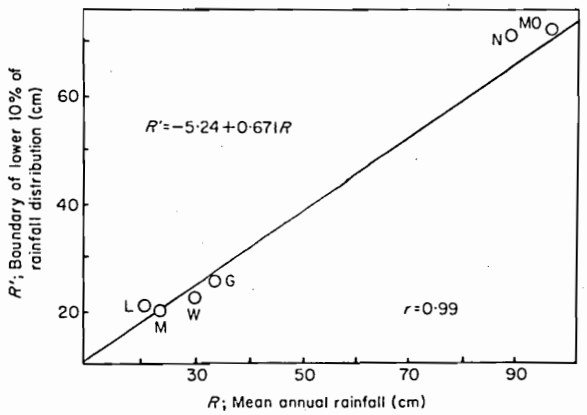

Figure 4. Relationship between mean annual rainfall (cm) at six Kenya weather stations (Lodwar, Mandera, Wajir, Garissa, Nairobi, and Mombassa) and the rainfall level above which 90% of annual rainfall rates will occur (R').

with the mean annual rate of precipitation (R) (Fig. 4):

$$R' = 5{\cdot}24 + 0.671\,R \;(r = 0.99;\, P < 0{\cdot}05) \tag{14}$$

The regression equation yields an estimate of R' and inserting R' into equations (12) and (13) should yield an estimate of the maximum population that can be supported per km^2 of arable land in 90% of all years. Estimates of minimum rainfall to be expected at other frequencies can, of course, be computed easily (see also Glover, Robinson *et al.*, 1954).

Solutions of equations (12) and (13), employing the estimates of R' [equation (14)] are shown in Fig. 3b. The safety margin obtained by considering a one in ten year minimum rainfall results in a large decrease in the predicted carrying capacity of the land. If populations accept the food shortage associated with a one in ten year low annual rainfall, and if virtually 100% of the semi-arid land in Kenya can be cultivated, then the plot in Fig. 3b should provide an upper bound to the population possible in semi-arid regions. Upper boundaries of ranges of 1979 population densities in the sublocations of four districts (ëe Fig. 3b), omitting sublocations smaller than 10 km^2 to eliminate town sites, are sometimes higher than the carrying capacity based on local crop yield (Fig. 3b). At long-term average rainfalls of between 51 and 76 cm, the maximum observed population was, according to the model, up to two times greater than calculated on the basis of yield from one cropping per year. At the low rainfall interval (25–50 cm, $\bar{x}$ = 38 cm) the present maximum population is just sustainable. Although higher populations than observed can be supported in years of average rainfall (Fig. 3a) the discrepancies between observed and predicted (Fig. 3b) suggest that, in the most densely populated sublocations, the people either have access to other food sources during droughts or are severely malnourished.

Livestock

Livestock could provide this alternative food source in semi-arid areas, if rates of production are high enough. No regressions exist that relate livestock milk and meat yield to rainfall in low rainfall regions (i.e < 50 cm); thus, detailed computations, like those performed for bean and maize production, cannot be made. However, wild herbivore and livestock biomass levels are positively correlated with rainfall (below 70 cm/yr), because greater rainfall allows greater growth of forage plants (Coe, Cummings *et al.*, 1976).

Because the biomass of livestock required to provide the amount of milk and meat needed by members of pastoral families is known (Pratt & Gwynn, 1977), human carrying capacities can be calculated from estimates of sustainable livestock biomass. Experienced

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range managers have estimated that each adult needs about 1350 kg of livestock (cattle, sheep, goats, camels) in the more productive regions (e.g. the Kajiado district) to 1880 kg of livestock in the very arid northern and north-eastern portions of Kenya and Tana River (see also Dahl & Hjort, 1976 for data from elsewhere in east Africa).

The amount of livestock required to support a human population was estimated from a relationship between lifestock biomass (B; kg/km^2) and annual rainfall (R; cm) computed for six Kenyan pastoral areas, in which livestock biomass was close to the long-term carrying capacity (Coe, Cummings *et al.*, 1976)

$$\log B = -0{\cdot}5103 + 1{\cdot}567\,[(\log R) + 1]\ (r = 0{\cdot}97;\ P < 0{\cdot}05) \tag{15}$$

Equation (15) applies only to large regions and cannot be used to predict small-scale temporal and spatial variations within regions. It should also not be applied, without the greatest caution, beyond the range of the rainfall data from which it was created (21–71 cm). There is good agreement between predicted livestock biomass in pastoral areas and that observed by livestock census (Mbugua & Stevens, 1979), with the average in the four districts within 16% of predicted values (Table 1). The degree of agreement suggests that total game biomass is also predictable, permitting assessment of the relative success of individual species over time. With decreasing rainfall cattle make up a declining fraction of total livestock biomass (Mbugua & Stevens, 1979) and although the prediction of cattle biomass is feasible (Bourn, 1978), it cannot be used as a predictor of either livestock grazing pressure or human food availability without equivalent data on other livestock.

Equations that predict human carrying capacity (L_H; adults/km^2) for pastoral areas as a function of rainfall (cm) can be created from equation (15) and the measurements of livestock biomass requirements per adult (Pratt & Gwynn, 1977).

$$\log L_H = -2{\cdot}07 + 1{\cdot}57 \log R \text{ (1350 kg livestock/adult; semi-arid, e.g. Kajiado district).} \tag{16}$$

$$\log L_H = -2{\cdot}14 + 1{\cdot}57 \log R \text{ (1575 kg livestock/adult; intermediate, e.g. Samburu district).} \tag{17}$$

$$\log L_H = -2{\cdot}20 + 1{\cdot}57 \log R \text{ (1800 kg livestock/adult; arid, e.g. Wajir district).} \tag{18}$$

A comparison of the observed population with that predicted from equations (16)–(18), after multiplying adult equivalents by 1·23 to obtain the number of individuals (Pratt & Gwynn, 1977), shows that most pastoral districts appear to have moved from below to above carrying capacity since 1962 (Table 2, Fig. 5). Some discrepancies are probably due to extrapolating rainfall measured at a single weather station to large districts as a whole. Other discrepancies, such as for the less arid Samburu and Kajiado districts, suggest

Table 1. *Comparison of predicted (e.g. 18) and observed (Mbugua & Stevens, 1979) livestock biomass (kg km^2) for semi-arid and arid regions of Kenya as a function of the mean annual rainfall. Biomass figures include cattle (180 kg), sheep (18 kg), goats (18 kg) and camels (300 kg). Deviations are expressed as 100 × (obs–pred)/pred*

District	Mean* annual rain (cm)	Predicted† biomass (kg/km^2)	Observed‡ biomass (kg/km^2)	Deviation
Mandera	25	1767	1658	−6%
Wajir	25	1767	1123	−36%
Garissa	25	1767	1461	−17%
Samburu	38	3405	3588	+5%

* *National Atlas of Kenya* (1970), pp. 15 and 17.
† Equation (18).
‡ Average of 1972 and 1977 computed from Mbugua & Stevens (1979).

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Table 2. *Predicted and observed human densities for semi-arid and arid regions of Kenya*

District	Year	Rain* cm/yr	Equation	Predicted†	Predicted‡ population/km^2	Observed§ 1962
Mandera	1962	25	(17)	1·2	1·1	2·1
	1979					4·0
Marsabit	1962	25	(17)	1·2	—	0·4
	1979					1·3
Garissa	1962	25	(17)	1·2	0·9	1·2
	1979					2·9
Wajir	1962	25	(17)	1·2	0·9	1·6
	1979					2·4
Tana River	1962	30	(17)	1·6	—	0·9
	1979					2·4
Isiolo	1962	25	(17)	1·2	—	1·6
	1979					1·7
Samburu	1962	38	(16)	2·7	2·3	2·0
	1979					4·3
Kajiado	1962	50	(15)	4·9	—	2·5
	1979					7·6

* Long-term mean estimated from isohyets, *National Atlas of Kenya* (1970), pp. 15 and 17.

† Based on equations (16)–(18) and multiplied by 1·23 to convert adult equivalents to population (Pratt & Gwynne, 1977, Ch. 5).

‡ Based on average observed livestock biomass (Table 1) and 1575 kg/adult for Samburu and 1800 kg/adult for 25 cm/y regions; multiplied by 1·23 to convert adult equivalents to density.

§ *Kenya Central Bureau of Statistics*, 1980.

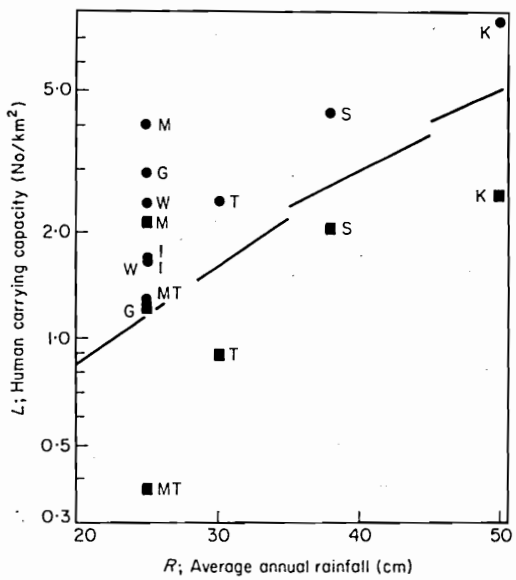

Figure 5. Predicted human carrying capacity (adult equivalents/km^2 × 1·23) (—) as a function of mean annual estimated rainfall, using equations (15)–(17). Observed 1962 (■) and 1979 (●) population densities for Mandera (M), Marsabit (MT), Garissa (G), Wajir (W), Tana River (T), Isiolo (I), Samburu (S) and Kajiado (K) districts.

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limited crop growing in the highest rainfall portions of the districts or trading and selling livestock to adjacent agricultural areas.

It is evident that even small changes in annual rainfall have an appreciable effect on livestock biomass [(equation (15)] and human carrying capacity [(equations (16)–(18)]. However, one or two year droughts do not have the same dramatic impact on pastoral people as on those facing a crop failure. Livestock grazes a much wider range of plant species, some being perennial and others differing in drought tolerance. Quantitative data on the time lag between the onset of droughts and their effects on livestock herds, and on human starvation are needed, as well as data on plant recovery following droughts and overgrazing; the short-term predictions that are not possible from averaged long-term rainfall data can then be made. A long-term drought (1968–1976) in an area east of lake Turkana resulted in annual rainfalls of only one third of the previous average of 15 cm (Lamprey & Yussuf, 1981). Extrapolating our model [(equation (18)] suggests a decline in livestock there, from 793 kg/km^2 to 142 kg/km^2, and a similar decline in human carrying capacity from 0·5 to 0·1/km^2. Although short-term food imports must have provided relief, such droughts lead to long-term herd decreases and severe human hardships.

Conclusions

Regardless of the crops they plant, farmers in the semi-arid regions of East Africa and the Southern Sahel are constrained by unreliable rainfall and the prospect of frequent crop failure. This limits the population, even though an ample crop would be obtained if only the average rainfall level was received in all years. On the other hand, the pastoralist depends on the conversion of grasses into herbivores, which sets low upper limits on the population that can be supported. The pastoralist can subsist in more arid climates and does not lose his entire food supply in dry years because livestock yields decline but do not disappear. Severe drought will be felt for many years, however, since herd mortality affects future yields.

This study is only a first step towards solving the predicament of people living in semi-arid lands. It explores food production under water limitation, suggests a preliminary framework for population planning, and illuminates areas in which more solid data are required. For example, better equations to predict crop yield, based on actual observations of food production on small farm plots, would improve the accuracy of predicted protein and calorie yields. Studies of crop losses to spoilage and vermin would provide more realistic projections of food delivery to human consumers, and the efficiency with which food can be stockpiled against dry years. Research on milk and meat yields as functions of rainfall history and herbivore stocking densities, would allow better predictions of carrying capacities in dry regions.

This study should be seen as a starting point. Analyses presented here suggest that many densely populated semi-arid and arid districts have populations well above their carrying capacities. If the natural capacity of the land to support populations is not considered in population planning and the establishment of settlements, tremendous human misery will result. This task will require the collaboration of both natural and social scientists as well as a greater recognition among planners of the limitation of average rainfall as a suitable predictor of crop and livestock yields in semi-arid and arid regions.

The Hon. Dr. Z. T. Onyonka, formerly Minister for Economic Planning and Development (Kenya), Mr. J. Kekovole, Central Bureau of Statistics (Kenya), Dr. G. Davies, formerly Head, Parks Planning Unit, Ministry of Tourism and Wildlife (Kenya), Mrs. V. Fortin, and Dr. E. Block, McDonald College of McGill University and Miss D. Brumelis, Department of Biology for data and/or other help; the Department of Botany, University of Nairobi for inviting and assisting the senior author in many ways during a sabbatical year; The National Science and Engineering Research Council for Canada for provision of travel and research funds and F.C.A.C. (Quebec) for a fellowship to J. A. Downing.

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