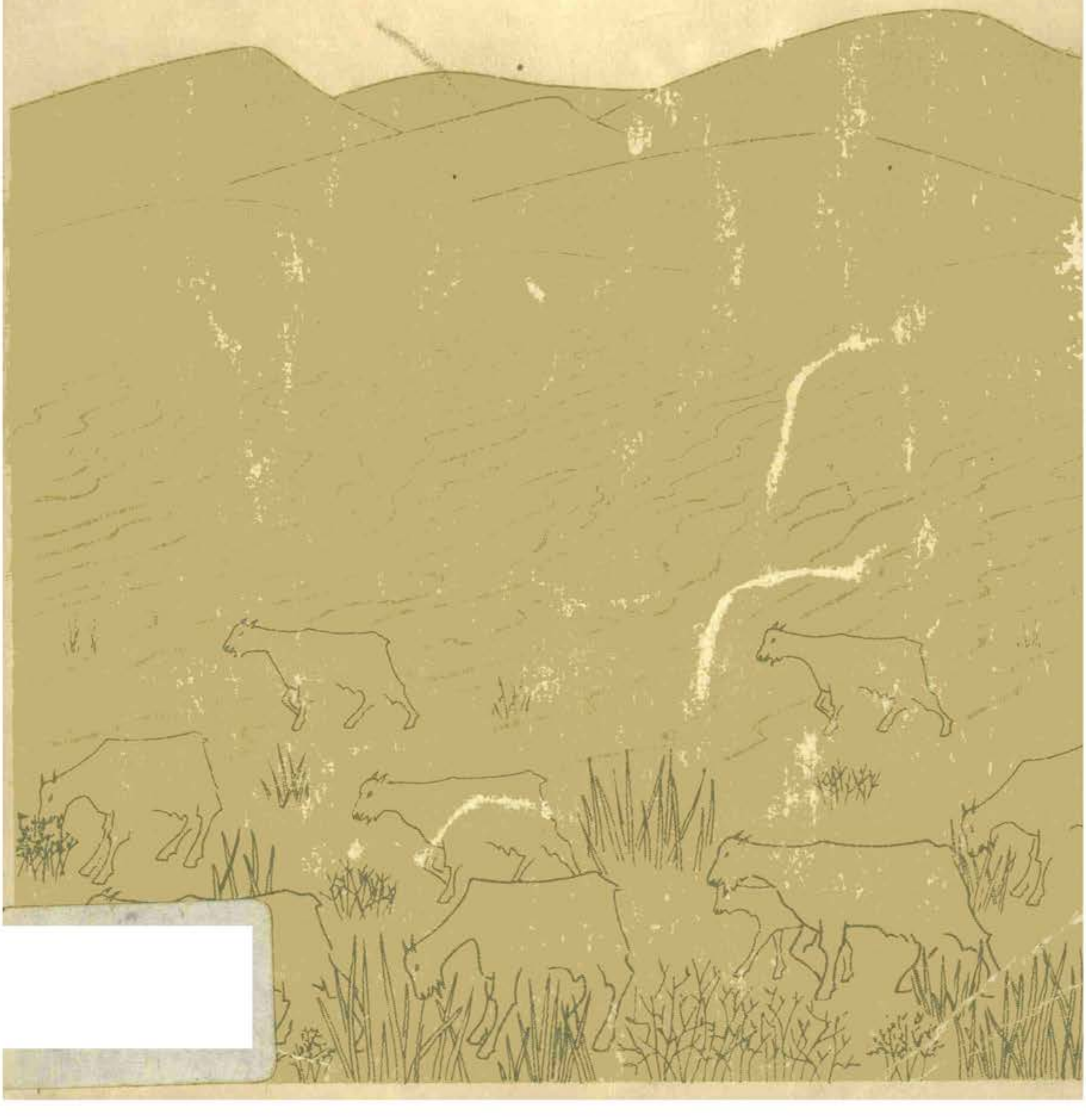
ECOLOGICAL BULLETINS/NFR 24

CAN DESERT ENCROACHMENT BE STOPPED ?



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Can Desert Encroachment Be Stopped?

A Study with Emphasis on Africa

A Rapp, H N Le Houérou and B Lundholm
(Editors)

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SERIES PREFACE

Man is increasingly changing his environment and this leads in many cases to unwanted effects. Pollution of air, water and soil is a problem in many countries, but this does mostly cause only irreversible effects and measures can usually be taken to counteract these, even if they are not always considered economically feasible. In marginal areas with low mean annual rainfall, the pressure of man can, however, often cause irreversible effects or effects which are not easily counteracted. The pressure of increased populations, together with severe drought situations during the past decade, has created both ecological and social problems in marginal dryland areas. The deserts are spreading with loss of productive soil and overexploitation of remaining resources.

This volume in the series *Ecological Bulletins* deals with the ecological and social problems of desert encroachment. It puts man and his activities into an ecological context and outlines the causes of desert encroachment and remedies which can be used.

The report has been prepared in close cooperation between UNEP and SIES as a background document for the 1977 UN Conference on Desertization. It is also a further step in the efforts of the Editorial Board of the *Ecological Bulletins* to publish reports which are relevant to the present discussions on important environmental issues.

Thomas Rosswall
Editor-in-Chief
Ecological Bulletins

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PREFACE

P. BRINCK

Present knowledge of arid ecosystems

One third of the earth's surface is arid or semiarid land. The territories of half of the world's nations lie partly or wholly in dry regions. Utilization of the primary dry land was ecologically tolerable for thousands of years. It is only in recent times that overexploitation has occurred – often in combination with climatic fluctuations – as as result of increasing population densities and social disturbances among the people inhabiting arid lands.

A characteristic of arid land – well described elsewhere in this publication – is the great variety in the environment. It is true that a common feature is the irregularity of the water supply available for man, but generally the environmental variations lead man to exploit the resources in many different ways. The wide variety of conditions and problems in arid and semiarid areas complicates development. Since Unesco launched the first arid zone programme 25 years ago, scientific and technological research has greatly advanced man's capacity to make use of dryland resources. On the other hand, the overexploitation mentioned above has resulted in increased desertization, which may counteract efforts at enhancing the quality of life in dry lands.

During the 1950s and 1960s international agencies such as Unesco, FAO, WMO, ICSU, and IUCN initiated projects which collected a wealth of information on environmental constraints of arid zones. Thus, Unesco's Arid Zone Research Programme, which ended in 1962, provided basic knowledge about arid areas in Africa and elsewhere. However, the practical results of the recommendations of the programme were rather limited. One reason was the insufficient contact between scientists, decision-makers and the people inhabiting the arid countries. Inadequate coordination of scientists – for example, social scientists and natural scientists – and lack of information concerning the practical applications of science also lessened the outcome of the International Biological Programme (IBP) of 1964–1974.

Ecosystem analysis developed, however, within the framework of the IBP, in the biome studies designed to investigate the structure and function of entire ecosystems. This became possible by the use of computers for testing and improving mathematical ecosystem models. In this way ecology has developed into one of the predictive sciences and become a central discipline of interrelations in nature. Studies of tropical ecosystems in the IBP were limited. Unfortunately, only a few scientists from developing countries took part.

Several of the early projects were run during periods of relatively high annual rainfall in West and North Africa. Then came in 1968 the prolonged devastating drought and famine in the Sahel and Ethiopia which culminated in 1973. These disasters shocked the world. It became plain that either knowledge of arid-zone conditions was not enough for predicting and avoiding such disasters, or there were barriers to the dissemination of information. The recently launched Unesco programme, *Man and the Biosphere* (MAB), brings man back into the forefront of integrated scientific research. At a MAB regional meeting in 1974, after listing a number of reasons for the comparative failure of previous development schemes for the Sahel, MAB experts concluded:

"Perhaps most important, however, is the fact that insufficient attention and importance has been given to the socioeconomic and ethno-cultural context of local populations . . . . It is recommended that:

- all research and development operations take into account the social and economic context of local populations;
- the experience and knowledge of local populations on cattlebreeding and on the local environment be considered the point of departure for studies which precede development projects;
- all research and development actions be accompanied by educational action so that local populations recognize their responsibilities in the use and exploitation of their environment;
- in the context of the recent drought, a detailed evaluation of the carrying capacity of the Sahelian zone be undertaken, as well as an examination of the behaviour of local populations, during the period prior to the present situation."

That is were we stand today. What is needed is integrated scientific research in combination with an evaluation of the results of previous arid zone programmes – all carried out in full awareness of the importance of social and economic factors.

Degradation of arid ecosystems

Desertization or the degradation of arid and semi-arid ecosystems is a stepwise decomposition of the plant and animal communities. Initially, there is a reduction of the production of part of the species within the amplitude – that is, the limits of variation – of the ecosystem. In terrestrial ecosystems the process usually occurs through soil deterioration via loss of primary species and invasion by new specific material. When the density of vegetation decreases, certain conditions of soil and climate may also induce desertization. Soil particles drift away, laying bare and exposing roots to desiccation. A secondary ecosystem is established, also containing species other than the primary ones and having a different production rate, not necessarily lower than that of the primary ecosystem.

There are no stable, unchangeable ecosystems (Orians, 1975). Most changes seem to occur along a gradient of increasing complexity, i.e. an increasing number of specialized animal and plant species (Margalef, 1974a,b). Climate or other physical factors may result in temporary deterioration of the ecosystem, lowering its productivity and species diversity. As long as they are reversible, such changes cause little harm to the ecosystem. The loss of species indicates an incipient irreversible evolution, which transmutes the system. For man, the turning point in a subsistence economy comes when the exploitable output – the yield of the ecosystem over a period of several years – drops below the energy requirements of the community unit in relation to its input of, for example, seed, corn and energy.

The ecosystems of the arid zone have high resilience and low persistence (see Chapter 1). This is a result of the fact that the species of simple ecosystems in physically broadly varying environments usually have wide ecological amplitudes and hold large niches – that is, they have considerable means of surviving extreme conditions.

Most ecosystems of the arid zone in the Old World have been experiencing accelerated deterioration for the past fifty years. For North Africa, Le Houérou (1970) summarized the present state: the deterioration is a result of an increased human pressure, which is expressed as intense overgrazing, extension of cereal growing and removal of woody plants. In certain areas introduction of cash crops into former pasture land – for example, groundnuts in Senegal – added to the pressure and initiated a rapid deterioration of the environment (FAO/SIDA, 1974). In North Africa, productive land bearing alfa grass (*Stipa tenacissima*) covered eight million hectares at the beginning of the twentieth century. Today, more than half this area has degraded severely, mainly because of the desertization process initiated by man.

In areas with a regular though small precipitation, steppe ecosystems have evolved from forest vegetation by degradation. For North Africa this has been pointed out by Le Houérou (1968, 1969) who demonstrated that since the beginning of historic time the vegetation of hills and high plains has passed through a series ranging from forest composed of *Pinus, Juniperus* or *Tetraclinis*, via shrubland dominated by *Rosmarinus officinalis* and *Stipa tenacissima*, to arid steppe where various species of *Artemisia* play an increasing role.

Heavy exploitation of a desert ecosystem means loss of biota (species) and soil resources. Provided that sources are available whence the species can re-immigrate, a natural restoration of the ecosystem is possible. The time scale for this restoration varies for different ecosystems, in relation to the initial state and the degree of destruction. It may be that the pressure of human activity does not allow the area natural recovery. Then a rational management of existing natural resources may establish a productive system at another level, but the extinction of particular species constitutes an irreparable loss.

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INTRODUCTION

A. RAPP

This report is the result of a joint effort by the Secretariat for International Ecology, Sweden (SIES) and associated authors. The views and opinions expressed in the different chapters are those of the individual authors. We have, however, attempted to use an integrated transdisciplinary approach in order to bridge the gap between the socioeconomic and ecological aspects.

The task of investigating and reporting on the acute problem of desertization and the possible means of controlling it was assigned to SIES in 1973 by SIDA (Swedish International Development Authority) and NFR (Swedish Natural Science Research Council). The work was planned to result in three reports dealing with the following subjects.

1. A review of desertization in Africa, its causes and effects. The report on the first topic was published in December 1974 (Rapp, 1974).

2. A survey of methods and experiences in counteracting desertization. The survey has resulted in the report now presented under the title "Can Desert Encroachment Be Stopped?". UNEP is financing the printing of the report.

3. A planned third report will focus on recommendations for pilot projects on ecologically sound land use in areas affected by desertization.

The chapters in the present report take up special problems for analysis and discussion, but do not claim to contain complete documentation for each topic. The emphasis is on recent literature, including the experience of the Sahelian drought in 1968–1973.

We had initially intended to make a literature review covering all the hot deserts of the world. Limitations of manpower, time and finances made it necessary to concentrate on the dry lands of Africa, where the problems are particularly acute. Socioeconomic factors are of the utmost importance in desertization and its control, producing very different situations in rich countries such as Australia and USA and poor countries respectively. The wide fluctuations in both human and cattle populations – with rapid rises above carrying capacity in years with abundant rainfall, and drastic decreases during drought years – by out-migration or death, is one of the key factors in desertization disasters. Our report is lacking in that we have not been able to highlight such fluctuations in a chapter on demography.

Chapters 1 to 7 describe the dry environments and ecosystems and the cultural patterns typical of them. Hence these chapters give a general background to the subsequent parts of the report, where chapter 8 contains a series of cases selected from a number of countries affected by desertization. Chapters 9 to 12 suggest solutions to the problems and chapter 13 is a summary.

The staff members of SIES are particularly grateful to the coauthors from other organizations for their contributions and cooperation: H.E. Dr. H. Idris, Ministry of Agriculture, Khartoum, Dr. G. Boudet, IEMVT, Maisons-Alfort, Dr. C.E. Gischler, Unesco, Cairo, Dr. A. Hjort, University of Stockholm, Dr. H.N. Le Houérou, ILCA, Addis Ababa, and Dr. G. Novikoff, US/IBP, Tunis. Their efforts have been invaluable, both as regards the chapters written by them as well as the encouragement they have given us in producing all parts of this book. Very constructive criticism and many suggestions for improvement have been contributed by the two reviewers of the manuscripts, Dr. D.W. Goodall, Australia and Dr. F.H. Wagner, USA. Last but not least, our thanks go to the Editor-in-Chief Dr. T. Rosswall and the assistants Mrs. Britt Paulsen and Mrs. Anna-Brita Hellström for great help in the completion of this work.

The Swedish authors who have written the other chapters have had the advantage of participating in a number of conferences, both within and without the UN system. These conferences and the contacts established with experts have been of great value to our work.

Summary of SIES's first report and additions to it

SIES's first report "Desertization in Africa" (Rapp, 1974) dealt particularly with the causes of desertization. After its publication in 1974, further material of relevance to its content has appeared. We are therefore including the following brief summary of that first report together with some additions.

Terminology

A common terminology used for African conditions distinguishes "natural" deserts as areas which have less than 100 mm annual average rainfall and scarce vegetation in a contracted pattern as in oases or near wadis (dry stream beds).

Desertization (desertification, desert encroachment) is defined here as the spread of desert-like conditions in arid or semiarid lands. The process of desertization is the result of two sets of factors operating either singly or in combination. These factors are: 1) severe and prolonged drought, 2) man's overexploitation of vegetation and soil in dry lands.

The term "desertization" was used in our previous report and is preferred by many French-speaking scientists. The term "desertification" is preferred by most English-speaking scientists and is used in official titles such as "United Nations Conference on Desertification" and the International Geographical Union's "Working Group on Desertification in and Around Arid Lands". The term "desert encroachment" is much used in the Sudan, by scientists as well as in official documents. Some authors distinguish between the three terms and give different definitions to them. The present author prefers to treat the three terms as synonyms owing to the practical difficulty of getting different definitions understood and accepted by both scientists and laymen.

After all, the process of desertization (desertification, desert encroachment) is not well enough described or known to allow of more than a broad and simple definition.

Causes of desertization

Desertization is an acute environmental and social problem on both the northern and southern sides of the Sahara as well as in many other hot dry lands. It is mainly man-made and results from overgrazing, overcultivation, woodcutting, and in some areas also from burning. These activities destroy the plant cover beyond the required minimum coverage for protection of the soil against rapid soil erosion by wind or water. A factor of particular importance in overgrazing is trampling by domestic animals (K. Curry-Lindahl, pers. comm.; Novikoff, this volume).

Desert encroachment resulting from such activities usually occurs in scattered patches of bare ground – from about a hundred metres to some kilometres in length – mainly in the steppe zones.

A common mechanism of desertization seems to comprise the following two phases:

1. Expansion and intensification of land use in marginal dry lands during wet years. These actions include increased grazing, ploughing and cultivation of new land, and wood collection around new camps or settlements.
2. Wind erosion during dry periods, or water erosion during heavy rainstorms.

Erosion creates deflation areas of total or partial loss of productivity via removal of topsoil, nutrients, and humus, in combination with desiccation caused by increased runoff from a crusted ground surface. Damage is also caused by deposition of dunes or slope-wash sediment, but these deposition features are probably smaller in area and often less sterile than the deflation scars. Increased salinity or alcalinity are other causes of local desertization.

The relative importance of wind erosion as compared with water erosion is probably different in the northern and the southern Pre-Saharan belts.

The different types of desert encroachment processes, their extent, and their rates are not well known. They ought to be much better analyzed and monitored in different environments as a basis for rational and efficient methods of combatting desertization.

Meteorologist E.G. Davy (1974) made a special study of the Sahelian drought for the WMO. He came to the following conclusion:

> "No serious analysis of available data is known to show a falling trend of rainfall in the zone over periods for which records are available. Probably an advance of the desert must be regarded as a step-by-step process; in a series of dry years another inhabited belt of the Sahel suffers complete imbalance of the system, and the vegetation and soil are degraded to such an extent that recovery is extremely difficult even when a period of wetter years occurs."

This is in our opinion a relevant description of actual desertization in the Sahelian zone. However, the rate and extent of recovery of vegetation, soils and animals is poorly known. Those desertized areas which require a time of recovery which is longer than the interval between drought extremes will suffer a cumulative desertization effect.

Records of the mean annual flow in rivers of the Sahelian zone, such as the Senegal and the Niger, clearly reflect three several-year drought periods in this century (Paris-Teynac, 1974), and so do also the fluctuations of the levels of Lake Chad (Fig. 0.1).

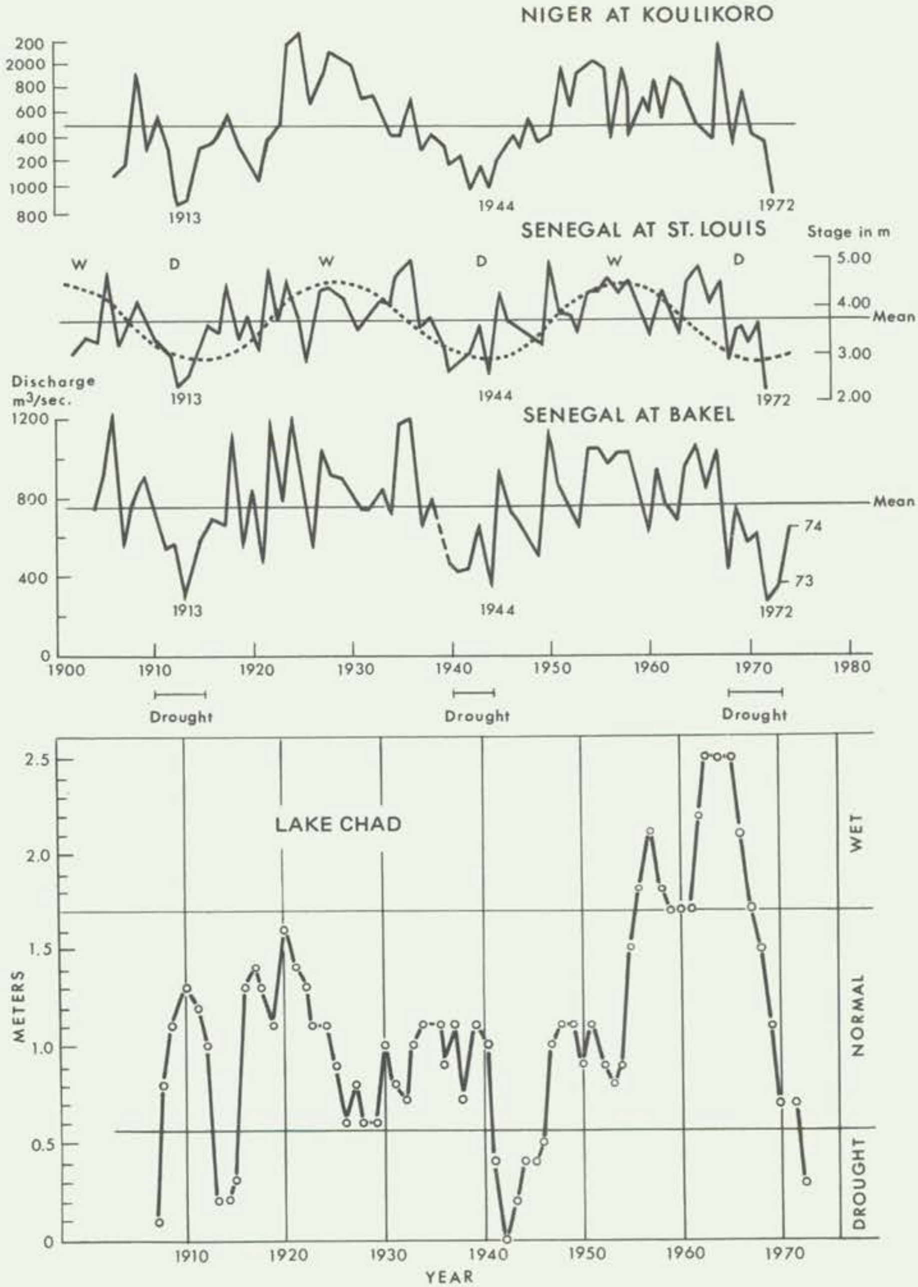

Figure 0.1. Comparisons of the annual fluctuations in water discharge of the rivers Niger and Senegal (above) and maximum annual levels of lake Chad (below). The major droughts during this century are obvious on all curves: around the years 1913, 1944 and 1972. From Paris-Teynac, 1974 (curves Nos. 1 and 2) Sircoulon, 1974 and pers. comm. (curve No. 3) and Matlock & Cockrum, 1974 (curve No. 4). The generalization into wet (w) and dry (d) periods in cycles of 28 years (curve No. 2) is suggested by Paris-Teynac.

The return to wetter years is indicated in the values for 1973 and 1974 in the diagram of the Senegal River. The culminations of extended droughts were approximately 30 years apart: 1913, 1944, and 1972, but single years of drought occurred with shorter and irregular intervals.

An analysis of the isohyets for annual rainfall in the Sahelian and Sudanese zones shows that the drought in 1972 meant a displacement of the 200 mm isohyet by 180–250 km south of its "normal" position in the period 1931–1960 (Fig. 0.2). The other drought years were less pronounced.

The Sahelian drought in 1968–1973 came after a period of "wet" years (Fig. 0.1), when cattle-grazing and cultivation had increased and been pushed beyond their former northern boundaries in the Sahel. Thus, both overgrazing and overcultivation added to the effects of the climatological drought. Ford (1975) and Lawton (1976) draw attention to cattle vaccination and tsetse eradication as major contributary factors in the recent Sahel famine: ". . . the success achieved by national and international veterinary campaigns, principally against trypanosomiasis and rinderpest, have removed causes of mortality essential to the attainment of adjustment to chronic Sahel instability caused by climatic fluctuation." (Ford, 1975).

Patches of deflated and wind-eroded surfaces or moving sand dunes were reported to occur as far south as the normal site of the 450 mm isohyet (Mensching, 1974; A. Seif El Din, pers. comm.). However, a clear overview of the extent of desert encroachment caused by the recent Sahelian-Sudanese drought has not been obtained, nor do we know to what extent and how soon soil and vegetation can recover after severe degradation. In view of this lack of clear information on the extent of desertization, the first report concluded with suggestions for the monitoring of desert boundaries.

Suggestions for monitoring

Desert boundaries are wide zones of gradual transition, their shifts thus being difficult to map. Monitoring of desert encroachment can, however, probably be done along well-defined ground transects, with reference plots of thoroughly documented vegetation and landforms. Such transects of combined ground checking and aerial and satellite remote sensing ought to be established at selected sites for desert boundary monitoring.

Another kind of urgently needed environmental monitoring is desert dust monitoring (Fig. 0.3).

Surveying, monitoring and mapping of desertization and related phenomena are dealt with in particular in chapter 12 of this report.

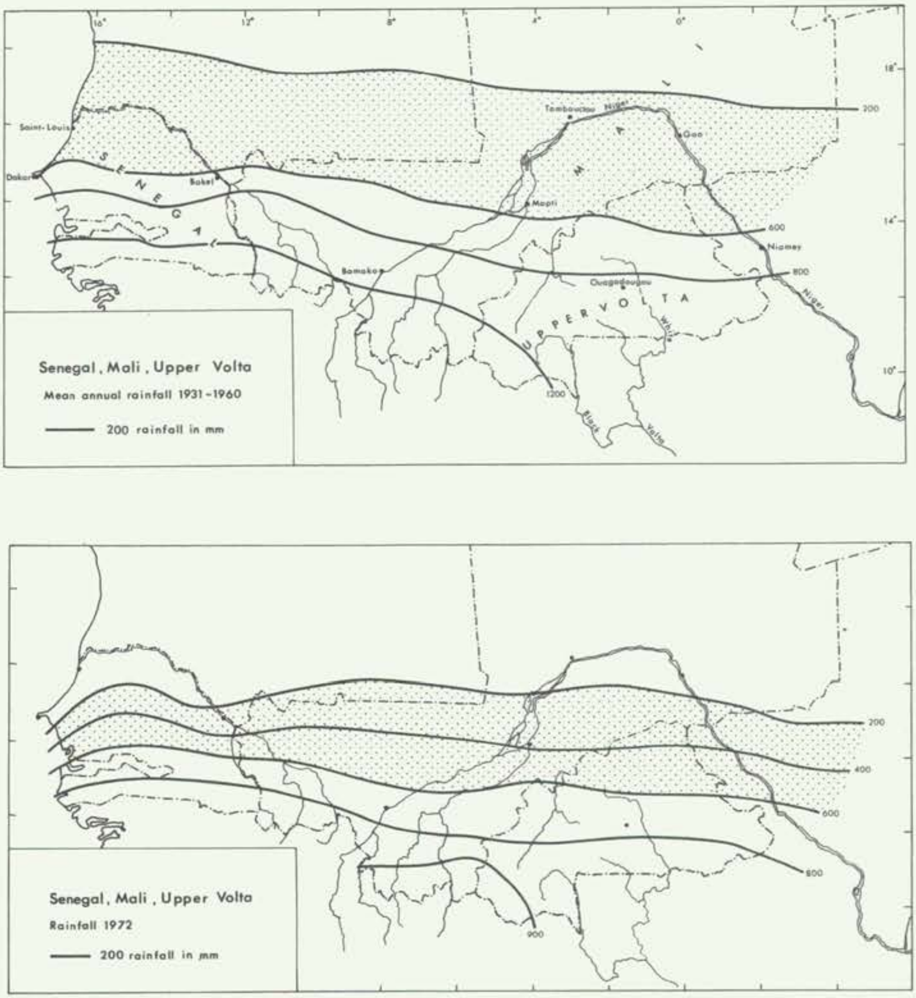

Figure 0.2. Map of southward shift of Sahelian rainfall belt of 200–600 mm annual precipitation in the drought year 1972 (below) as compared with the 1931–1960 "normal situation (above). Modified from FAO/SIDA, 1974.

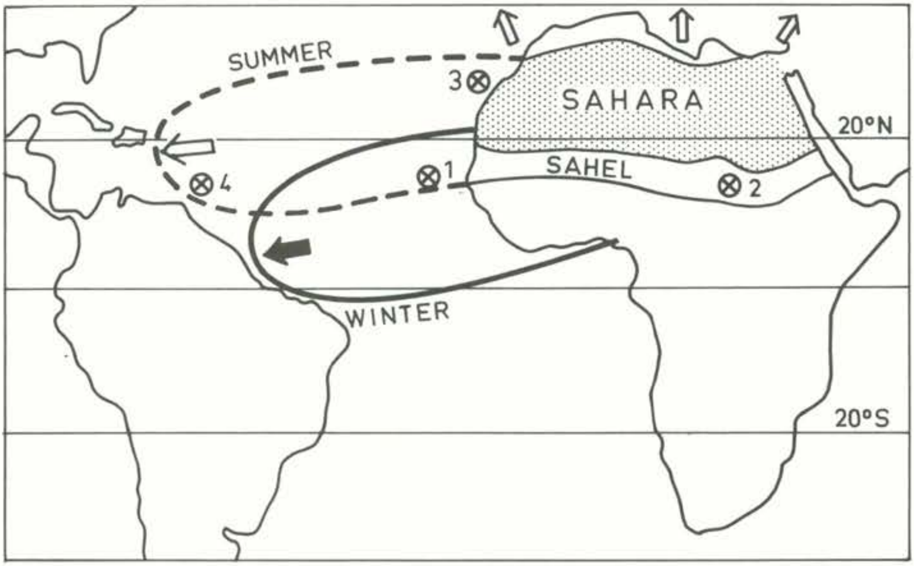

Figure 0.3. Major paths of airborne soil dust from West Africa and North Africa. Trajectories over the Atlantic from Carlson & Prospero (1972); over the Mediterranean from Yaalon & Ganor (1973). Dust monitoring stations on Barbados (4) and Tenerife (3) are in operation. Other stations on the Cape Verde Islands (1) and in the Sudan (2) are suggested.

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Chapter 1

ADAPTATIONS IN ARID ECOSYSTEMS

B. LUNDHOLM

The information on adaptations in animals and plants to arid conditions is very extensive. However, the structure and functioning of the whole ecosystems with its producers, consumers and decomposers is hardly known. For that reason it is very difficult to give a short overview of the situation, only details with special relevance to this study will be touched upon.

Limiting factors

Precipitation

The limiting factor of predominant importance in arid and semiarid zones is the scanty rainfall. The distribution of the arid zone and vegetational cover is determined by precipitation (Fig. 1.1). Detailed maps of precipitation as well as of the number of humid days were published in connection with the Sahel (Matlock & Cochrum, 1974). For West Africa it is stated that the average annual precipitation decreases 1 mm per kilometre in proceeding northward from the southern forests toward the Sahara. However, this kind of disjointed information gives a false picture of the ecological reality, which is characterized by variability and irregularity of precipitation. This variability increases when the precipitation decreases. An important fact is that this variation occurs in both time and space.

The variation of the precipitation in time has been fairly well studied. It must be pointed out, however, that long-term series are needed in order to provide a correct picture of the situation. In many cases such series are lacking in the developing countries. Development projects have failed for neglect of the temporal variation in precipitation (Talbot, 1971). Not only the annual and monthly variation but also the microvariation is of ecological importance. The amount and distribution in time of the showers are critical for the primary production. It is well known from North Africa that rainfalls of less than about 5 mm in 24 hours in summer or 48 hours in winter have no

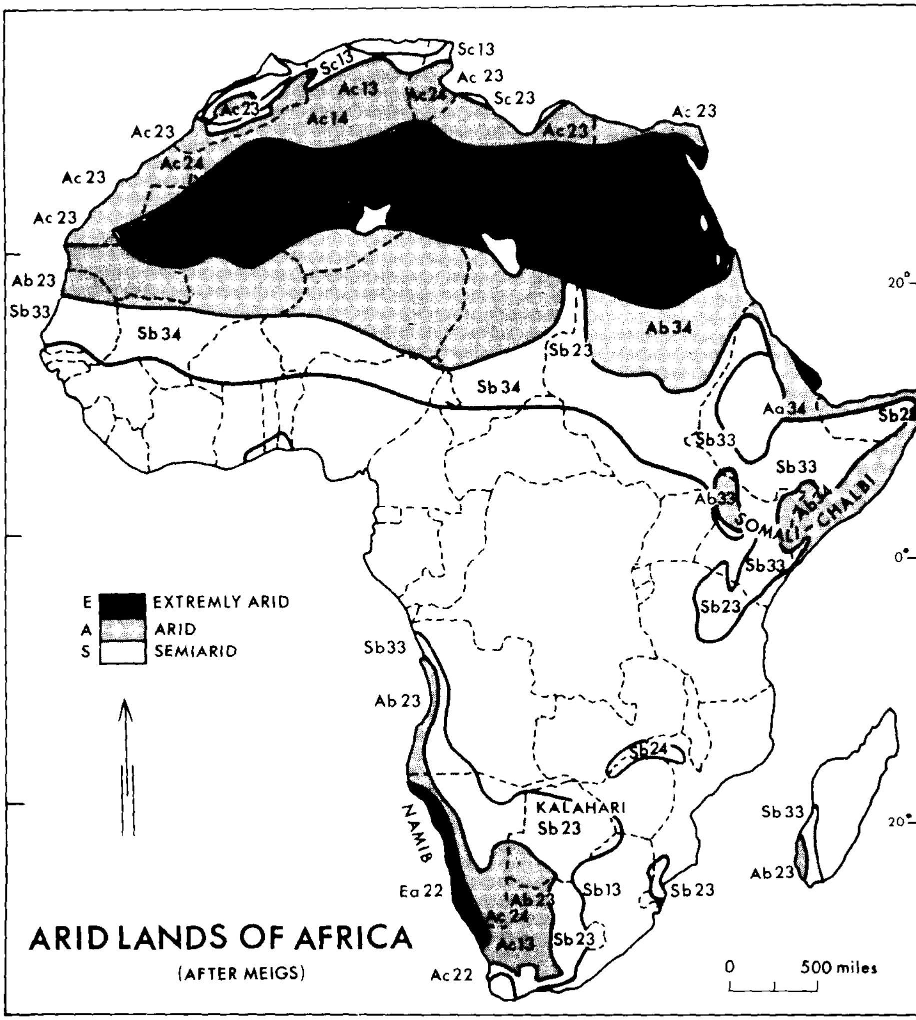

Figure 1.1. Arid lands of Africa (Mc Ginnies *et al.*, 1968).

effect on vegetation, since this amount is less than the potential evaporation (Le Houérou, 1959, 1969). Excessively heavy showers may also have an adverse effect on the vegetation, as all the pores in the soil are filled with water, preventing the oxygen supply to the roots or even causing surface runoff and soil erosion. Erosion experiments under controlled conditions have proved that the yields can be doubled by a proper distribution of the same amount of water (Bunyard, 1973).

Soil moisture

The soil moisture available to the plants depends on rainfall, incoming energy, infiltration, drainage, and evaporation. The evaporation varies with temperature, relative humidity and wind conditions. Whether the precipitation occurs during the cold season, as in the north of the Sahara, or during the hot season, as in the southern parts, is therefore significant. The ecological adaptations to the same amount of precipitation in these two areas are very different. Another factor of significance is whether the precipitation is deposited during a single rainy season or in two, as in certain areas near the equator.

The critical factor for the vegetation is not the precipitation as such, but the soil moisture. Soil structure, depth and texture are important for water retention. Owing to differences in capillarity, the evaporation losses from bare surfaces of clayey soils are much higher than in sands. Soil moisture, especially in certain dry areas, depends also on the occurrence of dew, which is partly controlled by the temperature gradients in the soil. "The study of dew may be more important to the deserts than to the humid regions because of the unfavourable moisture balance of arid lands" (Reitan & Green, 1968). Dew problems in arid areas have been especially studied in Israel. In coastal deserts (e.g. the Namib) sea fog may play the dominant role in the water balance. The amount of water from dew or fog depends on the microstructure of the soil surface and the amount of windblown plant debris (Tschinkel, 1973). Desert insects and plants are adapted for dew and fog collection by means of special structures.

Spatial variation of precipitation

From an ecological point of view, not only is the temporal variation of precipitation important but also its spatial variation. Detailed studies of this kind for larger areas are necessary for a proper understanding of the functioning of the ecosystems. Only a few points pertaining to this will be given here.

In plants the breaking of dormancy after a dry period might be triggered by a certain amount of precipitation. If these amounts fall at different times in different areas, the vegetation will develop differently. Every plant passes through a development phase accompanied by a change in palatability and nutrient content, with the result that it sometimes attracts the consumer only during a short period (M. Gwynne, pers. comm.). The spatial irregularity of the precipitation in an area causing variation in all development stages in the plants will supply mobile herbivores with food for a prolonged period.

Both for the nomads and their herds as well as for large herbivores it is vital that during the vegetation season rain falls somewhere in accessible areas in amounts sufficient to produce enough fodder. The former nomads in Tunisia have now been settled in spite of the fact that they still win their subsistence from grazing herds. Social conditions have also been taken into account in investigations of the ecosystems in southern Tunisia (Wagner, 1975). Every village has grazing grounds – sometimes up to 25 km distant – scattered over an extensive area. The inhabitants deem this dispersal as providing some guarantee against drought. This is a kind of rain insurance. In chapters 3 and 5 of this volume, dealing with the social aspects, other social systems are described which were developed to compensate for local droughts.

Soil nutrients

The soils in arid and semiarid areas have characteristics that put limitations on the ecosystems. The soils are formed by processes where water has played a limited role. As a result of this, the soils are not leached, but owing to evaporation have an accumulation of soluble salts (especially sodium salts) near the surface. Charley & West (1975) have shown that the nutrient patterns in the semidesert ecosystems of Utah are dominated by the individual shrubs both in the vertical and horizontal planes. From a fertility point of view plant nutrients are readily available. However, the amount of certain nutrients is very limited, especially the essential nutrients nitrogen and sometimes phosphorus. This lack of nutrients is associated with the lack of organic components in the arid soils because of the rapid decomposition processes. Bazilevich (1974) has brought together information on the reserves of nitrogen in litter, steppe or desert matting in the world ecosystems. The figures taken from her paper will illustrate the very important difference between different climatic regions (Table 1.1).

Table 1.1. Nitrogen content in litter of ecosystems in different climatic zones (modified from Bazilevich, 1974).

Region	N t km^{-2}
Polar	106.2
Boreal	76.0
Subtropical	
Humid	18.0
Semiarid	10.5
Arid	3.0
Tropical	
Humid	8.6
Semiarid	5.7
Arid	1.2

These very important facts are not always properly understood when Western agricultural technology is applied to tropical and dry areas.

Adaptations by plants and animals

The irregular changes between a short period with water and limited nutrients and a long period of dryness present animals and plants in arid areas with special problems. The larger animals, including man, have avoided the difficulties by migration; the sedentary species have solved the problem in two different ways. The larger group consists of the ephemerals, appearing in active form during humid conditions and surviving during the dry period as inactive stages (seeds, eggs). Both plants and animals occur in this group, the members usually being small in size. The second group consists of larger organisms provided with special mechanisms for resisting drought conditions. There are many different types of adaptations among the plants. Some plants can reduce the green biomass by a factor of 4–20 (Orshan & Diskin, 1968). Other plants are also adapted for reducing evaporation by modifications in the surface. Surface structures may also be used for collection of water (dew or fog). Many plants have reserves of moisture and nutrients. The adaptations in arid plants have been well described by Kassas (1966) and Evenari *et al.* (1971). Schmidt-Nielsen (1972) has given an overview of the different physiological adaptations in desert animals.

Of great interest in this connection is the C_4 photosynthesis pathway which was recently summarized by Black (1971) in an important review. This method of photosynthesis is twice as effective (increase of biomass per time unit) as the earlier known C_3 pathway. Plants with the C_4-system occur especially in tropical areas. The method seems especially adapted for plants where water resources are scarce and limited in time. "Most of the plants in the grazing lands of arid and semiarid Western India belong to C_4 high photosynthesis capacity ones" (Pandeya, 1974). Andrews *et al.* (1974) point out that during warm seasons grasses with C_4 assimilation dominate the American prairie. Caldwell (1974), however, found that there was no difference in assimilation efficiency between C_3 and C_4 plants in cold desert areas. He investigated communities dominated by shrubs featuring C_3 and C_4 photosynthesis. These different ways for the photosynthesis need to be studied intensively. There are good grounds for believing that the results will be of practical value in promoting productivity in arid areas.

Organisms living in arid conditions are characterzied by specific properties. These features have been reviewed by Noy-Meir (1974). He pointed out that organisms in an arid ecosystem have to meet the following five conditions:

1. Tolerance of extreme conditions.
2. Ability for rapid recovery. High growth rates, rapid successions of development stages, and high fecundity.
3. Adaptation of pulse-reserve transitions. "The problem then is how to regulate timing and intensity of these transitions when incidence and duration of good periods is wholly of partly random". In desert plants special delay and trigger mechanisms are at work.
4. Flexible and opportunistic feeding habits. Studies of the diets of desert animals have shown a wide dietary range and ability to switch between different types of food.
5. Nomadic migrations. Large-scale movements are probably the most important adaptation in mammals – including man – and birds for utilizing the resources of the arid zones.

To these five groups of characteristics mentioned by Noy-Meir (1974) a sixth group may be added.

6. Special distribution patterns. The organisms in dry areas are not only rare and dispersed over large distances but they show a characteristic distribution pattern which is pronounced on silty and clay soils, but not on sandy soils. The perennial plants are clumped together, the exposed interspaces being without higher plants (Norton, 1975). This spacing is very important as the perennial plant can use water from a large area. The infiltration rate is high beneath the perennials but mostly low at the interspace. At the interspace an algal crust may be formed which has a low infiltration rate and the precipitation is flushed away. The desert landforms also tend particularly to form closed basins both large and small. Such basins collect rainwater and dew and favour clumped perennial vegetation (Jewitt, 1966). The spacing between the species and also specimens may be caused by antibiotics (Odum, 1971). The root exudates may be toxic to other species, but in some cases also to the same species.

   The spacing is also important for the transport of airborne nutrients which are deposited and caught in the vegetation. The role of airborne nutrients has been very little studied, but it may be assumed that this transport is of importance and that it does not only have adverse effects, such as soil erosion (Rapp, 1974), but also favourable effects, such as increased productivity in sedimentation areas (Lundholm, 1975).

Noy-Meir (1974) has also described certain weak points in these arid ecosystems. He mentions the following four areas where disturbances may cause extensive changes:

1. Susceptibility to damage of reserves. Any factor which drastically increases the mortality of the resistant reserve forms (seeds or eggs) or the disappearance of the reserves of nutrients to be used for rapid response to pulse transitions will be dangerous.

   Rodents and ants are very important in the ecosystems in southern Tunisia, as durin some years they may consume up to 75 % of the seeds of the dominating plant species (G. Novikoff, pers. comm.). In the same way, grazing, which prevents seed setting or the build-up of belowground reserves of nutrients in grasses, may have very sizable effects. Franclet & Le Houérou (1971) reported from Tunisia rodent densities corresponding to a grazing pressure of 1.3 sheep per hectare.
2. Susceptibility to lagging components. As pointed out, it is important that the changes in population size of the different organisms follow the environmental changes. If some species lag in the response to these changes – for example, if a consumer continues to breed – the whole system may be destabilized. Introduced species may frequently produce this effect; examples of this are rabbits and sheep in arid Australia (Noy-Meir, 1974).
3. Low density, biomass and productivity. The irregular distribution pattern of the species requires extensive areas if the species are to survive. If sufficient areas are not available, species may be lost to the ecosystem. An important factor is whether species abundance and distribution ranges are influenced by neighbouring ecosystems.
4. Susceptibility to topsoil erosion. "Due to low plant cover, erosion forces are high in arid and semiarid regions. In many of these regions a thin topsoil layer (5–10 cm) is critical for the plant establishment and growth" (Noy-Meir, 1974).

Rapp (1974) has shown the extent of soil erosion. Novikoff (1975) has stressed both the biotic and abiotic factors influencing the different erodibility of soils. Lundholm (1975) has pointed out the characteristics and importance of dry deposition in relation to the ecosystems, with the concomitant transport of nutrients and hazard of accumulation of toxic substances.

Stability of ecosystems

The earlier ecological hypothesis about diversity-stability and a close correlation between these two concepts is now strongly questioned (Holling, 1973; Goodman, 1974; May, 1974; Margalef, 1974; Noy-Meir, 1974). It was formerly believed that the tropical humid forest with many different species was very stable but that the arid ecosystem or arctic areas with few species were unstable. In connection with the arid zone the term fragile was used frequently. The background to this discussion has been the human impact on the different ecosystems. Now it has turned out that the tropical humid forests are very sensitive to human actions.

The rather confused discussion has partly been caused by the fact that there are many different kinds of stability. To clarify this, Holling (1973) and Noy-Meir (1974) have suggested that the concepts of resilience and persistence be used. Resilience refers to the probabilities of qualitative changes and an ecosystem with high resilience has a large variation, but it springs back to its former structure. It has high plasticity around an average. Persistence refers to the ability of a system to remain constant under the environmental influences, and high persistence means a small variation.

Orians (1975) has pointed out that the analyses of the stability-diversity problems so far have dealt with variations in time and not in space and that the analytical problems in dealing with both time and space are formidable, but that such work has started. Murdock (1975) has suggested, based on model studies, that increased stability might be achieved by spatial diversity. In the real world this is what the nomads have created with their system of subsistence economy. An important variable in this spatial diversity in the arid zones is uneven distribution of precipitation.

There is a certain antagonism between the two concepts. Some arid ecosystems have high resilience but low persistence. The humid tropical forests have high persistence but low resilience.

The crucial question is the resilience of the arid and semiarid ecosystems and their ability to recover from the impact of man. Noy-Meir (1974) is of the opinion that the arid ecosystems in Asia and Africa have shown a high degree of resilience when the nomadism with its strong human impact was developed.

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Chapter 2

DOMESTIC ANIMALS IN ARID ECOSYSTEMS

B. LUNDHOLM

It is often said that the main reason why arid ecosystems are destroyed by overgrazing and erosion is that the domestic animals are not adapted to these ecosystems. The interaction between arid ecosystems and domestic animals has been taking place for thousands of years. Wagner (1975) points out that one of the most important differences between the North African and the North American arid ecosystems is that the former have evolved over a long period with man and his animals as integrated components. The adaptation of the various domestic animals to the arid ecosystems in Africa and the Near East will be analyzed below.

Domestic species

Sheep and goats

With the exception of the dog, the first animals to be domesticated were sheep and goats and, as far as is known, this took place in the Near East. The difficulties of distinguishing between the bones of the two species make it difficult to work out the early history in detail. The earliest remains of domestic sheep were found in Zwai Chemi in northern Iraq, and they are 10,800 years old (Reed, 1969). The earliest remains of domesticated sheep or goats in North Africa were found in Cyrenaica and have been dated on 6,800 or 8,400 B.P. The wild progenitors of both species, the mouflon (*Ovis musimon*) and the bezoar goat (*Capra aegagrus*), occur in the Near East and are adapted to semiarid areas.

From an ecological point of view both species are well adapted to coping with the fluctuations in arid ecosystems. They can have more than one young at the same time. This is particularly the case with the goat – the Black Bengal goat, for example, has about 78 % multiple births (twins and above) (Devendra & Burns, 1970). Most races are mature before they are one year old and produce their young after a gestation period of 140–150 days. The interval between kiddings may be as short as 240 days. One of the differences between domesticated animals and their wild progenitors is that the former mature earlier, and there is thus a shorter span between the generations (Lundholm, 1947). This short generational span allows of more rapid changes in population size and constitutes a good adaptation to the hazards of arid lands.

The importance of large litter size and short generation time is illustrated in Fig. 2.1, which shows the increase in the size of a population initially consisting of two adult females. Some generalized examples have been chosen here which could represent different races of domestic animals. The cow and the sheep are assumed to produce one young a year and the goat to produce twins. The sheep and the goat produce young at the age of one year and the cow at four. The camel produces a calf every second year and has the first calf at the age of five years. During a series of good years it is thus possible to build up large populations of goats.

The sheep is particularly adapted to grazing. Its wild progenitors lived in the dry forests of the Near East. The goat is originally a mountain animal and a pronounced browser. However, depending on available feed, the goat may also be a grazer and thus shows great adaptability (Knight, 1965). The goat also appears to have a better ability for utilizing fodder than either cattle or sheep (Table 2.1).

Table 2.1. Apparent digestibility (%) of various dietary constituents by different ruminant species (from Devendra & Burns, 1970).

Constituent	Goat (n=2)	Sheep (n=3)	Cattle (n=3)
Dry matter	59.7	59.9	53.5
Organic matter	64.0	62.6	56.4
Crude protein	66.4	64.1	49.5
Crude fibre	66.9	64.3	61.6

Even if the numbers on which Table 2.1 is based are small and even if there is variation between the races of the different species, it is clear that cattle use fodder in a less efficient way. This also depends on the quality of the fodder. Devendra & Burns (1970) say:

> "It is probable that under certain conditions or with certain feeds (particularly those of high fibre content, as is often the case in the tropics), goats can utilize nutrients better than other ruminants; if this is so it should militate in favour of their distribution in areas where food is scarce and fibrous".

In this connection it is of interest that the first domestic sheep were hairsheep and had no wool. The wool was developed later on (Ryder, 1969). The appearance of the white wool offered a good protection against excessively high temperatures. Schmidt-Nielsen (1964) gives an example where the surface temperature of the wool was 87°C and the skin temperature under a 4-cm layer of wool was 42°C – a difference of 45°C. Even if the wool did not initially evolve as a mechanism for heat protection, it served this purpose well in tropical dry areas. The domestic goat also shows adaptations to extreme arid conditions. Shkolnik *et al.* (1972) have reported that Bedouin goats from

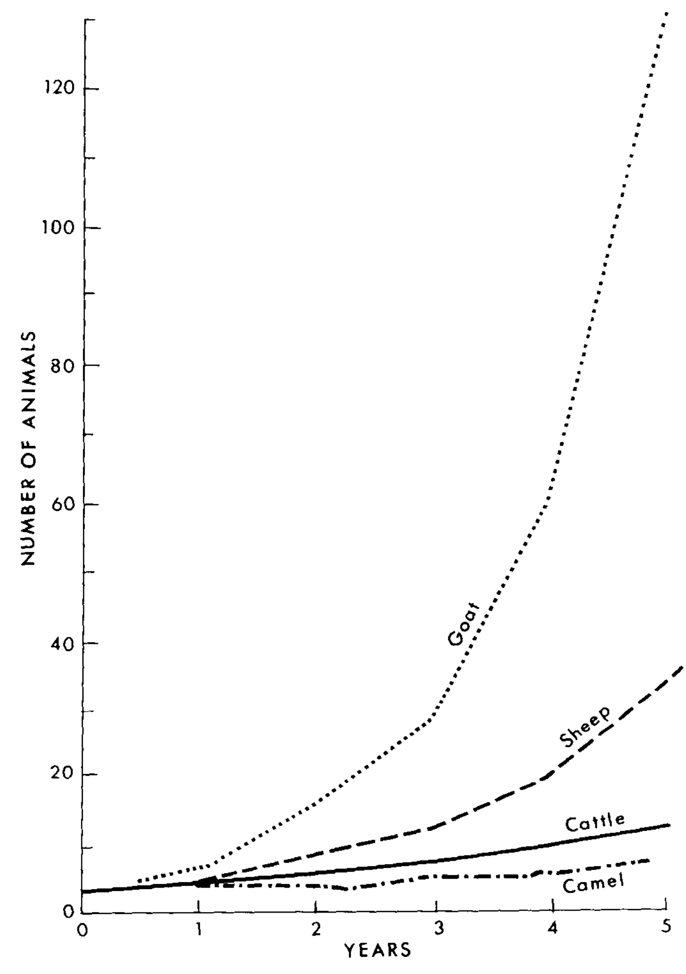

Figure 2.1. The increase of herds of domestic animals. Assumptions: The herds start with two females. Sex ratio 1:1. Number of young; cow 1 per year, sheep 1 per year, goat 2 per year, camel 1 per two years. First young: cow 4 years, sheep 1 year, goat 1 year, camel 5 years.

the eastern Sinai – where the average annual precipitation is only 20 mm – have a water consumption that is only a quarter or a sixth of that of mountain goats in Israel. The body weight of these Bedouin goats is half that of the mountain goats and their calorie intake only a third. The goat is more resistant to heat than the sheep. In Senegal it was observed that during the Sahelian drought the first animals to die were the cattle, followed by sheep, the last survivors being goats and camels (Le Houérou, 1973; G. Novikoff, pers. comm.).

The domestic sheep is more adapted for multiple use than the goat, but they both occur together in Africa and the Near East. The goat can use poorer feed, responds better to feeding in terms of meat, and is a good milk producer. By occurring together the two species can utilize the primary production in a more efficient way (Campbell *et al.*, 1962). Feeding differences in goats and sheep are now being investigated in Tunisia (Wagner, 1975).

Cattle

Wild cattle once occurred in Europe, northern Africa, Egypt, and the Near East. The first certain evidence of domestication comes from Thessaly in Greece, and is 8,500 years old (Reed, 1969). The earliest remains from Iran are 7,450 years old (Reed, 1969). The zebu type found in northern Mesopotamia has been dated back to 6,500 B.P. (Zeuner, 1963). In Egypt, domestic cattle occurred as far back as 5,700 B.P. at about which time the Pharaohs were hunting the aurochs in the Nile Valley (Zeuner, 1963). Information is scantier concerning the first appearance of domestic cattle in other parts of Africa. It is important to note, however, that cattle herders were well established in the Tibesti area in the central Sahara as far back as 6,000–7,000 years ago. During this period the climate was more humid and more surface water was present (Matlock & Cockrum, 1974). In general, early domestic cattle encountered less arid conditions than did sheep and goats. Today, the main cattle-producing areas in Africa are the Sahelian zone, parts of East Africa, and parts of southern Africa (Fig. 2.2). As the figure also shows, the distribution of cattle depends on the distribution of the tsetse fly and the trypanosome parasite.

From an ecological point of view, domestic cattle are not well adapted to coping with the fluctuations in arid areas. The slow maturation, with the first calf being born at the age of four years, implies that the cow has to go through several dry periods before calving. There is no increase in weight but during dry periods a loss instead. Western cattle races need eight kilos of fodder to produce one kilo of meat. West African races need twenty kilos of fodder to produce the same amount of meat (Matlock & Cockrum, 1974). These probably overgeneralized figures are quoted as examples of average values, although large variability can be expected owing to different qualities of cattle and grazing.

Another drawback is the strong water-dependence of cattle. They need water in arid areas – every or every other day during the dry season. The grazing distance from a water hole cannot thus be too long. Information on the grazing distances of different animals varies greatly, depending on local conditions and the environment. However, it is beyond the scope of this report to review this material.

Zeuner (1963) examined the reasons which led to domestication of the large and difficult wild oxen, when the more easily handled goats and sheep were at hand. He pointed

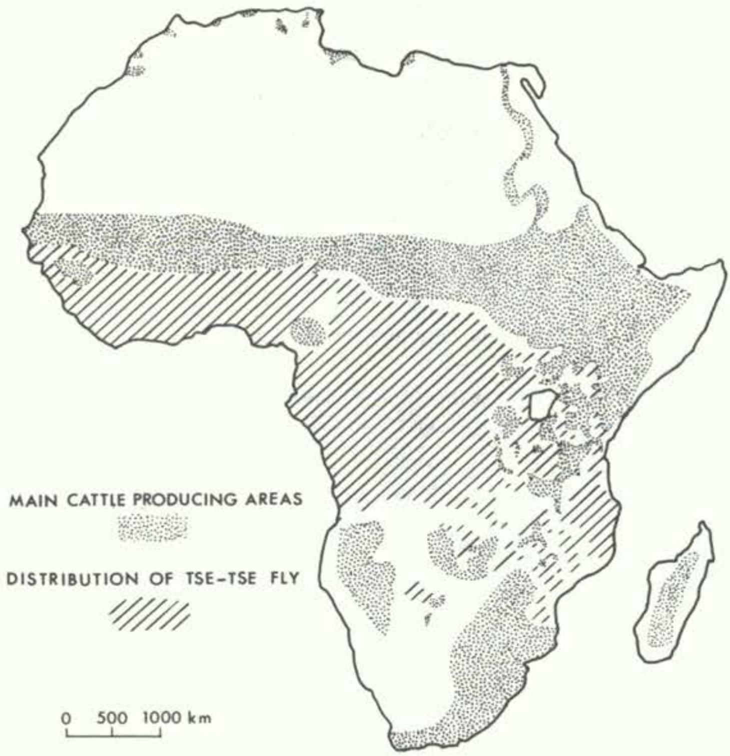

Figure 2.2. The distribution of cattle and tsetse fly in Africa. (Source Abercrombie, 1974.)

out that the need for meat was hardly the motive, since hunting readily provided the necessary meat. Zeuner concluded that milk was the essential product linked to domestication. It has also been suggested that social and religious motives were important for the early domestication. It seems clear, however, that meat production was not the goal of early cattle domestication and it is also important to keep in mind that the indigenous African cattle races have never been bred or selected for meat production.

Camels

The domestication history of the camel is not very well known. The wild single-humped camel occurred in the Near East, and the domestication was assumed to be in central Arabia and was dated to 3,800 B.P. (Zeuner, 1963). Zeuner, however, presents a picture of a loaded camel from Egypt dated to 2,850–2,650 B.P., and in a footnote he gives the date of the earliest domestication as 4,700 B.P. Wild camels occurred in North Africa, but it is uncertain whether they were later domesticated or whether the domesticated variety arrived in North Africa from Egypt. However, the important fact is that wild camels were once present in the North African arid ecosystems. Domesticated camels have been common in North Africa since the second century A.D. (Le Houérou, 1968).

The camel develops very slowly, maturing sexually at the age of five years. The interval between calves is two years or more (Sweet, 1965). Changes in population size are thus slow (Fig. 2.1). The camel has instead adapted itself to environmental fluctuations by a series of very special physiological and ethological mechanisms. These adaptations make the animal very independent of water resources. The camel can graze up to 80 km from the water hole and needs only to be watered every five or six days in the dry season. This depends of course on the temperature, and a review of the available data shows large variations. H.N. Le Houérou (pers. comm.) has pointed out that camels can stay without water for months when the fodder is suitable. Gauthier-Pilters (1974) has shown that camels can utilize very poor grazing. Her figures on camel density are, however, not realistic, as they assume a far too high productivity (H.N. Le Houérou, pers. comm.).

Camels are of importance to nomads, especially for milk. The lactation period is 11–15 months, the daily output being 1–7 litres (Sweet, 1965). A nomad family needs 18–20 camels for the annual milk supply. Half of these are in calf. Camels can traverse great distances. In Arabia they have a migration range of between 700 to 800 km (*op. cit.*). This mobility is necessary because of the sparse and sporadic distribution of vegetation and rainfall. The swiftness of the camel is also important for desert travel and for an exchange of information on grazing conditions. Sweet (*op. cit.*) gives account of the systematic collection of information on rains and vegetation by the Bedouins in Arabia. This can only be done in the traditional society by means of swift camels. The nomads also have very detailed knowledge of individual plant species and vegetational types.

Donkeys

Although not important as grazing animals in Africa and the Near East, donkeys occur in the whole area and are used mostly for transport. Their wild progenitors once occurred in both North Africa and eastern Africa; now they only survive in the most arid parts of Somalia and Nubia. This species is without any doubt very well adapted to arid ecosystems. The history of domestication is not well known.

Wild ungulates and domestic animals

Petrides (1974) has raised the question of whether the large hoofed wild animals in Africa are well adapted to the ōpen grasslands. He is inclined to assume that the present overgrazing in African national parks indicates a poor adaptation. The reason for this may be that the animals in the restricted areas have lost the possibilities of migration.

The ongoing research of the ecosystems of the Serengeti Plain in Tanzania is of great interest. This plain has been grazed for a long time by very large animal populations of wild animals, yet there are no signs of overgrazing. The movements of grazing herds are significant. They slowly describe large circular movements, covering a uniform area a few times. Herdsmen in Tunisia graze their herds in the same way. If the grazing is good, the herds move slowly, and if the grazing is poor they cover the ground more quickly (G. Novikoff, pers. comm.). Baskin (1974) pointed out that it is possible that these circular movements of the wild animals have been used in connection with primitive domestication (Fig. 2.3). He also stated that "free pasturing produces superior rates of body

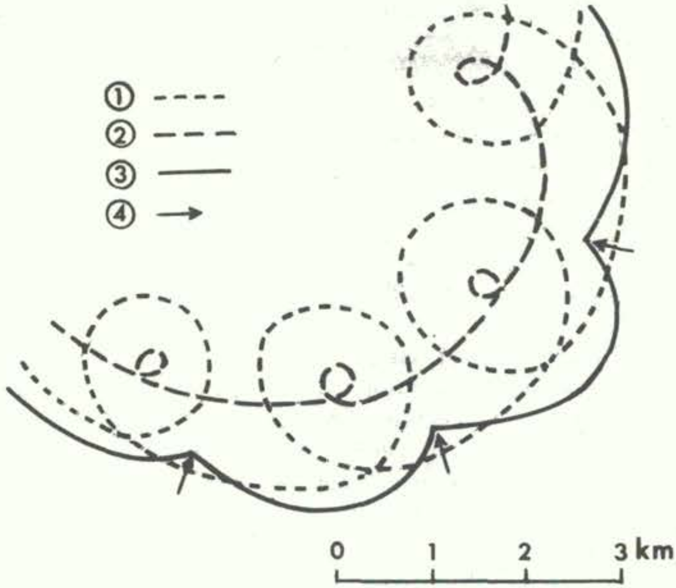

Figure 2.3. Diagram of movements of sheep and shepherd in hilly desert. 1 = track of the right flank of the herd. 2 = track of the more experienced and slower animals on the left flank. 3 = track of herdsman. 4 = points at which herdsman exercises influence. After Baskin (1974).

growth and fattening, and it allows a more even distribution of grazing which in turn aids the conservation of grazing grounds".

Walker (1974) claimed that it is lack of water that forces large herds of wild animals to leave an area, which is thus spared overgrazing. The opening up of new water holes in national parks and in grazing lands leads to increased risks for overgrazing. Too much drinking water and restricted migration result in overgrazing and in deterioration of rangeland. It is interesting to note the similarity to what happended in relation to the Sahel catastrophe where drilling supplied water and increasing agriculture restricted the movements of the herds.

To recapitulate, domestic animals have long been integrated parts of – and more or less adapted to – the arid and semiarid ecosystems in the Near East, northern Africa, Sudan, and West Africa. Certain domestic species have descended from wild progenitors in or near the area. The well-established pastoral nomadism has been competing with the large wild ungulates both for fodder and for water during the dry seasons. This confrontation has resulted in the disappearance or decimation of populations of wild animals. Sheep, goats and camels predominate in North Africa, and there are very few cattle. All four species occur in the sourthern parts. In East Africa the competition between domestic animals and wild animals has not been as strong, nomadism is of later origin than in northern Africa, and the pressure on the arid and semiarid ecosystems is recent. In the arid and semiarid areas of southern Africa the wild herds have not competed with nomads. The exploitation of these areas by means of domestic animals started with the arrival of the Europeans. It must be stressed, however, that in the more humid areas of southern Africa well-established animal husbandry existed long before the coming of the Europeans.

One of the last large arid and semiarid areas to be exploited is the Kalahari in Botswana. The exploitation is directed towards meat production by using methods developed in the USA and Australia. Here there are possibilities for studying how an undisturbed ecosystem reacts to the impact of modern man and his technology.

Productivity of arid and semiarid areas

The natural productivity in an ecosystem is of great ecological interest. However, in this connection, only the productivity from a human point of view will be considered. This is tantamount to asking the question: How much can man take out from the ecosystem? Margalef (1974) has pointed out that it is much easier to exploit ecosystems subject to variations than to exploit more persistent ones. It is thus very difficult to exploit the persistent humid tropical forests. One should thus not draw a parallel between the natural productivity expressed as a high photosynthetic rate and the yield man can obtain from a specific ecosystem.

Humid tropical forests, for instance, have a very high natural productivity, but would require large inputs of human and fossil-fuel energy if they are to be cultivated. They thus offer a high environmental resistance to Western methods of cultivation.

The possibilities for sustained yields and the needs for additional input of energy (labour, fertilizer, pesticides etc.) differs with the techniques and types of land-use. In Fig. 2.4 an example is shown where the nitrogen content in the soils is decreasing during agricultural cropping but increasing under pasture ecosystems.

Since information is lacking about both the structure and functioning of arid ecosystems, it is impossible to give advice on management for sustaining yields. Only some important points are given below for general guidance.

Primary production is naturally of importance, but it is difficult to measure. Instead, the biomass – which is the base for the production – is measured. However, the value of these measurements, is rather limited for an evaluation of the productivity, since very little is known about the statistical variation and the interrelationship of these two variables. This is especially the case in arid and semiarid ecosystems with their large environmental variations. An additional difficulty in arid areas is that a large part of the production is belowground and this, as well as the belowground biomass, is extremely hard to measure. These belowground parts often contain the reserves of nutrients and water that the plants need for surviving extreme conditions. The classical information about the direct correlation between primary production and rainfall was provided by Walter (1954) and is based on research in West Africa. Similar information is now available from Rhodesia (Walker, 1974) and from the arid areas in North America (Wagner, 1974). Detailed information from North Africa is given in numerous papers by Le Houérou (1962, 1975) and by Floret & Le Floch (1973). Wagner (1975) has also compared the productivity in the Tunisian ecosystems strongly influenced by man with corresponding ecosystems in North America. He

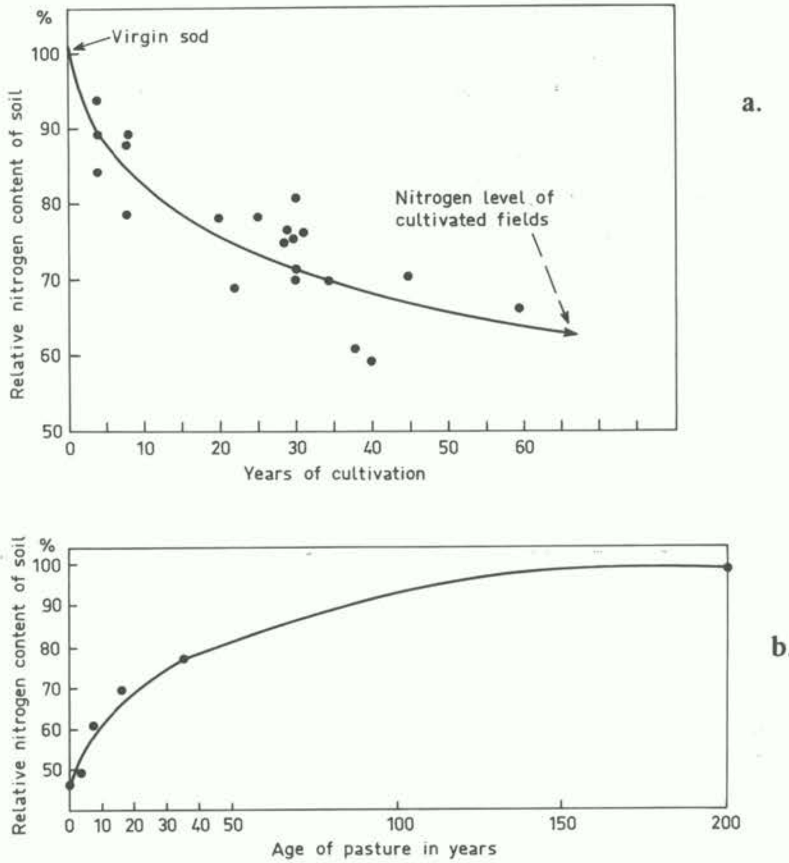

Figure 2.4. Changes in nitrogen content in the soil of cropped ecosystem (a) and pasture ecosystem (b) (Rosswall, 1976).

found the Tunisian ecosystems to have a higher productivity and less annual variation. An increase in precipitation by a factor of six, from 15 mm to 90 mm, resulted in an increase of only 10 % in the *Rhanterium* bush, which represents 96 % of the above-ground biomass.

Wagner (1976) has analysed the relationship between primary production and annual precipitation in North America (Fig. 2.5). The regression line for the arid end of the scale is very steep. There is a very pronounced variation between the different years in dry areas. "Thus a factor of 6 to 8 is not an excessive expression of the range over which the entire primary production may vary". In most forest areas the variation is about 20 %.

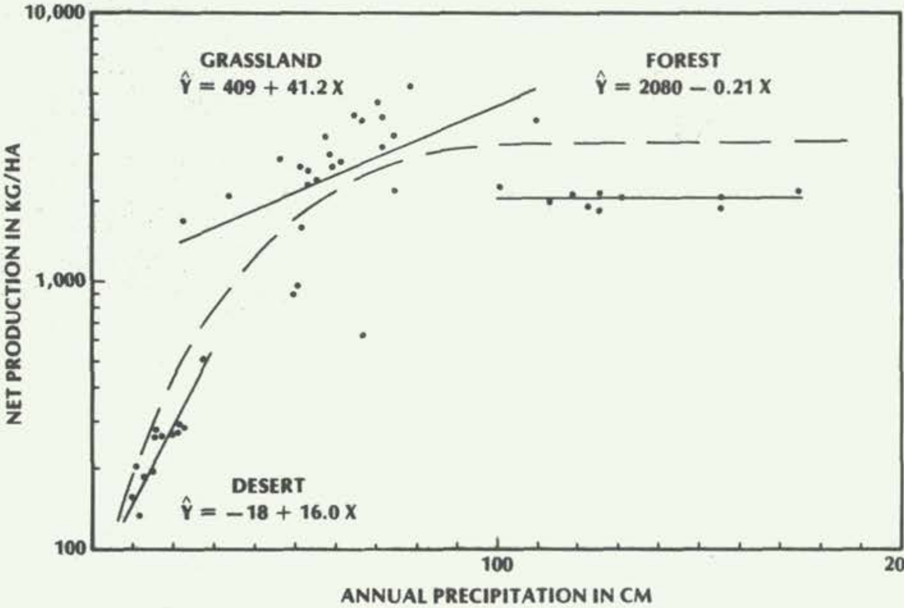

Figure 2.5. The co-relation between net production in kg ha^{-1} and the annual precipitation in cm. The equations and the straight lines show the slope in the different parts of the dotted curve (Wagner, 1976).

Walker (1974) has shown that it is possible to increase the grass cover by reducing the trees either by using animal grazing or by direct bush clearance. However, the protein content of the grass during the dry season is too low for the cattle, and the available protein comes from bushes, which have a high protein content.

In recent years it has been stressed that cattle can only survive in arid and semiarid areas when suitable browsing is available. It is difficult, however, to measure the browse and the amount which animals take out from the ecosystems. These problems have been treated from the methodological point of view by Ahlén (1975). Walker (1974) has investigated the role of trees in relation to available fodder. Even if there is competition for nutrients between the roots of the grasses and the trees, a sparse tree vegetation increases the available grazing. The shade from the trees creates a better microclimate for the grasses and nutrients are transferred via stem flow to the soil. Walker also showed that when the ground is covered with grass and litter, the infiltration rate of water is higher (Fig. 2.6). If litter is destroyed by burning or is blown away by wind, the infiltration rate is changed. The role of the matting in areas lacking higher vegetation has been discussed earlier.

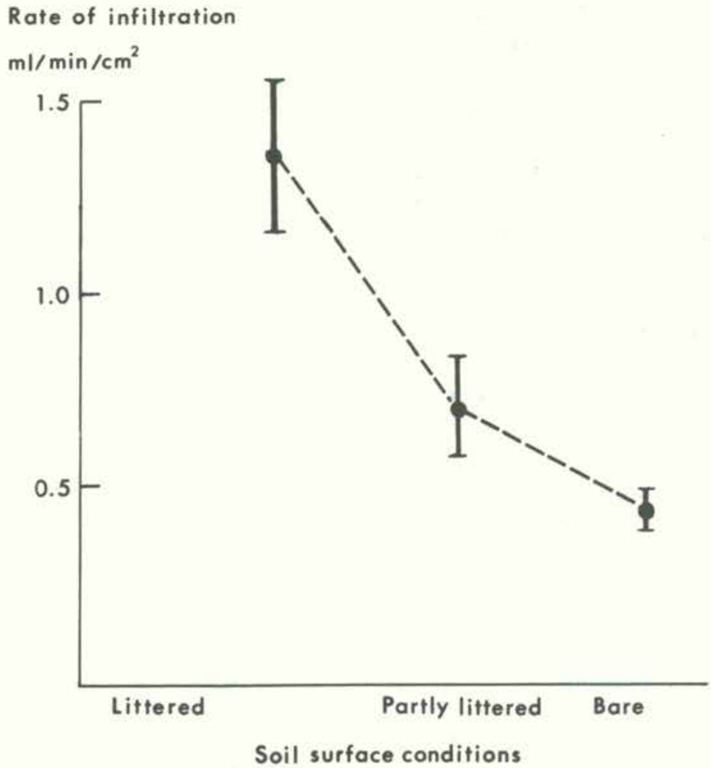

Figure 2.6. Rates of infiltration (ml min^{-1} cm^{-2}; mean ± 2 s.e.) under three soil surface conditions: littered, partly littered, bare soil (from Walker, 1974).

The annual productivity is not the crucial problem in discussing man's use of domestic animals in semiarid and arid areas. It is very important to realize that animal husbandry varies fundamentally in different areas. In some areas fodder may be available the year round, and in others it may be limited during certain seasons. The critical variable in the arid zone is the fodder supply during dry periods.

The nomads have tried to overcome difficult periods by resorting to special grazing reserves. However, in many cases it has been impossible to keep these areas intact for emergency use. The increased pressure from man and his animals has swamped these areas. In many cases, both in the Sahel and in Ethiopia, they have been used for agriculture, leaving the nomads without a possibility to survive the hard, prolonged dry periods. In some areas, such as in Tunisia, fodder for the dry season is collected from the annual plants during the wet season. Le Houérou & Froment (1966) have estimated the amount annually collected in Tunisia at 12 million F.U. (fodder units). Similar activities on a large scale are carried out in Senegal and Niger (Le Houérou, 1973) and have also been suggested for Somalia (C.F. Hemming, pers. comm.). The nomads have also tried to respond to the changes by selling out animals during the dry periods; this, however, is difficult in a subsistence economy. The only possibility for overcoming these difficulties is to try to introduce new methods to provide new feeding resources during the dry periods. This means lowering the seasonal changes in the vegetation and its nutritional value or trying to bring in additional resources from outside. Another possibility is to use combinations of domestic animals in order to promote a more multiple use of the vegetational cover and to adapt the changes in the population size both to available fodder and to man's need for food during different parts of the year. Changes in the age structure of the herd may also be of importance, as young and old animals graze in different ways which will effect the vegetation cover. However, if additional resources are put into the arid and semiarid ecosystems, the total ecological condition must be evaluated, since these ecosystems react quickly and the yields might easily be lowered.

The productivity of the arid zone has been discussed by many international bodies in connection with the Sahel disaster. During these discussions range mangement has often been the focal point. Two main aspects have been emphasized: to **create a vegetational cover** that – through the use of animals, mostly cattle – can produce **meat for sale.** In considering these two matters it is very often forgotten that one is dealing with ecosystems in which the flow of nutrients is essential for productivity. In the cycling of the nutrients the decomposers are as essential as the primary producers. The speed of this cycling determines the productivity rate. If the decomposers slow down their activity the productivity in the system decreases. The decomposers act in two main areas: in the digestive system of the ungulates and in the soil. According to preliminary results, investigations in the U.S. IBP grassland biome have shown that a large part of the nitrogen in the fodder is very quickly returned to the soil by the action of intestinal microbes. If the grazing animals are removed, the nitrogen cycling is slowed down. A certain amount of grazing thus improves the productivity. This has been proved for wild animals (McNaughton, 1976). The microorganisms in the upper layers of the soil are responsible not only for decomposition but also for fixation of atmospheric nitrogen. If this layer is destroyed through erosion by wind and water, productivity is seriously reduced. Research on these important matters has now started in Tunisia (Wagner, 1973, 1974, 1975).

When the productivity of an area is discussed, the term "carrying capacity" is used both in connection with man and with animals. However, this term must be clearly defined in order to be useful. As regards human beings, it is a question of how many people with a certain way of living and with a certain standard of living can be supported. As regards animals, it means a difference between a subsistence and a market economy. The goal for a subsistence economy could be that the highest possible number of animals survive drought periods. Another goal could be the supplying of blood or milk the year around. Cash production is the main thing in a market economy. It may be produce meat or hides, but what needs to be decided, however, is which kind (beef, mutton, goat meat) and which quality is to be produced. Production should be planned on the basis of these decisions. We have to remember that the domestic animals in Africa have been developed for a subsistence economy and not for a market economy. The confrontration between these two systems is one of the reasons for the present difficulties, arising when subsistence-adapted animal populations are used for meat production.

Pratt (1975) has given an overview of the present state of knowledge in relation to range research. He emphasizes the following elementary gaps in our knowledge: We have no reliable statistical data on livestock populations and we need methods for such assessments. There is also need for methods of measuring the productivity and utilization of browse plants. We must have an ecological and economic evaluation of mixed stocking. He also states: "The analysis of systems in terms of their socioeconomic, environmental and biological components is a major field of research in its own right".

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Chapter 3

TRADITIONAL LAND USE IN MARGINAL DRYLANDS

A. HJORT

Introduction

Geographically marginal areas hold out a precarious livelihood to the inhabitants – and depending on limiting ecological factors, a faulty decision or two might well spell catastrophe. In order to distribute the risk it is common to practise mixed husbandry. Trading or hiring out as labourers on various construction jobs is also practised when possible, but such activities are beyond the scope of the present chapter. The main subject for discussion here is how – given their complex and potentially dangerous situation – the people inhabiting marginal areas traditionally use the land.

There are many ways of categorizing this population – for example, in terms of mobility (nomadism) or of economic activity (pastoralism). Depending largely on the degree of organized agriculture, the population may be arranged into nomadic, seminomadic and transhumant (Fig. 3.1). A set of frequently used definitions is given below (for a similar set of definitions see FAO, 1972):

Nomadic people: pastoral groups depending largely on livestock for subsistence, and supplementing it with some farming when possible. Following the irregular distribution of rainfall, they migrate in search of pasturage and water for their animals. Since cattle also need salt, salt licks may partly influence the migrations.

Seminomadic people: pastoral groups depending largely on livestock, but also practising cultivation at a base camp where they return for periods of varying duration.

Transhumant populations: groups practising combined farming and livestock raising during favourable seasons, but migrating seasonally along rather regular routes when grazing diminishes in the farming areas.

These categories are not always distinguishable. However, they are useful in that they point to different kinds of land use. People in marginal lands adopt whatever land use is suitable, given local limitations. The complexity of the matter has been pointed out by Irons & Dyson-Hudson (1972), among others. They list a number of basic variables that may be different from one setting to the other – for example a combination of hoe agriculture and some form of transhumance during one season, or symbiosis

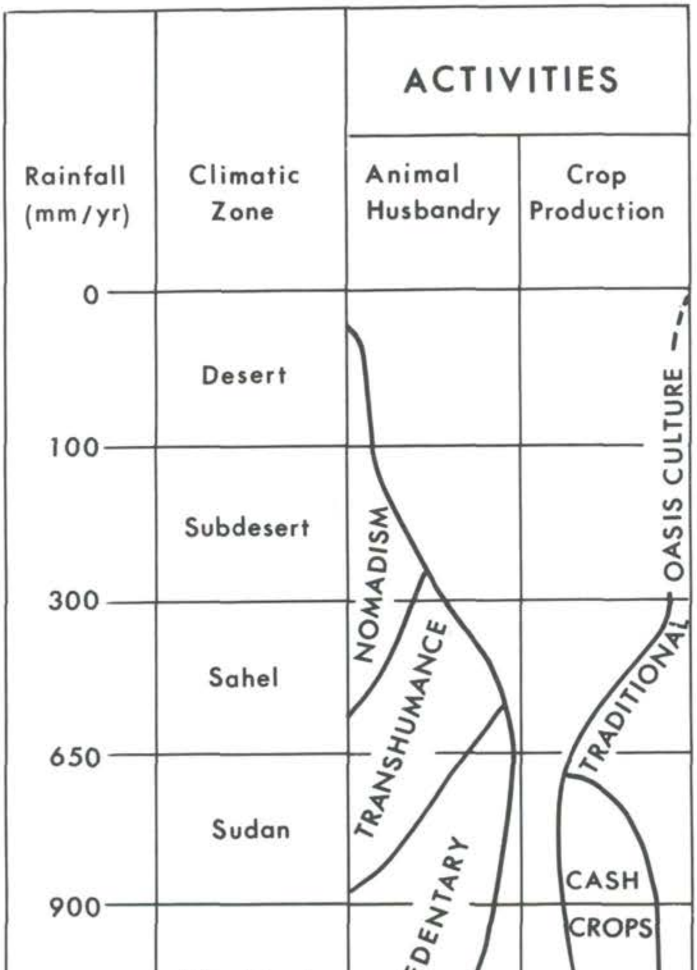

Figure 3.1. The general correlation between rainfall and human activities in Africa (Matlock & Cockrum, 1974).

between people practising different kinds of land use. These two cases will be exemplified below. However, it is necessary to make the distinction between predominantly pastoralist and agricultural groups as the different foci influence social organization, labour inputs, etc.

The land use of nomads is often a source of disquiet to sedentary farmers and regarded by them as a threat. The reason for this is that nomadism entails migration – often with total disrespect for boundaries – and has a connotation of "not respectably settled".

If one were to analyze the basic productive unit, normally the household, noting the economic and other goals at this level and taking into account all the constrains imposed upon it, one would have a better understanding of attitudes and practices all too readily labelled "backward" and "conservative".

Strategies against natural hazards

Two examples are outlined of different strategies based on varying local conditions. The cases selected are fairly typical of the respective kinds of economy. One concentrates on farming and herding and the other on herding strategies in making use of grazing areas.

Samburu strategy: pastoralism and diversification

The Samburu (Spencer, 1965) are a nomadic people numbering about 30,000 and inhabiting an area northwest of Mt. Kenya. Their economy is entirely based on cattle, sheep and goats. Donkeys are used for transportation. The staple food is milk supplemented with mutton and goat meat, and in times of drought, with blood from the cattle. Oxen are slaughtered in times of acute crisis.

A typical settlement consists of four to seven households situated not too far away from a water hole. The geographical position is often permanent but with a flux of households which migrate on the average every third month.

Social standing is measured by the number of cattle possessed, in a way typical of East Africa. One household (6–8 persons) has on the average 80 head of cattle. The variations are great, and poor households in a settlement are economically dependent on the richer for their daily rations.

It is possible to distinguish three limiting factors in regard to the sizes of Samburu cattle herds: firstly, the stocking rate; secondly, cattle diseases; and thirdly, herd administration techniques.

The Samburu claim that a good cow should reproduce from the age of 30 months, producing one calf every tenth month until the age of about 11 years. This must, however, be regarded as an ideal maximum (P. Spencer, pers. comm.). Other sources (Dahl & Hjort, 1976) indicate that it would be more realistic to assume an average rate of around half of the previously stated ideal.

Occasional epidemics kill off large proportions of cattle. Apart from relieving the pressure on grazing, a decrease in the herds reduces the economic base for household consumption and also causes trading difficulties. When quarantine restrictions are in force no cattle can be sold. Thus trade in cattle is a vagarious source of income.

We shall now discuss the third of the above-named limiting factors, *viz.*, herd administration techniques.

In order to optimize land use and safety, each family divides up its herd into two parts. The best grazing grounds near the settlement are used by the subsistence herd, which provides the household with milk. Cattle not immediately needed for milk production constitute the dry herd, which grazes further away so as to avoid overgrazing in the vicinity of the settlement. This herd is often administered independently as it may be quite far away. The cows in this herd often do not give milk as the grazing may be poor and foraging wearisome. Individual cows are circulated between the herds so that parturient animals are brought from the dry herd to the subsistence herd.

The herders of the dry animals may remain in one place for 2–3 weeks at the most, the course of migration depending on the unpredictable rainfall that varies greatly from year to year.

Another way of diversifying animals is via an institutionalized stock-friend system, where friendship is sealed with gifts of cattle. In this way a complicated mesh of debts and claims is established between male Samburu. The net result for each individual makes up his wealth in terms of cattle. Claims are pressed when more animals are needed, when, for example, animal numbers have been depleted by deaths or when animals are required for a dowry. In this way the stock-friend system may be seen as an insurance (see Chapters 5 and 10).

The Samburu relations with the Rendille, a neighbouring nomadic people, can be looked upon as a state of symbiosis (Spencer, 1973). The Rendille are camel nomads and thus practise a different type of land use; their camels are basically browsers, while the Samburu cattle are grazers. The following limiting factors keep the Rendille camel herds at a more constant level: the lower degree of fertility of the camels as compared with cattle; higher mortality of the young; and administrative difficulties. The camels of the Rendille need to move over much larger areas than the cattle and are physically harder to manage. This means that most male family members who are physically fit are far away with the surplus camel herds. For those remaining in the settlement it is not necessary to live very close to a water hole as camels move faster than cows and need less frequent watering. Accordingly, Rendille settlements are quite large as compared with Samburu settlements. This is yet another factor of security as networks of friendships are developed just as with the Samburu (Table 3.1).

In contrast to the Rendille area it is possible to build up a herd of cattle within the Samburu area in a relatively short period of time, provided that there is sufficient grazing. This situation enables the Rendille to migrate to the Samburu, that is, to "export their population increase", which is normally carried out via intermarriage.

In this way the Samburu and Rendille complement each other as far as land use is concerned. The alliance also includes a solution of possible shortcomings due to differences in the pastoral economies in a way that normally benefits both parts. However, when the ecological balance is threatened – for example, via overgrazing – the system breaks down.

The Nuer strategy: hoe cultivation, transhumance and pastoralism

The Nuer (see Evans-Pritchard, 1940) inhabit an area in southern Sudan which is flat and has clay soils. It is covered with high grasses during the rains and is sporadically

Table 3.1. Brief description of the Samburu and Rendille economies (Spencer, 1973).

	Wet season	Dry season
STOCK PERFORMANCE		
Camels	Not watered at all, copious supplies of milk	Watered every 10–14 days, moderate supplies of milk
Cattle	Watered every day, adequate supplies of milk	Watered every 2nd or 3rd day, limited supplies of milk
Sheep and goats	Watered every 10–14 days, left to breed	Watered every 4–5 days, useful for meat and (goats) milk
SOCIAL IMPLICATIONS OF ECONOMY		
Settlements		
Rendille	Very large and widely scattered	Smaller and concentrated on brackish water points
Samburu	Small to moderate and generally scattered	Smaller and concentrated on certain water points
Camps		
Rendille	Start to join settlements towards end of season	Leave for remoter areas and remain for long periods
Samburu	May occasionally leave settlements	*Ad hoc* arrangements, often not too far from parent settlement

wooded. The rains are very heavy and the area is traversed by large rivers that annually flood the flat land. Then the rains cease and the rivers subside, the area is subject to severe drought. These conditions shape the life of the Nuer and have implications for their economy as well as for their political and social organization. The inhabitants consider the country to be more suited for cattle husbandry than for horticulture. In spite of this, both activities are given great emphasis owing to great variations in rainfall.

There is one rainy period – roughly from mid-May to mid-November – when the plains are flooded by surface water from the rains and rivers. This necessitates transhumance for various reasons: the cattle would otherwise quickly develop diseases of the hoof from standing in water and the abundant insect life generated would plague them. Hence village sites are selected on patches of land at higher levels. Towards the end of the rains these areas dry out first. The cattle are then moved back to the lowlands along routes which vary from year to year, depending on the supply of grass on the way. Water is generally no problem since the rivers do not dry up. At the height of the drought people dig shallow wells in the river beds.

In the beginning of the dry season the villages are split up into smaller units or camps, practicable for grazing. These units, consisting typically of people from two or three households, are made up of young people, and are often on the move. They burn the old grass ahead so as to allow young shoots to grow. The cattle can then graze there after three days.

This practice is discontinued as the dry season progresses, since no more shoots will grow. The older members of the household then join the camps and settle down for the rest of the dry season. The respective households generally use one and the same site for years. At this time the villages are deserted completely. Fishing becomes the major source of food supply, making river banks much preferred as camp sites. Thus, grass and water are the limiting factors.

The return to the villages is usually very abrupt. When the rains begin the older people return in order to prepare the ground for sowing. The young people then return to the village with all cattle.

Millet, maize, and beans are grown at the village sites. They are consumed in large quantities (as porridge or for making beer) from August to November, that is, the time from the first harvest to the departure of the young people to the camps. When the harvests are good the women of the camps return to fetch further supplies.

The consumption of meat varies in the same way as that of millet and maize, *viz.*, low during the dry season and high during the rainy season. The meat comes mostly from cattle slaughtered for ritual and social purposes or, in situations of disaster, also from dead animals. Hardly any wild animals are consumed even though the area is rich in game. The bleeding of cattle and the hunting of wild animals are resorted to in difficult times during the dry season.

Land use is thus diversified so as to provide the following patterns of consumption:

1. Cattle generally provide the Nuer with milk the year around, the supply falling off at the end of the wet season owing to the bad grazing.
2. The milk consumption is not adequate for dietary needs. It is supplemented with fish during the dry season (or the latter part of the dry season if the harvest has been successful) and with grain and meat during the wet season (especially the latter part of it). The older people join the young folk in the camp when the grain

supply comes to an end; the storage of grains is limited.

3. If one of the food supplements fails – for example, if the fishing season is bad or if the harvest is poor, all is not lost: the cattle remain which can be bled or, at worst, consumed. Wild fruits ripening in the early part of the dry season can be consumed at times of difficulty; or wild animals can be hunted.

It is not possible to expand farming on a large scale by the traditional methods. One implication of this is that when the number of cattle decreases – because of drought, say – there are two possible responses: either to accept a deterioration in living standards or to "export" the problem of cattle deficit, that is, to raid the neighbours' cattle.

Conclusions

Three of the most general limiting factors in a pastoral economy are access to grazing, water, and salts. For transhumant people land rights are normally clearly defined, as nature is "predictable" and movements fairly well specified. For nomadic people movements are irregular, depending on prevailing conditions. Here, land rights in terms of access to grazing and salt licks are normally based on tribal or subtribal membership, while the rights to water holes are based on smaller units of membership, like clan or subclan. The reason for this is that water holes must be regularly repaired and evenly used. In addition the competition for water may be fiercer than the competition for grazing, since it is focussed on only a few points in the landscape rather than on an entire stretch of land.

A number of strategies in response to unpredictable climatic conditions have been presented above. They vary in different economies. In general terms, given limiting economic factors, the strategies aim at dispersing the resources so as to minimize risks. The traditional land use is carried out in an ecological system that is viable to quick changes, a fact that is clearly proved by present developments. Nowadays, for example, animal mortality may be drastically lowered by timely medication, which leads to a growth in the number of animals in excess of the limitations imposed by traditional land use. This in turn leads to overgrazing and, in the long run, to impairment of the system.

In the system of traditional land use, overgrazing meant a reduction in yields from the herds. With the introduction of other sources of income, it has been possible to compensate for this via alternative foodstuff sources, thus avoiding the slaughter of animals. In this way, one mechanism that in the traditional land use regulates the sizes of herds to a constant ratio vis-à-vis grazing resources no longer exists, which might result in further deterioration or collapse of the system. This and other factors of change are discussed in Chapter 5.

Agriculture is normally carried out to a certain degree in areas where it is possible to farm. However, in the traditional land use, all land that is suitable for farming is not used for this purpose. Such land is often kept unused as a reserve for grazing in times of drought. Many pastoral peoples seem to have chosen dry areas not because they are "left over" but because animal diseases are less common there (maybe also human diseases). The total farm produce in marginal areas is not sufficient, and the economies are therefore varyingly based on pastoralism-nomadism, seminomadism, and transhumance.

A brief description of the livelihood of the inhabitants of African marginal dry lands

The largest continuous areas of marginal dry lands are found in Africa. Fig. 3.2. presents the population distribution in Africa with an outline of the marginal dry lands.

The distribution of cattle is shown in Fig. 2.2. The pastoralists and semipastoralists inhabiting marginal dry lands depend to various extents on livestock. This is summarized in the following list and shown on Fig. 3.3.

The Bedouin Arabs. The Bedouin Arabs of North Africa can be classified as nomads or seminomads and they subsist mostly on meat, milk, and milk products. Their main animals are sheep, goats and camels, varying in mutual numbers such that camels dominate towards the coast. They also keep a complement of cattle, donkeys and horses. However, the Bedouin Arabs now living in the Sudan keep mostly cattle.

The Berbers. Around the eleventh century, when the Bedouin Arabs migrated from Arabia to North Africa, they forced many Berber groups to seek refuge in the oases of the Sahara and in the mountains, where they now make up the nomadic group known as the Tuareg. Other Berber groups have remained in the sub-Saharan fringes. Their economic activities vary from agriculture (e.g. the Nefusa of Libya) to transhumance (e.g. the Berbers in the Atlas mountains of Morocco) to seminomadism (e.g. the Tasuma of Mauretania) to nomadism (e.g. the Tekna of southwestern Morocco). Many Berber peoples have also played an important role in the trans-Saharan caravan trade.

The peoples of the Sudanese fringe. Further south where the four trade routes through the Sahara end, complex cultures and elaborate political systems have developed. The basic economy of all these peoples is founded on hoe cultivation with few exceptions. This is supplemented with the raising of a substantial number of cattle, sheep, and goats, and sometimes horses and donkeys. Camels are used for transporation only at caravan centres.

Mande, Voltatic, and Plateau Nigerian peoples. West of the Sudanese fringe one can identify three clusters of peoples whose economy is based on shifting hoe cultivation supplemented with the raising of some cattle. They can be regarded as an extension of the Sudanic complex or vice versa as they have several (mostly economic) features in common.

The pastoral peoples of Eastern Africa. The dry areas of Kenya, Ethiopia, and Somalia are often included in the sub-Saharan region. Here, many peoples practise nomadism to a large extent, but very little agriculture. The domestic animals are cattle/camels (usually one or the other), sheep, goats and donkeys.

The Southwestern Bantu. The economy of the Southwestern Bantu is based roughly equally on agriculture and animal husbandry. Agriculture dominates in the northern areas.

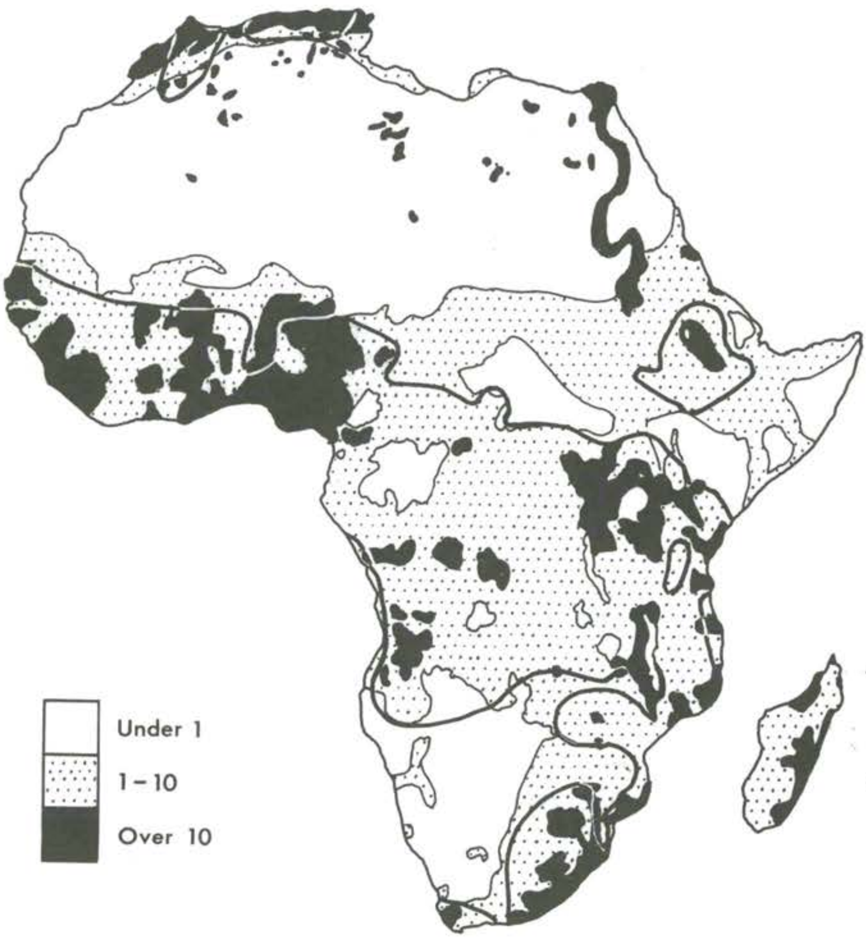

Figure 3.2. The marginal dry lands of Africa and population density (Carlson, 1967).

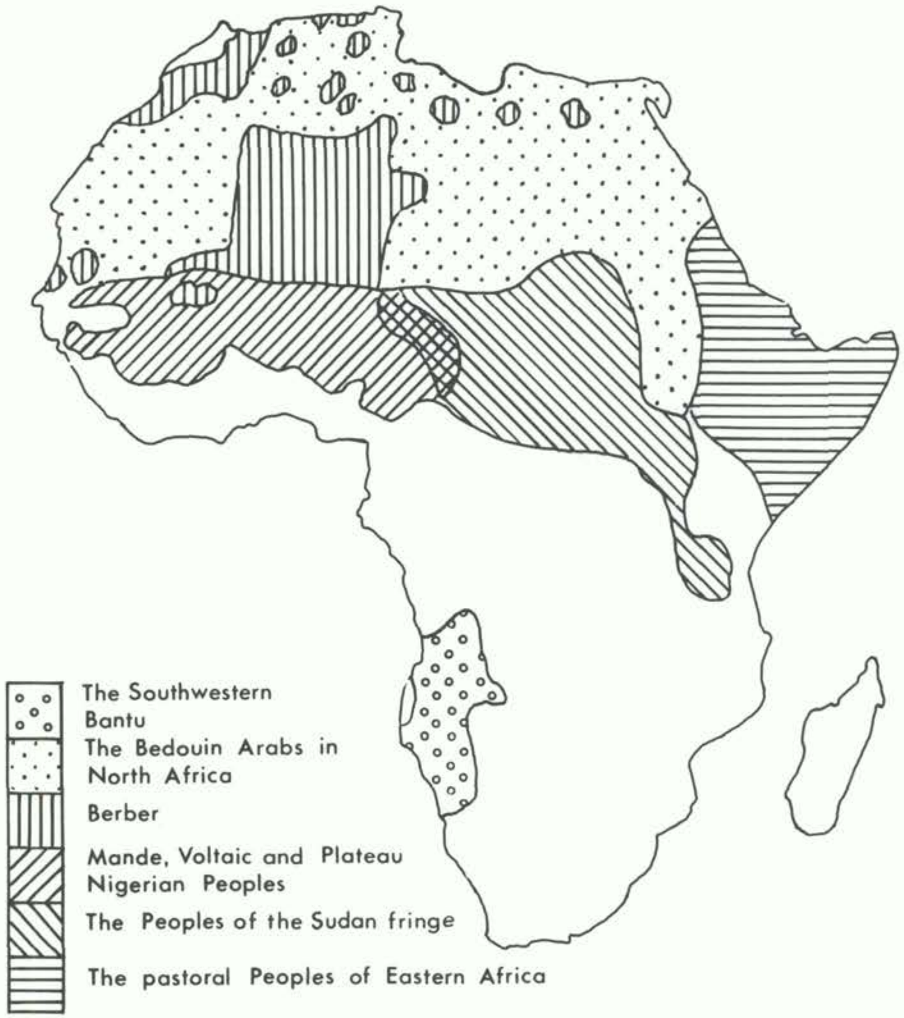

Figure 3.3. People inhabiting the marginal dry lands of Africa (Murdock, 1959. Used with permission of Mc-Graw-Hill Book Company.)

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Chapter 4

TRADITIONAL GRAZING PRACTICES AND THEIR ADAPTATION TO MODERN CONDITIONS IN TUNISIA AND THE SAHELIAN COUNTRIES

G. NOVIKOFF

The grazing practices referred to in this paper are of an extensive nature. Having large areas at their disposal, herdsmen let their flocks graze freely; they then move them away to other, sometimes distant areas.

In order to understand the relationship between the use of natural resources and causes of overgrazing and desertization, two types of grazing practice will be mentioned and possible control methods outlined.

Grazing in the Sahel

The Sahel is an area defined by a monsoon rainfall regime, a short rainy season lasting from June to October, with rainfall ranging from 350 mm to 600 mm and a long dry season from October to May. The temperature regime shows two annual minima – the first at the middle of the rainy season, the second at the beginning of the dry season. Its amplitude decreases closer to the desert (Riou, 1975).

The vegetational cover consists mainly of annual plants with a short vegetation period and sparse trees. The plant cover varies with the soil type (Boudet, 1975). For example, Boudet mentions that:

- in the subdesertic Sahel, on the dunes grow trees such as *Leptadenia pyrotechnica* and on sandy soils grow annual grasses such as *Aristida mutabilis* and *Schoenefeldia gracilis*;
- in the typical Sahel, annual grasses are the most abundant and reach 0.8 cm to 1 m height;
  - on sandy soils grow annual grasses such as *Aristida mutabilis, Cenchrus biflorus,* and also some trees such as *Acacia senegal* and *A. raddiana*;
  - on sandy clayey soils grow annual grasses such *Aristida adscensionis* and *A. funiculata*;
  - on slightly hydromorphic soils grow trees such as *Acacia seyal* and *A. ehrenbergiana*;
  - on sandy alluviums, flooded by rivers, and depending on the duration of flooding,

grow such species as (listed by increased duration of flooding): *Cynodon dactylon, Panicum turgidum, Echinochlora stagnina.*

The vegetation on hydromorphic soils and low-lying lands is most important for grazing as it stays green for a long period and thus provides forage during part of the dry season.

A knowledge of the nutritive value of range species is essential in order to understand the problems of grazing by cattle or sheep. In his handbook on tropical rangelands, Boudet (1975) considers as a good range forage species "any grazed plant which has a minimum of 25 grams of digestible protein content (D.P.C.) per kilogram of dry matter and which has an energetic value (expressed in forage units or F.U.) of at least 0.45 F.U.". Plant species containing such an amount of forage units and digestible protein cover the maintenance requirements of one tropical bovine unit (T.B.U.) of 250 kilograms, which is considered as a reference unit. One example of the nutritive value of such a plant species is given in Table 4.1.

Table 4.1. Nutritive value of *Aristida mutabilis*. F.U. = forage units; D.P.C. = digestible protein content. (After Boudet, 1975.)

Sampling period	F.U. per kilogram dry matter	D.P.C. grams per kilogram dry matter
Beginning of rainy season	0.55	38
During rainy season	0.50	82
End of rainy season	0.56	36
Beginning of dry season	0.46	10
Cool period of dry season	0.44	1
End of dry season	0.36	0

The following conclusions can be drawn from this table:

- During the rainy season *Aristida mutabilis* is a good forage species, since it covers the energy requirements of the tropical bovine unit (expresses as F.U.) as well as its protein requirements (expressed as D.P.C.).
- During the dry season, the energy requirements of the T.B.U. are attained, whereas there is a protein deficiency for the animal (low D.P.C.).

Similar values were found for *Aristida funiculata* and *Schoenefeldia gracilis* with an earlier decrease in D.P.C. than in *Aristida mutabilis*. Similar conclusions may therefore be drawn for these plants.

Cattle traditionally graze two categories of rangeland:

1. Rainy season rangeland. (Cattle drink from temporary ponds.)
2. Dry season rangeland. (Cattle drink from permanent wells.)

During the rainy season, the cattle graze over the entire rangeland and water at temporary ponds or wells. During this period, herdsmen try to exploit rangeland without permanent underground water supplies, since such land can be grazed only in the rainy season (Atlas pratique du Tchad, 1974). The cattle gain weight and produce milk. This is possible because of the good nutritive value of forage species during this period (see values for rainy season, Table 4.1).

As soon as the dry season begins, the supply of drinkable water becomes the limiting factor for the use of the rangeland. The herds are therefore moved to rangelands located around a permanent water supply (Atlas pratique du Tchad, 1974; Angladette & Deschamps, 1974; Mosnier, 1961). The animals consume dry plants and have to forage more intensively. Consumption of dry food and foraging in the heat increases water requirements to more than 30 litres every two days; milk production ceases and the animals lose weight. This can be explained by the low D.P.C. during this period (see Table 4.1 for dry season values). Cattle cluster around wells during this period. Once grazing lands have been exploited to a distance of 20 km around the well, cattle have to move to other areas with a remaining grass cover, unless hydromorphic soils or low-lying depressions exist locally (Angladette & Deschamps, 1974). On these lands grow such tree species as *Balanites aegyptiaca, Acacia seyal* and *Acacia ehrenbergiana*. Their fruit and leaves meet the protein requirements of the cattle during the dry season, and during this period the leaves and branches are cut down by cattle breeders or directly grazed by goats (Aubreville, 1949; Boudet, 1975). When such resources do not exist, cattle have to migrate to locations sometimes up to 400 km from their rainy season ranges. This is the case for the Quaddai breeders in Chad (Atlas pratique du Tchad, 1974) who sometimes follow a certain circuit in their migration (areas of *endodromie pastorale*; Barral, 1974).

In conclusion two distinct types of grazing land have traditionally been exploited by the same herd:

- that grazed during the rainy season. There is strong evidence indicating that such areas are choosen by breeders because of the lack of permanent water supply (SCET, 1973; Atlas pratique du Tchad, 1974; Angladette & Deschamps, 1974)
- that grazed during the dry season and where water resources for cattle are available (permanent water supply).

Grazing in Pre-Saharan Tunisia

An important rangeland in Pre-Saharan Tunisia is the *Rhanterium suaveolens* sandy littoral steppe (Vernet & Gaussen, 1958). A plant association occurring frequently in Jeffara (the coastal plain north of the Matmata mountains) is the *Rhanterium suaveolens* and *Asphodelus refractus* association (Le Houérou, 1969). It is usually found in mosaic formation with sandy accumulation or dunes on which the legume *Retama raetam* and the perennial grass *Aristida pungens* grow in well-defined cases. These are perennials that stabilize sand. The experimental plots of the US IBP Desert Biome, Tunisian Pre-Saharan project, are located in such an area. The estimated annual mean rainfall at this plot is 120 mm, but with a large amplitude of variation. At the meteorological station of the project rains were recorded as listed in Table 4.2.

The rainy seasons are autumn and winter and, less often, spring. According to a study of A. Southard, the soil of the experimental plots contains a large amount of very fine sand, highly susceptible to wind erosion.

Table 4.3 shows the nutritive value of the two species *Plantago albicans*, which may be considered a biannual, and *Rhanterium suaveolens*, the most important among shrubs from the production point of view. Values are expressed in F.U. and D.P.C., as in Table 4.1.

Table 4.2. Annual recorded rainfall at the experimental plot of the US IBP Desert Biome, Tunisia.

Period	Rainfall (mm)
1 Sept. 1972 – 31 Aug. 1973	15.3
1 Sept. 1973 – 31 Aug. 1974	94.2
1 Sept. 1974 – 31 Aug. 1975	186.3
1 Sept. 1975 – 30 June 1976	490.0

Table 4.3. Nutritive forage values of *Plantago albicans* and *Rhanterium suaveolens* (after Sarson & el Hamrouni, 1974).

Species	F.U. per kilogram of dry matter	D.P.C. grams per kilogram of dry matter
Plantago albicans	0.42	39
Rhanterium suaveolens	0.28	42

The plant samples were harvested during the grazing season. In spring, when these species grow in sufficient amounts, they meet the nutritional requirements of milking sheep and goats.

Flocks in this area are mixed (half sheep and half goats). In 1975 – an average year – the flocks had grazed around the owner's houses since September 1974; in summer, flocks graze only from 04.00 to 08.00 in the morning because of the heat. From the end of August the animals are fed in their paddocks (close to their owner's house) with khortan, a hay prepared by harvesting native range species (Bedoian, 1975). Lambs born on 16 December 1974 attained 31 kg on 12 April 1975, and goat kids of the same age attained 20 kg (Bedoian, 1975).

In poorer years (rainfall of 60 mm), the peasants let the flocks graze around their houses, but feeding with khortan may start as early as the beginning of July. According to information provided by the peasants, during such years goat kids gain more weight than lambs.

In dry years such as 1973 (15.3 mm of rain) flocks migrate to other locations in Jeffara where rain has fallen. As an experiment, a small flock of ewes with their lambs and nanny goats with their kids was kept in a Pre-Saharan project test plot during the spring of 1973. During 25 days of the experiment, ewes and lambs lost weight, whereas goat kids gained 2.2 kg and nany goats 0.7 kg (Novikoff, 1972).

The mixed flock composition of Jeffara herders is a strategy aimed at obtaining maximum animal production from the land throughout years with varying rainfall.

Prolonged grazing, particularly by an excessively large number of sheep and goats, leads to trampling of the soils of such grazing lands, and the lack of litter and anchored vegetal residues left on the ground causes soil aggregates to be broken and eroded. Hot and dry winds beginning in May are the major agents of sand and dust transportation.

Causes of desertization as related to the grazing practices under review

Desertization in rangelands is a result of overgrazing by excessive numbers of animals and of wind erosion of soils (Fig. 4.1). Much information exists on wind erosion of soil in cultivated lands, but less is known about erosion in rangelands (Jakoubov, 1955; Anon., 1961; Gavaud, 1975; Boudet, 1975).

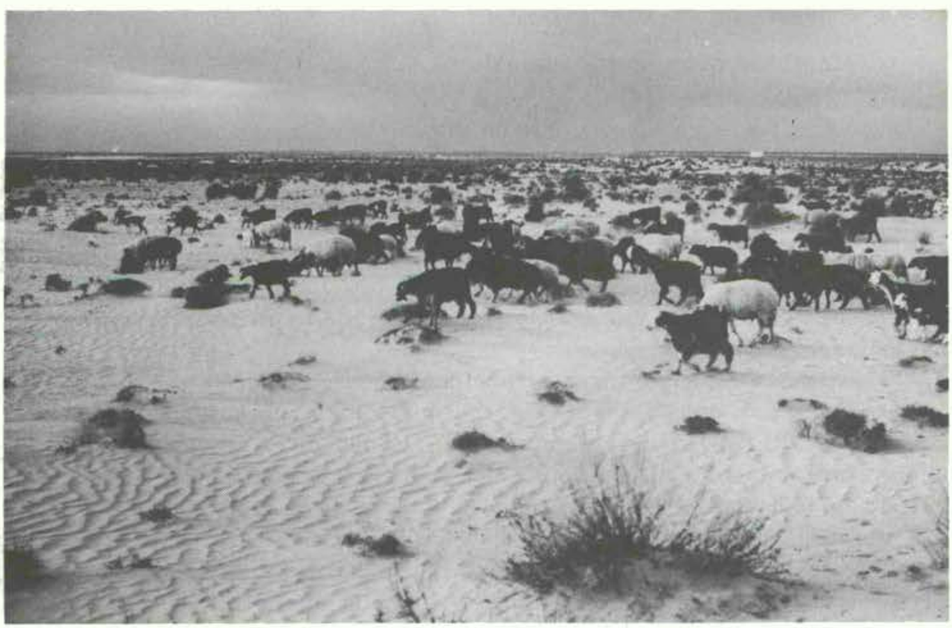


Figure 4.1. Desertized area of overgrazed *Rhanterium* steppe near Zarzis, Tunisia. A 20 cm layer of topsoil has been eroded in five years. Note wind ripples in sand. Photo Anders Rapp, 1974.

Wind erosion is furthered if the soil is loose, dry and finely divided into single grains. A high percentage of sand increases erodibility and so does a low percentage of organic matter (Chepil, 1953, 1955a, 1955b). Both heavy grazing and trampling by animals increase erosion hazards by removing the protective vegetational cover and pulverizing the soil. The erosional effect of the wind increases with wind speeds above the critical value for erosion. In rangelands the wind speed at the soil-surface depends on the density and structure of vegetation and also on the amount of litter and anchored vegetal residues left on the ground. Only a few studies have been made on this subject. A portable aerodynamic funnel such as Zingg's (1951) could be used for such research, especially in order to quantify the minimum amount of litter and anchored vegetal residues to be left on the ground to prevent wind erosion.

For more details on aerodynamic problems related to wind erosion, see Bagnold (1965) and Zvonkov (1962).

Areas having similar soil conditions are subject to wind erosion to varying extents (Jakoubov, 1955). Examples of susceptible areas are hilltops, hillsides exposed to wind, and alluvial fans. Observations made by the present author in Tunisia confirm these conclusions.

For purposes of land management, it is possible to classify soils in increasing order of susceptibility to wind erosion, using vegetation as an indicator and verifying results by a quick soil structure study and eventually soil analysis. This approach has been used in the sandy soils of central Tunisia to define land-use categories (Bureau & Novikoff, 1959).

Excessive number of domestic animals

The stocking rate is the number of heads of cattle or sheep (expressed as tropical bovine units – T.B.U. – or ovine units) grazing per surface unit (Boudet, 1975). The stocking rate can be expressed on a yearly or seasonal basis or in terms of any convenient time unit; it is defined in relation to the nutritive forage value of a rangeland and the requirements of a T.B.U. or any other convenient animal unit. The range condition is also taken into account (Boudet, 1970; Mosnier, 1961) and the stocking rate is adjusted to the vigour of the most palatable species and also to the species whose presence indicates overgrazing.

Various types of overgrazing have been noticed in the Sahel area:

A. *Permanent grazing around watering points*. An excessive number of cattle graze throughout the year around watering points. According to G. Boudet (pers. comm.), this permanent grazing is the most frequent and most dangerous type.

B. *Overcultivation and combined grazing*. Under conditions of drought or cultivation, for example, grazing occurs only on rainy season rangelands (Angladette & Deschamps, 1974; Barral, 1974; Mosnier, 1961). In his study, Barral compares two categories of peasants as regards grazing practices and utilization of the same resources:

- the first uses grazing land the traditional way (stabilized dunes covered with vegetation and grazed in the dry season; low-lying lands grazed in the rainy season). The stocking rate is 1 T.B.U. per 8.5 ha; there are no traces of desertization or of active formation of sand dunes, and there is no decrease in production of low-lying, flooded grazing lands

– the second has put the dunes under cultivation; as a result, *Pterocarpus* and *Acacia* trees have been destroyed and the dunes have started to shift. At the same time, production of the constantly exploited low-lying rangelands has decreased. The average stocking rate of these areas is 1 T.B.U. per 3.7 ha.

C. *Excessive use of trees as fodder*. This dry-season practice has already been mentioned; it consists in overgrazing the upper parts of trees (Van Thai, 1975; Boudet, 1975).

D. *Use of fires.* The peasants set fire to a piece of land before cultivating it or when the stems of the grasses have become hard and difficult for the cattle to graze. This practice is more common in the Sudanian area than in the Sahelian area and, when properly timed, allows of a new sprouting of perennials whose buds are below the soil surface. And, of course, accidential fires also occur in the Sahel. In many cases fires are very destructive, consuming large amount of organic material, and reduce grazing potential.

All studies carried out in the Sahel (Boudet, 1970; SCET, 1973; Atlas pratique du Tchad, 1974; Angladette & Deschamps, 1974; Barral, 1974; Mosnier, 1961; Van Thai, 1975) indicate an excessive number of heads of cattle or sheep and goats on grazing lands. In Pre-Saharan Tunisia overgrazing has been noticed around villages as well as in rangelands (Le Houérou, 1969).

Counteracting overgrazing and desertization

Keeping the practices based upon traditional grazing (seasonal use)

In the Sahel and other areas with similar grazing practices, a separation between rainy season rangelands and dry season rangelands is necessary. A certain area, for instance, is only grazed during the rainy season, whereas another area is excluded from grazing during the rainy season so that it can be used as dry season rangeland (SCET, 1973; Barral, 1974; Boudet, 1975). If such areas do not exist and there are no spots where native leguminous trees grow, the planting of such trees should be encouraged whenever economically feasible (Boudet, 1970). When new settlements in the Sahel have to be created, it is advisable to associate rangelands on hydromorphic soils with rangelands on sandy soils (Van Thai, 1975). An example of this arrangement comes from Pre-Saharan Tunisia, where rangelands covered with *Artemisia herba alba* and rangelands covered with *Rhanterium suaveolens* are exploited jointly.

The practice of deferred seasonal grazing can be applied to other geographical areas. For example, in experimental grazed plots of the Tunisian Pre-Saharan project in Jeffara, deferred grazing during winter suppressed eolian erosion which previously affected 60 % of the surface of the plot grazed by a mixed flock of sheep and goats. In practice, a year with good rainfall has to be chosen and half of the grazed land has to be put under deferment; in the next good year, part of the plot under deferred grazing will be the half which was previously grazed normally.

Adjusting the number of cattle allowed to graze in a rangeland according to its specific stocking rate

The number of cattle should be adapted to the stocking rate corresponding to each rangeland. For the moment, large-scale application of this concept seems difficult partly because of the insufficient number of trained technicians, and partly because of the herdsmen's lack of education. As a first phase, this could be applied in critical areas where herdsmen have agreed to participate in a range-management scheme, or in fattening ranches (Boudet, 1970; Mosnier, 1961). In Sahelian areas, stocking rates have been defined for a certain amount of land. As an example, Mosnier mentions for the Niono area (Mali) that rangeland with *Schoenefeldia gracilis* during the rainy season has a stocking rate of 1 T.B.U. per 4 or 5 hectares on a geomorphological type called "inactive delta" and decreases by half during the dry season. When overgrazing and desertization become too serious, exclusion from grazing for a year or two allows recovery (SCET, 1973; Aubreville, 1949; Boudet, 1970; Van Thai, 1975; Bernus, 1974; Rapp, 1974). See also the case study on the Sudan in this volume (Chapter 8.5).

When exclusion from grazing exceeds one year, grazing is possible during periods when vegetation is dormant. This applies to the formerly bare dunes in our experimental plots which were excluded from grazing since two years back (1973, 1974) and became covered by vegetation. These dunes are now being grazed during the autumn by a mixed flock of sheep and goats, and vegetation recovery on them is the same as before.

The number of cattle should be adjusted to the stocking rate in coordination with the spacing of the wells and their management. An optimum spacing between watering places is needed for rational exploitation of rangelands. This spacing is related to the maximum daily distance traversed by a cow or a sheep. In the Kanem area in Chad (Atlas pratique du Tchad, 1974), which is very suited to cattle breeding, a grid of 600 wells was dug out at every 10 to 20 km according to rangeland forage values. Regulations have to be established and strictly followed so as to avoid problems created by the management of the wells (Bernus 1974; Boudet, 1974). The only livestock admitted to a well are those authorized to graze the rangelands nearby. When the range has been overgrazed the well is closed, if necessary, to allow the vegetation a rest period.

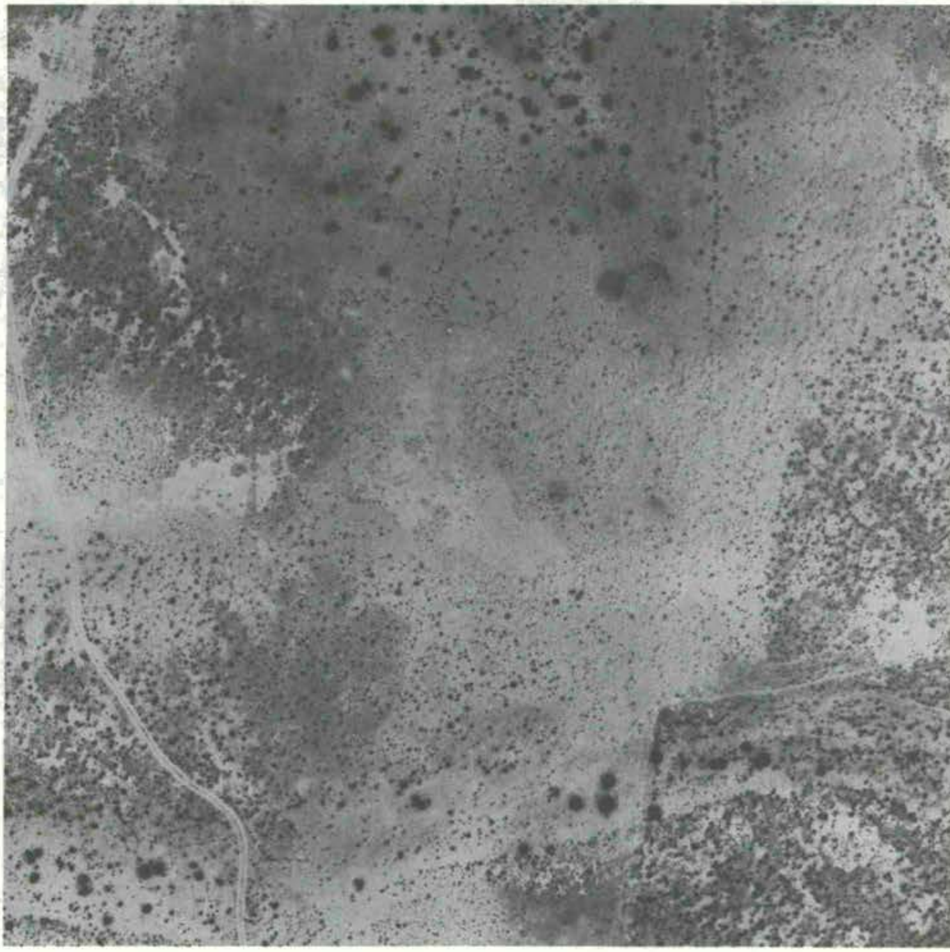
Controlling the grazing and cutting of forage trees; their plantation as forage reserves

In rangelands, only a certain proportion of the aerial part of the fodder tree can be harvested; this has to be strictly regulated (Aubreville, 1949; Van Thai, 1975) and the rest periods have to be well defined. In some cases, the planting of *Acacia senegal* or other leguminous trees can be recommended (Mosnier, 1961). Experiments should be made with other species, such as *Cucurbita foetidissima* which grows well under similar rainfall and temperature conditions. This perennial species provides a good yield of seeds as rich in protein as cottonseed cake. Young steers have been successfully fattened in the USA with these seeds (Havener, 1974).

Controlling overgrazing and desertization

Through SIES, an aerial survey of a 10 km × 15 km tract around the Tunisian Pre-Saharan project's plots was carried out by Dr. R. Larsson, Dept. of Physical Geography, University of Uppsala. Photographs were taken at low altitude in black and white, infrared, and in colour. Preliminary studies of the pictures (scale 1:1000) show clear differences (for a given soil type) between deflation areas (Figs. 4.2–4.4) and areas with sand accumulation.

By using photographs along transects it should be possible to evaluate quantitatively the extent of desertization in test plots and to correlate it with the desertization balance of a large area.



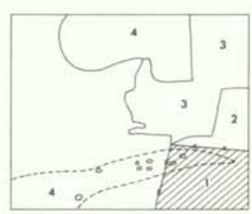


Figure 4.2. Case of improper land managemant through cultivation by disc ploughing. Aerial photograph, R. Larsson, SIES, May 1975. Road track indicates scale.

1. Intact *Rhanterium* steppe with deferred summer grazing (experimental plot). Line with crosses = fence.
2. Heavily grazed *Rhanterium* steppe with 20 % soil surface covered with small sand dunes.
3. Area cultivated by polydisc for 4 years and entirely covered with small sand dunes.
4. Tufts of *Retama raetam* and *Aristida pungens*.

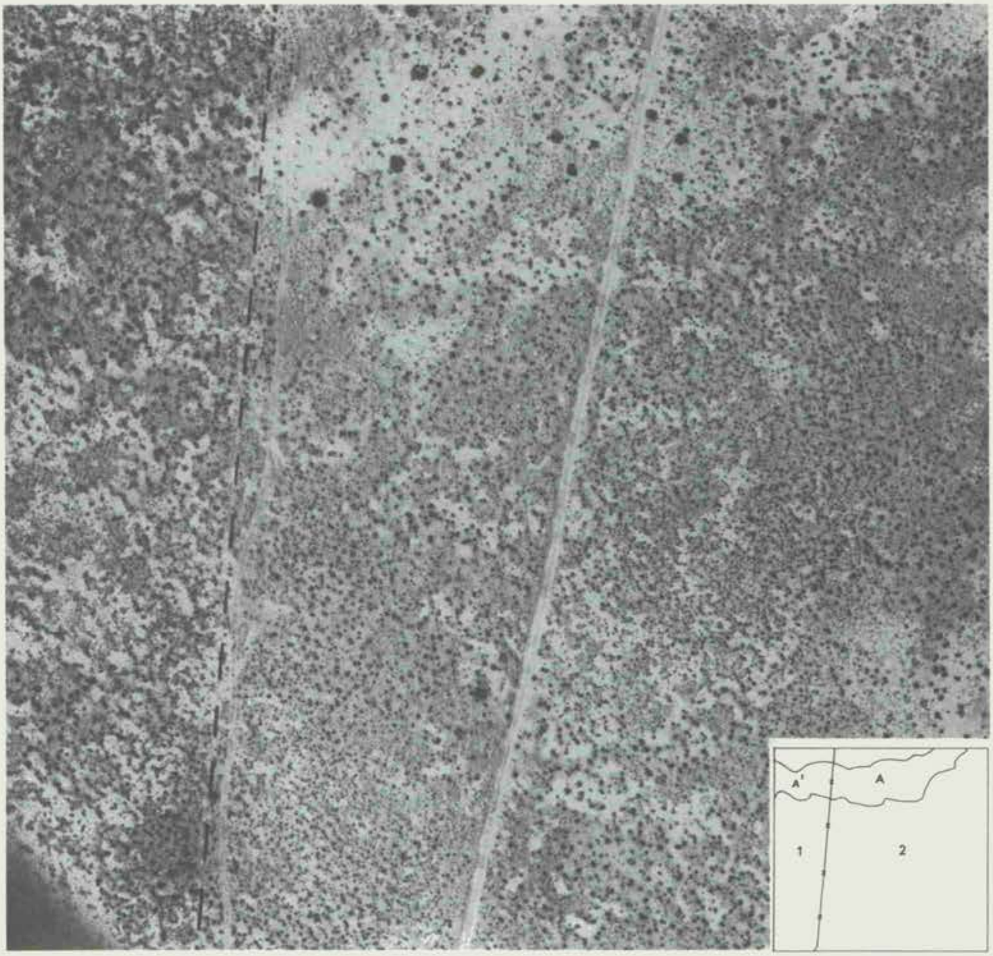


Figure 4.3. Desert encroachment caused by improper grazing; possible methods of stopping it.
Aerial photograph, R. Larsson, SIES, May 1975.
Line with crosses = fence. Road track indicates scale.
Area outside the experimental plot = 2. It includes a dune area A with some patches of *Aristida pungens*. In July 1975, this dune was covered with 40 % ripple marks; in August 1976, because of polydisc cultivation followed by grazing, one part of the dune was blown away, leaving an accumulation 25 cm thick; the remaining part of the dune was 70 % ripple-marked.
Area inside the experimental plot = 1. It includes A^1 which is the extension of the dune A across the experimental plot; A^1 was entirely stabilized after 3 years of exclusion from grazing; vegetation now covers it completely and it is grazed during summer, that is during the period of vegetation dormancy. No traces of ripple marks remain.
Patchy appearance of the grazed plot: typical feature of grazed areas subjected to desert encroachment.
As the photograph was taken in spring, the dark patches represent areas covered with dense annual vegetation, the soil being undisturbed and the sandy topsoil layer remaining intact.
The white patches represent desert pavement with sparse or no vegetation: the sandy topsoil was blown away from these spots, leaving a bare compacted surface (desert pavement).
The measurement of the extension of these patches (with reference points) may be a possible method for measuring desert encroachment extension.

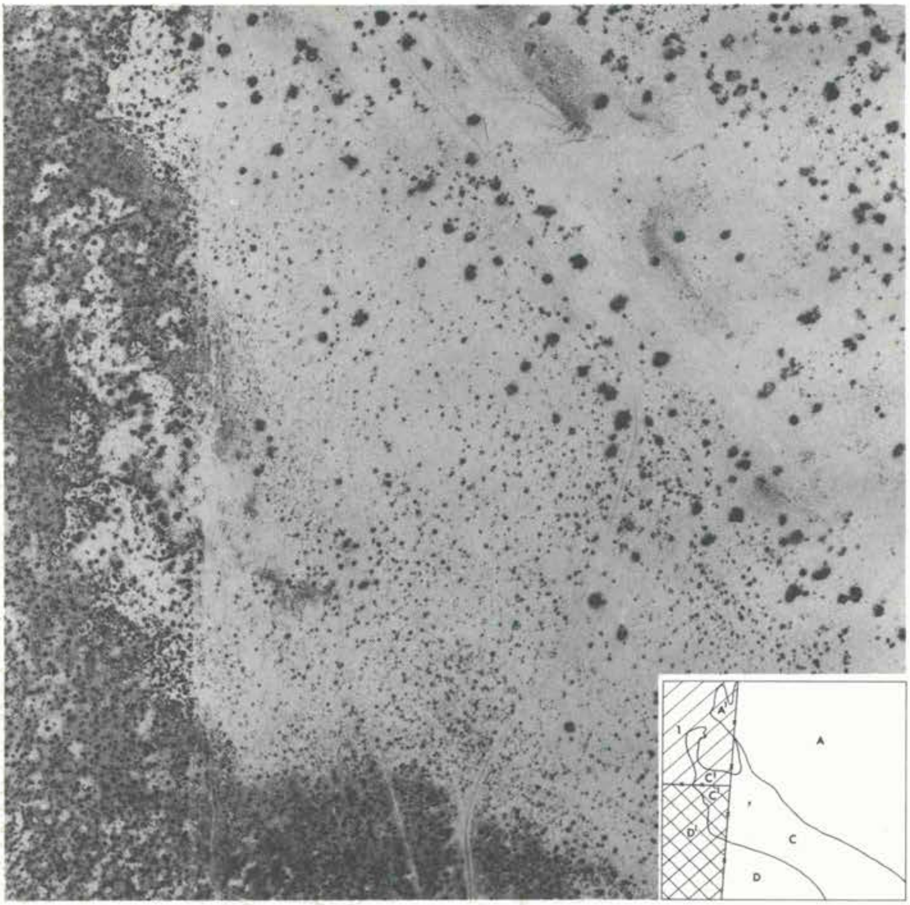


Figure 4.4. A case where desert encroachment is linked with geomorphology, and wind erosion related to water erosion. Aerial photograph, R. Larsson, SIES, May 1975.
Line with crosses = fence. Road tracks indicate scale.
Areas outside the fenced plot include:
A: active sand dunes with 80 % ripple marks. Some tufts of *Aristida pungens*.
C: hummocky area with dunes more diffuse than in A. In August 1976, 70 % of the surface was covered with ripple marks.
D: undisturbed *Rhanterium* steppe.
Areas inside the fenced plot: They include soil vegetation units A^1, C^1 and D^1. Area 1 has been excluded from grazing since May 1972 and area D^1 is spring deferred grazing.
A^1 was partly stabilized but sand accumulation still continue in some places.
C^1 was previously covered with 60 % ripple marks but now shows no traces of ripple marks.
Lower C^1 is entirely stabilized and there are no traces of ripple marks.
In dune area A, and to a lesser extent in area C, the loose sand derives from water erosion of upper parts of a watershed: when improperly cultivated or grazed, the sandy soils are eroded; the sediments are carried to lower parts of watersheds, deposited, and then blown onto the sides of embankments. This is the case in A which is the upper part of an embankment. Accumulation still continues.
Stabilization of the entire dune area may become problematic. To make it feasible it is necessary to:
- stop or decrease water erosion in the upper parts of watershed by appropriate grazing measures (light grazing, for instance) and cultivation methods, both leaving soil covered with litter and anchored plant residues
- stop sand movement by reseeding strips with *Retama raetam* and *Aristida pungens* at right angles to the prevailing wind, and exclude it from grazing.

In order to evaluate quantitatively the degree of palatability of range species as related to grazing, such techniques as bite counts or oesophagal fistula could be used (Novikoff *et al.*, 1975).

Developing irrigation farming

Irrigation needs to be developed in small village plots (Boudet, 1970) as well as in big schemes such as that on the Senegal River (Van Thai, 1975). The limiting factor is the cost per cubic metre of water available to produce both food crops as cereals and other cash crops or forage crops. Irrigation will stop the extension of rangelands into cultivated lands, as the cultivated strains will give higher yields under irrigation compared with the yields from nonirrigated lands. The Senegal River irrigation schemes are planned for the cultivation of peanuts, sorghum, rice, sugar cane and tomatoes (R. Fauck, pers. comm.). The fodder crops produced by irrigation can only form part of the cattle diet. For sheep, the optimal percentage of fodder in the animal diet pertaining to the fattening of lamb has been worked out by economic studies in Southern Tunisia (Le Moing & Novikoff, 1968).

Educating the herders

The most serious future problem in range management will be to convince the herdsmen to accept these remedies. There is much educational work to do, not only among adults but also among young people (Atlas pratique du Tchad, 1974). The following are a few suggestions, which are by no means complete. It is recommended that the traditional system of values be used as much as possible and cultural patterns onto which new techniques can be grafted be picked out.

For example, cattle migration circuits could be used (and some ORSTOM cattle breeding maps of Cameroun show that this has already been done), along which watering places and veterinary care stations could be built. Fattening ranches could eventually be placed at circuit ends. Another example is to use the traditional concept of "insurance systems against drought" wherever they exist, to develop the idea of storing forage reserves (Copans, 1975). (See also Chapter 10) Another way is attempting to integrate completely new techniques in a traditional society. For adults all possible mass media techniques including songs and dances should be used. This is already being implemented in Egypt, according to a communication by Dr. Barrada, Head of the Institute of Cattle Breeding. Herdsmen should be trained in new methods for application on return to their villages. They should also be encouraged to visit experimental farms.

For young people it is important to organize lectures or guided visits to demonstration objects in order to show desertization and overgrazing. This could be done in schools, colleges, or in scientific clubs for youth.

Fields of research in which some supplementary data are needed

- Grazing vegetation on soils with high erodibility to wind. Some experimentation is needed for determining the duration and the period of grazing. According to Jakoubov (1955), the control of wind erosion on grazed lands, especially on soils with high erodibility, requires an accurate knowledge of the duration and also of the period at which grazing occurs, and the observations of the author in Pre-Saharan

Tunisia agree with Jakoubov's conclusions. Such experiments have to take into account the growth period of vegetation, its vigour, and also the manner of movement of sand particles (on soil surface only, carried in the air, or in both ways). As previously mentioned, studies with a wind tunnel would help to relate the duration of grazing with the amount of litter and anchored residues to be left on the ground so as to reduce (or prevent) wind erosion.

- Tillage and cultivation practices on soils with high erodibility to wind. Keeping the stubble over the cultivated land is a first step, and other land management practices could be linked with it, such as perpendicularly orientated cultivated plots to prevailing wind, alternating with strips of vegetation excluded from grazing (such as is done in Australia, J. Stewart, pers. comm.). The next step would involve experiments with stubble mulch farming, which requires special tillage implements (USDA, 1957).
- Study of how subsistence economy should be associated with market economy, and, more broadly speaking, the organization of market systems.
- Since several years ago, several prototypes of solar pumps are functioning south of the Sahara (SOFRETES, 1972). These pumps can haul water for villages or cattle and could be used for irrigation of small plots. Experimentation on a broad scale is required. (See Chapter 7)

Conclusions

The following recommendations are made for the improvement of grazing practices in areas where desertization and overgrazing occur:

Maintenance of the traditional seasonal grazing practice

This consists of grazing on rainy season rangelands and then on dry season rangelands; reestablishment of this seasonal practice where it has been discontinued. This traditionalism does not mean merely reverting to the past. The following regulations and improvements are needed:

1. *Regulations*

- Limitations of the number of cattle. For most critical areas the number of cattle to be adapted to the desirable stocking rate. The number of animals to be reduced as only animals grazing in ranges located around wells should have access to the wells.
- When a rest period is needed for vegetation, the well in that area has to be closed. This is possible if the well is only used for the watering of animals
- When new wells are planned for cattle, the discharge has to be restricted to the amount of water required by the cattle grazing in rangelands around the well, and the number of wells proportioned to the number of animals fixed by the desirable stocking rate.
- All these regulations have to be accepted by the herdsmen.

2. *Improvements*

- Development of dryland fodder reserves: natural hay gathered from ranges (such as khortan in Pre-Saharan Tunisia), planting of forage trees and shrubs, or management of existing "forage" forests by fixing rest or rotation periods, and also regulating the cutting of leaves and branches. To date there is no exhaustive catalogue of all fod-

der trees and shrubs in arid zones, including native climatic conditions, yields, water requirements, soils and forage use (see Chapter 9), associated with feeding experiments on these plants, and limits of use.
- Increasing the number of fattening ranches, and instituting improvements along the long circuits leading to slaughterhouses, especially in Chad.
- Increasing irrigation farming.
- Providing better veterinary care, but always considering the critical number of animals.
- These improvements to be accompanied by a technical education of the herders.

Other problems of importance

1. The author would like to point out the necessity of a long-term study comparing the advantages and drawbacks of subsistence economy versus market economy under difficult ecological conditions such as those in the Sahel, and the extent to which they can be associated.
2. Another problem is the working out of new grazing or cultivation methods adapted to highly erodible soils:
- To study grazing practices it is necessary to study the duration of grazing and its timing in the year as related to the loosening of the soil and to hot and dry winds. The size of the flock in relation to the trampling effect has to be evaluated for highly erodible soils.
- On cultivated soils, methods close to stubble-mulch farming need to be worked out (USDA, 1957). Such experiments have started in the Tunisian Pre-Sahara project.

The only way to apply the grazing practices – such as, exclusion from grazing or fixed stocking rate, recommended above – in the field, is to associate them very closely with the development of areas with high forage productivity, such as irrigated areas (G. Boudet, pers. comm.).

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Chapter 5

CONSTRAINTS ON PASTORALISM IN DRYLANDS

A. HJORT

The areas characterized by highly variable and sparse rainfall, and often known as marginal dry-lands, make up about one-third of the total land surface of the earth. About 15 % of the world population inhabits such areas. As pointed out in previous chapters, the economies of these peoples are often based on varying degrees of pastoralism. For various reasons, many of these areas are in a state of ecological imbalance at present. The purpose of this chapter is to draw attention to some important factors that might hinder future attempts at creating an ecological balance. The discussion will be structured into socioeconomic, technical, and administrative aspects.

Socioeconomic aspects

Under this heading some basic social and economic features of a pastoral livelihood are touched upon. Since social and economic institutions are closely interlinked, often being two aspects of the same phenomenon, they are treated together.

Rational behaviour

The information available at present about pastoralists is not very substantial. It is plain that they act rationally from the point of view of their situation. In spite of this, they are often labelled in certain circles as "conservative" or even "lazy". This attitude – sometimes based on ill-founded knowledge – will be discussed under "Administrative aspects" below because of its political implications.

It is postulated here that pastoralists behave rationally with respect to their present sub-goals, *viz*., to survive with a known standard of living within a certain culture.

System of redistribution

Dependence of the population on prevailing ecological conditions in marginal lands has been discussed earlier. The organization of some economic activities is presented in Chapter 3 – for example, diversifying livestock, splitting up the animals in different herds, and farming to some extent. Such activities are intended to limit losses in times of hardship rather than to maximize a possible economic return. This basic underlying reason is often overlooked by planners.

In spite of precautions, such as those just mentioned, drought or even prolonged dry periods often result in substantial loss of cattle. Many societies apply redistribution systems of large stock for compensating individual households that are hard hit. An important aspect of these systems is that they make up an effective insurance system, provided they are not disturbed too much.

An insurance system is essential amid the uncertainties characterizing a nomadic way of life. The present redistribution systems are liable to be inadequate when ecological imbalance sets in; an effective alternate insurance system must then be developed. In some areas, ranching is an answer to this problem. It, however, needs adequate grazing. Where this is lacking, as in northern Kenya, a possible alternative is to complement a nomadic way of living with some ranching for added insurance. This is further elaborated in Chapter 10.

We shall now touch briefly upon four traditional forms of redistribution systems: stock-friends, raiding, redistribution via ritual leaders, and barter.

Stock-friends

The stock-friend system consists in a mutually beneficial arrangement between any of two adult males – kinsmen, relatives or friends – whereby the one who happens to be in better circumstances at some point of time undertakes to help the other. This means that each individual male is involved in a complex network of debts and claims. The help given to a person may take the form of a loan – a heifer, say – which has to be "repaid" in similar fashion at some later date when circumstances so require. A "creditor" may press his claim for either of two basic reasons: on marriage, when he needs to pay substantial bridewealth, or after a disaster, when he needs to build up his herd again. Such a system is effective against limited or local drought, that is, when the total number of animals in the mutual insurance networks is not drastically reduced.

Raiding

Another way of compensating for animal losses is to raid neighbouring peoples and steal enough heads of cattle to build up a herd again (Sweet, 1965). Although this system of redistribution is more drastic than the stock-friend system, there are grounds for believing that it was institutionalized and subjected to cultural restrictions in precolonial times without much bloodshed. Though the colonial powers tried to counteract the practice, there are indications in some developing countries that the frequency of stock raiding is increasing.

Redistribution via ritual leaders

In certain societies, ritual leaders receive substantial gifts of animals for their services which they then proceed to distribute to poor households in the community. One example of this is the Kallu system of the Boran people in southern Ehtiopia.

Barter

The economic precaution of diversifying herds when suitable also makes it possible to barter animals with neighbouring peoples in order to start rebuilding a herd again. Spencer (1965) mentions that this was the general strategy of the Samburu; the entire tribe had lost its cattle through rinderpest during the 1880s and tried to barter sheep and goats for cattle. From the Samburu point of view, cattle are absolutely necessary for survival; their purchasing of cattle for sheep and goats is then seen as a redistribution of cattle at the expense of the secondary food resource consisting of their sheep and goats.

Land availability

Traditional systems of land use in marginal dry-lands are usually based on the assumption that land as such is not a scarce resource. Land is property normally held in common either by a tribe or by a clan. Rights to waterholes are often based on invidual households or small kin-groups like lineages, rather resembling land rights among farming peoples. Individual rights are linked with the fact that a considerable labour input may be needed to keep the hole or well in order and with the need for organization at watering (Dahl & Hjort, 1976).

Seasonal migration is often central to pastoralists. As an illustration of this, the location of Karamojong cattle (northeastern Uganda) during a dry season in 1956 is shown in Fig. 5.1. The permanent settlement areas are outlined on the map. Most of the cattle are concentrated along rivers where subsurface water is available in dry seasons. In wet seasons the cattle are herded in the outer grazing areas, away from the river courses (Dyson-Hudson, 1966). Thus, the grazing area varies according to the season.

The problem of land fragmentation (because of land scarcity) faced by farmers is not experienced by pastoral nomads. They instead face the problem of overgrazing accompanying the excessive use of waterholes. The result is that the surrounding grazing is destroyed and the grazing areas become bushy.

This situation prevails in many areas today. There is no easy solution even if the people (at any rate in northern Kenya, where the author has been working) are aware of the deterioration – manifested dramatically by the expansion of bush, in turn attracting more tsetse flies. The people must live and they need a certain minimum number of domestic animals. (See "Household viability" below).

Two reasons are given for the increased pressure on land occurring in dry marginal areas. One is that the animal population has increased to an absolute figure exceeding the limit which traditional land use can feed. The other is that the available pasturage has been drastically reduced by the establishment of farms taking the best grazing areas or occupying areas vital for access to water. This pressure against the interests of nomads is strong and seems to be increasing (see Rigby, n.d.). Land scarcity, whether caused mainly by population growth or mainly by other forms of land use, has today created a labile situation characterized by ecological imbalance, a certain degree of outmigration, and deteriorating nutritional standards.

Some even see a parallel between the present situation of some pastoral nomads and that of the Indians in North America 200 years ago. It would be safe to say that stopping the trend of deterioration and keeping marginal lands inhabited would be success enough for rural development.

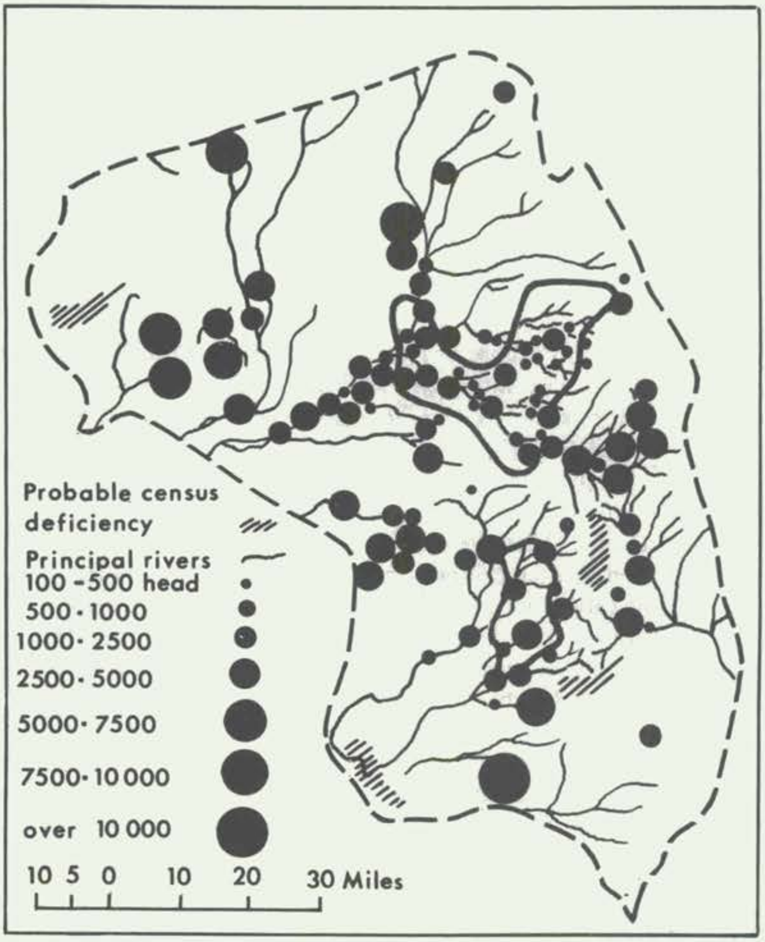

Figure 5.1. The distribution of Karamojong cattle (north-eastern Uganda) during dry periods (based on a 1956 cattle census; from Dyson-Hudson, 1966). The cattle population is concentrated along river courses, where subsurface water is available in the dry sandy riverbed. In wet seasons cattle are also herded away from the rivers. The used area is outlined on the map.

Impacts of cash economy

Cattle and camels are highly valued in most pastoral societies in marginal lands. The social and economic values of these animals and some effects of the introduction of cash have been touched upon in Chapter 3. One major problem today is caused by the conversion of incomes from other economic activities, like fishing or employment, into cattle or camels for prestige and other social reasons. In this way a traditional system is no longer effective; redistribution mechanisms are of no importance to those having access to cash incomes. The tedious work of building up a herd may be replaced by a few years' work within a cash economy since money is often given too high a value (for instance, in terms of cows) in most nomadic societies. Some major hindrances to development present themselves. Firstly, societies in such a changed situation easily become stratified, as regards both the human and animal populations. Where they have the possibility people invest in animals; owing animals becomes a regular and individual business and the owners form an upper stratum. They invest money in improved health for their animals via vaccinations, etc. Accordingly, these animals have a longer life expectancy and may reproduce better. The owners do not enter these animals into their kinship or friendship networks as they would traditionally have done (see above). Instead, all animals are kept segregated and are herded by employees.

In a subsistence pastoral cattle or camel economy the major produce from the herds is milk, meat being a supplementary source of food (Dahl & Hjort, 1976). Those people who have a monetary surplus to invest in their herds do not value milk production as highly. The possible offtake for slaughter may become a major goal. Some engage in specialized trading in livestock and purchase cattle in poor condition cheaply, give them good grazing and sell them for slaughter. This complex situation was touched upon very briefly in a FAO expert consultation report (FAO, 1974).

Such development opens up a possibility for very rapid increases in the number of animals in an area as the herds may be managed in larger units. At the same time it may "empty" the stock-friend networks of animals, thus giving rise to acute effects on the social side, such as, a lack of cattle for paying bridewealth or establishing kinship alliances. There are several examples where the introduction of cash economy possibilities without proper regulation has led to a deterioration of the grazing within a short period of time.

The only way to deal with this problem, as Henriksen (1974) points out, is to limit the number of animals for each household (somehow related to the number of household members), possibly linked with a new redistribution mechanism – for example as outlined in Chapter 10. To introduce such schemes is, however, not politically possible in all states at present.

Household viability

The term "household viability" was introduced by Stenning (1966). It signifies a proper ratio between animals (diversified in different combinations) and those people who are to take care of these animals and make a living from them. Given the nomadic situation, one can devise a general strategy in this connection, *viz*., that people increase the number of animals so as to achieve household viability rather than limit the increase in the number of family members. The reason for this is not "cultural conservatism" or something metaphysical, but simply a matter of precaution; the general aim in a geographically marginal area – so as not to make it economically marginal – is to develop a system of several herds, spread out geographically.

Since the environment today places certain constraints on traditional land use, one constraint on to development towards ecological balance is the problem of maintaining household viability in areas that do not become sedentarized or deserted. This is, perhaps, a more agreeable way of formulating the problem than discussing labour productivity, as the relevant economic unit in this context is not the individual labourer but rather the household of which he forms a part.

Nutrition

The standard of nutrition follows other aspects of the standard of living, normally correlated with stratification (see above). For those who are better off, the transition will be to better health conditions, but for those who cannot cope, the nutritional standard may deteriorate completely (Knutsson, 1972; Jelliffe, 1972). Such is the situation among many pastoral peoples today who must trade milk from their animals in order to raise money to purchase enough farm produce to nourish themselves. This means a severe shift from a protein and fat-rich food composition to one rich in carbohydrates but lacking in proteins. Fat may still be supplied by sheep that are kept partly for the fat in the tail and breast.

With the introduction of a cash economy, money may easily be spent on alternative items instead of on purchasing proper food. The cheapest way of stifling hunger is generally to purchase maize flour or similar foodstuffs and eat porridge made from them. A situation with a deteriorating food standard again develops, owing to shift from protein-rich to carbohydrate-rich food.

A deteriorating nutritional standard may also occur in cash-crop economies. Capot-Rey (1962) showed that nomads in the Sahara actually had a higher standard of nutrition than those who had been sedentarized.

Technical aspects

Herd composition

Pastoral cattle herds show low milk productivity and low slaughter offtake as compared with other herds. Though this has often been pointed out, the major underlying reason has sometimes been overlooked, *viz*., that these breeds are typical of geographically marginal areas and are highly suitable for extreme climates.

If it is assumed that local populations are by and large competent enough to handle their own affairs (on which they are experts), only marginal changes may be possible in the existing economy. Such changes may relate to the composition of the herd, especially the distribution of males and old females. For example, both Demirüren (1974) and Ruthenberg (1972) suggest that the number of animals in these two categories is too high. In this context, it should not be forgotten, however, that beef is spare food to be used during dry seasons. Furthermore, cows may also become pregnant at an old age, a possibility that nomads take into consideration. These animals may provide a basis for rebuilding a herd that has been hit by disease as, having survived earlier epidemics, they are more resistant (Capot-Rey, 1962).

One great drawback in discussing herd composition and herd growth for pastoral livestock is that stock censuses are often unreliable. There are several reasons for this. The act of counting by an outsider is itself often a direct cultural offence. Besides, stock censuses are associated with taxation, which people are anxious to evade. Yet anonther reason is that it is physically strenuous for a surveyor to collect his data by moving around from settlement to settlement in areas that are often hot and dry. Even when, despite the inconvenience, he does manage to travel, it is normally impossible to obtain reliable information on the age of adult large stock.

Aerial surveying has been attempted, at any rate in Kenya and the Sudan, in an effort to obtain proper data on the composition of the animal population. However, the method involves many sources of error and – so far as the author knows – has not yet produced sufficient detailed information on age and sex structures of the herds. For a more detailed discussion, see Dahl & Hjort (1976).

Marketing

Pastoralists may have a substantial contribution to make to world meat production. In subsistence pastoralism, male cattle have the role of breeders and meat producers. Dahl & Hjort (1976) calculate a possible annual offtake for slaughter of cattle (male and old female cattle) corresponding to ca 8 % of the total herds, given a "normal" age structure and around 70 % calving rate. With this level of offtake, herd reproduction is not threatened. As local needs for protein can be filled by milk, sale of meat may be a feasible alternative to local consumption, if agricultural produce is available to cover remaining nutritional needs.

However, marketing entails great difficulties. Long transport distances make it difficult to organize effective sales and processing, and the factors which induce the herd-owner to sell do not encourage sale of the best animals in the season when they are most well-fed. As shown by the case of the cattle trade in Karamoja, Uganda, the seasonal fluctuations in the number of marketed animals are often considerable (Baker, 1968). Rather than seeing his cattle die during drought, a pastoralist may decide to sell them. By that time the animals are in poor condition and the meat is of low quality.

In a stratified society, the interests of people at different levels often diverge. The local population increasingly need cash and must sell a few animals several times a year. Their interests clash with those of cattle traders, who are often associated with local politicians and administrators. Local traders often act as middlemen between the producer (the pastoralist) and the large-scale buyer. Thus it is in the interest of the middlemen to keep the number of cattle auctions down. These middlemen make high profits since the herd-owners, having no alternative cash income sources, are forced to sell to them. For Fulani cattle only 11 % of the consumer price of beef is paid to the producer; 25 % goes to the middleman (FAO, 1972).

Land

Farms have been established to an increasing degree in areas, such as riverbeds and the borderland between farming and pastoral zones, where nomads formerly had recourse in dry seasons or years of drought. Low agricultural returns previously hindered extensive settlement there. Other areas are lost to the nomads in the name of game conservation. The risk that a drought will have disastrous effects for nomads has generally increased owing to loss of land and changes in land rights. The rapid change can in part be ascribed to the pro-agriculture attitude of many governments (Rigby, n.d.).

Two immediate issues related to land rights should be emphasized. They both originate from the weak legal position of nomads (see "Legal conflicts" below). Firstly, the rights to border lands, where marginal agriculture as well as pastoralism are possible, should be clearly defined. Today there is a considerable outflow into such areas from neighbouring agricultural areas in many countries owing to increased pressure on land; the latter is in turn a result of population pressure and the concentration of land in the hands of fewer landowners that is one of the symptoms of increased rural stratification.

In Kenya, for example, Mbithi & Wisner (1972) noted a population increase in such areas that is 10 times the national average growth. Secondly, if development projects like group ranches are pursued, the land right for the individual pastoralists must be clearly stated.

When land rights are considered, the importance of variations in rainfall as well as in soil quality should be remembered. Soil type and quality are important for pastoralists. Epstein (1955) pointed out that different animals need different kinds of soil for grazing. In a Kenya Government report (Anon., 1971) it was stated that Somalis distinguish between four different soils with reference to grazing: cotton soil (dusty, grey, soft) where grass grows and cows mature early; *boji* (rich in salts) necessary for camels; and two different kinds of red soils suitable for goats.

Water

The supply of water is an obvious limitation in arid zones. There are two ways of increasing this supply, both needing heavy investment. One is to make boreholes to exploit the groundwater and the other is to build dams to store water from surplus rainfall during rainy seasons.

Water holes need to be located well apart, supplying a limited number of animals, so that the grazing in the surrounding area does not suffer. This ideal goal is not always possible to achieve and overgrazing and trampling occur around water points.

Diseases

A number of diseases limit the life expectancy and quality of the animals of pastoral people. It is not unusual that a major epidemic may kill off up to half of the cattle population in an area. Flocks of small stock may be even harder hit.

Vast areas are not used for grazing today owing to the occurrence of the tsetse fly. Extirpating the flies (or rather, the bushes on which they live) would result in a substantial increase of pastoral land. Some of these areas are not used at all today, others only during dry seasons.

Food storage

Cattle and/or camels constitute a major source of food, providing milk, meat and sometimes blood. They are supplemented with sheep and/or goats kept primarily to provide meat, but also yielding milk. In addition, agricultural activities are practised to a varying extent, depending on local conditions.

There are two aspects of storing food which are of interest here. One is the volume that has to be stored to compensate for seasonal differences; it also has to be taken along when the household moves. The other is what foodstuffs it is possible to store; these are mostly meat and various milk products, like ghee and yoghurt. Such items can be stored successfully for a period of several months by pastoralists. Experiments have also been made to set up small local industries based on milk products, such as ghee, but not with very encouraging results.

In certain areas it might be possible to store surplus grass from rainy periods to be used for fodder during dry seasons.

Administrative aspects

Communication and attitudes

Communication between national administration and pastoral peoples living within the national boundaries is often strained or even lacking. Each side tends to be suspicious about the other's intentions. The administration finds nomadic behaviour difficult to cope with, as movements are determined basically by natural conditions and do not take account of regional or even national boundaries. In this respect, nomads may often constitute a very inconvenient group for political reasons. Also, the fact that these people are not settled makes administration different and difficult. The nomad's attitudes toward the national administration are reflected in his actions: he often treats the administration as another ecological factor – an external constraint similar to unreliable rainfall, say – that he must take proper precautions to cope with (Spencer, 1965).

The sceptical attitude of pastoralists towards central administrations has saved them from many poorly devised projects – particularly agricultural projects in areas not very suitable for farming. Rigby (n.d.) illustrates this point with the Gogo settlement in Tanzania, where it took several years of crop failure before the "experts" would face reality and accept pastoralism as a basis for development in the area.

Many governments have attempted to forge a causal link between "pastoralism" and "conversatism", especially by pointing at the special values connected with livestock. There has been talk about a "cattle complex" (formulated by Herskovits, 1926) leading to resistance to change, and about internal factors like economic and social organization, and value systems. Added to all this is the attitude that development only takes place in one unique direction, crushing those who are not capable of accepting change. In this spirit Huxley writes about the Masai (Huxley, 1949):

> ". . . these obstinately conservative nomads, wandering with their enormous herds from pasture to pasture, seem like dinosaurs or pterodactyls, survivors from a past age with a dying set of values – aristocratic, manly, free, doomed . . .".

Many nomadic peoples (e.g. the Lapps in the seventeenth century and the Masai at the end of the nineteenth century) have thus been wrongly doomed to extinction.

Rigby points out that such attitudes have led not only to governmental indifference but even to attempts at promoting the wrong kind of interests, as seen from the pastoral and semipastoral peoples' point of view. Any attempts at development very strongly emphasize making local people more "agricultural", that is, to sedentarize them, which is often linked with a policy of creating permanent villages. This kind of policy is also, by and large, pursued by new independent governments.

The exchange of information should create few difficulties. As a FAO-report (FAO, 1972) indicates, nomadic societies offer ideal conditions for dissemination of information owing to their mobility.

The same report identifies perhaps the most crucial political reason for governmental resentment of nomads:

> "It was underlined that nomads are no respecters of national frontiers which they cross and re-cross very rapidly, evading arrest or taxation, avoiding some new 'modernising' programme or any of those other intrusions of modern administration or 'good government' which the exponents of urban culture seek to impose on their 'more backward' subjects. This elusiveness curtails the nomads' commit-

ment to the state. This, combined with an independent attitude and bellicose character, has often given rise to hostility between the State and the nomads, and a fundamental issue in this situation is the attitude of the authority towards the development of nomadic populations. This has varied from neglect, or even hostility, to forceful settlement; it has resulted also in an unduly small share by the nomads in the political power of the state and the allocation of its resources for development."

The tendency on the part of experts and politicians to overemphasize the emotional attitudes of pastoral peoples has been seen by many, notably by Rigby (n.d.) and Dyson-Hudson (1962). In order to create a fuller understanding of why pastoral societies seem more resistant to change than others, Dyson-Hudson (1962) adds ecology as another "general and irreducible" factor besides the pastoral value set. The latter feature should not be unduly emphasized at the expense of the former.

Regionalism

Regional interests may often present severe threats to attempts at establishing an ecological balance. They may sometimes clash head-on with national interests. and local patriots may be tempted to press unduly for allocation of benefits to their own regions (see Finkel, 1973). For reasons of local politics they may also defend a *laissez-faire* policy *vis-à-vis* land use that obviously leads to land degradation.

Organizational problems

When carrying out projects aimed at restoring the ecological balance, a number of difficulties are encountered because of poor organization. Finkel (1973) mentioned poor coordination and weak cooperation between different aid organizations.

After a general political goal has been set, much of the decision process falls within the administration. Decisions, such as selecting areas or approaches for a project having great political significance overall, often lie with technical experts who use their specialized criteria in making choices. By focussing discussion instead on technical questions of economic feasibility it is possible to avoid the central issue of how the pastoral economy should be integrated with the development of the livestock industry (see Rigby, n.d.).

Responsibility for the several aspects of a project is usually divided among the various ministries of a government. Given poor communication between these ministries, projects may easily be delayed at various points.

For the reasons given above, contacts between government representatives and the people may be strained on the local level, adding further to the difficulties of carrying out a project.

Legal conflicts

There are often two partly contradictory systems of law in a region, one national and one local customary. The question of land rights should be taken up again in this context. For example, the grazing areas of nomads are considered by the government as belonging to the state, and to the tribe or the clan by the local people. The conflict becomes acute if agricultural peoples are resettled within pastoral areas.

Another legislative issue arises when there are several conflicting sets of "legitimate" traditional rights, for example in a multi-ethnic situation, when different groups can all adduce historial evidence for rights to water and grazing. The process of creating national laws is a slow and intricate one, since some minimal consensus must be reached among groups with different interests in a country before a law may be passed.

Implementation of development schemes

Whether they are intended to improve the subsistence economy or to give the "modern" monetary economy a stronger foothold, new development schemes often give rise to unexpected spin-off effects. This is even more so if the "feed-back information" from the field to planners/administrators does not flow properly and the projects are not carefully evaluated.

In some local communities, life quality and living standards have even deteriorated as a result of development efforts. For one thing the differentiation has increased the gap between the rich and the poor. For another, the issue is not only whether the rich have become richer, but also if the poor have become poorer.

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Chapter 6

HYDROLOGY OF THE SAHARA

C.E. GISCHLER*

The climatologically determined location of the Sahara

Deserts occur in areas with subsiding air masses, causing high pressure areas. The largest and most stable zones of high-pressure areas are found on both sides of the tropical equatorial belt of low atmospheric pressure. Of course, owing to the distribution of land and sea, this zone is more developed in the northern than in the southern hemisphere – the Sahara being the most striking example.

The wide Sahara reflects the stability of the high-pressure zone separating the tropical monsoonal air circulation – with rains from July to September and, more south, from June to October – from the Mediterranean air circulation – with less pronounced rains between September and May, while in some years September, October and November may also be dry.

The southern margin of the Sahara is a ca 800 km wide Sudano-Sahelian savanna belt, having a dry period of up to 9 months. The northern Pre-Sahara steppe zone is about ten times narrower and has a dry period of 4–7 months (Table 6.1).

Although both marginal zones, under the influence of population pressure (water needs exceed water availability), suffer much from aridity, the two margins of the Sahara differ in many aspects, as can be seen from Table 6.1. The desert proper in between these margins receives less than 100 mm rainfall a year. In fact, the average annual rainfall figure in these areas has no practical meaning, since the only significant precipitation is supplied by the rare and unpredictable rainstorms which occur with a frequency of less than once a year and may strike any part of the entire desert area.

In the latter case, very occasional rainfall – although of great importance for all life in the desert – should be clearly distinguished from the reliable rainfall supply, on which, for instance, dry farming in the marginal zones depends.

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* The opinions and views expressed in this paper are the author's and not necessarily those of Unesco.

Table 6.1. Characteristics of the Sudano-Sahelian and the Mediterranean Pre-Sahara zones.

	Sudano-Sahelian savanna belt	Mediterranean Pre-Saharan steppe
Width	Up to 800 km	$\leqslant$ 80 km
Dry season	Coinciding with winter, low relative humidity	Coinciding with summer; relative humidity not so low owing to vicinity of the Mediterranean
Rainy season	Between May and November, with maximum in August Period of rains well defined but quantity uncertain	Between September and May, with maximum either in spring or autumn. Period of rains, as well as quantity, always unpredictable
Aquifer lithology	Decomposed basement or deposits consisting of detrital products of basement	Mainly precipitates and some evaporites
hydrology	Often phreatic and shallow; low transmissivity	Mostly artesian and deep; high transmissivity
chemistry	Slight amounts of $NaHCO_3$; only very low Cl^- concentration < 500 mg l^{-1}	Mainly considerable amounts of $CaSO_4$ and NaCl $\gg 1000$ mg l^{-1}
Adaptation		Greater ingenuity required to grow crops
Autochthonous technology	Hand-dug wells down to 100 m depth, hafirs, "terps"	Craddle of civilization, with highly developed skills in rainwater harvesting etc. Cisterns, qanats, aqueducts, irrigation
Main problem	Is becoming drainage since salinization requires more time owing to low salt content. Chari-Logone riverwater less 100 mg l^{-1}. Huge quantities of surface waters are lost owing to evaporation from free water surface. Conservation methods have to be tried out.	Was and still is bad drainage, leading to salinity owing to salt concentration through evaporation of waters with already high initial salt content. Seawater enchroachment along populated areas of the Mediterranean coast.

The mountainous water divides surrounding the Sahara

From the point of view of conventional climatology, the southern boundary of the Sudano-Sahelian savanna belt may be defined differently. However, for hydrological reasons, it is practical to take as the southern border the mountainous water divides from where tropical downpours are drained towards the north, influencing soil and climate in the savanna belt. With the exception of the high East African lake district south of the equator, these are the Congo divides for the headwaters of the Bahr El Ghazal, confluent of the Nile and Chari hydrological system feeding Lake Chad, the Cameroon basalt plateau and Mandara Mountains drained by the Logone river system, confluent of the Chari river. The Mandara mountains, together with the Nigerian basaltic Biu and Jos plateaus, give rise to the Yedseram and Komadugu rivers respectively, also supplying Lake Chad.

The Niger river system forms two breaches in the closed front of water divides separating the Sudano-Sahelian savanna belt from the tropical equatorial belt:

a. the Mayo-Kebbi, a natural spillway from the Chad basin giving access to the Benue river and

b. the present fossil river system, which in the last pluvial drained the Saharan massifs of Air, Hoggar and Adrar des Iforas, captured the Upper Niger east of Tombouctou and turned its water towards the south.

The Upper Niger draining the southern highlands of Guinea is very similar to the previously mentioned Chari and Bahr el Ghazal river systems (see Fig. 6.2).

Finally, the mountainous region of Foutah Djallon in western Guinea gives rise to the Senegal river.

These water divides are situated between 4° and 12° N latitude with only the catchment area of Lake Victoria, the source of the White Nile, reaching to 4° S latitude.

In the east, the Ethiopian highlands receive their share of the monsoonal rains amplified by the orographic effect, resulting locally in rainfall exceeding 2000 mm yr^{-1} at latitudes up to 12° N. The northern continuation of the Ethiopian highlands via the Sudan into the Egyptian Red Sea hills forms a pronounced water divide separating the Saharan Nile basin from the Red Sea drainage area.

In the west, the Sahara continues without water divide to the Atlantic.

In the northwest, the Atlas Mountains function as important collectors of precipitation locally – over 2000 mm yr^{-1} – and also receive an important part of the precipitation in the form of snow.

The southeastern slopes of these mountains form the recharge areas of the large aquifers of the northwestern Sahara.

The Djebel Akhdar in the Cyrenaica region of Libya receives up to 600 mm rainfall per year.

Further, there are the isolated massifs in the interior, such as Air, Hoggar, Tibesti, Ennedi, Djebel Marra and the Kordofan mountains, which force relatively dry and hot air masses to rise and cool down to saturation point, thus bringing about precipitation.

With the exception of the tropical southern boundary, all these mountains belong to the arid and semiarid regions of the world, characterized primarily by pronounced periods of drought in between rainy seasons at latitudes where evaporation through intensive solar radiation is high and exceeds precipitation, at any rate on a yearly basis.

The sketch map of the hydrology of the Sahara (Fig. 6.1) illustrates the preceding description.

Surface waters introduced from the south

The southern boundaries of the Sahara drainage area fed by the tropical rains supply the large quantity of surface runoff denuding the Precambrian land surface forming 99 % of the basement complex, indicated on the map (Fig. 6.1).

These waters annually flood the vast clay plains extending northward into the Sudano-Sahelian belt. In fact, these clay plains have been built up by the gradual deposition

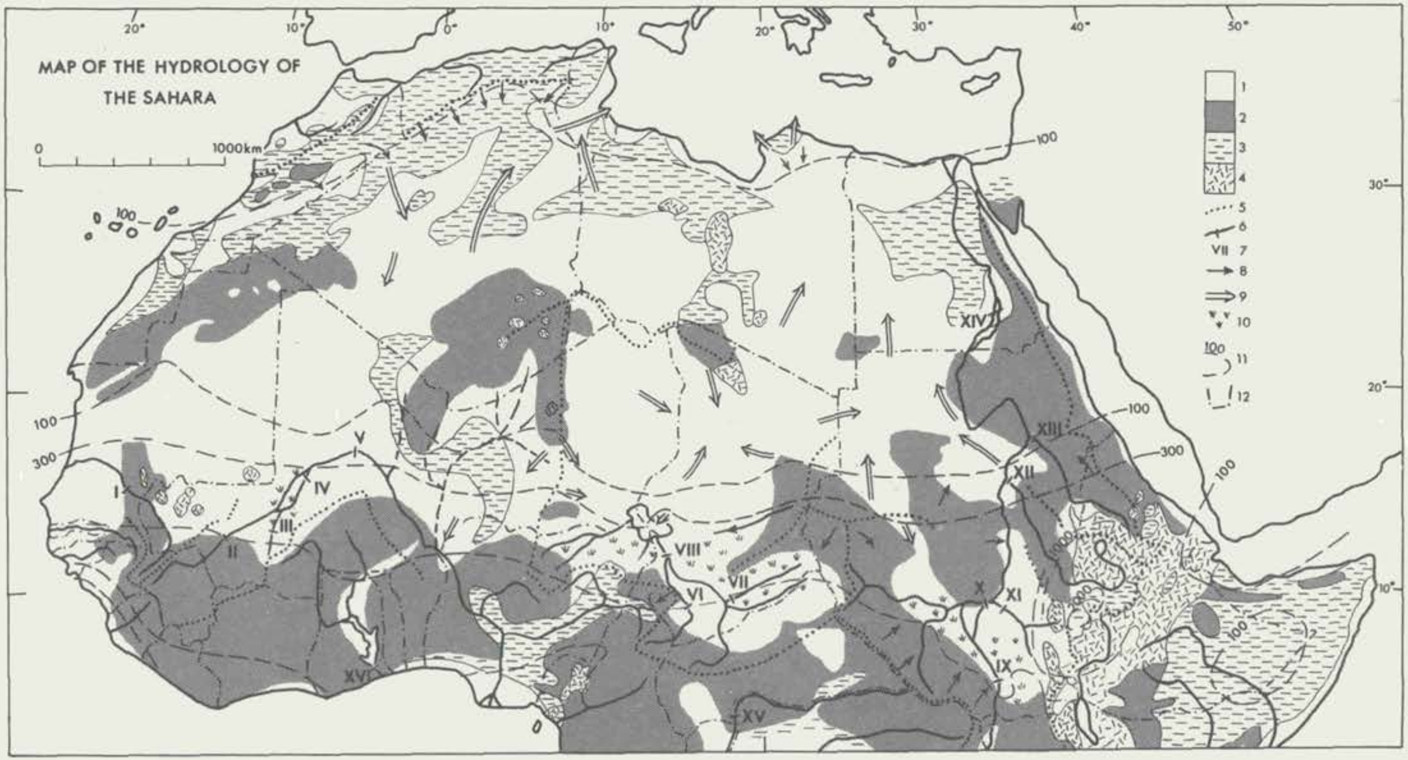


Figure 6.1. Map of the hydrology of the Sahara. 1. Clastic rocks including eolian sand cover – 2. Basement complex at or near the surface – 3. Precipitate rocks with fracture and channel porosity – 4. Basalt cover, generally of Tertiary age – 5. Water divide – 6. Perennial river with gauging station – 7. Number of gauging station – 8. Direction of surface drainage – 9. Direction of groundwater flow – 10. Zone liable to flooding and permanent swamps – 11. Isohyet with mean annual rainfall – 12. National boundary.

of the high suspended load content of rivers where the flow velocity decreases. The river banks generally consist of sandy sediments, while the finer-grained clay minerals are deposited in the floodplains.

The rainy season starts with single thunderstorms and tornadoes, which follow each other with increasing frequency. A considerable proportion, if not all, of these first rains evaporates or is absorbed by the vegetation parched by the long dry season. For this reason, a practical approximation has been adopted by a number of hydrologists to the effect that the rainy season in dry areas is taken as starting with the first continuous shower exceeding 10 mm rainfall.

The rainy season, gradually getting under way, raises the vapour pressure of the atmosphere until the evaporation losses can no longer be compensated by the peak flows of the rivers coming from the south, where the rainfall is much higher.

Thus the vapour pressure of the atmosphere drops again as the inundated area decreases. This process is accentuated by the dry northeastern winds (harmattan) which gradually invade the entire savanna belt for the duration of the next dry season.

The corresponding shape of the hydrographs of the rivers flowing north reflects the rigorously similar hydrological regime (Figs. 6.2a–e).

The following flow pattern can be distinguished from the headwaters starting at the water divide and flowing towards the north, reaching semiarid and arid zones while their gradient is decreasing.

The drainage increases initially with drainage area until a maximum value is reached. This location often coincides with the point where the river starts to traverse its own deltaic deposits with minimal gradient. The river which so far drained the river basin, will – downstream from here – recharge the groundwaters whose water table sinks away from the river through the permeable bank deposits. Also, from here onwards, the river will provide the floodwaters, helping the local rainfall to inundate the clay plains as soon as the river levels exceed the natural bank levels or water spills through the levels into the slightly lower backswamps. In many cases, the clay cover, deposited in the floodplains, forms an effective separation between surface water and groundwater, only linked by the river itself during the flood season.

Evaporation losses

The quantities of water lost by evaporation, mainly from the free water surface, are enormous, as the following water balance shows. (Figs. 6.1, 6.2, and 6.3 should also be considered). The data presented below and in Figs. 6.1–2 have been extracted from ORSTOM reports (1969a,b,c), Unesco, 1969, 1971, 1972 and from the map "Aquifers of Africa" (UN, 1973).

Niger

From two upstream stations (II on the Niger river, Koulikoro, Mali, and III on the Bani river, Dire, Mali, feeding the swampy region west of Tomboucto from the upstream side) and to station V on the Niger river, Dire, Mali, downstram of the swamps, 34.7×10^9 m^3 yr^{-1} is lost, which is 48 % of the total 72.0×10^9 yr^{-1}. The losses evaporate over a surface smaller than 118×10^3 km^2. This corresponds to a sheet of water of an

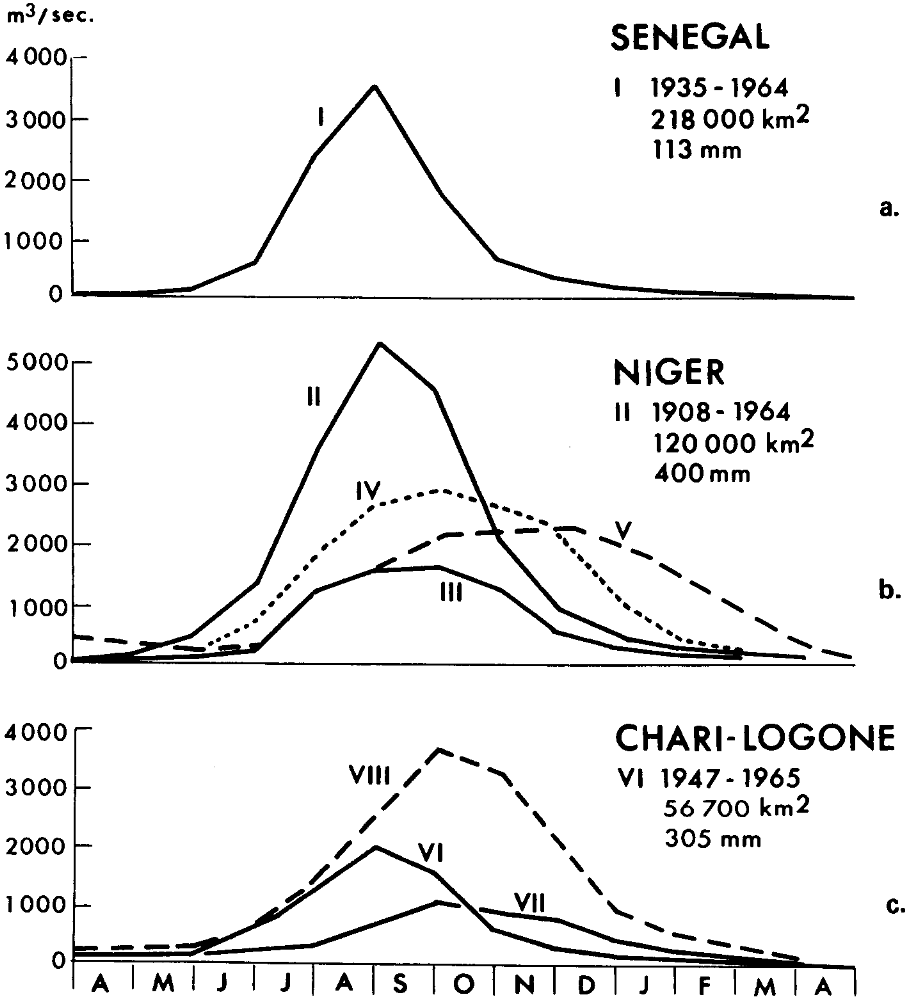
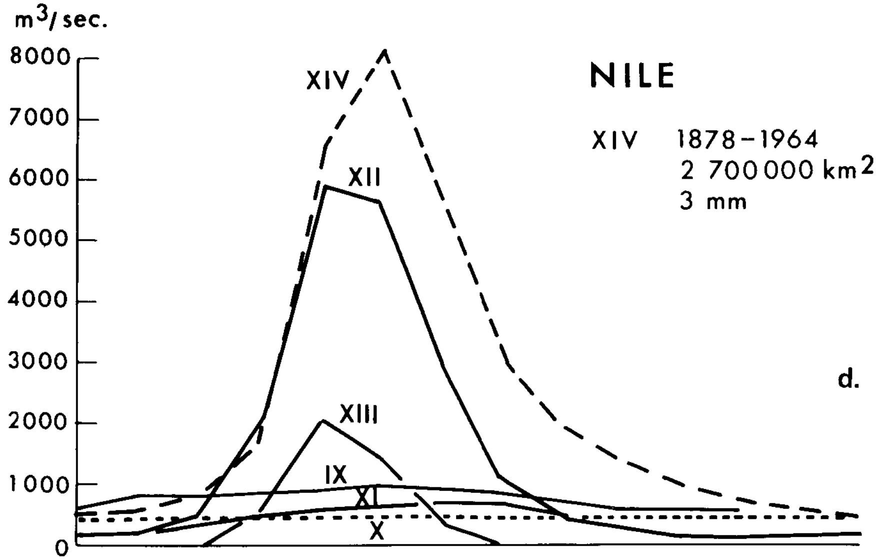


Figure 6.2a–e. Average monthly discharge over the hydrological year. I to XVI refer to gauging stations on the map in Fig. 6.1.


m3/sec.
8000
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2 700 000 km2
3 mm
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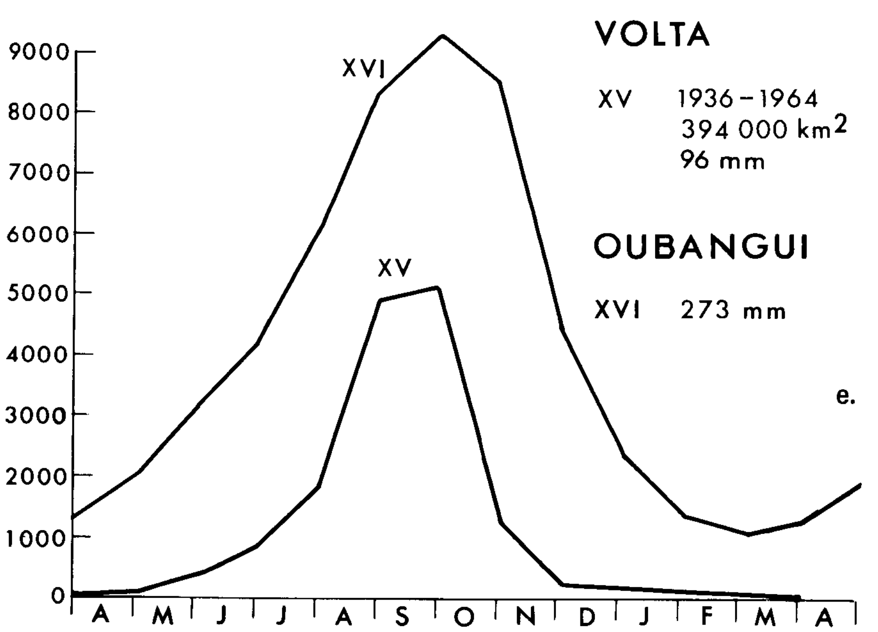
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
XVI
XV
VOLTA
XV 1936-1964
394 000 km2
96 mm
OUBANGUI
XVI 273 mm
e.
A M J J A S O N D J F M A

Table 6.2. **Hydrological data for 15 river gauging stations at the Senegal, Niger, Chari–Logone, Nile and Volta rivers. Cf. Figs. 6.1–2.**

River	Gauging station	Annual discharge $\times 10^9$ m^3	Years of observation	Catchment area km^2 $\times 10^3$	Specific annual run-off mm
Senegal	I	24.5	72	218	123
Niger	II	49.1	70	120	409
	III	22.9	38	102	226
	IV	37.0	40	282	131
	V	37.3	53	340	110
Chari–	VI	17.7	29	57	305
Logone	VII	10.2	30	193	53
	VIII	40.5	39	600	66
Nile	IX	26.5	35	400	–
	X	14.2	35	–	–
	XI	13.3	35	–	–
	XII	51.4	$>$ 64	325	157
	XIII	14.7	50	69	213
	XIV	84.0	96	2400	3
Volta	XV	37.8	28	394	96

average minimum thickness of 30 cm (assuming that the entire 118,000 km^2 were swamp). The average yearly rainfall is about 30 cm. Thus the annual evaporation corresponds to a total sheet of 60 cm thickness or 70×10^9 m^3 yr^{-1}.

Chad basin (Chari–Logone)

Excluding the extensive swamp area upstream of Station VIII (Fort Archambault), the amount of river water lost in the Chad basin supplied by the Logone, Chari, Komadougou Yobe and Batha rivers is 54×10^9 m^3 yr^{-1}.

This volume in excess of the local rainwaters inundates an area of about 90,000 km^2 floodplains and supplies Lake Chad, the drainage terminal of the surface waters in this closed basin.

Water balance of the floodplains covering about 90,000 km^2		Volume in 10^9 m^3 yr^{-1}
Input:	Overflow from streams and rivers	14
	Average rainfall intercepted by floodplains	61
	Total	75

Output: Evaporation of a sheet of water with average thickness 80 cm, while only a very small part feeds the groundwater. It is estimated that these surface waters disappear in a period between 2 and 5 months after the rains have stopped.

Water balance of Lake Chad		Volume in 10^9 m^3 yr^{-1}
Input:	Average discharge of rivers into lake	40
	Average rainfall intercepted by lake surface	7
	Total	47

Output: Equivalent to loss of a sheet of water with an average thickness of 228 cm from the free water surface in Lake Chad.

On the basis of the evaporation rate, the surface of Lake Chad is 47 km^3/2.28 m = = 20,614 km^2. This figure corresponds very well with the actual surface. As a result only a negligible percentage of this volume infiltrates into the ground, recharging the aquifers. In all, about (75 + 47) x 10^9 m^3 = 122 x 10^9 m^3 will mostly disappear as evapotranspiration.

The Nile

In all, 45.3 x 10^9 m^3 is yearly lost by evaporation in the joint Bahr el Ghazal and Bahr el Jebel swamps. In addition the average yearly rainfall of about 900 mm intercepted by the clayey floodplains also evaporates, to the amount of about 80 x 10^9 m^3 yr^{-1}.

Hurst carefully studied the permanent Bahr el Jebel swamps (Hurst & Phillips, 1938; Hurst *et al.*, 1946). During flooding the river spills through the alluvial banks into the slighly lower plains. The flood advances from the river inland to a distance of 80 km, depending on relief and resistance of grass cover. The average annual loss of river water in this stretch is 12.3 x 10^9 m^3 over a permanent swamp area of 8,300 km^2. Depth of the water lost in these swamps is 1.5 m. If the average rainfall of 900 mm – which also disappears – is included, the total depth of the water lost is 2.4 m.

The area of the non-permanent swamps covering the floodplains has been estimated at 70,000 km^2, with large additions outside the central part of the Sudd swamps. Hurst estimated the Bahr el Ghazal losses, mainly from its non-permanent swamps, at 15 x x 10^9 m^3 yr^{-1}. The average depth of the water lost in these non-permanent flooded regions will probably not exceed 1.5 m, including the rainfall of 0.9 m.

The average discharge at Malakal which can escape evapo(transpi)ration in the upstream swamps by the White Nile is 27.3 x 10^9 m^3 yr^{-1}. The White Nile, Blue Nile, and Atbara supply a total of 93.6 x 10^9 m^3 yr^{-1} (see Fig. 6.1) to the so-called Main Nile. The Main Nile is the only river which can resist the extreme aridity over the entire width of the Sahara and still be able to build up its prototype delta on the North African Mediterranean coast. A huge initial amount of water was and is the first prerequisite for this result.

At Aswan, the Main Nile previously transported an average of 84 x 10^9 m^3 yr^{-1}. The difference of almost 10 x 10^9 m^3 yr^{-1} consists of conveyance losses. Of this amount, 50 % may recharge the large Saharan aquifers of Nubian facies in those sections where the river has cut its valley into these formations.

Recharge also takes place into the banks of the newly created Lake Nasser in Nubia south of the Aswan High Dam, which has been filled up since 1964. The more intensive use of Nile water caused by extension of the irrigation network in Egypt and the

Sudan has had the effect that at present only 11 x 10^9 m^3 yr^{-1} reaches the Mediterraenan, mainly as inferior quality drainage water.

The above-mentioned water balances of the Niger, the Chad basin and the Nile give an idea of the water losses north of the Sahara water divide; summarizing in total in the three basins gives 327 x 10^9 m^3 yr^{-1}.

The hydrographs of Fig. 6.2a–d show a retardation of the peak discharges and general smoothening of the curve as a result of the dampening effect of the floodplains traversed by the rivers in question. This also makes the groups of related hydrographs asymmetrical compared with the symmetrical Oubangui and Volta hydrographs fed by the same rainfall regime – but under less rigorous conditions – south of the Sahara water divide. Here can be seen the influence of the rather dense vegetation (high woodland savanna) drawing its water from the soil moisture complex in a drainage basin, with otherwise little possibility for groundwater storage, as basement immediately underlies the soil cover. Only rainwater in excess of the soil moisture capacity will contribute to river flow via runoff.

It is a sad reality that most of the Sudano-Sahelian surface waters are carried away as vapour by the northeastern winds (harmattan) with high evaporating capacity, in the months November–February. In this period, the low pressure belt of the Inter-Tropical Convergence Zone resides south of the Equator, where the vapour condenses and precipitates as rain.

The probably sole overland water flow compensating for this loss is the overflow of an average of 23 x 10^9 m^3 yr^{-1} from Lake Albert at Nimule. There will certainly be no groundwater return flow. This means that the water supply of the Sudano-Sahelian zone, with the exception of the overflow from Lake Albert, is entirely meteorologically controlled.

The study of the deviation from the average yearly water supply, the notorious droughts, is outside the scope of this paper. Any such study should be based on these grounds.

Recharge and groundwater between 12° and 16° N latitude

Recharge of groundwater occurs to a more significant extent where rainwaters are not any longer intercepted by the Holocene clayey floodplains or by drainage basins supplying runoff waters to these floodplains. However, the average rainfall quickly decreases northward here, from 500 mm yr^{-1} to 150 mm yr^{-1}. The result of this combined effect can be observed in the Chad basin (especially east of the lake) where a protracted E-W groundwater mound dips southward under the northern edge of the floodplains from 5 metres below ground level to over 50 metres below ground level. The vast sandy Sudano-Sahelian savanna belt is situated between the Holocene floodplains, which tend to disappear north of 12° to 13° N latitude, and the actually windblown sand cover (ergs) starting north of 16° N latitude. The floodplains and windblown sand cover only have a common boundary in the region of Tombouctou, where the floodplains extend more to the north.

The sandy Sudano-Sahelian savanna belt is made up of the following geological units:

Pleistocene

Sandy deposits with eolian reworked regions and fossil dunes of the so-called Old Erg, with developed – and more north, weakly differentiated – soils. They contain a shallow water table aquifer (Chad basin).

Tertiary

The extensive laterite plateaus of the Continental Terminal consist of more or less ferruginous sandstones with water table aquifer and semi- and full artesian aquifers owing to clay lenses concentrated in some parts of the profile. If covered by the Old Erg, this formation is separated from it by a vast load of Chadian fresh-water clays. Sometimes it directly overlies the basement complex (East Chad basin; Niger, around Niamey).

Cretaceous

The extensive undulating stretches of the Continental Intercalaire and/or "Nubian Series", with a wide drainage pattern, are often hardly visible from the ground but are always recognizable from an aircraft.

The sandstones are of an arkosic character, with rapid changes in facies, containing clay lenses and cross-bedding. The lack of fossils, except fossil wood and plant remains, proves the continent origin. The sandstones are often lithified. Iron, manganese and other oxides form the cement, never carbonates.

In the area under consideration, this formation practically always directly overlies the basement complex, from which it is derived.

If covered by Continental Terminal it is generally separated from it by marine Cretaceous marls and Eocene precipitate rocks and clays.

Basement complex

In the wide sandy savanna belt, consisting of the above-mentioned elements, emerge some large eroded basement uplifts, in which the intrusions of the so-called younger granites have mainly rejuvenated the topographic relief.

All basement uplifts together form the coherent undulating substratum on which mainly continental units have been deposited. The marine intercalations, absent in the Sudan, only appear in the extreme western part of the Chad basin and towards the Atlantic (marine Cretaceous and Eocene).

The basement complex consists mainly of:

a. Granites and gneisses
b. Mica schists and phyllites
c. Some isolated quartzite enclosures.

These rocks are all impermeable unless they have been weathered. Groundwater basins in the basement complex are always very small and hydrologically unrelated in contrast to the vast regional aquifers which developed in the clastic sedimentary deposits.

The depth of weathering is a function of the average rainfall, the vegetational cover and the average temperature. The vegetational cover enriches the CO_2 content of the infiltrating waters which attack the rock minerals. A higher temperature will accelerate the chemical processes. In this way, owing to continuous and permanent abrasion of the old African shield zones, chemical decomposition can penetrate into the rock joints and decompression cracks. This renders granites and gneisses permeable mainly in the front line of chemical attack, while continued decomposition can change all feldspars and dark minerals into clay minerals and silica – even the quartz crystals, which are otherwise resistant to weathering under more moderate climatic conditions.

Consequently, the groundwater in these rocks normally comes from the deeper parts of the decomposition basins, reaching to a depth of about 100 m below ground level in North Ghana (11° N latitude), but only 20 to 40 m in Liptako, Niger, west of Niamey (14–15° N latitude).

If weathered, mica schists and phyllites may become so clayey that lack of permeability will prevent the groundwater from flowing to the wells unless cracked and partly decomposed quartz veins intersecting the decomposed rock drain the waters towards the well.

This explains why drilling for water wells in the basement areas of the savanna belt has resulted in such a high percentage of dry holes where no geophysical electrical resistivity surveys or eventual seismic and gravity explorations were carried out beforehand. The traditional hand-dug wells normally do not penetrate into the most productive deeper levels where water under pressure may also be struck.

Since the quartzites are most resistant to weathering, they should normally be excluded from water exploration activities.

In the very sensitive zone around an average of 300 mm rainfall per year (150–500 mm yr^{-1}) with sandy Sudano-Sahelian savanna belt, infiltration depends on soil structure, topographic relief and rainfall distribution.

Evapotranspiration may just balance precipitation if the latter is evenly distributed over the rainy season. This is practically never the case. The distribution in space and time becomes more uneven with increasing latitude. Rainwater from heavy, concentrated downpours may accumulate to such an extent that, in spite of evaporation losses, part at least can penetrate to deeper subsoil levels, where even the plant roots cannot reach it and where its conservation is assured.

At lower annual precipitation – even as low as 100 mm yr^{-1} – runoff water can accumulate via surface drainage in the depressions, from where it can infiltrate into the alluvial deposits.

Depending on the runoff concentration capacity, in the area of average 300 mm rainfall yr^{-1} and less, infiltration may not occur every year. It may even occur once every few years.

Rainstorms following their individual tracks may not cover the entire land surface but may exclude certain small regions. If this phenomenon persists for some time, acacia trees die in such areas.

Biseau sec or dry zones surrounding basement uplifts

Where basement dips away under permeable deposits, a dry zone or *biseau sec* (dry wedge) exists between the surface contact basement/sediment and the intersections of the basement with the water table. The deeper the water table and the smaller the gradient of the dipping basement, the wider the zone of the *biseau sec*.

Astonishing phenomena may occur in such zones after periods of relatively heavy rainfall. For instance, north of Niamey (Niger) at 15° N latitude, initially dry wells started producing some water during 2–3 years before reverting to their original state. Large volumes of water must apparently have passed the well sections on their way down to the water table.

More south (12 to ca 15° N latitude), owing to the shallow aquifer of low permeability, mainly hand-dug wells tap the water table from a few metres to over 60 m depth. These wells produce drinking water for the local villages and their livestock, while the rain just maintains a sparse vegetational cover and some crops.

Sedentarization is not feasible towards the north, since the required minimum crop yields cannot be obtained. Only nomads with their cattle can exploit the pastures insofar as these grazing grounds can be reached from the existing networks of water points (hand-dug wells, boreholes, etc.).

Cattle herds were formerly restricted to the few open wells dug in depressions, often tapping perched aquifers which could dry up during successive dry years. At present, boreholes normally not exceeding 350 m in depth, exploit the deeper artesian aquifers. The boreholes generally yield from 10 to 80 $m^3 h^{-1}$. These wells are not yet adequate for irrigation but suffice to supply drinking water for large herds of cattle and livestock, which depend for their food entirely on the meagerly rainfed pastures.

Here the differentiation between permeable aquifers and more impermeable aquicludes is more marked than near the basement outcrops. The degree of sorting of grain size of continental deposits becomes higher with distance from the source area (basement complex) while compaction primarily affects the clayey part of the total sediment profile.

The large Saharan aquifers

Up to 18° N latitude, the strata are mainly subhorizontal and – with only a few exceptions – undisturbed. The basement is generally not deeper than 300–500 m. Large-scale folding and faulting starts north of 20° N latitude, with uplifts having their climax in the central Saharan massifs – Hoggar, Tibesti, etc. – followed by downthrust into the deep north Saharan basins. Aquifer depth can here reach 2000 m, while total aquifer thickness is often 500 m or more.

Immediately west of the Nile, the strata stay undisturbed up to 23° N latitude, with the basement not much deeper than 300 m. Northward, under the western desert, the basement gradually dips from 600 m in Kharga (aquifer thickness about 120 m) to 1800 m in Bahariya oasis. In a zone of 300 km from the Mediterranean, the sedimentary complex increases further to 5000 m owing to the transition from mainly continental to mighty marine deposits.

The bulk of the total water reserve stored under the Sahara can be found in these high potential Saharan aquifers. From east to west, the most important basins are: the western desert, in the sense of the deeper northern part of the Nubian sandstone aquifers with a total area of 1,800,000 km^2; the Marzuq basin (700,000 km^2); the west Sahara basin (800,000 km^2); and Tanezrouft (250,000 km^2).

Probably not much more than 20 % of the total volume is stored in the southern shallow basins. Among these the most important are, from east to west: the southern shallow part of the Nubian sandstone aquifers (about half of the total area), the Chad basin (1,400,000 km^2) and the Niger basin (525,000 km^2).

Radiocarbon dating has revealed that the water contained in these basins is between 10,000 and 35,000 years old. Apparently after the last pluvial, about 10,000 years ago, recharge of these basins ceased almost entirely.

Recently, Burdon (1975) described the possible mechanisms which, alone or in combination, could keep the flow of fossil aquifers under condition of nil recharge. Among the most important mechanisms, he mentions the following effects:

- Residual difference in ground water elevation
- Reactivation of flow by compaction; for example compaction following basalt loading
- Thermal drive, caused by the heating up of groundwater during its passage of the deeper sections of the longitudinal profile. Here also the high thermal gradient to be expected around younger granites could play a role. Increase of temperature decreases the density and viscosity of water
- Lowering of discharge level by tectonic actions
- Lowering of discharge level by pressure burst
- Lowering of lake levels resulting in their complete drying up
- Evaporation from sebkhas (temporary lakes).

In the last case, the volume of outflow can be estimated on the basis of the quantity of the salt deposits left behind.

In order to understand the role of the present recharge with respect to the total water balance of a large Sahara basin, the example is given of the western Sahara. This basin was studied in detail by the project UNDP/Unesco, Reg 100 (Unesco, 1972).

It should be noted that this complex aquifer still has a significant present-day recharge, compared with the other aquifers. It can be divided into three major units:

Aquifer of the Continental Intercalaire
Aquifer of the Complex Terminal
Coastal aquifer of South Tunisia.

Aquifer of the Continental Intercalaire (C.I.)

Main aquifer characteristics:

- Area of extension over 600,000 km^2
- Effective thickness from 0 to over 1000 m with an average between 250 and 600 m
- Porosity generally between 22.6 and 28.7 % with assumed effective porosity of 20 %
- Permeability varies from 1 to 10 x 10^{-5} m s^{-1}
- Transmissivity varies from 1 to 50 x 10^{-3} m^2 s^{-1}
- Total dissolved solids content is from 1 to 6 g l^{-1} with an average of 2–3 g l^{-1}
- Very deep aquifer providing water with temperatures up to 80°C and high artesian pressure except along marginal zones where recharge still takes place.

Measuring campaigns carried out in 1932, 1949–1950 and 1959–1960 have shown that the yields of the foggaras have not changed. They can be considered as constant.

The first boreholes were drilled at the end of the last century. The number of boreholes was afterwards increased gradually until, from 1950 to 1960, the groundwater exploitation accelerated suddenly. After recovery, levels did not revert again to the initially observed water levels. The water levels very slowly started to fall in the regions of groundwater development. A stationary regime became a non-stationary regime around 1956. Parallel to this history, the aquifer was tested in a steady-state model valid for the period until 1956. All new water exploitations since, either under free-flowing or pumped regime were individually introduced in a second time-dependent non-steady-state model, in which the fluctuations in exploited yields in the different periods between 1956 and 1970 were simulated. These exploitations resulted in drawdowns, which can be observed and measured in the field and should appear in the model in a corresponding way.

On the basis of a water balance established during more than two years of calibration of diverse hydrological models, accompanied by continuous control in the field, the following findings were obtained (Table 6.3).

Table 6.3 Water balance of the C.I. in units of $m^3\ s^{-1}$

	1956	1970
Input:		
Recharge through infiltration of runoff water from the Atlas mountains and others; Infiltration of exceptional heavy rains on the Grand Erg Occidental directly overlying C.I.	8.5	8.5
Output:		
Subsurface outflow towards South Tunisia	3.6	3.6
Vertical upward seepage feeding the chotts	0.9	0.8
Groundwater exploitation: Foggaras, developed springs (before feeding the sebkhas in the south-west), and borehole	4.0	6.8
Total	8.5	11.2

Considering the fact that outflow towards Tunisia and upward seepage have remained practically unchanged, the increase of exploitation of groundwater of 2.7 $m^3\ s^{-1}$ through a great number of boreholes, some of them 1500 m deep, in the period from 1956 to 1970, has come almost entirely from storage and has been manifested in the lowering of the water table or water pressure levels.

Aquifer of the Complex Terminal

Some aquifer characteristics for orientation:

- Area of extension is about 350,000 km^2
- Depth of aquifer generally from 100 to 400 m, except a deep trough reaching to 2000 m depth, immediately south of the Atlas
- Water quality from 1.5 $g\ l^{-1}$ to 6 $g\ l^{-1}$, with an average of 4 $g\ l^{-1}$.

A summary of the water balance for the Complex Terminal is found in Table 6.4.

Table 6.4 Water balance of Complex Terminal in units of m^3 s^{-1}.

	1950	1970
Input:		
Recharge along the marginal mountainous zones Infiltration of exceptional rains on the Grand Erg Oriental feeding the underlying Complex Terminal	18.5	18.5
Output:		
Vertical upward seepages evaporated in the sebkhas and feeding the chotts	10.0	8.9
Exploitation by boreholes and developed springs	8.5	12.6
Total	18.5	21.5

As the aquifer is more easily exploited by boreholes than the deeper aquifer of the C.I., the non-stationary phase of the steadily falling water table and water pressure-levels had been reached as far back as 1950. Practically all wells have to be pumped.

Again, it can be seen that from the increase of 4.1 m^3 s^{-1}, groundwater exploitation between 1950 and 1970, 3 m^3 s^{-1}, have been drawn from storage.

Coastal aquifer of South Tunisia

This aquifer is completely isolated from that of the Complex Terminal but is fed by the aquifer of C.I.

This aquifer is arteisan over its full length along the coast up to 10–20 km inland (total area of extension about 3000 km^2). The aquifer is 100–200 m deep; water temperature 25°C, with higher temperature along the El Hamma fault (40°–50°C); and total dissolved solids content of 3–4 g l^{-1}. However, the salinity increases towards the northeast and towards the southeast (about 8 g l^{-1}). The water balance is summarized in Table 6.5.

The total amount of water reserves stored in the three above-mentioned aquifers is estimated to be 6×10^{13} m^3. This volume could supply a hypothetical continuous discharge of 1000 m^3 s^{-1} for 2000 years. From this point of view, exploration could be increased in the future without any short-term harmful effects. In practice, however, the water table will go down continuously at variable rates, depending on the locality and the intensity of pumping.

The drawdown will be maximum in the larger centres of water withdrawal and zero in certain areas far away from points of water extraction.

From the increased groundwater exploitation of 0.9 m^3 s^{-1} between 1950 and 1970, 0.5 m^3 s^{-1} is drawn from storage.

Table 6.5 Water balance of the coastal aquifer of South Tunisia in units of $m^3\ s^{-1}$.

	1950	1970
Input:		
Recharge along the marginal mountainous zones from occasional rainoff and rain water	2.6	2.6
Recharge from the aquifer of the C.I.	3.6	3.6
Total	6.2	6.2
Output:		
Vertical seepage (evaporation) sebkhas	0.3	0.3
Seepage into the sea	2.7	2.3
Exploitation by mainly artesian boreholes and springs	3.2	4.1
Total	6.2	6.7

Conclusions and recommendations

It is mainly the twin dependences on rainwater (or surface water) for food production and well-water (groundwater) for drinking, which make a region sensitive to drought.

In the dry season, without exception, the area surrounding an exploited water point, otherwise dependent on rain for food production (pastures or crops), will suffer degradation. If the situation persists, this degradation could finally lead to desertification.

Exclusive dependence on groundwater needs not pose any unexpected problem with respect to water supply, so long as the water exploitation is well guided by competent groundwater hydrologists and measures are taken for the maintenance of wells and pumps.

Groundwater models, if well calibrated, form an excellent tool for predicting drawdowns related to the production of the quantity of water required to satisfy the needs of an oasis population, with its livestock and irrigated agriculture. On the basis of such forecasts, appropriate pumps can be chosen to bring the well-water to the surface.

In fact, as long as the groundwater reserves are sufficient – even if these reserves do not receive any new supplies – and as long as the economic resources are adequate to cover the cost of groundwater exploitation, no additional water will be needed. Of course, good soils and the necessary skills should be available for obtaining the agricultural production required and for avoiding harmful effects, such as waterlogging and salinity.

Exclusive dependence on rain water, although precarious, can be feasible if the nomads and their herds have freedom of movement.

Unfortunately, political boundaries, space allocations for agriculture or sedentarization in general, levying of taxes per head of cattle to be paid at certain times in certain locations, etc., have hampered the nomad in his movements. Already his freedom is restricted by the rules of the transhumance to make the best use of the distribution in time and space of certain complementarities in the diet of his animals, which form the basis of nomadism. For instance, the quest for salts – an item which is very scarce in the Sahel – causes the nomad to travel long distances, since salt is a physiological necessity for his cattle. Salt was and is, here, a valuable item which was once exchanged on an equal weight basis for gold in the days of the trans-Saharan trade with the medievel empires of Ghana and Songhai.

Not being free to follow the rains or what is left by the rains in the form of ponds and pastures, the nomads need the support of the local authorities to solve their water problem by establishing water yards of cattle pumping stations. If the authorities cannot help, the nomads and their herds will perish.

More than the narrow Pre-Saharan zone, the wide Sudano-Sahelian belt, with its large surface-water supplies, has attracted large populations with their livestock and agriculture. However, groundwater is relatively scarce for replacing the vanishing surface water at the end of the dry season. Permeability is low, aquifer thickness restricted and recharge uncertain. Drilling campaigns for water wells – even if this can be financed – will only provide temporary relief. Degradation of land in the vicinity of wells will make a small contribution to desertification unless very strict rules and discipline are observed.

One way of conserving water in the floodplain area is to draw irrigation water from the sandy river banks instead of directly from the river. This exploits the bank storage capacity, either by preventing the groundwater from being drained towards the river, or better still, by making the river recharge the depressions created in the water table. Water in the banks is well protected from evaporation, and high permeability allows of high pumping rates. In the Sudan alone, $6{-}10^9$ m^3 yr^{-1} is directly pumped from the river for irrigation purposes.

Another way of conserving water is to create shallow reservoirs where the otherwise flat plains show maximum topographic gradient. Here flood waters could be stored at a depth exceeding the annual evaporation rate. The idea is to have some water left for the dry months preceding the next rainy season. These structures are different from hafirs serving the same purpose; these are closed artificial reservoirs of much smaller horizontal dimensions.

Another solution is to restore the Sudano-Sahelian savanna belt to its old flexibility so as to enable it to react more quickly to rainfall fluctuations. This remark may need an example to show its significance. In the 1960s, during the second five-year plan of the Niger Republic, it was decided to encourage the support of villages of more than 300 inhabitants. Only in such a village would the appointment of a governmental paid schoolteacher be justified. However, permeability of the subsoil and the limited carrying capacity of the land did not allow population concentrations of this size without causing ecological degradation. Although the problem was discussed – and to a certain extent also recognized – priority was given to the criterion for the appointment of a schoolteacher.

The flexibility of the Sudano-Sahelian savanna belt can be restored by supporting nomadism without increasing the numbers of cattle, by restricting the cultivation of cash crops to regions with a certain amount of mean annual rainfall in combination with certain soil types, by a practical weather forecasting system which also keeps track of the quality of the pastures and the movements of the nomads, and by providing simple and adequate information for agriculture. People should also be able to benefit from the provision of such services, for instance, via the creation of a network of village associations where each is equipped with a television set, etc.

Finally, there remains the widely disputed problems of the predictability of the monsoonal rains. This difficult problem needs the combined integrated support of environmentally oriented advanced science centres, and the different UN member organizations. The wellfare and well-being of many peoples and countries will depend on the solution of this problem.

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Chapter 7

ENERGY PROBLEMS IN ARID COUNTRIES

H. IDRIS

Introduction

In October 1975, the Royal Swedish Academy of Sciences arranged an interdisciplinary conference on energy with representatives from both the industrial and the developing countries. A special group within the conference dealt with energy in relation to the developing countries. During the proceedings the situation of Sudan was especially analyzed as an example of a developing country without oil resources (Anon., 1976).

This paper is a summary of the material presented and of the conclusions and recommendations made, with special relevance to arid and semi-arid areas. The main objective of the conference was to establish research priorities for the Swedish research councils in the energy fields. These research recommendations of relevance to the developing countries are summarized here.

Differences between the industrialized and the developing world were stressed during the conference. An important point to remember is that these differences are not only quantitative – such differences are in Table 7.1 – but that the basic problems are quite different.

There is thus a large gap in energy consumption between the industrialized and the developing world, and there is no indication that this gap will diminish. On the contrary, the increase in *per capita* energy use for certain regions during 1951–1969 (Table 7.2) indicates that the gap will widen.

The risk of further widening the gap between the industrialized countries and the developing world was discussed during the conference, and the following statement was made: "If this is to be avoided, the industrialized countries have to consider switching from oil to other energy sources, with which their sophisticated technology is able to cope, in order to conserve oil and increase energy resources available to the developing countries, and thus ensure these countries access to the energy immediately necessary for development. On their side, the developing countries would have to abstain from social and technological imitations and instead develop energy-efficient social systems and methods of energy conversion which would enhance the possibilities of energy self-reliance".

Table 7.1 Energy consumption *per capita* in kg oil equivalent (kg oe) in 1970 (1972) (Anon., 1976).

	kg oe cap^{-1}
Industrialized countries	4548
Developing countries	254
Sudan (1972)	150
Countries with central planning	1311
World	1897

Table 7.2 Increase in *per capita* energy use 1951–1969 (Kristoferson, 1973).

	MWh cap^{-1}
North America	23.6
South America	2.5
Western Europe	10.1
Africa	0.8

The wood fuel problem

As already mentioned, there is not only a quantitative difference between the industrialized and the developing countries, but also a qualitative one. In the industrialized countries the main problems are oil prices and nuclear technology, but in the developing world the major problem is a wood fuel crisis. Over 95 % of the households in developing countries, where wood fuel is readily available, use wood as a primary source of energy (Table 7.3).

Table 7.3 *Per capita* consumption of wood in some developing countries (Openshaw, 1974).

Country	Consumption of wood fuel *per capita* per year (tons)	Wood fuel out of total timber consumption (%)	Charcoal consumption out of total wood consump. (%)	Urban population (%)
Tanzania	1.8	96	4	7
Gambia	1.2	94	26	23
Thailand	1.1	76	45	15

Somewhat lower figures are presented by Abayazid (1975) for the Sudan for 1972. Consumption in urban areas was 135 kg firewood *per capita* and the figure for rural areas was 350 kg. Fifty-seven per cent of all energy used in 1972 in the Sudan came from firewood. The total amount of firewood used is about 6 million tons per year, which is one-fifth of the total forest regeneration in Sudan. However, only forests close to human habitations can be used for firewood. In the Sudan only half of the forest area is suitable for supplying firewood.

Wood fuel represents 65 % of the total wood use (2300 million tons) in the world. This is equivalent to 1300 million tons of coal. The demand is increasing because of population growth. Demand exceeds supply, however, and this trend will intensify in the future.

At present, wood removal from the forests exceeds annual production. The biological capital is used up as the forests disappear, particularly in tropical and subtropical areas. The dwindling supply becomes evident in several ways – for example, an increase in prices and an increase in the time spent in collecting fuel wood. This process may be accelerated by charcoal production around urban areas. The town of Mopti on the Niger in Mali requires 130,000 tons of wood annually for smoking fish. Deforestation around Mopti affects an area of radius 100 km (FAO/SIDA, 1974). Kano in Nigeria has an annual firewood consumption of 75,000 tons and there is no firewood within 64 km of Ouagadougou in the Upper Volta (Lawton, 1975). The woodlands around Khartoum are now completely denuded and wood for charcoal is exploited at distances up to 400 km.

Another example is given in Fig. 7.1, which is an image from ERTS-1, using band No. 5. It shows that around the Tanzanian town of Dodoma there is a "white circle" of 40 km radius caused by the patchwise degradation of vegetation. This destruction around the towns means, in turn, that the cost of transportation of energy increases.

An increase in wood production would satisfy the immediate energy needs in many developing countries, while, at the same time, plantations would improve the quality of life in other ways.

> "Fuel wood plantations could be grown on a 6 to 10 year rotation using such species as Eucalyptus, Indian neem and Cuvelinea, giving an average annual yield of about 8 tons per acre (including branches), enough for an average family . . . . Such plantations if grown for the non-subsistence sector of the community could yield about 5 % per year on invested money, assuming a selling price of 80 pence a ton for the standing tree (1.6 p/cu.ft). It would also provide many rural people with cash incomes from plantation work and the manufacture of charcoal". (Openshaw, 1974.)

It is also stated that with current technology, a ton of wood fuel can produce 2 barrels of oil and that this wood-to-oil process becomes competitive when the oil price is $ 10 per barrel. The price is now (November, 1976) $ 11.51 per barrel.

In the first SIES report on desertization, Rapp (1974) pointed out that overintensive wood collecting has contributed to desertization. In dealing with these problems it is necessary to take an integrated view of the entire ecosystem. From man's point of view, the forests in the dry ecosystems have many functions. They should not only provide firewood, but also protect against erosion and desertization. Woody plants offer valuable fodder during dry seasons and they may be the nomad's last resource during

Figure 7.1. Part of an ERTS-1 satellite image (Dec. 25, 1972, channel 5) of semi-arid land with degradation perimeter in the surroundings of Dodoma (D), central Tanzania. Black patches = woodland.

drought disasters. The forests may also, as in the Sudan, provide valuable commodities (gum arabic). Timber for building and material for fencing are also very important in dry areas. It is thus obvious that the multiple functions of forests must be carefully considered before any action is taken. There are, of course, many technical possibilities for increasing forest production but the most acute need at present is, however, to lessen the pressure on the existing forest resources. This could be done by finding and utilizing new energy resources.

Additional energy sources

An additional input from new energy sources is needed not only for the protection of vegetation and the prevention of desertization, but also for improving living conditions. Earlier in this report it has been stressed that the irregular productivity of the dry ecosystems can only be utilized by some kind of nomadism. For several reasons there is, however, a trend towards eliminating nomadic ways of life by persuading nomads to settle, one of the motives being to attempt to raise the now unacceptably low standard of living of these peoples. Changes are necessary for dealing with problems such as health care, education, housing, etc. If the nomadic way of life is to continue, then the situation of the nomads is in urgent need of improvement, such improvement being possible only if new local energy sources can be tapped. It has to be kept in mind that the amount of energy used in these areas is extremely low (as the figures given above from the Sudan show) and that even a very limited amount of additional energy can change conditions considerably.

The dominant energy resource is the sun. Man utilizes solar power through the ecosystems, but there are also other technical possibilities for the use of solar energy. This is especially the case in tropical and subtropical areas receiving a constant inflow of such energy, the highest yearly average being in the region of the Sahara. (Fig. 7.2.)

Various physical systems exist for converting solar power to energy for human use (Fig. 7.3). The large-scale production of these systems will require a completely new technology. They are most attractive from a theoretical point of view owing to their high efficiency (10 %) as compared with a much lower efficiency for the biological systems (around 1 %). Extensive research activities, particularly in the United States and France, are now taking place to overcome the technical problems involved.

On a small scale, there are several methods which might easily be adapted to the local conditions of the developing world. A good summary of these problems has been provided by Moumouni (1973).

> "For years, different types of solar devices, e.g. solar water heaters, stills, refrigerators, engines and batteries have been used in countries such as Senegal, Mali, Upper Volta, Niger and Mauritania."

This small scale intermediate technology needs strong support. Abayazid (1975) has pointed out that in the Sudan the utilization efficiency for wood fuel is only 17 % for cooking and water heating, compared with 85 % for electricity. Even here small-scale technology could improve the situation (Fig. 7.3).

Rivers such as the Nile, the Niger, the Volta and the Senegal, fed by rains in the humid tropics, offer a large potential for hydroelectric power generated with the help of

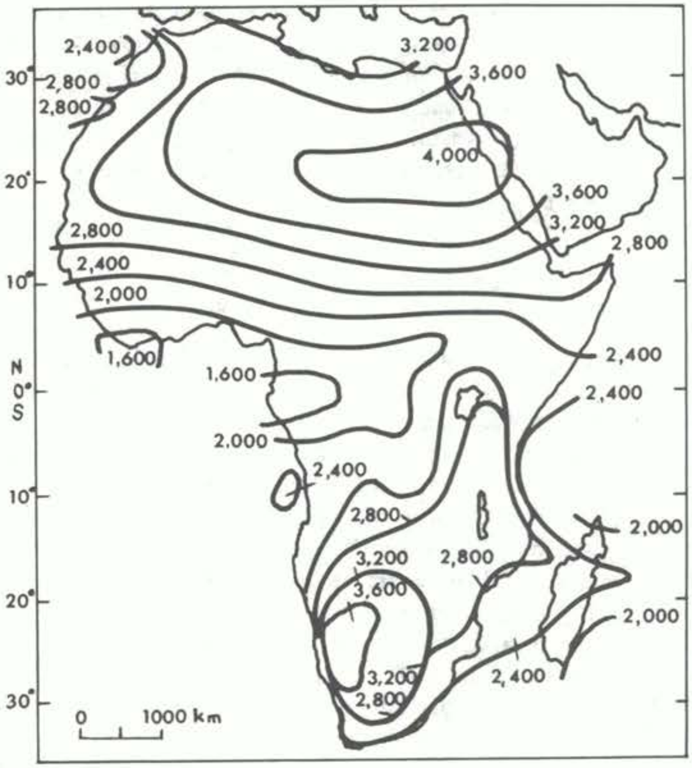

Figure 7.2. Mean annual sunshine hours in Africa. Note maxima in the Sudan and the Kalahari. From Griffiths, 1972.

large dams or man-made lakes. These reservoirs have an immense influence on the ecosystems, on the social patterns, and of course on the economy. The techniques for dam construction and hydroelectric power generation are very well developed and are usually handled by international firms with excellent results. However, other skills necessary for coping with the enormous resultant changes in the environment are often lacking. From an economic point of view, the problem is not to maximize power output but to optimize multiple output from the man-made lakes. This means that studies of both land-use and water-use must be undertaken, but here we are often faced with conflicting interests. These problems have been dealt with in a report entitled "Man-made Lakes as Modified Ecosystems" (SCOPE, 1972). Special attention should be paid to the unwanted side-effects that may occur – for example, silting, pollution, changes in disease patterns, and climatic changes. It is, moreover, not enough to consider only the man-made lake as a modified ecosystem, but rather to take an overall view of the effects on the entire watershed. Here integrated transdisciplinary studies are needed. A good example of such a study from a dry area has recently been published about the Kamburu dam in Kenya (Odingo, 1975).

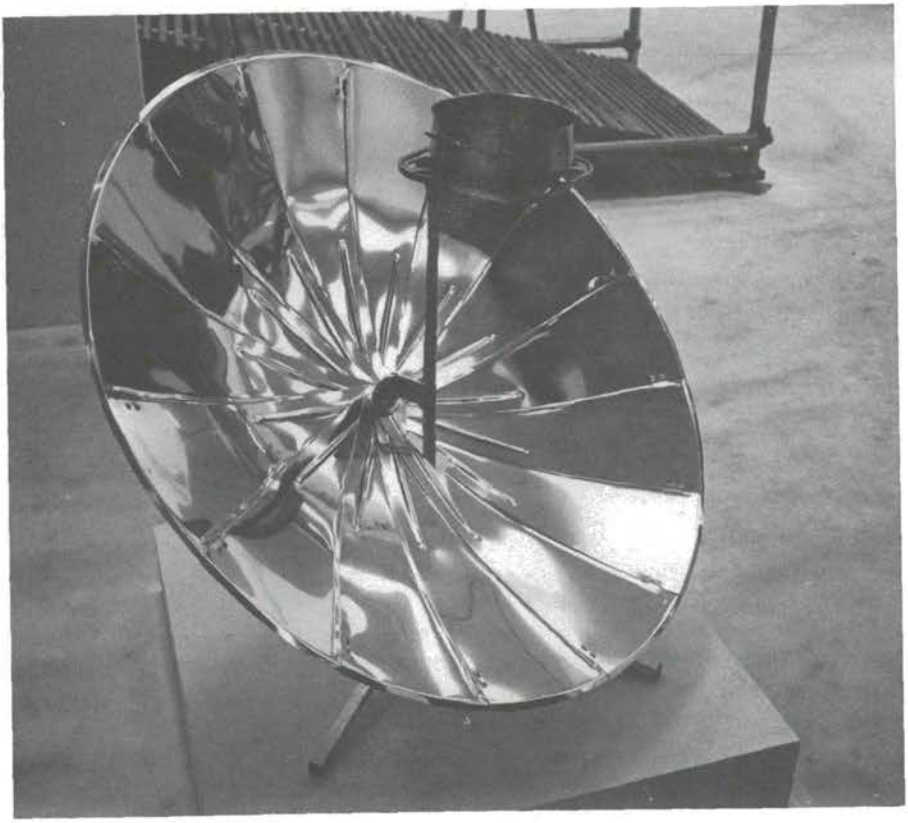

Figure 7.3. Solar energy cooker, with reflector, 1 m wide.

Too many cases are known where dam construction has led to unpleasant surprises. For this reason it is necessary to establish research instruments to predict what will happen when the dam is built. During the conference arranged by the Swedish Academy of Sciences it was pointed out that the link between ecological and socioeconomic systems must be studied more thoroughly. The social costs are in many cases larger than the actual construction costs. As an example, of the total costs for building the Kossou Dam in the Ivory Coast, 34 % went to actual construction, while 66 % went towards resettlement of local inhabitants. Of course the population to be resettled in arid areas is rather small but, nonetheless, it is essential to take social effects into account in any project of such a nature.

Alternative sources of energy which also need to be harnessed in developing countries are wind energy and energy from agricultural waste. Windmills for low-lift pumping of water from rivers and surface wells and for limited electricity generation are suited to isolated locations distant from national main electricity grids. Agricultural waste like bagasse, from the sugar industry, and straw is another source worth tapping.

In general, arid ecosystems react strongly to human impact. An input of additional energy may easily cause disturbances, which can be triggered by an inflow of capital and the following activities: tractors run with cheap oil, too many vehicles, too many buildings and roads, too many tourists, etc. These factors can, if the proper safeguards are not taken, cause erosion and degradation of land. This is evident in certain areas in North Africa owing to the money sent from Europe by guest workers of North African origin, causing such areas to deteriorate much more than undisturbed "poor" areas. It is thus very important that special measures be taken in arid areas, and that additional inflow of energy or money be used not only for exploitation but also for the conservation of natural resources.

Research needs

The following comprises a summary of the recommendations presented to the Swedish research councils regarding areas where research is most needed in an attempt to tackle the problems of the developing world. The recommendations of relevance to this report on desertization are given below (Anon., 1976).

Research results, knowledge, skilled experts and well-trained personnel are of no value if not utilized. The problem of information transfer and acceptance is vital to the developing world. The only way to overcome the difficulties is to build up capabilities for research and development in each of the developing countries. They will never be able to solve their problems without their own firmly established scientific and technical expertise. In order to achieve this the following should be taken into account.

Many if not most of the numerous current environmental problems arise from a failure to integrate physical, biological, economic and sociological aspects into the planning and execution of development projects. All countries and agencies sponsoring bilateral or multilateral programmes in connection with development projects should give high priority to the establishment of local expertise suited to the decision-making process by ensuring that:

- national know-how will be involved from the planning stage onwards;
- on-the-spot training of scientists and technicians will be given high priority as a component of the research activities;
- national research institutes and organizations will be strengthened materially and/or financially;
- the results of research carried out will be made available to the national counterparts and decision-makers as quickly as possible in a form which is useful for them.

The following areas were stressed as those where support from industrialized countries would be most effective.

Energy system studies and training

Analysis of the energy flow is essential to the understanding of the energy situation in any country. The interlinked pattern of different kinds of energy, the costs of energy production and energy consumption should be known before improvements are attempted. It is now possible to explore these conditions by energy system studies, where systems analysis and modern data handling allow us to predict the consequences of different ways of solving problems. It is important to have experts who can apply this technique, which can be used for dealing with the integrated problems in any society. Therefore, not only technicians and scientists but also administrators and politicians responsible for integrated planning should be trained. It must also be pointed out that this is the sound foundation for Eco-development that has been given very high priority by UNEP.

Firewood and forests

Wood is a most important source of energy in developing countries and will remain important for a long time. Besides its present use, there will be an increasing demand for wood as raw material for paper mills. Current trends spell the destruction of indigenous forests, the eradication of advanced ecosystems and the overconsumption of plantations. Soil destruction, lack of water and deterioration of the environment are inevitable consequences.

There is a great need for research on the structure, function and values of indigenous forests in tropic and subtropic countries. Village forestry – including local management of plantations – should be developed. The efficiency of collecting, handling and using wood as fuel can be much improved. A broader selection of tree species for plantation and information on their dependence on the environment are needed.

Technology for small energy-producing units

In the developing countries small energy-producing units are urgently needed. Continuous or renewable energy resources are particularly suitable for this technique. In spite of this, limited attention has been devoted to these problems except in numerous committees at international and national levels. So far, little research has been carried out within the developing countries, where massive support is required to develop new techniques and adapt them to the conditions and resources within. The focussing of attention on alternative energy resources and rural communities is especially important.

Strengthening of microbiology

Microbiological processes are of importance both in the natural energy flow system as well as in the man-induced attempts at improving the energy situation. In the ecosystem the biological energy flow through decomposers is responsible for recycling material and thus determines the productivity of the ecosystem. This was also stressed in Chapter 1.

In general, microbiology hardly exists as a science outside the industrialized countries. There are a few exceptions, but there is a great need to build up institutions and promote research in microbiology in the developing world. Both technical and ecological microbiology are required. The possibilities for using microbiological methods for supplying combined nitrogen in agriculture and village or farm based methane fermentors (biogas plants) are two examples of microbiological processes which could be used in order to decrease the demand for conventional energy sources.

Increased energy production and consumption in relation to the economic and social environment

Research has to be carried out on the best methods of adapting increasing energy consumption to existing economic and social structures in order to obtain a higher standard of living and better quality of life for the population.

Comparative research needs to be done on actual energy needs and expenditures in different modes of production, with the aim of assessing living standards actually attained by the prevailing energy expenditure.

Research on the energy costs of "status consumption" in developed countries as compared with energy expenditure for filling basic human needs must be carried out.

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Chapter 8

REGIONAL STUDIES AND PROPOSALS FOR DEVELOPMENT

Introduction

A number of case studies from various countries affected by desertization are presented in this chapter. They try to answer the question: What experience of counteracting desertization has been gained in various countries and under different conditions? As it was impossible to make a complete inventory of all countries and projects, we had to be content with a selection. The seven countries represented among the case studies are Iran, Syria and Tunisia from the north Saharan margins, Mali and the Sudan from the south Saharan margin, and Kenya and Botswana, predominantly semiarid dry lands in eastern and southern Africa. Apart from the factor of climate, other reasons behind the selection are: economy – Iran is rich in oil, the others are not; and history of exploitation of grazing lands – Botswana has only recently been exposed to ranching and grazing by cattle and sheep. The other countries have a long history of impact from grazing by man's herds.

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Chapter 8.1

IRAN

H.N. LE HOUÉROU

Climate

With a total surface of 1,650,000 km^2, or 165 million hectares, Iran is the second largest country in the Near and Middle East. It is extremely varied from the standpoints of climate, physiography and vegetation. The climate is of the Mediterranean type with rain in the cool season and with a long summer drought. In respect to aridity, the main climatic zones represent the following surfaces:

– Semiarid to humid	($P > 400$ mm)	200,000 km^2 = 12.5 %
– Steppe arid zone	($400 > P > 100$ mm)	1,250,000 km^2 = 75 %
– Desert	(100 mm $> P$)	200,000 km^2 = 12.5 %

Arid and desert zones thus represent 87 % of the country's area. These figures are a rough estimation from the bioclimatic map drawn by Pabot (1967).

These main zones may be further subdivided as follows (Pabot, 1967):

A. according to average annual rainfall
   100–200 mm steppe arid zone
   200–400 mm substeppe arid zone

B. according to winter temperatures
   mean January temperature (= tj) $tj > 16°C$
   $16 > tj > 10$
   $10 > tj > 5$
   $5 > tj$

The combinations existing in the arid and desert zones are shown in Table 8.1.1.

The arid and desert zones of Iran are usually divided into the following main bioclimatic zones (Pabot, 1967; Zohary, 1963):

– *The Baluchi bioclimatic zone*, bordering the Gulf of Oman in the southeast from the Pakistan border to the Strait of Hormuz. This area is characterized by warm winters ($tj > 16°C$), winter rainfall averaging 100 to 200 (300) mm, and it has strong tropical affinities in its flora and vegetation.

Table 8.1.1 Climatic zones of Iran, based on combinations of average annual rainfall and mean January temperature (tj).

	Upper arid 200–400 mm	Lower arid 100–200 mm	Desert less than 100 mm
tj > 16 warm winters	–	+	–
16 > tj > 10 mild winters	–	+	+
10 > tj > 5 cool winters	+	+	+
5 > tj cold winters	+	+	–

\+ existing combination
– non-existing combination

– *The Irano-Turanian bioclimatic zone* is characterized by rather cold winters (three to six months of frost) and strong Mediterranean floristic affinities. It is subdivided into desert, steppe and substeppe zones.

The desert zone is characterized by rainfall ranging from 50 to 100 mm and average January temperatures between 5 and 10°C. It occupies the bottom of the central Iranian Plateau with the great Dasht-e-Kevir Desert to the north and the Dasht-e-Lut to the south. The central parts of the Kevir and Lut are true deserts almost void of vegetation.

The steppe zone surrounds the previous zone and also stretches south and west of the Zagros Mountains from the Strait of Hormuz to the limit of Kurdistan along the border with Iraq. It is characterized by rainfall ranging from 100 to 200 mm. This zone is subdivided into three subzones according to winter temperatures:

cold winters 55°C > tj
cool winters 10 > tj > 5
mild winters 16 > tj > 10.

The substeppe zone forms a continuous strip around the Zagros Mountains and to the south and northeast of the Elburz range and occupies the entire western part of the Iranian plateau between the Elburz, Zagros, Kurdistan, Caucasus and Kopet-Dag mountain ranges. Rainfall averages 200 to 400 mm; winter temperatures are cold in the western central plateau and northeast; but they are mild south of the Zagros along the Persian Gulf and the Iraq border.

– *The semiarid to humid zones* consist of the semiarid xerophilous forest zone (400–800 mm) and the humid hyrcanian forest zone (800–2700 mm) between the Caspian Sea and the Elburz Mountains.

Physiography

Iran is basically a high plateau of 1200–2500 m elevation in the north and 500–600 m in the south, and bordered to the north, south and west by ranges of high mountains reaching an altitude of over 4000 m in the Zagros and over 5000 m in the Elburz. These ranges lie in the form of an inverted V, with the vertex at the Turco-Soviet border and the branches opening widely towards the Afghanistan and Pakistan borders. This V encloses the internal plateau and profoundly affects its climate and topography.

This physiography also greatly affects plant, animal and human life. Settled agriculture on the plateau is difficult without irrigation (hence the development of the Qanat system); similarly pastoralists practising transhumance move their livestock from their winter pastures on the plateau to the summer grazing areas on the mountains in order to find a year-round living.

Vegetation

– *The Baluchi zone.* The vegetation has a strong tropical affinity with dominant species such as:

Acacia arabica
Acacia nubica
Acacia seyal
Nanorhops ritchieana
Balantines aegyptiaca
Panicum antidotale
Cassia sp.pl.
Tephrosia sp.pl.
Prosopis cineraria
Ziziphus spinachristi
Calotropis procera
Salvadora persica
Leptadenia pyrotechnica
Lasiurus hirsutus
Crotalaria sp.pl.
Indigofera sp.pl.

– *The desert zone.* The vegetation is dominated by chenopodiaceae both in the saline depressions and in the sand dunes.

The saline areas bear a vegetation of:

Hammada sp.pl.
Halocnemum strobilaceum
Haloxylon aphyllum
Anabsis setifera
Tamarix sp.pl.
Salicornia herbacea
Sedlitzia rosmarinus
Cornulaca aucheri
Arthrophytum persicum
Salsola sp.pl.
Suaeda sp.pl., etc. . . . .

The dunes are colonized by:

Aristida pennata
Aristida plumosa
Ephedra strobilacea
Haloxylon persicum
Calligonum polygonoides
Calligonum comosum
Cyperus conglomeratus

– *The steppic arid zone.* The main characteristic and abundant species are:

Artemisia herba alba
Stellera lessertii
Acantholimon sp.pl.
Launaea spinosa
Noaea mucronata
Astragalus sp.pl.
Acantophyllum sp.pl.
Lactuca orientalis

Cousinia sp.pl.
Hammada salicornica
Carex stenophylla
Gymnocarpos decander
Poa bulbosa

These species are absent in the desert zone.

The fallows and abandoned fields are covered by the following vegetation:

Peganum harmala
Glicyrrhysa glabra
Alhaghi maurorum
Alhaghi camelorum
Prosopis farcta
Hulthemia persica
Gundelia tournefortii
Cousinia sp.pl.

Land use

Out of 165 million hectares of the national territory, 100 million are rangelands (Shaidae, 1973) supporting about 80 million sheep-equivalents (31 million sheep, 13 million goats, 5 million cattle, 222,000 camels and 2.7 million equines). The average stocking rate is thus 0.8 sheep ha^{-1}, whereas the carrying capacity is estimated at 20 million sheep-equivalents or 0.2 sheep ha^{-1}. Almost 90 % of the livestock feed is provided by rangelands.

Rain-fed agriculture applies to 4 million hectares. Irrigated areas represent 3.5 million hectares; most of them are irrigated by the old Qanat system (similar to the Saharan "Foggaras") which initiated a technological and urban revolution sometime between 2000 and 3000 years ago (Firouz, 1975).

Land use in Iran has a long history since there is evidence of man's presence for more than 6000 years. As a result, natural vegetation and rangelands are extremely depleted. Sand dunes cover over 5 million hectares; desert soils with scattered dunes amount to about 6 million hectares and desert regs and sierozem represent about 7 million hectares (Niknam & Ahranjani, 1973). The human population numbers about 25 million; a good part of the population lives in the arid zone: Tehran itself (over 5 million) is an area receiving only 220 mm of precipitation.

Most of the main cities lie in the arid zone (Shiraz, Isfahan, Kerman, Meshed, Tabriz, Ahwaz, Yazd, Zahedan, Bander Abbas). This is due to the existence in Iran of an old urban civilization based upon irrigation (Qanat) and caravan trade.

Tables 8.1.2 and 8.1.3 show some area statistics of different rangelands in Iran. However, potentials are much higher and measurements from protected areas give evidence that proper management can increase range production threefold (Le Houérou, 1975). The causes of desertization are the same as in North Africa: overcultivation, overgrazing, fuel gathering. Recent sand dunes threaten villages, towns, wells, oases and arable land.

Table 8.1.2 Land use in the arid zone of Iran (according to Shaidae & Niknam, 1973).

Land classes	Area million ha
Desert rangelands	40
Depleted pastures and wasteland	32
Good to fair pastures	8
Fallows	12
Depleted forest, shrubby range	14
Total	106

Table 8.1.3 Classification of rangelands in Iran.

Rangeland type	Annual forage production ha^{-1}	Area million ha
Good to fair	450 kg	19
Fair to poor	150–450 kg	25
Poor to very poor	30–150 kg	56
Total		100

Iran's achievements in the struggle against desertization

Arid land rehabilitation has been carried out over huge areas in Iran for the past ten years. These include:

- sand dune stabilization over 3 million hectares, of which 20,000 hectares treated with bituminous mulch, 137,000 hectares of transplantation (*Tamarix stricta, T. pallasii, Panicum antidotale, Haloxylon persicum, Calligonum comosum*) and 247,000 hectares of seeding (mostly *Haloxylon persicum*)
- windbreaks, 2800 km
- pasture reseeding, 20,000 hectares (*Agropyron desertorum, A. cristatum*)
- fodder shrub plantations (*Atriplex canescens, A. lentiformis, Haloxylon persicum)*, 43,000 hectares
- pasture rehabilitation, 3,300,000 hectares
- nursery facilities, 318 hectares
- areas protected to various degrees, parks, wildlife reserves, sanctuaries, 8 million hectares
- building of 18 dams and management of their watersheds, 170,000 hectares
- watershed surveys, over 17 million hectares.

These outstanding achievements have been made possible by adequate legislation:

– nationalization of all forest and rangelands in 1963
– nationalization of all water resources in 1966
– the Environmental Protection Act 1974 (Firouz, 1975).

These legal provisions enable the Ministry of Agriculture and National Resources – through its forest and range organization – and the Forest and Range Research Institute to take proper action for the regeneration of natural vegetation and to combat desertization. Rehabilitated areas are progressively returned to production under strict and controlled management conditions.

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Chapter 8.2

SYRIA

A. RAPP

Climate

Syria belongs climatically to the Mediterranean region, with winter rains and dry, hot summers. Aridity increases towards the southeast, where the Euphrates Valley near the Iraq border has an average annual rainfall of about 150 mm. P.V. Meigs (see map in McGinnies *et al.*, 1968) has classified this areas as Ac 14, meaning arid, with winter rains and a mean January temperature of below 10°C. Summers are hot with mean July temperatures above 30°C. Syria's central and northern areas are semiarid steppes with 150–500 mm of rainfall. The mountainous western zone receives more than 500 mm.

Wallén (1967) made a climatic analysis of data on precipitation and evapotranspiration in the Near East. He concluded that a limit for dryland farming in the area can be drawn at "240 mm of annual rainfall with an interannual variability of 37 %" (Fig. 8.2.1).

History of the vegetation

Many scientists have expressed the opinion that the countries of the Near East, including Syria, have had a long history of overexploitation and severe ecological degradation (e.g. Monod, 1959; Whyte, 1961; Draz, 1974).

> "Almost without exception the areas still covered by anything in the way of vegetation have been characterized by ecological regression for thousands of years. The effects have been of a biotic nature, the influence of man and his grazing and browsing animals. This regression is probably due only slightly, if at all, to any major or local climatic changes, although it has had a great effect on the microclimate around and within the plant communities and thus has led to greatly increased desiccation." (Whyte, 1961.)

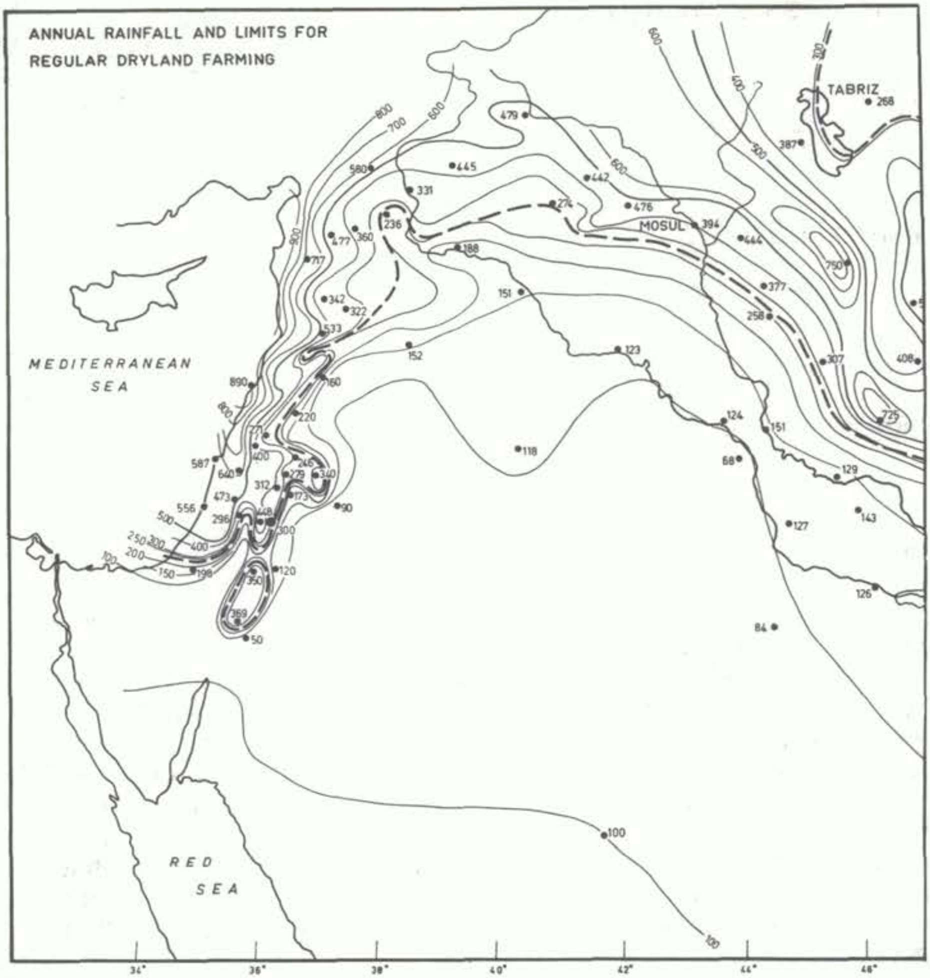

Figure 8.2.1. Annual rainfall and limits (= dashed line) for regular dryland farming in the Near East (Wallén, 1967).

Domestication of goats and sheep took place about 11,000 years ago in the areas presently constituting Iran, Iraq, Lebanon, Syria and Saudi Arabia. The first inhabitants depended mainly on herding and grazing or on primitive agriculture.

The first agriculture on the floodplains of the large rivers of the region started civilisations, dating back to about 4000 years B.C. With the increase of human population and expansion of grazing areas in these regions, man's impact on the environment was evidenced by cutting of trees for housing, or later on for shipbuilding, for fuel in the pottery and brick industries as well as for other purposes. With more grazing pressure close to settled communities, the natural vegetative cover was affected variably according to the degree of misuse. Vast areas that were once dense forests of good grazing land became barren and are considered now as "man-made deserts".

Utilization of rangelands

The following sections of this chapter are based on a report by Draz (1974).

The rangelands with natural vegetation provide the principal feed resource for livestock production in Syria. More than 70 % of sheep food is produced on the steppe and sub-humid rangeland including fallow fields and uncultivated parts of the agricultural zones.

Perhaps about half the sheep population in Syria is owned by town dwellers and is shepherded by Bedouins with their own flocks. The sheep graze on the free ranges of the steppe along the traditional eastward-westward or southward migration routes corresponding with annual rainy and dry seasons.

With the low, erratic and uncertain rainfall and years of drought that occur at intervals of about five to eight years, wide fluctuations in numbers of sheep have occurred between one season and another. Over 40 % of the flocks have been lost during a series of unfavourable seasons.

The human population of Syria was 6.3 million in 1970, and the annual increase is 3.3 %. This increase and a rise in the standard of living, expressed as a doubling of the *per capita* consumption of meat from 1970 to 1985 and a 20 % increase in *per capita* milk consumption, will require a considerable increase in livestock production.

Causes and extent of rangeland deterioration

As a result of overgrazing and in the absence of control measures, the more palatable subshrubs, perennial grasses, and legumes such as *Salsola* spp., *Stipa barbata, Astragalus* spp., etc., formerly common in the Syrian steppe, have been replaced by less palatable plants and several spiny shrubs of very low forage value. Where *Poa sinaica* was the dominant species, overgrazing has brought about an increase in *Carex stenophylla*, a less valuable species.

Ploughing of the original lands has completely destroyed a number of valuable plant associations. Under Syrian conditions re-establishment of the natural cover after ploughing is a slow process. In many cases unpalatable shrubs have become the dominant species on previously ploughed land.

As a result of degradation of the plant cover, wind and water erosion is intensified, causing a decrease in soil fertility, including marked loss of organic matter, accompanied by a subsequent downward trend in both long-term water-retaining capacity and total production in forage or grain yield.

Cutting of trees and shrubs for firewood has also increased soil erosion with subsequent decrease in soil fertility and productivity. The animal population has been deprived of an important source of forage of great value during certain seasons of the year since palatable subshrubs or trees such as *Salsola vermiculata, S. lancifolia, Haloxylon articulatum, H. salicornicum, Quercus* spp. are rated highly as firewood.

Feed reserves to carry animals through critical periods such as drought have not been adequate. Although approximately one-third of the steppe ranges, including the most fertile parts, have been ploughed for grain production, no substitute for forage crop production in the higher rain-fed or irrigated areas has been made available with the result that more animals are now grazing smaller areas of less productive ranges.

In the past, traditional rights of use were claimed by most tribes on certain range sites and were recognized in Syria with the support of the former Tribal Act, together with its related "Traditional Laws" or "Ourf". Most recent governments of the region have considered the steppe as state or government-owned land open to grazing by all. The abrogation of previous grazing rights by tribes without compensation by a practical substitute system opened the way for the destructive system of free uncontrolled grazing.

Previous approaches for improvement

After a series of drought years (1958–59–60) which caused the loss of two million sheep, Syria began to develop its range and sheep resources on a sound scientific basis.

This was started by the establishment in 1959 of the Wadi A-Azib Range Research Station in the Steppe Department. Seven warehouses for storage of feed reserves were built at selected key points. A programme of well digging and water development was also launched. Later on, a fuel oil stove specially designed to suit Bedouin requirements and minimize their need for shrub and woody plants as firewood was produced and distributed to Bedouins.

The World Food Project (WFP) Syria 002 – Stabilization and Development of Nomadic Sheep Husbandry – started in 1964 and was completed in 1967. WFP assistance provided, amongst other things, emergency feed stocks for use in periods of feed scarcity in the form of loans to Bedouin stockowners. Yet, as indicated by an interim evaluation mission, this first phase of the project (up to 1968) did not materially change the precarious situation of nomadic sheep husbandry in the Syrian steppe. The evaluation report indicated that the sheep population had increased from about 3.9 million in 1963 to 6 million in 1969. WFP assistance might even have supported such a sheep population increase during the drought year 1965/66 and proved effective in maintaining a growth in livestock numbers. Any benefits derived from partial control of the range were destroyed through overgrazing by Bedouin flocks largely from outside the district.

A major defect of the initial grazing control measures was that, while pastures were demarcated into special grazing districts, no attempt was made to organize the Bedouins and their sheep into groups, which would have facilitated the task.

The preliminary success achieved in the establishment of the first "Hema-Cooperatives" (within Project 002 Extension and Expansion) has given some hope of finding a grazing system that may lead to range improvement and help in the process of Bedouin settlement.

A Range and Sheep Experimental Station was established in 1959 and used for demonstrating benefits of range conservation and controlled grazing practices to the nearby tribal communities. In addition, six government-owned "Hema Range and Sheep Production Centres" have been established according to the Syrian Third Five-Year Development Plan 1971–75. Each centre has about 20,000 hectares of grazing land.

From 1971, ploughing and cultivation of land within the steppe region in Syria was prohibited by law. Syria has thus become the first country in the region to support such a conservation action.

The *hema* system of range reserves

The Arabian *hema* (pl. *ahmia* = protection) grazing system which was in use before the birth of Mohammed, may be the world's oldest effective range conservation programme. The *ahmia* may be controlled for use by individuals, by tribes, or by the government. The following are the various types of *hema*:

a. animal grazing is prohibited. Cutting of grasses, however, is permissible during specified periods and droughts. A specified number of members of each family are allowed to cut mature grass during the season, either for storage or for direct use
b. grazing and/or cutting is permitted, but restricted to certain seasons of the year
c. grazing is allowed the year around. The kind and number of animals permitted for grazing is specified – for example, goats in some areas, camels in others
d. the reserve is kept for beekeeping. Grazing restrictions are relaxed after the flowering season
e. the reserve aims to protect forest trees such as *Juniper, Acacia* or "ghada" (*Haloxylon persicum*). These reserves are usually the common property of a village or a tribe. Cutting of trees is prohibited except in great emergencies or needs, such as rebuilding a house destroyed by a disaster or for building a mosque or school.

Draz (1974) has studied reserves of forest and grazing lands in Syria and other countries. He concluded that probably man rather than goats is responsible for the destruction of the forest. Elimination of goats has not proved to be the answer but rather has aggravated the situation. As demonstrated in the protected *ahmia*, a system of grazing management with the correct numbers of goats and sheep has proved effective.

The *hema* system was once common in parts of the Arabian Peninsula and is still used in parts of Saudi Arabia, Yemen, Oman and Syria. It originated in the Near East and is suitable as a means for controlled grazing in selected areas in arid, semi-arid and mountain ranges where nomadic grazing is the only system practised. Carefully protected *ahmia* would furnish fodder reserves essential for the stability of nomadic grazing. They would also change the attitute of the people towards the range, introducing the philosophy of protection and improvement instead of exploitation. Soil and water conservation programmes could include several physical or mechanical methods. In most cases, there is no substitute for re-vegetation for which the *hema* system has proved its worth.

In Saudi Arabia, marked denudation of plant cover occurred in most of the previously protected *ahmia* as a result of free grazing of these reserves which took place through misunderstanding of a 1953 decree. Most of the ancient dams and water conservation systems, which previously worked efficiently under the prevailing climatic conditions and protective measures of the *hema* system, failed to withstand the flooding and siltation that occurred when the protective vegetational cover was destroyed.

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Chapter 8.3

TUNISIA

H.N. LE HOUÉROU

Introduction

The arid zones of Tunisia have been the subject of extensive studies over the past thirty years and are certainly among the best known arid zones in the world as regards flora, vegetation, climate, ecology, geology, geomorphology, hydrogeology and soils.

Large tracts of lands are cultivated by dry farming (cereals and olive groves) and about 70,000 hectares are irrigated. Agricultural and range developments have been practised on a large scale for almost 100 years but have been very intensive since World War II and especially since independence (1956).

The arid zone is defined as comprising the areas between the 100 and 400 mm isohyets, which corresponds to steppe vegetation (Le Houérou, 1958, 1959, 1962, 1969a,b, 1973). The desert zone stretches south of the 100 mm isohyet and is characterized by vegetation distributed on a contracted pattern on the regs (pebbly plains); unlike the case of the arid zone, cultivation cannot be practised in the desert zone without irrigation.

Thus defined, arid and desert zones occupy the areas listed in Table 8.3.1.

Table 8.3.1. Areas of desert, arid, semiarid, and humid land in Tunisia

	Area 10^3 km^2	Percentage of the country's surface
Desert	63	40.0
Arid	55	34.0
Semiarid to humid	42	26.0
Total	160	100.0

Climate

Rainfall

The climate is of the Mediterranean type with rains falling in the cool season with short days. Maximum rains generally occur in autumn, but sometimes in winter or spring. There are practically no effective rains from May to October.

Rainfall variability increases with aridity (Vernet, 1954; Le Houérou, 1959). The maximum rain observed in any particular year is four times the minimum under the 400 mm isohyet; it is five to six times that figure under the 200 mm isohyet and over 10 to 12 times under the 100 mm isohyet. The coefficient of variability (Table 8.5.2) is defined as:

$$\nu = \frac{\sigma}{P} \times 100$$

Table 8.3.2 Variability in annual rainfall of different bioclimatic zones in Tunisia.

Rainfall variability	Bioclimate	Annual rainfall
30–40 %	upper arid	300–400 mm
40–50 %	middle arid	200–300 mm
50–60 %	lower arid	100–200 mm
60–80 %	Saharan	less than 100 mm

Rainfall increases with altitude along a gradient of 20–25 mm per 100 m (Le Houérou, 1959).

Temperatures

The average daily minimum of the coldest month (m) is 6–8°C at the coast and decreases with altitude (0.5°C per 100 m) and continentality down to 0°C towards 1200 m elevation; m is correlated with the number of days of frost (under shelter) in the following way (Le Houérou, 1973):

$m > 7$	warm	winters =	no frost
$7 > m > 5$	mild	winters =	5–10 days of light frost
$5 > m > 3$	temperate	winters =	10–20 days of light frost
$3 > m > 1$	cool	winters =	20–30 days of light frost
$1 > m > -2$	cold	winters =	30–60 days of light frost

These thresholds have been defined by plant community distribution and phenological studies (Le Houérou, 1969b).

The average daily maximum of the hottest month (July/August) is 35°C at the coast and in the highlands and reaches 42°C in the desert zone.

Potential evapotranspiration (PET)

PET has been measured at several stations for more than 10 years. It varies from

1400 mm yr^{-1} in the upper arid bioclimate to 1600 mm yr^{-1} in the Sahara. It is about 1–2 mm d^{-1} in January and 6–8 mm d^{-1} in summer; it is over 10 mm d^{-1} during sirocco dry spells. Variations in PET are very small compared with variations in rainfall. Moreover, PET varies inversely with precipitation. These reasons explain why precipitation is so well correlated with the distribution of plant communities.

Air moisture

Relative humidity exceeds 70 % throughout the year at the coast; in the interior it is of the order of 60–65 % in winter and 35–40 % in summer. In the desert zone it drops to 25 % and less in summer and does not rise above 55 % in winter. Hot and dry winds (sirocco) blow 20 to 60 days yr^{-1} and may lower the relative humidity to 10–15 %.

Geology and geomorphology

Geological formations are all of sedimentary nature, aged from Trias to Quaternary with a huge extension of Cretaceous, Tertiary and Quaternary deposits. Since Tunisia was at the junction of the Thetys and the Saharan shield during sedimentary times, the nature of these sediments are alternatively of a neritic lagoon and continental origin with some facies of deep deposits in the zones of subsidence and in relation to marine transgression over or regression from the Saharan shield. The lithological assemblage includes mainly limestones of different kinds alternating with marls and sandstones with gypseus and saline formations of Triassic, Liassic, Eocene, and Miopliocene times. Marls themselves are often gypseous in the series from Permian to Pliocene time.

These facts are of extreme importance and explain the great extent of saline alluvia as well as the quality of deep and surface waters and consequently the difficulties of irrigated agriculture which usually uses waters and soils that are more or less saline.

The sedimentary series was folded during the Atlasic orogenesis during Oligocene-Miocene time. These chains play a major role in climatology, physiography, and the distribution of water resources. There are three main chains:

- "Tunisian Backbone" (Dorsale Tunisienne), oriented SW-NE, stretching from Kasserine to Cap Bon and limiting the arid steppe zone towards the north
- "Chott Range", oriented W-E which lies immediately north of the large salt marshes of Chott-el-Rharsa, Djerid, and Fedjadj from Gafsa to Gabès and which roughly separates the arid from the desert zone
- "Matmata chain", which is a tabular eastern end of the Saharan plateau and which separates the Sahara from the Djeffara coastal plain.

These chains are carved by erosion according to structure (typically Jurassic) and lithology.

The synclines represent huge areas where interlocked quaternary pediments numbering three to five and overlain by thick calcareous or gypseous crusts have developed.

These pediments are dissected by wadis which have developed 2–4 pleistocene terraces.

Water erosion

Like all arid zones, central and southern Tunisia are characterized by temporary rivers (oueds or wadis) which flow only a few hours after a rainfall; a rainfall of 10–15 mm is enough to induce some flow. Five to ten per cent of the rain runs off from large catchment basins (several thousand km^2) and up to 80 % from small basins of a few hectares (Tixeront & Berkaloff, 1958; Licitri, 1966; Le Houérou, 1969a). Water erosion removes 0.5 to 1.5 mm of topsoil per annum; the silt load of wadi flows is of the order of magnitude of 50 kg m^{-3}. In the lower arid and in the upper Saharan bioclimates wind erosion can remove several centrimetres of topsoil per year, especially after cereal cultivation on sandy soils (Le Houérou, 1959, 1962). Floret & Le Floch (1972) have measured soil losses of 10 m^3 ha^{-1} $month^{-1}$ in such conditions.

Vegetation

The vegetation of the arid zone of Tunisia is probably the best known in the world. Over 1000 plant communities have been identified, described, and mapped. The whole area is covered by vegetation maps of various scales (1:50,000 to 1:500,000). A synthetic map of 1:500,000 scale was published by Le Houérou in 1967. The main plant communities and the surfaces covered are listed in Table 8.3.4.

The production of these plant communities has been determined (Le Houérou, 1958, 1959, 1962, 1969b). See Table 8.3.4.

Table 8.3.3. Average production in kilo dry matter per hectare per year in Tunisia (Le Houérou, 1969b). Production decreases by about 50 % from each bioclimatic subdivision to the next and more arid subdivision.

Bioclimate	Average production kg ha^{-1} yr^{-1}
Upper arid	930
Middle arid	660
Lower arid	320
Upper Saharan	150
Lower Saharan	63

Table 8.3.4. **Main plant communities in Tunisia and their areal size. From Le Houérou (1959, 1962, 1969b).**

Plant communities	Area in km²
Upper arid bioclimate (300–400 mm)	
Pinus halepensis forest communities	700
Tetraclinis articulata forest communities	350
Rosmarinus officinalis communities	1000
Artemisia herba alba silty steppes	2000
Stipa tenacissima steppes	500
Artemisia campestris Echiochilon *Fruticosum* sandy steppes	1000
Cultivated fields and fallows	3000
Miscellaneous	800
Total	9350
Middle arid bioclimate (200–300 mm)	
Pinus halepensis forest	500
Rosmarinus officinalis degraded forest	600
Juniperus phoenicea degraded forest	4235
Artemisia campestris sandy steppes	1500
Artemisia herba alba silty steppes	4800
Stipa tenacissima steppes	200
Ziziphus lotus formations	500
Rhantherium suaveolens	600
Cultivated and fallows (of which 5000 km² of olive groves)	11000
Legeum spartum gypseous steppes	800
Total	24735
Lower arid bioclimate (100–200 mm)	
Hammada schmittiana sandy steppes	2500
Hammada scoparia silty steppes	2200
Gymnocarpos decander stony steppes	4300
Anarrhinum brevifolium gypseous steppes	4400
Stipa tenacissima steppes	1100
Rhantherium suaveolens sandy steppes	4200
Cultivated and fallows (of which 1500 km² of olive groves)	5000
Aristida pungens dunes	300
Total	24000
Upper Saharan bioclimate (50–100 mm)	
Rhantherium suaveolens sandy steppes	800
Anthyllis henoniana stony steppes	13000
Cornulaca monacantha sandy steppes	1400
Hammada schmittiana sandy steppes	4200
Stipa tenacissima steppes	2500
Traganum mudatum gypseous steppes	6800
Calligonum/Aristida pungens dunes	20500
Total	49200
Lower Saharan bioclimate (20–50 mm)	
Calligonum comosum dunes	3800
Salsola zygophylla gypseous steppes	3700
Total	7500
Halophytic crassulescent steppes	11500

Soils

The soils of the arid zone in Tunisia are characterized by:

a. alkalinity – pH varies from 7.5 to 9.0
b. high calcium carbonate content
c. large tracts of saline soils
d. immense surfaces of shallow calcareous crusts of early and middle Pleistocene
e. large surfaces of gypseous crust especially in the lower arid bioclimate
f. mature soils are scarce; they are of the isohumic type with 2 % of organic matter in the upper layers.

Man, agriculture, livestock

The arid zone of Tunisia has a long history. There are relics of several prehistoric civilizations: Aterian (Bir el Ater), 20,000–40,000 B.C.; Ibero-Maurisian, 5000–10,000 B.C.; Capsian (Gafsa), 2000–6000 B.C.; Saharan neolithic, 500–3000 B.C.

The area was densely inhabited and cultivated during the first seven centuries A.D. under Roman and then Byzantine dominations. From the mid-seventh century after the Arab conquest until the late nineteenth century, the area was devoted to pastoral nomadism. Then with the progress of hygiene, medicine, and education a demographic explosion took place and the population is now about seven times larger than at the beginning of the century.

Nomadic pastoralists have become settled farmers. Some 15,000–20,000 seminomads still remain in the south: Nefzaoua Beni Zid.

Population densities are extremely high. On the coastal strip of the Sahel, the density is over 80 inhabitants km^{-2}, in the hinterland steppes about 40 inhabitants km^{-2}, in the southern desert 5 to 10 inhabitants km^{-2}. The population growth is about 2.2 % per year, that is, a doubling time of 31 years or an eightfold increase per century. These densities are extremely high; the densities of population are far above the carrying capacity and emigration is high, especially in the south: Gabès and Medenine governorates.

The total population of the arid zone is around 2.5 million, that is, 50 % of the national total.

About 18,000 km^2 of land, that is, one-third of the arid (non-desert zone), is permanently cultivated. Of these 1.8 million hectares there are about 800,000 hectares of olive groves and other fruit plantations cultivated by dry farming and 500,000 hectares cultivated for cereals (wheat and barley) plus about 500,000 hectares of fallow.

The total acreage cultivated for cereals varies widely from one year to the next, depending on outcome and early winter rains. During some particularly rainy years the total acreage cultivated is several times the above figures.

Average livestock numbers in Tunisia (Le Houérou, 1958, 1962; Le Houérou & Froment, 1966):

Sheep	1,500,000
Goats	850,000
Cattle	60,000
Camels	150,000
Mules, donkeys	60,000

Variations in livestock numbers are almost similar in magnitude to rainfall variations (Le Houérou, 1962). In the upper and middle arid bioclimates maximum numbers after a series of rainy years are four to five times larger than the number of animals that survive a series of drought years. In the lower arid and upper Saharan bioclimate this ratio is one to seven (Le Houérou, 1962). These variations concern only small ruminants, sheep, and goats; donkeys, cattle, and camels are relatively little affected by climatic factors (Le Houérou, 1958, 1962).

Desertization in southern Tunisia

The definition and the process of desertization were explained by Le Houérou as early as 1959:

> "In the case of southern Tunisia it is man who has made the desert, climate is only a favourable circumstance"

and

> "desertization occurred mainly during two periods of peace and high demographic pressure: the Roman times and the present". (Le Houérou, 1959.)

The phenomenon was further studied by the same author (1962, 1969a,b) and by others (Floret & Le Floch, 1972, 1973; Ionesco, 1972; Novikoff, 1973, 1974, 1975; Wagner, 1974; Flohn & Kettata, 1971).

A national seminar on the subject was held at Gabès in December 1972, where the causes and the extension of desertization and the ways of combatting were discussed by some 65 specialists in charge of the agricultural planning and development in the arid zone of Tunisia.

This seminar confirmed the conclusions already drawn by Le Houérou many years earlier, *viz.*,

i. Desertization is a man-induced phenomenon; there is no evidence of increased climatic aridity during the period of instrumental record.

ii. Desertization is a result of high demographic pressure which results in
   - generalized overgrazing
   - clearing of natural pastures for cereal production and overcultivation of sandy soils
   - destruction of woody species for fuel
   - extension of mechanized ploughing.

   These cumulative causes result in accelerated soil erosion (both water and eolian) which in many cases leads to new desert landscapes.

iii. Each year desertization affects several tens of thousands of hectares on the average in southern Tunisia; however, it is a discontinuous process which mainly takes place when several consecutive dry years occur. Firewood collection alone destroys 18,000 hectares of steppe per year in the governorate of Gabès (Floret & Le Floch, 1972).

   However, there has hitherto been no accurate overall study and monitoring of the phenomenon but only numerous scattered observations.

   A very interesting study was published by Floret & Le Floch (1973). This study, using simulation models, gives quantitative figures of desertization and its progression as a function of various hypotheses of land use over a period of 25 years on a test zone of 20,000 hectares. This study shows that if the present trend continues up to the year 2000, the desertized areas will increase from 35 % to 65 % of the land surface. Production would decrease by 35 %.

The struggle against desertization

Much work has been carried out in Tunisia on desertization in the fields of research and of agricultural and range development.

In the field of research an *ad hoc* inter-agency (FAO/Unesco/CNRS/ORSTOM/INRAT) project was established in Gabès in 1969 following a recommendation of the IBP/CT meeting in Hammamet during April 1968. I had the honour of formulating this project and of being its first project manager in 1969/70. This project has produced outstanding results in the field of range survey, vegetation/soil/water relationships, study of desertization, and study of primary and secondary productions. There is also a US desert biome project working in the Medenine area on the functioning of the *Rhanterium suaveolens* plant community and ecosystem (Novikoff *et al.*, 1973, 1974, 1975).

Many experiments have been carried out during the past 10 to 15 years on range regeneration, tree planting, and shrub plantations in the arid zone.

In the field of agricultural and range development five pilot range-management units covering some 10,000 hectares have been established in various parts of the arid zone. Detailed surveys of an area of 100,000 hectares are under way (Oglat Merteba) and over 50,000 hectares have been successfully planted with fodder shrubs (mainly spineless cactus, *Atriplex numularia, A. halimus, Acacia cyanophylla, A. ligulata*).

Several hundred hectares of sand dunes have been fixed with the help of exotic (*Acacia cyanophylla, A. ligulata, A. salicina, Parkinsonia aculeata*) or native species (*Tamarix articulata, Calligonum arich, C. Azel, Retama raetem*).

Legislation was passed in 1969 to help establish fodder shrub plantations by granting subsidies and credit facilities to farmers who undertake such plantations. A UNDP/FAO/WFP project in central Tunisia has achieved much in this field (about 50,000 hectares of fodder shrubs planted between 1970 and 1975).

However, much remains to be done and legislation should be enacted and enforced regarding range exploitation and cereal cultivation. Fuel gathering should be discouraged by appropriate measures as it is, for instance, in Algeria and in Libya, where butane gas is heavily subsidized. The example of the Willayd of Saida in Algeria shows that prohibition of cereal cultivation and mechanical ploughing in sensitive areas is a workable measure provided there is the will to tackle the problem seriously.

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Chapter 8.4

MALI

G. BOUDET

Mali covers 1,240,000 km² in the heart of West Africa, between 10° and 25° N latitude.

If the 100 mm isohyet is taken as the boundary of the Sahara, and the 550 mm isohyet as that between the stock-breeding Sahel and the more agricultural Sudanian zone, then Mali is divided into 430,000 km² of desert, 500,000 km² of Sahelian area and 310,000 km² of Sudanian sector (Fig. 8.4.1).

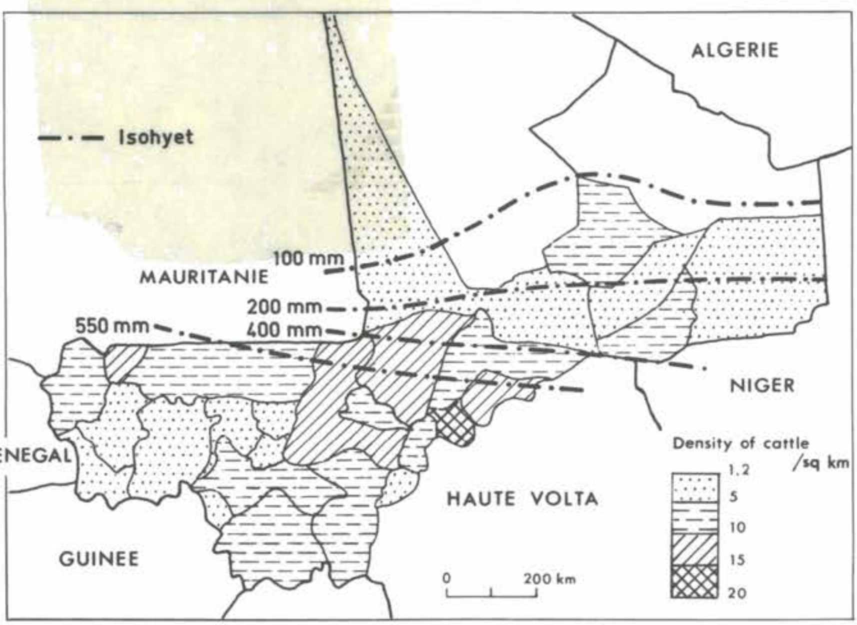

Figure 8.4.1. Map of Mali with rainfall and cattle density.

Drought and pastoral economy

The drought period has made itself cruelly felt in Mali (Table 8.4.1), as can be adjudged by the rainfall measured at Gao (latitude 16° 16′ N):

Average: 263 mm
Coefficient of variation: 31 %
Standard deviation: 182 mm.

Table 8.4.1. Rainfall recorded during the drought period at Gao, Mali.

Year	Rainfall recorded (mm)
1968	256
1969	186
1970	238
1971	173
1972	157
1973	144
1974	128
1975	307

Appreciable losses have resulted, not only in herds of cattle (Table 8.4.2) but also in the numbers of sheep and goats; the nationwide stock of these fell from 11.5 million head in 1971 to 9.2 million in 1974.

Table 8.4.2. Livestock in Mali (thousands of head)

	Cattle						Sheep/Goats	
	1970		1972		1974		1972	
Regions	Number	%	Number	%	Number	%	Number	%
Sahelian zone								
Gao (G)	1,800	33.6	1,266	23.9	384	10.5	3,884	44
Mopti (M)	1,400	26.2	1,596	30.1	1,493	41.0	2,129	24
Total	3,200	59.8	2,862	54.0	1,877	51.5	6.013	68
Sudanian zone								
Ségou (Se)	620	11.6	509	9.6	280	7.7	592	7
Bamako (B)	530	9.9	675	12.7	432	11.9	609	7
Kayes (K)	520	9.7	547	10.3	471	12.9	1,285	15
Sikasso (Si)	480	9.0	707	13.4	581	16.0	266	3
Total	2,150	40.2	2,438	46.0	1,764	48.5	2,752	32
	5,350	100	5,300	100	3,641	100	8,765	100

A substantial decrease has followed in the livestock supported (Table 8.4.3).

Table 8.4.3. Variation in number of cattle supported.

	Area ($1000\ km^2$)	Cattle per km^2		Hectares per head of cattle	
		1970	1974	1970	1974
Sahelian zone	500	6.4	3.8	15.6	26.3
Sudanian zone	310	6.9	5.7	14.5	17.5
Mali	1,240	4.3	2.9	23.2	34.5

Drought and potentialities of the rangelands

Impact of the drought on sandy soil

At a normal rainfall of 200 mm, woody species with thorns thrive and production of the herbaceous cover varies between 400 and 800 kg ha^{-1} on a dry-weight basis. Areas denuded by wind and sheetwash erosion may reduce the productive surface by 5–50 %, according to where the areas are situated on the catenas; gentle slopes are the most affected. The consumable production may be estimated at 300–400 kg ha^{-1} of dry matter.

At a normal rainfall of 300 mm the ligneous species are always thorny, and the productivity of the herbaceous cover then varies between 1600 and 2200 kg ha^{-1}, but the areas denuded by erosion spread over nearly 20 % of the countryside. The mean consumable production may be estimated at 1600 kg ha^{-1} of dry matter.

At a normal rainfall of 500 mm the woody species are no longer thorny but bear large, deciduous leaves. The herbaceous cover does not now give way to eroded areas, but the biomass produced contains a large proportion of non-consumable species – possibly as high as 50–70 %. In spite of their greater rainfall, these rangelands provide a consumable herbaceous production of less than 900 kg ha^{-1} of dry matter out of a total production of 1300 kg ha^{-1}.

The typical, sandy Sahelian rangelands, which have an average rainfall of 300–400 mm and are situated not far from 16° N latitude, prove to be the most productive, with a consumable production of 1500 kg ha^{-1} of dry matter.

The scoured areas in these rangelands are probably recurrently eroded in a cyclic manner.

Particularly under a tree, the shady herbaceous carpet may promote intense biotic activity, which reduces resistance to erosion of the upper soil horizon and can lead to scouring followed by cementation of the soil pores on the surface of ablation. Later, the heavy seeds of perennial species (*Blepharis linariifolia, Chrozophora brocchiana, Tephrosia purpurea*) can be caught at the bottom of cracks in the scoured surface and there germinate during the rainy season. Then, in the dry season which follows, the hardy stems of these plants will trap small eolian deposits, and in subsequent rains the deposits will serve as seedbeds for annual graminoids (*Aristida mutabilis, Cenchrus biflorus*) and for the wild water-melon (*Citrullus colocynthis*). Accumulations of sand around obstacles – "nebkas" as they are called – spread year after year until they restore the scoured area; meanwhile, the perennial species dwindle and the herbaceous cover is reconstituted.

Effects of drought on skeletal soils

Rocky outcrops are often characterized by scattered domes of dazzlingly white quartzite stones. The only growth here consists of rare and stunted *Acacia ehrenbergiana*, which manage to form groups along the drainage axes, and together with them areas of the annual graminoid *Tetrapogon cenchriformis*. Drainage channels at the bases of the domes are at present silted up with erosive deposits, and here, curiously, the stands of *Acacia ehrenbergiana* have become destroyed; probably the great bulk of their roots has been overly obstructed, and prolonged insufficient aeration has brought on the death of the trees.

While a few exceptional shrubs may survive on rocky outcrops, because of their location at spots where their roots can enter cracks and find enough moisture, trees on the sandy cover around the outcrops generally die from an inadequate supply of moisture.

Where there are semiskeletal soils with light horizons at about 10–20 cm and receiving less than 400 mm of rainfall, vegetation consists of striped bush (*brousse tigrée*). In 1970, thickets of *Pterocarpus lucens* were accompanied by grassy borders whose floristic zones were adapted to microvariations of the soil, and in the microbasins dominated by *Diheteropogon hagerupii* production was able to reach 7000 kg ha^{-1} of dry matter. In 1975, the shrubs in the thickets appeared to be dead, but some shoots revealed that many individual plants were capable of regrowing from stocks. The herbaceous cover seemed, however, to have completely disappeared, and the soil was evidently scoured and rendered sterile by sheetwash.

At a rainfall of about 500 mm the development of vegetation on identical soils seems less dramatic. Shrubby steppe containing *Pterocarpus lucens* tends to be scoured on slight and little-wooded slopes, with elimination of the herbaceous cover, crusting and sealing of the soil; meanwhile dense stands of *Pterocarpus lucens* survive in microbasins and at the tops of slopes in spite of some individual withered growths, along with the herbaceous vegetation they entrain (Fig. 8.4.2).

Effect of drought on colluvial soils

In the 200 mm rainfall zone, the countryside can be unrecognizable, as is the case at Tin Ahara in the Gourma. In 1970, the plain was covered with micro-dunes of sand, not more than 5–10 cm high, and it was colonized by annual graminoids: *Aristida mutabilis, Cenchrus biflorus, Schoenefeldia gracilis* and *Tribulus terrestris*. In 1975, the undulations of the dunes had disappeared, and the herbaceous vegetation was replaced by a dusty expanse of sandy loess (Fig. 8.4.3).

On the drainage axes, thick stands of *Acacia ehrenbergiana* and areas of the perennial graminoid *Cymbopogon proximus* have been succeeded by assemblages of the cruciferous *Schouwia thebaica*, a Saharan species which, owing to the period of drought, seems to have widely extended its spread on colluvia in the Gourma. It adjoins the clumps of *Cymbopogon proximus* that have kept their hold and also isolated stems of such other semi-desert species as *Corchorus depressus* and *Morettia philaeana*.

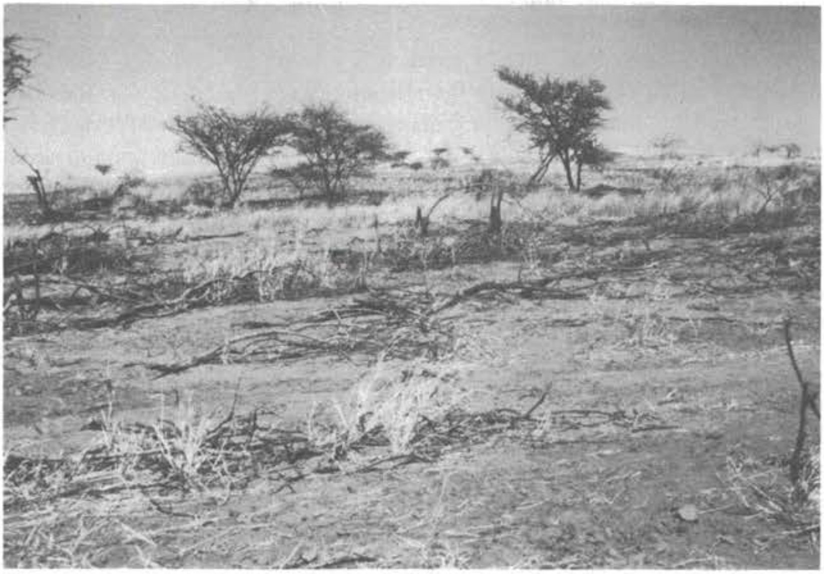

Figure 8.4.2. Death of shrubs in the drainage channels of skeletal soils.

Figure 8.4.3. Shrubby steppe with *Pterocarpus lucens* denuded and sealed slope with withering thicket of shrubs.

Ought we to conclude from this that the territory is turning into a real Sahara? We have increased reason to do so as woody species are no longer represented by more than a few stumps, and only rare leafy shoots of *Cadaba glandulosa* and *Maerus crassifolia* survive there.

Parallel to the observations already given, it is interesting to compare the development of vegetation on vertisols where there is an average rainfall of 400 mm. On one site, a thick stand of *Acacia seyal* and a compact sward with *Schoenefeldia gracilis* were withering in strips, the herbaceous cover was disappearing, bringing denudation, crusting and sealing of the soil. Five years later, crusted and denuded zones were still to be found, but beside them now were patches of herbaceous cover in which the graminoid *Schoenefeldia gracilis* surrounded central assemblages of *Schouwia thebaica*. Curiously, although a comparable community had been observed on another site, it was replaced by a dense herbaceous one dominated by the annual graminoids *Brachiaria ramosa, Dinebra retroflexa, Sehima ischaemoides* and a composite, *Bidens* sp.; in the shelter of this, vigorous young stalks of ligneous species flourished: *Acacia laeta, Balanites aegyptiaca, Grewia villosa*.

Perhaps we may already deduce the following outline of vegetative succession:

Acacia seyal – *Schoenefeldia gracilis*

↓

Disappearance of vegetal cover and glazing of soil

↓

Schouwia thebaica – *Schoenefeldia gracilis*

↓

Acacia laeta – *Dinebra retroflexa*

Vegetation on colluvia would, then, be evolving towards a Saharan type in the north of the Gourma and towards an adaptation to very impermeable soils in the south.

As a rule, the colluvia of large drainage axes are sealed and crusted generally and only patches of herbaceous sward with *Panicum laetum* survive, but on rather thin colluvia and on localized outcrops of ferruginous sandstone, the vegetation – striped bush – is diversified in strips that seem distinctly to shift their positions, an impression confirmed by stumps still existing on denuded and crusted soil.

Drought and its effect on fodder

Sometimes the herbaceous cover is totally different on two adjacent sandy formations, although the woody vegetation there is comparable. In particular, there may be a marked decrease in palatable forage species to the advantage of nonpalatable ones and an increase in the proportion of bare earth. Parallel to this, even if the overall productivity of the herbaceous sward remains above 1000 kg ha^{-1}, palatable production, except at the foot of slopes, diminishes. This change in vegetation might suggest that there has been overgrazing, but we should not ignore the hypothesis of a slight localized rainfall, such being frequent in the Sahel where squalls take certain directions for no apparent reason.

B. Toutain, a researcher of IEMVT (Institute for Research in Stock Farming and Veterinary Medicine in Tropical Countries) has been able to make some very interesting observations in the Upper Volta, where he is carrying out a three-year study of South Sahelian pasturelands. While the mean annual rainfall there is 413 mm, it was 422 mm in 1974 but only 322 mm in 1975. At the end of July 1974, 284 mm had fallen as against only 164 mm in 1975. The result on sandy rangelands was a change in the herbaceous sward comparable to an effect of overgrazing: a proportion of 92 % of annual graminoids in 1974 and 8 % in 1975; no unpalatable varieties in 1974, but 37 % in 1975; 2000 kg ha^{-1} of dry matter in 1974, but only 200 kg ha^{-1} in 1975.

This change in the herbaceous flora and its productivity was sharper because the shortage of moisture is accentuated by slanting drainage. There are thus few or no graminoids on the sandy summits; they occur in slight density on slopes, but are relatively abundant at the foot of these slopes, where productivity reached 3000 kg ha^{-1} in 1975.

The grazing effect can be elucidated by continuous monitoring, starting from a watering-hole. Observation points for this purpose are chosen on the most representative facies of the pasturelands. The ligneous cover here is calculated by using a reference scale:
r = rare (a few individual growths per hectare)
f = frequent (numerous individual growths, but covering less than 5 % of the area)
a = abundant (convering more than 5 %).

The herbaceous species are estimated by computing from 100 readings, and the contribution they make is given in percent (calculated within a confidence interval of 10 %). These species are divided up into palatable graminoids, diverse palatable species and nonconsumable ones.

Productivity of the herbaceous cover is assessed as consumable or nonconsumable, then a balance is worked out which takes into account the denuded areas and the relative importance possessed by the facies of the characteristic sequences.

Where a dry-season water-hole is concerned the ligneous stratum is fairly homogenous (Table 8.4.4), even if *Balanites* and *Acacia raddiana* are more abundant in the vicinity of the pool. In fact, *Balanites* constitutes a genuine, semiclosed forest cover, 200 to 300 m wide, surrounding the pool. The herbaceous sward has no large scoured areas and grassy growth varies between 85 and 100 %.

In the herbaceous cover the importance of the decreasers is diminished by the grazing effect, particularly in the first kilometre: this makes it of interest to place the observation points at close intervals – the more so, since an inverse situation applies to the increasers.

Stationing livestock in the vicinity of a pool seems to promote both the species *Chloris prieurii* and productivity. Further outward, production increases progressively up to 5 km; it is as if, in the long run, dry-season grazing had a depressive effect on yield, a circumstance that could be explained by transfer of nutrients to the neighbourhood of the pool by the manure from cattle on places at rest.

Around a dry-season watering-hole, the woody vegetation is comparable, but the herbaceous flora is distinctly altered, especially close to the pool, where the invader *Heliotropium strigosum* is semi-dominant. To a distance of 4 km from the pool, the increaser

Table 8.4.4. Effect of grazing on the herbaceous stratum

Localization	Dry-season watering-hole										Rainy-season watering				
	0.5 km	1 km	2 km	3 km		4 km	5 km	6 km	7 km	8 km	5 km	4 km	3 km	2 km	1 km
Ligneous															
Cover (100 points)	5	5	5	1		5	5	5	15	1	5	5	5	+	5
Balanites aegyptiaca	a	a		f			r		r	f	f	r	f	f	f
Acacia raddiana	a	a	f	a		f	f	f	a	f	f	f	a	r	f
Acacia senegal		r	f	f		a	a	a	a	f	a	a		r	a
Combretum aculeatum		r	a	a				f	f	f		r	r	r	f
Commiphora africana		r				r		f	r	r	r		f		
Herbaceous cover (%)															
Bare soil	8	22	15	19	13	9	13	15	17	12	9	20	14	22	36
Number of readings	119	107	107	119	373	127	118	127	144	156	129	92	103	87	80
Accuracy	±8.0	±9.6	±9.3	±9.1	±5.1	±8.5	±9.2	±8.5	±8.1	±7.2	±8.8	±9.3	±9.8	±10.5	±10.8
Species															
Aristida mutabilis	2	8	36	33	44		8	9	12	29	24	1			
Brachiaria xantholeuca		8	14	3	1	64	49	9	3	1	47	12	37	28	1
Alysicarpus ovalifolius	4	18	14		3	1	8	12	6	8	3	9	4	7	3
Gisekia pharnaceoides		2	3	8	5	1	3	36		3					
Fimbristylis hispidula				4	2	1			40	19					
Tragus berteronianus									5	13					
Total of decreasers	6	36	67	48	55	67	68	66	66	73	74	22	41	35	4
Chloris prieurii	26														
Digitaria horizontalis	18	1						1							
Cenchrus biflorus	25	51	27	44	32	30	28	30	32	19	23	73	56	59	38
Zornia glochidiata		4												1	9
Tribulus terrestris	21					1		2	2	5					
Diverse	4	2					2			1		1	3	5	
Total of increasers	94	58	27	44	32	31	30	33	34	25	23	74	59	65	47
Heliotropium strigosum		6	6	8	12	1	1	1		1	3	4			36
Other invaders					1	1	1			1					13
Productivity (kg ha^{-1} d.w.)															
Nonpalatable varieties				50								50			495
Graminoids	1300	300	625	1185		2000	2175	1500	925	625	1125	1000	1125	1175	665
Legumes	50	100	60					50		125	100	150	125	60	
% of area	100	85	95	100		95	95	95	100	85	100	95	90	100	95
Yield per geographical ha	1350	340	650	1185		1900	2065	1470	925	635	1225	1090	1125	1235	630

Cenchrus biflorus clearly dominates, but *Brachiaria xantholeuca* takes over at 5 km, along with its companion *Aristida mutabilis*.

From 2–5 km productivity becomes stable at over 1000 kg ha^{-1}. This production, remaining after rainy-season grazing, testifies that a moderate number of livestock can be supported in spite of degradation of the rangeland near the pool.

Management of Sahelian lands

In using the Sahelian pasturelands, there should be a system which would allow a certain number of livestock to be kept there throughout the year, thus profiting from the water and forage, but by which the production potential would be retained. The livestock ought, meanwhile, to ensure the economic survival of stockbreeders by their production of milk and meat, and their increase in number.

Principles for managing a Sahelian area

At the juncture where rain will probably arrive, residual dry forage is indispensable to ensure a satisfactory feed of dry matter, and the young ligneous production, regrowth of perennial graminoids and young growth of annual ones should make an addition to this.

Thereafter, annual growth can provide what is necessary to maintain forage and also for production on new rangelands reopened for use because temporary watering-holes there are replenished with water. All the herbaceous production should not be consumed in the rainy period: some graminoids ought to remain so that they can multiply and the straw protects these pastures against wind in the dry season.

At the end of the rains, when the armed spikelets of graminoid seeds not yet have fallen on the dunes, it is indispensable that pastures should be rich in graminoids with invulnerable infructescences (*Schoenefeldia gracilis, Panicum laetum*). Unfortunately, the channels in loess and sand, which carry these graminoids, are often subjected to the effects of erosion with sealing of the soil; this leads to disappearance of the herbaceous cover and causes the woody vegetation to die out.

At the height of the dry season, the graminoids are all consumable in a dry state, and they constitute the basic fodder of ruminants. The legumes and various herbaceous species, along with leaves and fruits of ligneous ones, provide the necessary nitrogen. Recent observations have established that, during this period, cattle are in better health if they are watered only every other day, if they are able to graze both day and night, and if they can visit shrubby pasturage as they move about.

Livestock in these conditions show no clinical signs of vitamin-A deficiency at the end of the dry season, and their daily activity becomes similar to that which applies in temperate countries:

7 hours 10 minutes spent grazing
6 hours 40 minutes ruminating
3 hours 30 minutes resting
5 minutes watering.

To improve the management of pasturelands, it is necessary to take into account not only the watering possibilities there but also the extent and allocation of the principal types of pasture. The necessity for vegetation mapping thus arises, adapted to the needs of those using the maps.

Here the regional carrying capacity of livestock enters in, provided that we are able to estimate the capacity of the principal existent rangelands. This can be assessed with exactitude only through a valuation of the herbaceous biomass which is palatable. The result must be given per geographical unit of the rangeland and with reservations made for variations due to climatic and grazing hazards.

It must not be forgotten that the Sahelian ecosystem also involves natural consumers – insects (ants, termites), birds and mammals – and that the litter cover is permanently bombarded by soil particles carried by the wind. A large part of the biomass is consumed and another portion is integrated with the soil in the form of debris of varying size.

Recent observations establish that there is a loss of about 40 % of the biomass during four dry-season months, so it is reasonable to assume that half of the net herbaceous biomass remains at the disposal of herbivorous domestic animals. However, it is necessary to keep the soil covered and to provide for residual straw at the beginning of the rains, the proportion consumable by herds could thus be a third of the herbaceous biomass, estimated on parts undisturbed at the end of the active period.

As a bovine daily consumes on average 2.5 kg of dry matter for 100 kg of its liveweight, its needs for a year can be estimated at 913 kg for each 100 kg of its weight, which requires a herbaceous biomass amounting to 2750 kg of dry matter.

The theoretical carrying capacity of Sahelian pasturelands can thus be calculated by starting from an average estimate of the aerial herbaceous biomass and using the following critera:

– 27.5 kg of dry matter for 1 kg of liveweight supported per hectare and year
– 19 kg of dry matter for a day's grazing on one 250-kg Tropical Bovine Unit (TBU).

When a pastureland no longer possesses more than a slight carrying capacity – less than one TBU to 10 ha – it does not justify the making of expensive arrangements. Either it can be used seasonally to support a satisfactory number of livestock, watering them from natural sources (pools) during brief transhumance in the semiarid Sahel, or it is suited only for use as a reserve: a nature reserve or one for wild animals (this in Sahel-type pasturelands on outcropping rocky substrata, with colluvial and grass-grown drainage axes). If made a reserve, the pastureland would later warrant being equipped for tourist purposes or with organized game-meat business in view.

As far as one knows, the way of dealing with climatic hazards would be to place 30 % of the pasturage in reserve, but leave it at rest for no more than a year or two. This would permit regeneration of the ligneous cover.

Many individual young ligneous plants are destroyed by rodents, but those of medium size develop even if they are habitually browsed on. The small branches lengthen until they reach the ground (*Balanites aegyptiaca, Ziziphus mauritiana*); shrubs which are reduced to stumps produce leafy branches more than 50 cm long; and shrubby trees diminished to dwarf size develop branches from 20 to 30 cm in length (*Cadaba glandulosa*). The quantity of leaves available increases to a notable extent and constitutes a living reserve rich in nitrogen.

Parallel with this, it is possible for the herbaceous cover to be regenerated on eroded and sealed zones merely through scraping with a harrow or a scarifier, preferably in contour-line strips. In 1974 and 1975, spectacular results were obtained by this in the Voltaic section of the Oudalan. Simple tilling of the soil in contour-line strips a few metres wide permits regeneration of a cover with *Schoenefeldia gracilis*: this comes without preliminary sowing, the seeds being supplied by surface drainage. Young plantlets of *Acacia seyal* then sprout under the cover.

To sum up, one may say that reorganization of Sahelian rural territory should aim at rationalizing and improving the transhumance system, meanwhile reducing the distance traversed to only about 10 km between rainy-season pasturelands and dry-season ones. Nevertheless, with a view to maintaining rights to seasonal pastures in the north and to their use, a herd could be selected – oxen, dried-up cows and so on – at the beginning of the rains and sent on the long trek to pasturelands previously allocated within the framework of regional planning. Similarly, each year the surplus of animals (culled, steers) should be removed from the land, placed on the market or sent to re-breeding centres (cooperative or otherwise) either in the Sahel or in the Sudanian zone. Each area of land could be organized in accordance with the following plan (Fig. 8.4.4):

- Rainy-season pastures served by temporary watering-points, preferably pastures on sandy substrata even if the points are mostly establishable on skeletal soils.
- Dry-season pastures served by a permanent watering-hole. Dry-season foraging would take place along a centripetal course: at the start of the dry season and in cool weather, the herds graze at a distance, and they draw near only with the heat. Movement back and forth to the water would follow a favoured path, trampling of the herd thus becoming a genuine measure against the outbreak of fires. In a year with normal rainfall, 30 % of the pasturelands should be kept in reserve, various sections being placed at rest for a year or two in rotation. A shortage of rain in one section would automatically bring about its exclosure, at the expense of a more favoured part.

Dry-season foraging ought to take place in different kinds of pasture: on sands, at the beginning of the dry season, on loess, starting in January on wooded land that can be ranged through. Some wooded sites or those being covered with bush might not be used for pasture but kept in reserve to supply those who use the land with firewood.

These disposed pasturelands should be apportioned according to their resources of water and forage, and if possible along lines that follow the traditional ones for the whole rangelands as these have long been used by groups of breeders.

Use of the newly-arranged lands ought to be judiciously scheduled in order to prevent the created centres of attraction from being damaged by an afflux of stockbreeders. As far as financing permits, the units of pasturage should be set out on an ethnic or administrative basis and the scale adapted to their resources. The dispositions made at watering-holes should proceed in a parallel manner at the various sites and if necessary be spaced out in time.

The management of newly-equipped land ought to be delegated immediately to its users, the council administering it being guided during the first period by a multivalent and closely worked-out framework for their actions.

Although the theoretic scheme of organization can be followed without great alterations in a well-equipped forage region, certain adaptations may be required in such areas as the Malian part of the Gourma.

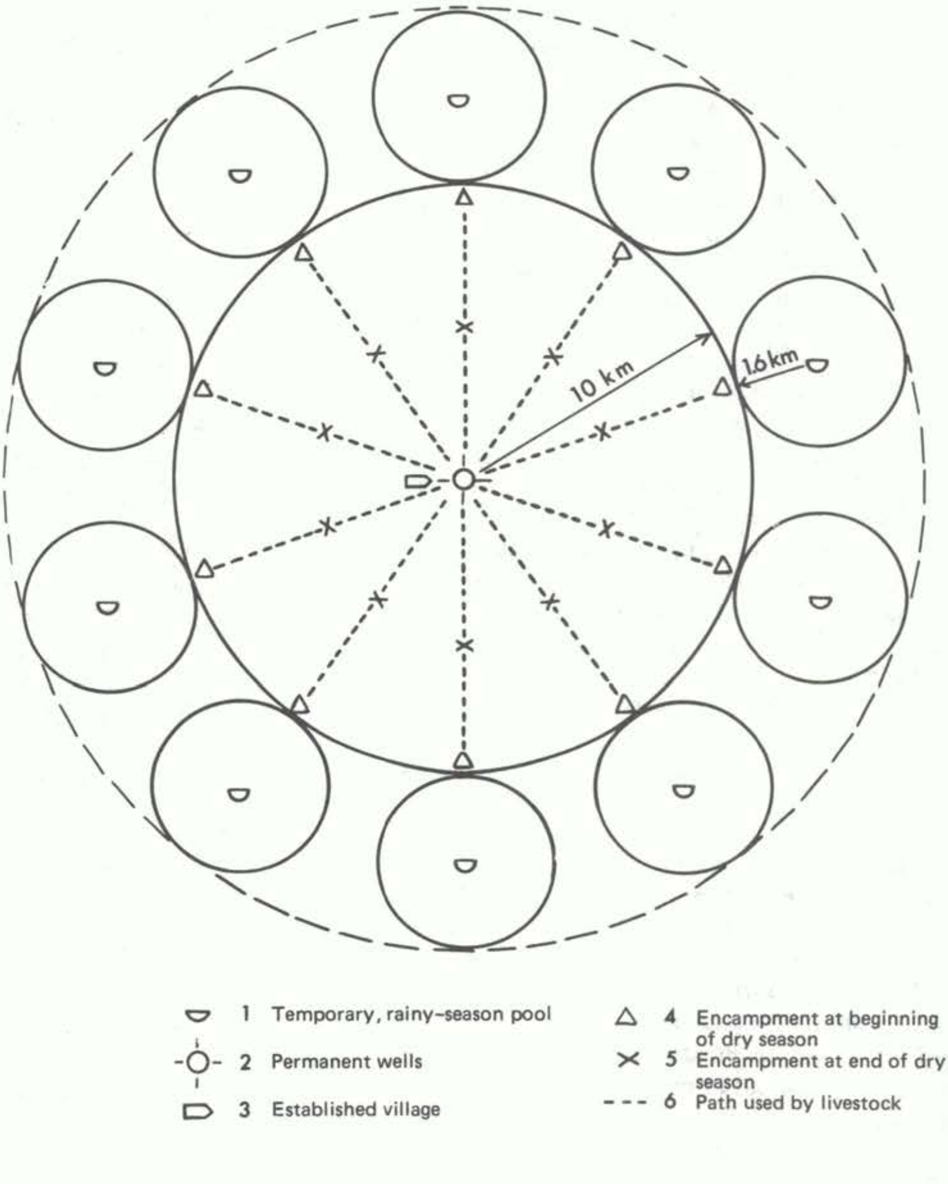

Figure 8.4.4. Planning of Sahelian land.

Case of the Malian Gourma

J. Gallais has located the main zones of traditional group-usage in the Malian Gourma, these sectors of transhumance being superimposed on the principal gathering places: water-holes and salt licks (Fig. 8.4.5).

On the inclined north-south line between Gourma Rharous and Ndaki, there are two main zones of traditional group-usage: these contain 17,500 head of migratory livestock out of the 117,000 officially counted within the bend of the Niger River.

10,500 Igouadaren, belonging to the warrior group under Commander Imochar, move between the river, the salt licks of Karouassa and the pools of Bambou, Fintrou and Gossi. 7000 Kel Gossi, belonging to the Imrad warrior group, move among the pools of Doro, Gossi, Ndaki and the salt licks of Amniganda.

Where the Igouadaren are concerned, transhumance takes place according to the following itinerary:

After the belated arrival of rains in the Gourma Rharous neighbourhood, herds must fortify themselves on the regrown pasturage; then, in July and August, moving in easy stages they reach the salt licks of Tin Ahara and the pools of Bambou and Fintrou.

In September and October, they graze around the little pools near Gossi and visit the salt licks of Karouassa.

At the end of October, they return to the sandy formations along the river; starting in February, they enter marshes of the inland Niger delta which are rich in "bourgou", a graminoid of the *Panicum* family.

This itinerary is marked by drawbacks that should be removed in order to improve management of the pasturelands:

- The line of verdure advances from south to north, and the breeders have to wait near the river in pastures which are overcharged and unproductive because they are semidesert.
- The fodder yielded by these pastures is further reduced as a result of the young shoots being grazed on at the beginning of the rains.
- The salt licks of Karouassa is visited by three groups of breeders; 10,500 Igouadaren, 2,500 Takarangat and 3,700 Kel Reris overgraze the surrounding pastures.
- Pasturage around the pools of the south (Adiora, Tézé, Fintrou) and the hill dam of In Alata is curtailed by the necessity of reaching the river before the pools in between – such as that of Tin Tadeini – dry up.
- The "bourgou" marshes of the Gourma Rharous region cover about 10,000 ha with a production reduced to 6000 kg ha^{-1} as result of the semidesert surroundings. They are used from February to June: with the capacity to supply 315 days of grazing. They can theoretically support only 21,000 TBU, but the livestock able to visit the marshes in 1971 was estimated at 130,000 TBU.

The result of these drawbacks is that, while pastures lying to the south of rangelands used by the traditional groups are comparatively little used, those of the Gourma Rharous region are overcharged during nine months of the year (November to July) in spite of their low productivity. However, isolated areas of overloading often exist at gathering places (salt licks and principal pools) to the south, for breeders give proof of a highly developed gregarious instinct, but the overloading is frequently due to the concentration of watering-holes.

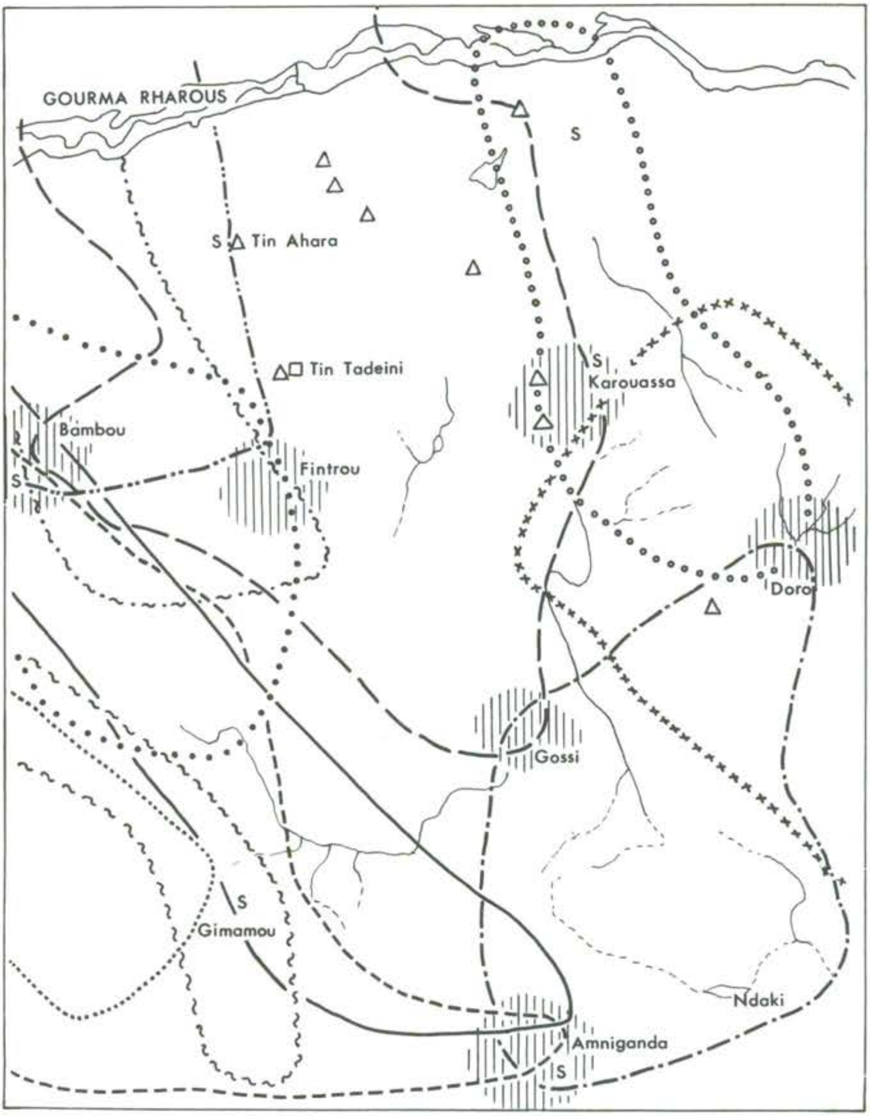

Figure 8.4.5. Grazing areas of different nomadic groups south of the Niger River. The boundaries of the different groups are marked on the map.

Improvement in management of the pasturelands means altering the dates of migration, but this cannot be done by making regulations and inflicting penalties on those who break them. Before that, "safety exits" must be offered to breeders.

While it has been possible to codify and regulate entry of herds into the "bourgou" delta-lands, the date of their return towards the river depends mainly on watering opportunities along the way. The authorities responsible have tried to improve water resources by a campaign for water prospecting by drilling.

Water resources are limited, by proximity of the basement bedrock, to a few localized ground-water supplies along the drainage axes, and the wells sunk are often adjacent to pools which are much frequented in the rainy season (Tin Tadeini, Ararous, Quinarden). Thus, forage in the vicinity is already consumed when the wells are put to use. The output of these wells, which have a depth of 60–100 m, is estimated at between 1500 and 3000 $l\ h^{-1}$ hour (0.4–0.8 $l\ s^{-1}$). Water can be drawn up from 50–70 m by pumping with animal power. Each well has five forks, and about 700 cattle can be watered there each day. While the wells are capable of supplying some breeders in the course of the dry season, they are unable to ensure the watering of the bulk of animals in movement at the time of return to the river.

In the past, two cisterns were fitted into the Bambou and Tin Tadeini pools, and they constitute, along with the In Alata dam, an attempt at what could be done to make the best use of the territory. There have, however, been only a few years when water has remained in the In Alata dam throughout the dry season. It would be preferable to establish less ambitious dams on rock bases and to deepen pools where temporary ones already exist, thus ensuring certain watering points every 30 or 40 km during a late withdrawal of herds towards the river (in December–January). This relay system of surface watering points should lead to other such places, also of small capacity, which would add to the opportunities of watering offered by the large pools, and thus serve the pastures on dunes and drainage channels.

Such an arrangement would prevent too many visits to watering-holes on what may genuinely be called the axis of herd movement – where the forage stock, being left in place, would be consumable at the first rains, as soon as the impluvia, prepared if need be, allow a start at filling the reservoir to a satisfactory level for watering herds.

Management of the pasturelands ought, then, to be directed at carrying out the following ideal plan:

- Gradual departure of the herds as soon as the pools have water for them, without waiting for a fresh growth for browsing on land near the river
- Dispersal of the herds as quickly as possible to the small, prepared pools
- From the end of October, concentration of the herds at the big pools
- Starting in December, gradual return of the herds, in stages and on a schedule of which the Peul transhumances from the Niger Delta give an example
- Stay on the dune pastures bordering the river
- Starting in February, use of the "bourgou" land, then return towards the dunes in order to permit fresh growth of the "bourgou". After consumption of the "bourgou" stock, it is alternately left at rest for one month because of the return to the dunes, then grazed upon the next month.

Parallel with this activity, the manufacture of licking blocks, with addition of elements which the land lacks, could be organized at Karouassa. At the height of the rainy season, these blocks would be distributed to encampments at the level of the little pools, traditional concentration around Karouassa would thus gradually be limited.

The surface of vast stretches of land in this pastoral area is sealed and denuded. Although its regeneration may be difficult because of the light rainfall, efforts to bring this about are justified.

Possibility of complementary activity in the Sudanian zone

Sahelian stockbreeding might be considered to aim at reproduction, and the rearing of young livestock ought to be carried out in the Sudanian zone. Such a scheme for tropical stock-farming of the future may, however, encounter numerous problems which for the moment are insoluble.

The Sudanian zone is primarily of an agricultural function, and its inhabitants are for the most part strictly farmers. However, revenues from farming activities are habitually invested in livestock. This is usually entrusted to salaried Peul herdsmen and badly managed. The herds – genuine savings banks for large farmers – are pastured in uncultivated areas and consume what remains of crops in the fields. At the height of the dry season, they may range over the vast expanses of brush, scoured by fires, where the total carrying capacity at this period can drop as far as a single TBU to 10 ha.

This extensive breeding of acessory type is, by itself, incapable of absorbing the surplus Sahelian animals, and the traditional system would have to be totally altered. The pasturelands would need to be demarcated and protected against the spreading of fires, which could not be done without previously revising the distribution of cultivated areas and their concentration on land with the most profitable yield. Adoption of crop rotation would also be required, as well as measures for preventing erosion and conserving fertility.

Along with the improved management of cultivated lands, adequate terrain could be freed for use as rangelands. However, in order to obtain the necessary intensification of stock-rearing, preliminary experiments need to be carried out, both as regards management of the rangelands and the introduction of breeds which will give better herds. Options and techniques involved here have only been outlined, especially where the northern Sahelian districts, with their long dry periods, are concerned.

At the first period, however, a certain number of young Sahelian steers could be absorbed by developing the use of draught-oxen in land cultivation. If the use of animal traction by farm-workers becomes general, after 4–5 years the steers will furnish good-quality meat.

If we consider the current rise in population, only the poverty of the soil, the dearth of permanent watering places or the presence of endemic diseases can explain the empty areas encountered in the Sudanian ecological zone. If it is possible to remove these obstacles, plans could be made to colonize the new lands, and here consideration should be taken of the need to ensure a certain complementary activity in the Sahel, with a greater amount of stock-rearing there in view. However, we must also take into account the necessity of diminishing the population in certain districts where it is too great and consider the unsolved difficulties posed by breeding in the Sudanian zone. Here, again, agreement should be reached on an effort to carry out experiments related to pastoralism in order to prepare for this new stage in national and transnational development.

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Chapter 8.5

SUDAN

A. RAPP

The Sudan is Africa's largest country. It covers many ecological zones, from the Sahara in the north to the rain forest in the south. It probably has larger areas of arid and semi-arid land than any other country in Africa. The country also has a long scientific tradition. These are two apparent reasons for the inclusion of the Sudan in this report as one of the countries selected to represent the Sahelian and Sudano-Sahelian zones south of the Sahara.

Earlier work on conservation

A Soil Conservation Committee was set up by the Sudan Government as far back as 1942. In 1944, it published a report (Sudan Government, 1944) which demonstrates an early awareness of environmental degradation in the Sudan.

The following views summarize the background of the work:

> "There has been much discussion of the desiccation of the African continent which in places is proceeding at an alarmaing pace. Lake Rudolf is receding rapidly, Karamoja in Uganda shows signs of the advance of aridity and villages have been buried by sand on the southern fringes of the Sahara, to give only three well-known examples. From the point of view of recommending soil conservation measures it is essential to understand what is really happening and whether we are in fact dealing with a new change for the worse in basic climate or whether the advance of aridity is due to the habits of mankind and his domesticated animals.".

The Committee arrived at the conclusion that the land degradation was due to man "rather than to any change in basic climate". Their recommendations for reclamation measures were particularly focussed on the surroundings of towns – the so-called town perimeters.

> "Town and village peripheries generally are deteriorating rapidly due to overcultivation, overgrazing, to cutting trees for firewood, or to combinations of these activities. Important examples are Tokar town, Khutsum, Omdurman and Khartoum North, El Obeid and Nahud."

A number of measures – particularly enclosures of green belts for town perimeter conservation – were recommended for combatting this deterioration.

Actual plans

The period 1968–1973 was characterized by drought all over the arid and semi-arid belts of the Sudan, and the deficiencies in rainfall were as large as in the Sahelian countries of West Africa.

> "In the last few years of disastrous drought in West Africa and Ethiopia very little has been heard from the Sudan. Maps in the international press have shown the drought areas as a broad band from the west coast of Africa to the Chad/Sudan border. In fact, of course, there has been no discontinuity in the climatic pattern... The consequences of the decline in rainfall are serious.... A great belt of country, 100 km from north to south and stretching right across the savanna, is no longer suitable for millet cultivation three years out of four." (Adams, 1975.)

The Sudan was less severely affected by famine than the neighbour states of Chad and Ethiopia for three reasons: emigration of pastoralists southward, government-planned food relief from surplus areas in the country, and awareness among leaders and people about the necessity for combatting desert encroachment.

A thorough and well-founded plan for analyzing and counteracting the desert encroachment in the Sudan was recently worked out and published by the General Administration for Natural Resources jointly with the Agriculture Research Council (Desert Encroachment Control Project proposed by the Sudan Government, 1975–1980, Khartoum, May 1975). This was one of the plans on "Pilot Projects in the Sahelian and Sudano-Sahelian Zones" recommended by a working group meeting of Unesco's MAB programme (MAB, 1974). The other project recommended was for the Liptako-Gourma area in the Niger, Mali, and Upper Volta republics.

The desert encroachment control plan

The long-term objective of the Sudanese proposal is to "curb down the desert encroachment to size, and if possible bring it down to a halt with the hope of protecting, securing and reclaiming as much useful land as may practically be possible to cater for future needs on the local, regional and international levels." (Sudan Government, 1974).

The project area consists of the arid and semi-arid lands of the Sudan in a belt west of the White Nile through the Kordofan and Darfur provinces between latitudes 12°N and 18°N, and the Nile valley to the Egyptian border. The whole area covers about 650,000 km^2, with three main ecological zones: desert along the Nile strip north of Atbara, semi-desert, and low rainfall savanna southward to about 500 mm average annual rainfall. A number of pilot projects are planned within this area.

The "Plan of Work" describes the present situation as follows:

> "The impact of man on the natural resources of the Project area since the turn of the century has been accompanied by growth as well as deterioration processes brought by tribal technology and culture, as well as by modern development.

Growth has taken the form of increase in population, expansion in agricultural lands with effective rise in volumes of production, opening of grazing areas resulting in the multiplication of stock, attraction of population and livestock from other areas, and growth of human settlements, commercial activity, service facilities and transportation.

Deterioration on the other hand has taken the form of decline in soil fertility, in crop yields, disappearance of palatable grasses, fall in carrying capacities, depletion of water sources, expansion in areas affected by wind and water erosion, decline in quality of animals, decrease in areas under hashab trees (gum trees, *Acacia senegal*), rain fluctuations and failures, village desertion etc., which all culminate in what has come to be known as desert encroachment southwards. " (Sudan Government, 1974).

The extent of the desert encroachment during the past fifteen years cannot be stated with any exactness, as no detailed and quantitative mapping of the ecological zones was made in the 1950s, when the vegetation maps of the Sudan were produced (Harrison & Jackson, 1958).

The 1975–1980 plan (Sudan Government, 1974) lists the following activities and pilot projects of land reclamation:

1. aerial reconnaissance survey
2. proposed piloting operation
   a. pilot sand dune fixation
   b. rehabilitation of resources using protection (exclosures)
   c. range improvement around water points
   d. conservation of range using firebreaks
   e. surface water provision using rainfall harvesting techniques
   f. shelter belts of vegetation
   g. modernization of nomadic migration cycles and areas
   h. reorganization of land use and village settlement through integrated land use planning.

Points 1, 2a, b, c, d, g, and h will be commented upon here since they are of particular importance.

Aerial reconnaissance survey

The final plan of operation will largely be based upon aerial reconnaissance, photo-interpretation and production of accurate basic maps. First priority will be given to the determination of the actual areas affected by desert encroachment in the country. Vegetation, present land use, landforms, dune movement, and soil erosion features will also be mapped.

Detailed surveys using photo-interpretation will be needed for the production of specialized detailed basic maps of all representative areas chosen for piloting purposes.

Pilot sand dune fixation

Three representative sites are proposed in the mobile zone for experimentation in the implementation of methods for sand dune stabilization, two in Kordofan (El Bashiri, Umm Badr) and one in Darfur (Meliet). Each area is supposed to cover 20–45 km^2. The main project supervised by Mr. A.G. Seif el Din, has been in operation since

1969/70. It is based on the protection of dunes from grazing, the planting of *Acacia senegal* and other tree species and facilitating the growth of grasses between them. It is remarkable that the project was successful although it was started during the drought years (Figs. 8.5.1 and 8.5.2).

Rehabilitation of resources using protection (exclosures)

The main objective of this experiment is to test the effect of absolute protection in the natural recovery of the vegetation cover. For this purpose, three representative exclosures are recommended, each 100 km^2 in extent. Other improvement methods might bring faster results if compared with improvement by natural plant succession. The latter seems to be more economical since any other method would require fencing, especially under the communal grazing systems of the nomads (cf. results of Halwagy (1962) and others from exclosures).

Advice is needed on the following points:

1. time required to reserve an area before it can be utilized
2. grazing systems to be applied within the reserve (Comments: cf. *hema* system in Syria, described by Draz, 1974)
3. animal classes to graze an area, herd formation, and common use.

Comments: examples of exclosures and their importance for knowledge about recovery of vegetation were described and discussed by, for example, Halwagy, 1962; Kassas, 1970; and Bari, 1968.

Kassas (1970) reports that

> "although plant growth varies in response to year-to-year rainfall and protection is only partial and fences are often broken through, there is a tendency toward improvement of plant cover."

This example refers to areas near Omdurman and Alexandria. Both have an annual rainfall of about 150 mm.

Range improvement around water points

Water provision programmes for cattle by drilling for groundwater or constructing surface water *hafirs* reached a peak in northern Kordofan in 1967 and 1968. The establishment of water points in rangelands has led to an accelerating damage to surrounding areas. The depleted envelope has reached a diameter of 100 km in several areas, especially in the more vulnerable northern parts of the project areas.

The purpose of this pilot project is to develop improvement and protective measures to renew the deteriorated ranges and to conserve the ones that were not subject to overgrazing. The problem in the already depleted areas is mostly related to loss and removal of vegetation and to soil compaction.

Advice is needed on the following points:

1. techniques required to restore soil permeability and vegetation cover
2. protective measures required to stop further range deterioration
3. grazing systems recommended
4. determination of the capacity of each water point that is correlated with range potentialities around it
5. preservation of forage in the form of silage or hay to relieve pressure around water points

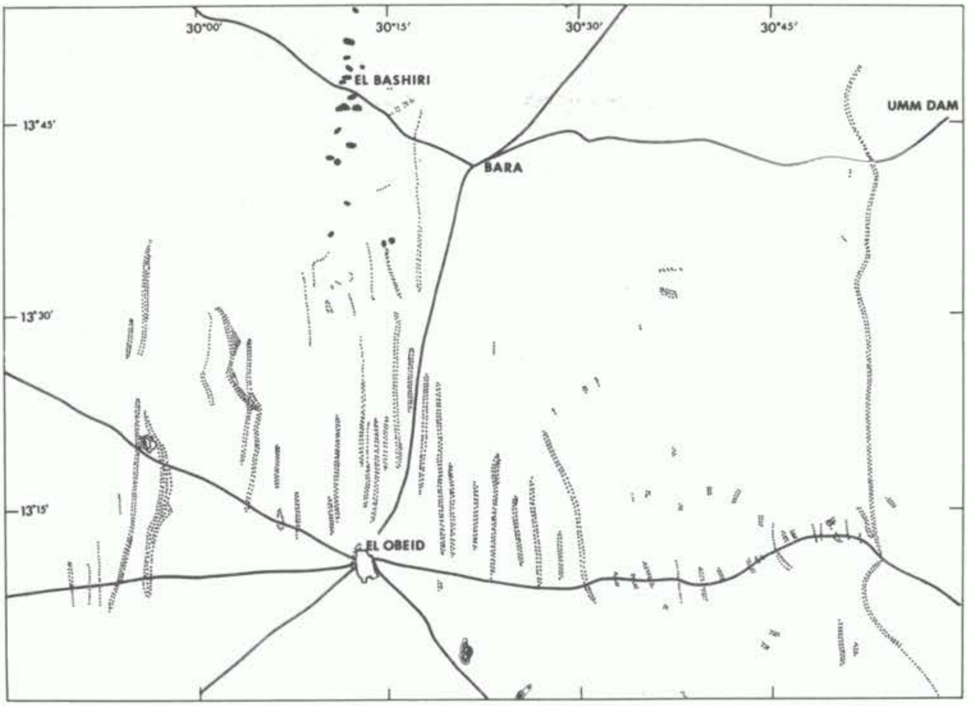


Figure 8.5.1. Sketch map of El Obeid in the Sudan with El Bashiri village in the north. Dashed lines indicate fossil longitudinal dunes in N–S direction.

Figure 8.5.2. El Bashiri village, Sudan, with dune stabilization projects. Foreground: mechanical stabilization by branches in sand is visible together with planted acacias. Centre: buildings and irrigated land with vegetables. Background: grey area of projected dune stabilization. Moving dune sand outside exclosure appears bright in the picture. Photo: A. Rapp, 1975.

6. determination of water intervals of livestock
7. development of a complete land use map covering all areas affected by the water point
8. evaluation of current criteria used in siting water points, and advice on adequate distances separating these water points.

Comments: points 7 and 8 above are highlighted by the grazing land use model suggested by Boudet for the 100–300 mm rainfall Sahelian zone and presented in the case study of Mali in this report. (Chapter 8.4)

Range conservation using firebreaks

Seasonal fires in the dry savanna usually occur either because of carelessness on the part of nomads or because of fire cultivation in dryland farming. As reported from the grass management studies by the Range Department, seasonal fires annually removed about 80 million tons (air dry matter) from the dry savanna range resources.

Modernization of traditional nomadic migration cycles and areas

Additional water sources have led to alterations in migration routes and grazing durations with little concern for grazing potential and similar aspects, while protective range management has hardly added to the already existing grazing capacities. The same applies to veterinary services, which have intensified the problem by adding more animals to the tribal grazing lands without a corresponding offtake.

Plans for range, water supply, veterinary services, other social welfare services, marketing, feeding centres near towns, and transportation terminals are fundamental.

Community development work, agricultural extension, adult education and similar measures are expected to be incorporated in the final plan recommended for the purpose of natural resource conservation and management through actual participation of nomads.

Reorganization of land use and village settlement through integrated land use planning

> "Unless the realization of the need for improved land use, better soil conservation measures, more rational distribution of water services, and the like, is coupled by optimum geographical distribution of population and village settlements, results in integrated natural resource planning could seldom be achieved.
>
> Piloting in this area is expected to examine:
>
> i. Previous plans and concepts developed so far with regard to collectivization of villages, and establishment of village hierarchies.
> ii. Selection of a densely inhabited area (possibly eastern Kordofan, or eastern Darfur) where signs of material resource deterioration are accelerating, for the planning of improved settlement patterns.
> iii. Formulation of integrated types of land uses to suit the evolved patterns, taking into consideration areas under different kinds of crops, individual size of family holdings, cycles of cultivation, protective and natural resource control measures to be adopted, etc."

There are, in addition, the following points: "Specification of the approach to be adopted to work with local communities" and "Delineation in the preparation of the final plans of localities within the project area where there is need for village resettlement projects".

In conclusion, it can be fairly considered that most of the work envisaged in this project lies within the framework of MAB Project 3, as well as the relevant programmes of UNEP, WMO, and FAO. The regional and multidisciplinary nature of this proposal clearly falls in great part within the criteria established for MAB.

This region presents similar problems to those occurring in many neighbouring countries, including Chad, Ethopia, and Somalia. The regional benefit of the proposed research programme is evident. A joint Sudanese-Scandinavian research project is also under consideration within the framework of the "Desert Encroachment Control" programme.

Aerial survey of desert encroachment

The aerial reconnaissance survey is a priority point under the desert encroachment control project in the Sudan. Such a survey was carried out in late October-early November 1975 and also included ground checks and comparisons with the ecological situation in the 1950s and early 1960s. The reconnaissance was planned and executed as a joint venture by the Sudan's National Council for Research and the Ministry of Agriculture, Food and Natural Resources, with the financial assistance of the UN and the IUCN. Dr. H.F. Lamprey was a special consultant from Unesco and UNEP on the team (Fig. 8.5.3).

The position of the boundary between subdesert scrub and grassland and the desert was noted during the course of 10 north-south reconnaissance flights in a four-seater light aircraft and ground traverses by car. The desert boundary is diffuse, but it was possible to mark it on the map to the nearest 5 km. This map also shows the position of the same ecological boundary as mapped in 1958 by Harrison & Jackson (Fig. 8.5.3).

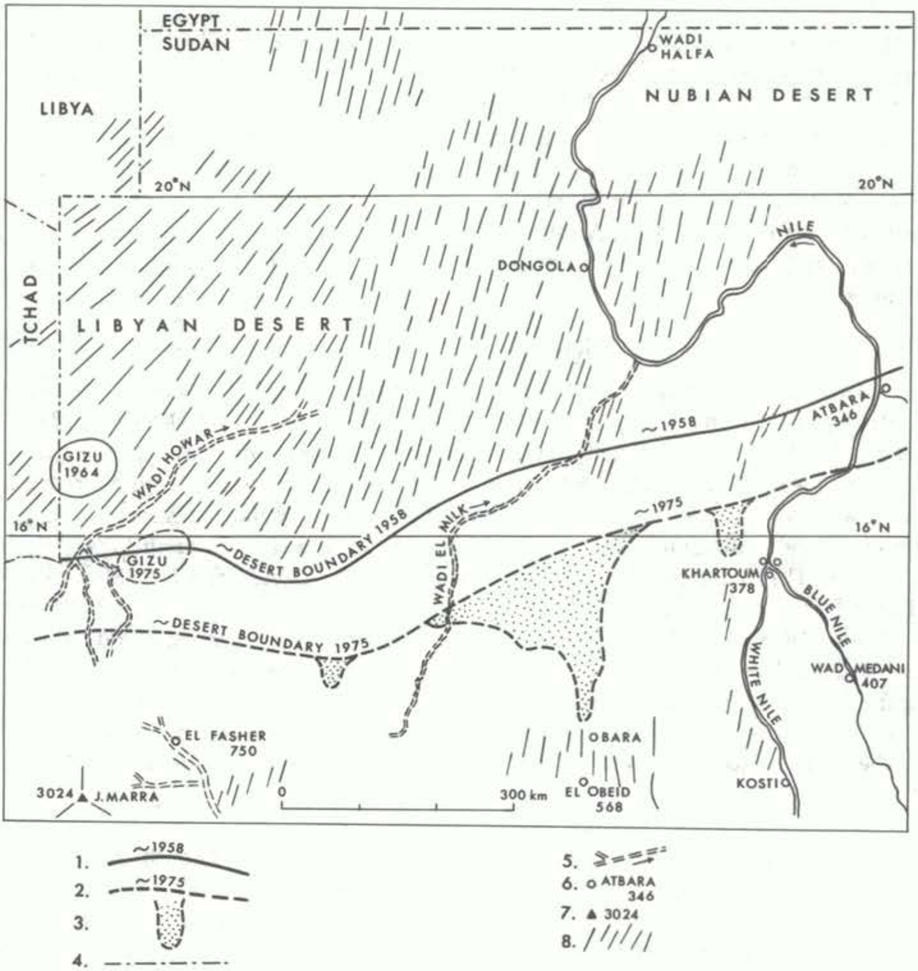
Lamprey (1975) describes the above change as follows:

> "It is evident that the desert southern boundary has shifted south by an average of about 90–100 km in the last 17 years. The southward shift can be readily appreciated in the vicinity of the Wadi Milk in northern Kordofan. Harrison and Jackson showed that the boundary between the desert and the *Acacia mellifera-Commiphora* desert scrub occurred where the Wadi turned from its northward course to the north east, passing the Al Ain escarpment . . . Wadi Milk now passes out of the desert scrub zone into full desert . . . some 110 km south of the El Ain escarpment, which now stands in total desert."

A similar shift of the boundary was observed along several transects in the air and on the ground. *Gizu* ephemeral winter vegetation, which occurs in the desert near the Wadi Howar at intervals of several years, is much valued by the nomad pastoralists as browse for their camels. One of the main areas of *gizu* grazing in the western Sudan had shifted 80 km southward since 1964. Lamprey is of the opinion that the encroaching sand is transported over large distances, whereas other authors claim that sand shifting is a local process in deserts.

The report also describes a very extensive die-off in the *Acacia senegal* woodlands along the 14th parallel. The xerophytic shrub *Leptadenia* has replaced the acacias, particularly on areas of relatively loose sandy soil (Fig. 8.5.4). An example of a desertized area with clayey soil is shown in Fig. 8.5.5.

The reconnaissance team also made flights along the Nile north of Khartoum along



Key to map a:
1. Approximate desert boundary 1958, from vegetation map by Harrison & Jackson (1958)
2. Approximate desert boundary 1975, from H. Lamprey and Sudanese team
3. Protruding area with many mobile dunes in 1975
4. National boundary
5. Wadi, dry stream bed
6. Town – altitude in metres
7. Mountain – altitude in metres
8. Direction of longitudinal dunes, recent and fossil.

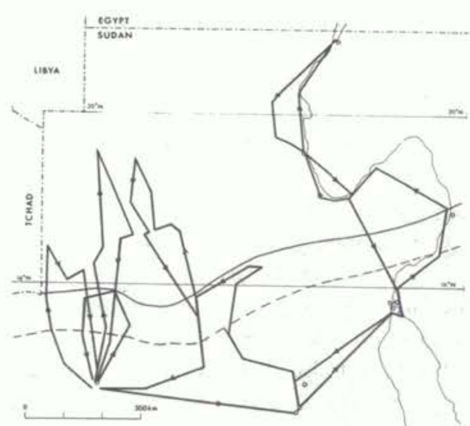


Figure 8.5.3. Map a) shows desert encroachment in the northern Sudan, 1958–1975. Based on reconnaissances by air and on the ground. Map b) shows air reconnaissance routes. Both reconnaissances were made by Sudanese experts and H. Lamprey, UNEP/Unesco, in November 1975 (Lamprey, 1975).

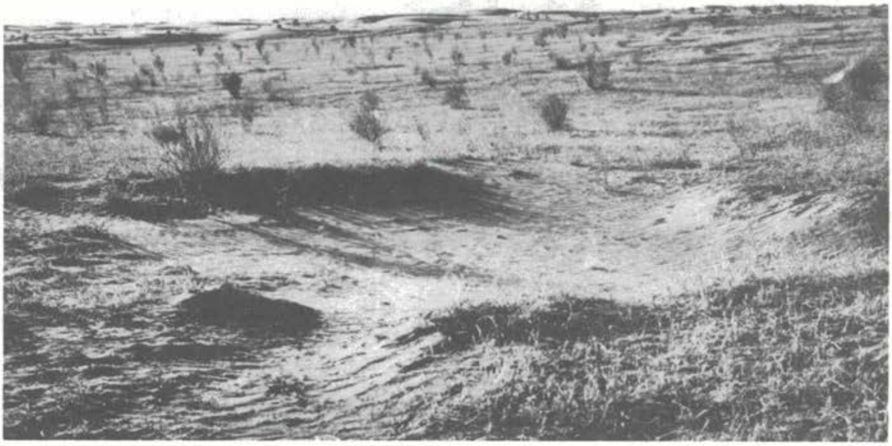


Figure 8.5.4. Deflation hollow in foreground and moving dunes in background. Formerly stable sandy soils with sparse grass cover and *Leptadenia* brush. North of Bara, Sudan, Photo A. Rapp, 1975.

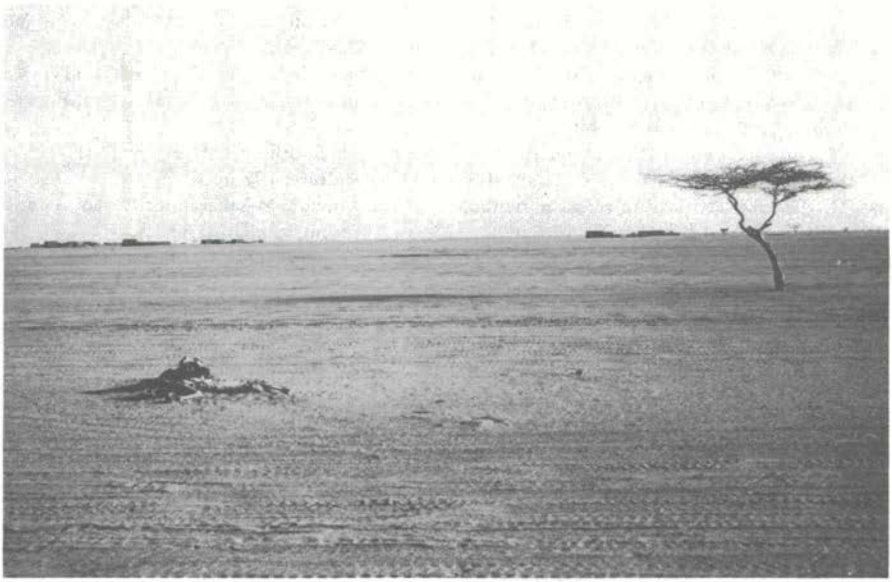


Figure 8.5.5. Man-made desert on clayey soils, 30 km south of Khartoum. Photo A. Rapp, 1975.

the Egyptian border. The team concluded that the cultivable lands on the floodplain along the river and in the nearby depressions are being steadily reduced by the encroachment of the drifting sand from the north and the east.

Wildlife in the arid zone of the northern Sudan is very scarce, and for many formerly numerous bird and mammal species it may be too late to promote recovery.

Similar reconnaissances made by inventories along transects on the ground and in the air ought also to be applied elsewhere in the desert margins, as a beginning of desert boundary monitoring. See further Chapter 12.

Land use plan for southern Darfur

The land use plan for southern Darfur (Hunting Technical Services, 1974) is another important source of information on current ideas on reclamation through improved land use in the Sudan. The southern Darfur area has an annual average rainfall of 450 to 750 mm, and is thus more humid than the desert and dry savanna country considered in the plan for "Desert Encroachment Control". Hunting's land use plan for southern Darfur is principally concerned with the improvement of rainfall production and focusses attention on the needs of the small farmer.

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Chapter 8.6

KENYA

A. HJORT

Kenya shows great topographical diversity, most landform types being represented. In the National Atlas of Kenya (1970), six broad ecological zones are distinguished, based on the following corresponding climatic zones: afro-alpine, equatorial, dry subhumid to semi-arid, semi-arid, arid and very arid. The seventh climatic zone, that of true desert, does not exist in Kenya.

The substantial European settlement in Kenya began with the establishment of the Uganda railway in 1902 and soon developed into tension between settlers and the local population over land issues. As far back as the early 1930s, grave soil erosion was reported from the Kikuyu reserve. The reasons, according to Sorrenson (1967), were "a growing congestion of population, over-cultivation of land without necessary periods of fallow and over-grazing".

In the 1940s a number of projects were organized on soil conservation. At this time land was considered to be eroding rapidly. The task of stopping this degradation was regarded as the most important one facing the colonial government. A massive programme of bench terracing – carried out by communal labour – was launched in heavily populated farming areas. This project caused great political tension and virtually ceased in 1947 owing to opposition. Other programmes included reforestation.

Shortly before the Mau Mau emergency, which began in 1952, responsibility for land consolidation was turned over to the Department of Agriculture with a view of improving farming. At this time the Swynnerton plan, entailing registration and consolidation of small holdings combined with a credit system, was gradually accepted. A farmer was supposed to practise mixed farming, thus obtaining sufficient produce for subsistence plus an annual income of £ 100 from cash crops. Soil conservation was included in the plan as part of the improved farming. The major drawback of the plan was that it did not include any crash programme for training the farmers; see Sorrenson (1967) and the ILO (1972) report.

With the coming of independence in 1963, the people were urged to go back to the land. Large settlement schemes were started to resettle people from high-density population areas to low-density areas. An effort was also made to plan the present land use.

In spite of this, there has been a tendency in densely populated areas to clear more land in forests for agriculture, caused increased erosion on the hillsides.

A major problem in the drier areas of the country, where farming can only be carried out on a small scale, is that of overgrazing. Almost three-quarters of the total area of Kenya is made up of low-potential lands with low and erratic rainfall (below 500 mm annually) and high evaporation. These regions are inhabited mostly by pastoralists. Agriculture is practised only to a very limited extent, mostly for subsistence, the main form of land use being grazing. Table 8.6.1 presents an estimate of the numbers of animals in these areas. The figures are only approximate, since no accurate stock census has been carried out. The estimate is based on the figures for land having less than 5 % of its area under cultivation, as presented in the National Atlas of Kenya (1970). No dairy cattle exist within the area and practically no wool sheep. No estimation is made of the number of camels, which are, however, common in northern Kenya.

Table 8.6.1. Estimated number of stock in low-potential areas in Kenya (in 1968).

District	1000 cattle	1000 sheep	1000 goats
West Pokot	150	39	119
Kajiado	450	62	105
Narok	450	422	106
Samburu	300	132	132
Turkana	180	130	522
Lamu	9	3	2
Tana River	139	15	73
Garissa	260	–	219
Mandera	58	–	111
Wajir	115	–	408
Isiolo	150	155	365
Marsabit	280	200	418
Total	2541	1158	2580

An effort to achieve soil conservation and at the same time to promote Kenya's livestock industry is being made by "Kenya Livestock Development Project", dealing with various ranching activities: commercial ranches, company ranches, individual ranches in nomadic areas, group ranches and grazing blocks.

Commercial ranches are situated in the Kenya Highlands; they are, or have been, owned by Europeans.

Company ranches are intended to develop unoccupied range areas, mostly in the coastal hinterlands. Land is leased from the state. The leasehold fee is very small during the first five years, then gradually increasing. The ranches are owned by companies. Jahnke *et al.* (1972) summarized the effects thus:

> "The government has set the scene for a massive accumulation of private capital and for a high capital income of the shareholders in the future".

Individual ranches in pastoral areas were established in the past by individuals (formerly nomads) who through their education, connections, or political power managed to legalize their demands on certain areas – mostly neighbouring areas intended for group ranches (the patches in between were too small for group ranches).

Group ranches constitute an effort to encourage pastoral groups primarily in areas with high grazing potential to come together, agree on an application for land adjudication, and elect a committee to be in charge of the group ranch. So far, experiments have been carried out among the Kaputiei section of the Masai in the Kajiado District.

Grazing blocks are intended for areas with seasonally poor grazing or areas where the principle of group ranches would not be workable. Certain areas are set aside for use only during dry periods, when there is no grazing or water elsewhere. Up to now, three grazing blocks have been established in northern Kenya among the Somali people.

It is generally possible to tell commercial ranches from group ranches, the former being economically stronger. If such ranches lie next to each other, the commercial ranches may easily monopolize the available resources, especially water, at the expense of group ranches or traditional herding, as has been the case in the Afar Valley in Ethiopia. A similar problem might develop, particularly in southern Kenya.

One purpose of group ranches and grazing blocks is to counter overgrazing and land degradation by stabilized ranching. This aim is threatened by sociopolitical difficulties. One problem is that the ranching must be based on effective groups – that is, a clear identification with the common activities should exist. The Masai group ranches do not seem to be a great success in this respect. Halderman (n.d.) shows that though the intention has been to make the boundaries of the group ranches coincide with clan land, this has not been sufficient to develop effective groups. Jahnke *et al.* (1972) hint that the groups are heterogeneous; individual members identify equally strong outside the group as within. There has been a tendency for each person to established relations with several groups with a view to reducing the risks of diseases and drought. Such a strategy is logical for a pastoral household, as indicated by the presentation in Chapter 3.

Another difficulty with similar implications towards decreased identification within the group is the fact that the power-wielding age-group (elders) refused to give up authority after about 15 years, when they were supposed to, owing to the new economic opportunities that presented themselves for some of them as members of the group ranch committee. This created great tension within the community until mid-1973, when the new age-group was finally instituted.

Yet another difficulty exists in the formation of a committee in charge of decisions in matters concerning the group. Traditionally the Masai make unanimous decisions (the elders deciding, while others simply listen to the debate) at meetings that continue until a consensus has been reached. This means in reality that an elder traditionally has a veto right; to him a majority decision in a committee may seem unfair and revolting.

These and other sociopolitical difficulties tending to decrease identification with – and consequently confidence in – the group ranch may result in group ranches being looked upon as just another resource that can be exploited by the individual household. Any considerations about overgrazing then become superfluous, since the land is bound to be exploited by somebody anyway. The usual maximizing principle will become overwhelming, and there may be a development towards uncontrolled increase in the number of stock, each household having been provided with new methods of expanding and diversifying by the application of well-known strategies.

Halderman (n.d.) called for effective stock control measures in order to counter overgrazing:

> "The economic and social pressures, compounded by the more favourable conditions brought about by development could produce a tremendous increase in the number of livestock in Kaputiei Section."

A second aspect of the risks of overgrazing is that the incipient cash economy will give rise to new and intensified flows of money for investment in cattle. Such a development would be completely analogous with what is happening in Turkana in Northern Kenya, where money earned from a newly established fishing industry is being invested in cattle in the area. As no effective stock control exists, the number of cattle has gone up tremendously, especially as the animals are not slaughtered during drought periods – farm produce being instead purchased from other parts of the country. This in turn has led to serious overgrazing. Henriksen (1974) also emphasizes the need for stock control. His suggestion is to prevent money earned in one sector of the economy, such as fishing in the case of Turkana, from entering another, such as herding.

In general, some kind of effective stock control is vital for countering the tendency towards overgrazing (and thus land degradation). In one group ranch the Range Management Division tried to introduce a system of stock control by applying a principle whereby each member was allotted a minimum quota, the remaining quotas being alotted in proportion to the number of animals brought to the ranch. The herds of large herd owners were thereby reduced. The principle was not accepted and this approach failed. Jahnke *et al.* (1972) point at a number of difficulties connected with the prevention of overgrazing without presenting a solution. One is left with an unresolved discussion:

> "Stabilized ranching provides a better opportunity to control overgrazing. By assigning definite property rights to groups the consequences are more observable for each group member. The problem, of course, remains whether they can agree on destocking or not. It seems that there is simply no other alternative which would offer better chances of success or to be more in the national interest than the group ranch approach."

A similar conclusion is reached in a recent report by Pratt (1975):

> "The foremost task at this time, overshadowing all others, is to ensure that recently established ranches and grazing schemes work, i.e. that they achieve the status of viable self-sustaining units, in reasonable balance with the land resources. The fact that the obstacles to be overcome are more socioeconomic than technical underlines the necessity for incorporating socioeconomic studies within the scope of range research."

A suggestion is presented in Chapter 10 as to how socioeconomic factors may be incorporated in further range research.

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Chapter 8.7

BOTSWANA

M. ZUMER-LINDER

Introduction

The Kalahari is in many ways very different from the other grazing lands in the world which have been utilized by man and grazed by his livestock for centuries, often back to prehistorical times. Until very recently, the Kalahari has remained a "virgin region", endowed with rich and varied wildlife, and a home for the oldest race in Africa, the Bushmen. The hunting and gathering way of life among a sparse and scattered population of Bushmen is a long experienced adaptation to a special environment and has no significant impact on existing resources (Story, 1958).

The Kalahari still has a chance to follow its own way of development and to avoid the plight of other heavily overgrazed areas in the world which have already become desert or are in the process of becoming so. It is a great national responsibility and an international challenge to direct the development in an environment of serious limitations.

The Kalahari basin probably represents the largest sand-covered surface in the world, covering about 2.5 million km^2 (Hyde, 1971). Since the time of Livingstone – who was active for five years (1846–1851) on the edge of the Kalahari (near Molepolole) – this region has been regarded as the one having the least development potential, and as such it was largely neglected by the colonial powers. The role of the British Government, which in 1885 formed the Bechuanaland Protectorate, was expressed in the following statement:

> "We have no interest in the country north of the Limpopo, except as a road to the interior" (Smit, 1970).

It was not until the late 1960s that the Kalahari was "discovered" by economists and politicians, who dubbed the region of "no development potential" a "major underutilized resource of the country" (Mettrick, 1971; Landell-Mills, 1971). In fact, the difficulty of obtaining water in much of the Kalahari has contributed to the protection of veld, of wildlife, and of the Bushman habitat.

Topography, soils, climate, groundwater

The Western State Lands are a part of the Kalahari Desert covering about one-tenth of Botswana. It is mostly a flat region, having an elevation of some 1000 metres above sea level and covered by the Kalahari sands, where the villages have evolved around pans. The pans are flat-bottomed depressions of calcrete sediments several metres below the surrounding sand dunes. These pans are of vital importance as a temporary source of surface water during the rains, for welldigging and boreholes, for summer grazing and salt licking both for livestock and game (Parris, 1968).

The soils are structureless and are composed almost entirely of coarse and fine sand, generally mildly acid and of low fertility (Blair Rains & Yalala, 1972). The nutrients most commonly deficient are nitrogen and phosphorus (Siderius, 1972).

The sand cover is fixed except where vegetation has been seriously disturbed. The fine sand fraction of the Kalahari sands varies between 30 to 65 % (Blair Rains & Yala-

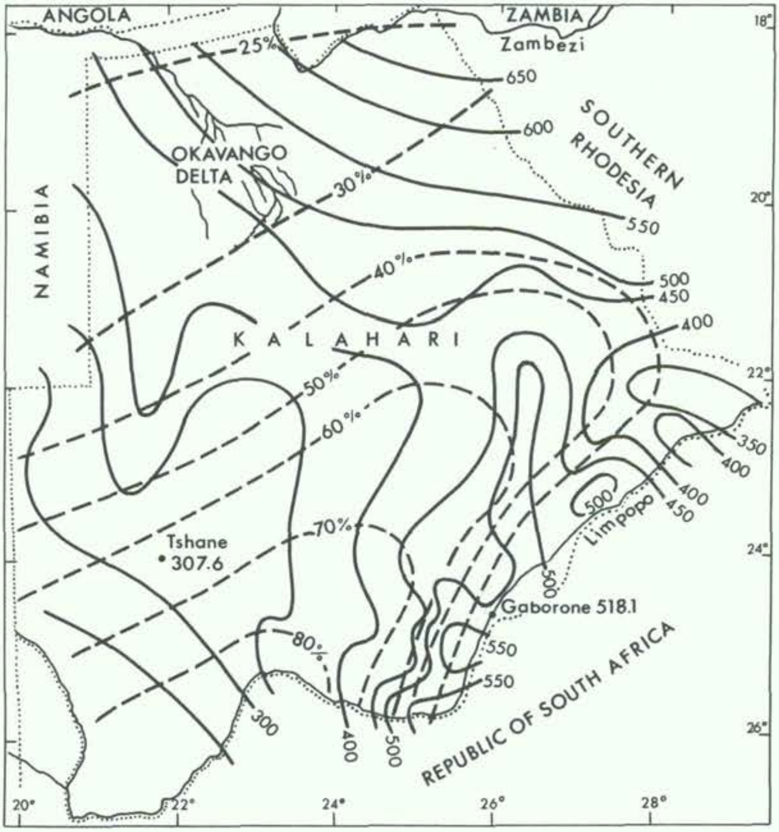

Figure 8.7.1. Mean annual rainfall and percentage of variability from men annual rainfall (Pike, 1971).

la, 1972) which can be blown about whenever exposed to strong winds. Wind erosion is therefore expected to become a serious threat with the increasing depletion of the vegetational cover, particularly since the Kalahari is considered to be the largest continuous sand-covered surface in the world.

The climate of the Kalahari is arid to semi-arid, with increasing aridity towards the southwest. The rainfall is erratic and unreliable, and the variability of annual rainfall increases from 30 to 80 % southwards (Fig. 8.7.1). Rainfall occurs mainly from November to April. The mean values in the Western State Lands are below 300 mm and are of little importance if the variation of intensity and distribution are taken into account. During a period of 13 years, the "seasonal rainfall" was below 300 mm for nine years and less than 200 mm for four years (see Fig. 8.7.2).

Local variability of rainfall is an important fact, and it does not rain sufficiently and every year to enable the grass cover to reproduce or to prevent perennials from dying during the drought. There is also less green browsing during the drought years, since bushes remain defoliated longer and there is generally less production of pods and seeds.

Owing to evaporation losses, showers of less than 1 mm can hardly penetrate into the soil. It is considered that an initial rainfall of more than 5 mm is required to penetrate into the soil when the weather is hot and dry (Whiteman, 1971; Gibbon, 1974).

The Kalahari is one of the hottest regions in southern Africa, with considerable temperature fluctuations, both daily and seasonally (Leistner, 1967). The climatic conditions in the Western State Lands are quite unknown, except for the observations at Tshane during the past decade. The mean maximum temperature was found to be 29°C, the mean minimum temperature 12°C, the wind run 160 km d^{-1}, and potential evaporation 3000 mm yr^{-1}. The highest rates of evaporation were recorded during the rainfall season (Fig. 8.7.3).

Daily variations of temperature and air humidity are greatest at ground level and are thus very important for the development of grasses. Measurements at ground level have shown that the microclimate is less favourable, drier, with higher extremes of temperature and more exposure to wind on the bare ground than under the vegetation cover (Fig. 8.7.4). The highest temperature differences were thus recorded just at ground level, with an average daily maximum of 48°C on bare ground and of 35°C under bush cover during a 12-day observation period in September 1972. The minimum values recorded during the same period were 6°C on bare ground and 8.5°C under bush cover (Zumer-Linder, 1972b).

Permanent settlement in the Western State Lands would today require a groundwater supply by wells and boreholes. Boreholes are a rather recent technical innovation. In general, groundwater development in the Kalahari is expensive because the successful borehole ratio is relatively low, the depth of drilling is substantial (down to 300 metres), and the yields are comparatively small (Hyde, 1971; Jennings, 1969). Where the sand cover is thick, the success of drilling is very uncertain and the water might be saline.

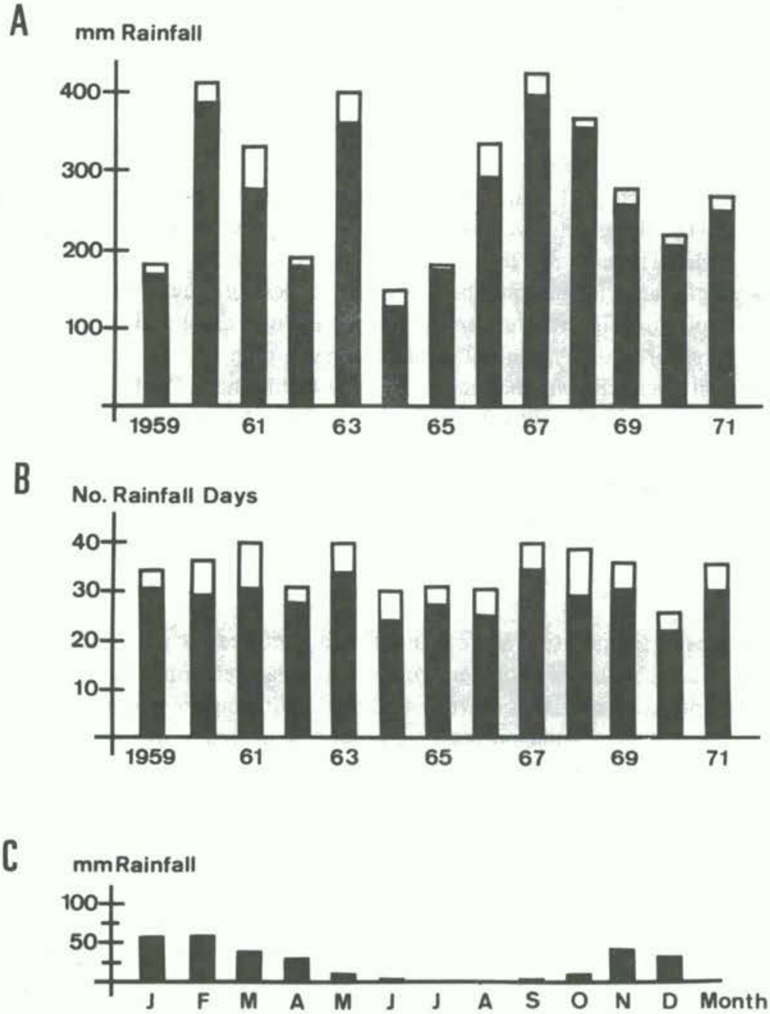

Figure 8.7.2. Mean annual rainfall (A), number of rainfall days per year (B), and average rainfall per month (C) at four rainfall stations in the Western State Lands, Botswana. Black bars represent the seasonal rainfall from November to April and white tops the unseasonal rain during the dry period (Botswana Meteorological Department).

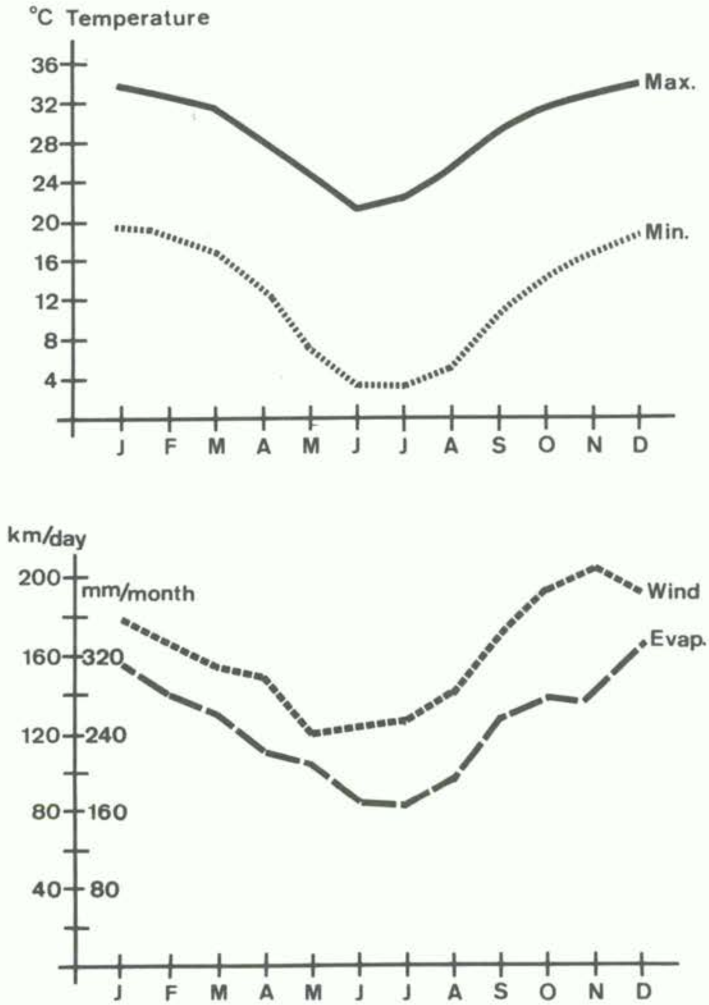

Figure 8.7.3. Tshane – Meteorological Station. Maximum – minimum temperature, wind speed and evaporation (Pan A-mm) shown as means per month for the period 1959–1971. (Botswana Meteorological Department.)

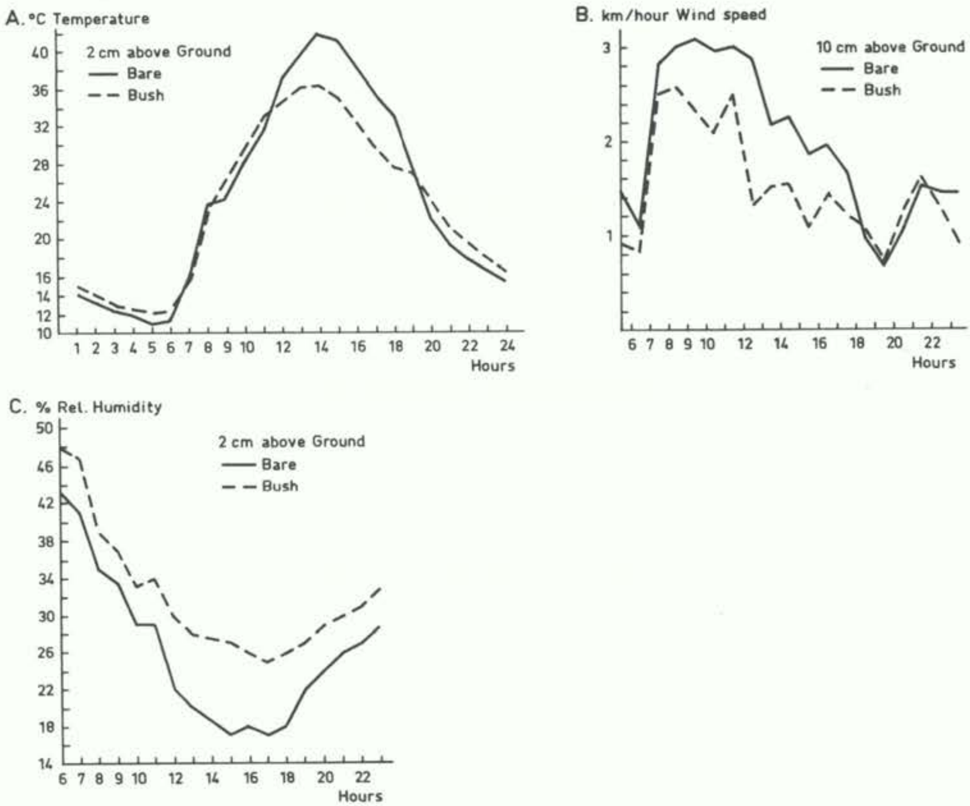

Figure 8.7.4. A) Temperature, B) wind speed and C) relative humidity recorded on bare ground and under bush cover, at 2 cm above ground-level between September 21–October 2, 1972 (Zumer-Linder, 1972b).

Vegetation and fires

The vegetation of the Kalahari sandveld shows a mosaic pattern of trees, shrubs, grasses and herbs of varying density and height (Blair Rains & Yalala, 1972; Leistner & Werger, 1973). The main characteristic of the vegetation is the low grass cover, and even in the best areas the grass density is relatively low. The grass production is liable to the variability of rain, fires, natural variability of the grass-bush cycle, and effects of grazing by livestock and game.

The natural variability of the vegetation cover in the Western State Lands is an important fact. Even in areas where the effect of grazing has been negligible, the percentage of grass cover varies from 16 % to almost 0 %. As an example, the variation of ground cover for perennial grasses 10 to 50 miles (recorded 1971) east of Ncojane is shown in Fig. 8.7.5. The highest density of grasses was about 15 %, the lowest density was associated with pans (owing to edaphic conditions), burning, or shortage of rain.

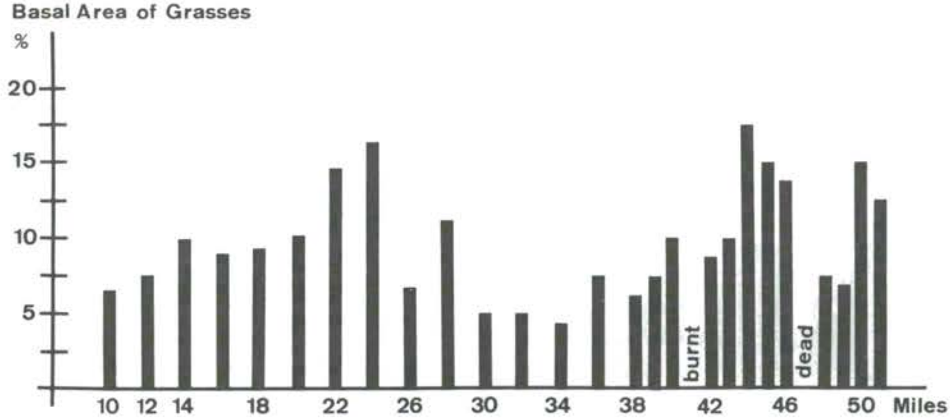

Figure 8.7.5. Variation of the perennial grass cover in the Western State Lands. The starting point is 10 miles east of Ncojane to Matlo-a-Phuduhudu, not or only occasionally grazed. Recorded October 1971. (Zumer-Linder, 1972b.)

No information is available on dry matter production per unit of area in the Western State Lands. The production figures for the eastern border of the Kalahari show an annual fluctuation between 800 and 1900 kg ha^{-1} (average 1290 kg ha^{-1}) with a much higher basal area of grasses than in the west (data from Masiotilodi, Mantswobese, Matlolakgang – by courtesy of the Agricultural Department, Sebele, 1972).

Fires are common in the Kalahari. They are either set purposely for hunting and clearing or accidentally. It is reported that burning in the Western State Lands has become more extensive as a result of the increasing invasion of cattlemen (Child, 1971b).

In tropical grassland regions, burning is often recommended against bush encroachment. Under very arid conditions in the Kalahari, burning usually does more harm than good and accelerates the natural decline of perennials. It happens that perennial grasses die off over large areas as a result of burning, which, in turn, promotes bush encroachment.

Grazing pattern

The grazing pattern in the Western State Lands involves continuous grazing everywhere all the year round, with the highest pressure in the vicinity of watering points (Martin, 1972; Ghanzi District Development Plan, 1972). The gradual impact of increased grazing pressure is as follows:

a. Selective impoverishment of species. The palatable perennials are grazed out first and replaced by less palatable grasses, annuals and herbs.
b. Grazing out of perennials. General overgrazing or continuous grazing during the growing season will result in the weakening of perennials, followed by deficient seed production, and eventually dying out of grasses.
c. General downgrading of productivity. Of the ground vegetation, only annuals and herbs of low productivity and nutritive value are left.
d. Only bare ground or a few unpalatable bush species are left.

At this stage of deterioration it is often considered that the productivity of the area cannot possibly be further diminished, which is not necessarily the case. The bush encroachment might become heavier, with an increasing amount of less palatable thorn species like *Acacia mellifera, Dichrostachys cinerea* or bush possibly becoming reduced by browsing, excessive cutting for fuel and fencing, and increased trampling and desiccation. A shortage of poles and firewood is becoming serious close to the villages and settlements.

From the point of view of conservation, bush encroachment may be considered less disastrous than the depletion of all vegetation, which exposes the soil surface to the free action of wind and water. The blackthorn bush of the southern veld and *brousse tigrée* of the Sahel can diminish the effects of erosion and even provide some protection under the thorny branches for the regeneration of other desirable species.

Child (1970a) considers that the veld deterioration is seldom a regular process; it is usually characterized by a number of critical thresholds. His illustration of overgrazing from Nxai pan in the Southern Kalahari shows that the initial deterioration of the range would not be reflected in livestock population. However, at the point when the pastures have been transformed into an impenetrable thicket, the livestock numbers would decline drastically towards extinction (Child, 1970a).

The main daily routine of cattle in the Kalahari during the dry season appears to be walking from the grazing areas to the watering point and back again. The one-way walking distance in the majority of permanent places was above 10 km. In all villages the grazing was deficient or entirely lacking where water was available, even where the borehole had been functioning for only one year (Fig. 8.7.6).

In general, no satisfactory grazing remained at a distance of 10 to 15 km from a borehole, and where boreholes had been drilled too close to each other, degradation of grass cover was continuous. The situation was found most serious at the central Kgalagadi villages where hardly any grasses were left between the villages and within the areas which were assigned for grazing by a demarcation commission. The cattle there were not watered daily because the distance from grazing areas to the watering point was more than a one-day walk.

The main reasons for rapid degradation in the Kalahari are overgrazing and heavy trampling by livestock. The ability of grass roots to resist grazing pressure on loose sand

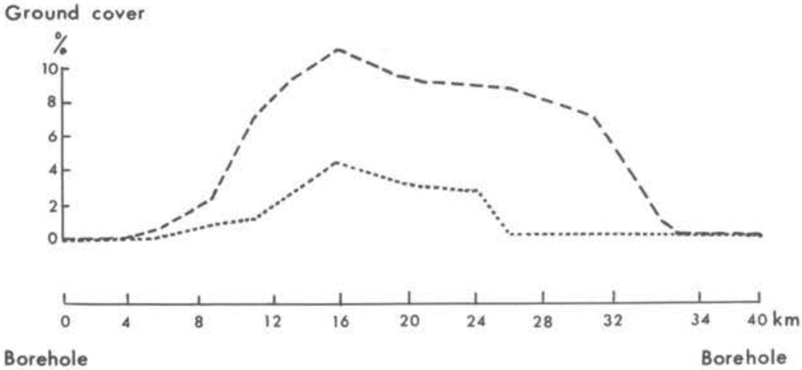

Figure 8.7.6. Variation of grass coverage in % between two boreholes. Dashes = total grass cover; Dots = perennial grass cover. (Zumer-Linder, 1972b.)

appears to be very limited. It is believed that broad-leafed palatable species are more heavily affected by desiccation than the narrow-leafed unpalatable ones.

The grasses in the Kalahari are relatively shallow-rooted, which means that they are more directly exposed to the changes of microclimate and the effect of desiccation whenever the ground coverage and density are reduced. Some observations of shoot/root ratios on species grown on loose sand may illustrate (Table 8.7.1) that the grasses are relatively shallow-rooted compared to herbs, which seem to have sizeable proportions below ground. Around the boreholes, the desiccation of the ground is reported to be very severe owing to continuous trampling so that no ground vegetation is able to survive (Martens, 1971).

Previous experience from Botswana has shown that the building up of livestock numbers has been strongly related to rainfall conditions. After a number of favourable years, such as in the 1950s and early 1960s (see Fig. 8.7.7), livestock numbers increased rapidly, resulting in heavily overgrazed pastures. During the subsequent drought in the 1960s, the losses accounted for more than 50 %. As reported recently, livestock numbers are building up again at the present time, owing to the exceptionally good years in the early 1970s.

Van der Merwe made an analysis in 1937 of drought year fluctuations in the southern Kalahari, concluding that at least four serious droughts lasting two years or longer occurred during a period of 25 years (Interim Report, 1968).

Droughts in the Kalahari are not exceptional but are among the most characteristic climatic phenomena, although they cannot be predicted with accuracy (Andersson, 1970, 1971). Failure in any form of land use planning to adapt to the probability and expectations of drought situations often results in dire consequences (see Fig. 8.7.7).

The wish to expand cultivation after a good rainy season and to multiply cattle herds has been very obvious during the last two decades in the Kalahari. Serious concern

Table 8.7.1. **Basal area, shoots and roots of some grasses and herbs. Measured September 1972, Kuli-Ncojane (Zumer-Linder, 1972b).**

Vegetation	Species	No. of observations m^{-2}	Basal area (m^2)	Shoot height (cm)	Root depth (cm)
Perennials					
Palatable and intermediate	*Brachiaria nigrepedata* *Schmidtia bulbosa* *Eragrostis lehmanniana*	10	73	60	35
Non-palatable	*Aristida uniplumis*	7	87	58	41
Herbs	–	6	32	13	62

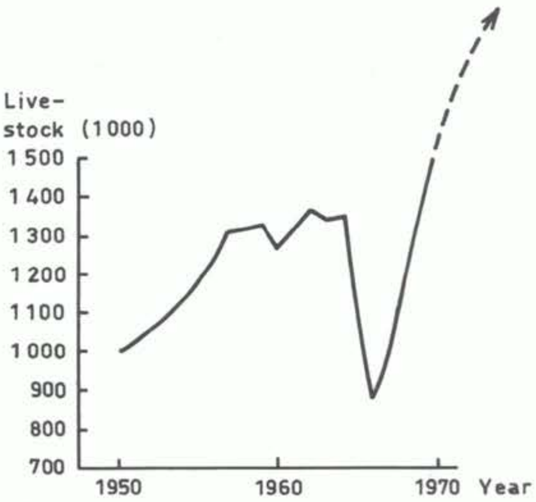

Figure 8.7.7. Fluctuations in livestock numbers in Botswana (after Fosbrooke, 1970a).

was expressed by the Minister of Agriculture (Dambe, 1972):

> "The agricultural industry of Botswana is in danger of collapsing because of appalling overgrazing . . . . In many areas of this country we are approaching a threshold and once we have crossed it recovery will be virtually impossible."

Yet, contrary to earlier situations, the pattern of land use and the way of living have altered somewhat during the recent preparation period for an international livestock production project in the Kalahari. The changes are connected with higher concentration of dwellings in the villages, increased trade, accelerated construction of boreholes and watering points, resulting in higher and higher pressure on existing pastures. The changes in recent years also involve a larger clearing of pastures for arable fields, since the higher rainfall and more concentrated dwellings encouraged cultivation. There has also been an excessive cutting of trees near villages for building material, fencing poles, and firewood.

As the situation is now, the overgrazed areas near villages and boreholes have not regenerated nor have they been reclaimed during the favourable years, as was previously the case. This means that the next drought will probably strike the hitherto highest livestock numbers in the Kalahari, and the population depending on them, much harder than ever before.

Wildlife and the Western State Lands livestock project

The most important adaptation of the wildlife in the Kalahari today is the great mobility which allows the game to utilize the uneven rainfall and fresh grazing found at different places. Many animals, particularly the large herd species, can sense rain at great distances and move to where the rain has fallen (Parris, 1971).

The large browsing and grazing animals can be divided into two groups. The first group includes species such as steenbok, duiker, kudu and warthog, which live more or less alone and do not move around over very large areas. The second group comprises animals like wildebeest, hartebeest, springbok, and eland, which live in big herds that range over extensive areas. The very mobility of the wildlife with its regular and irregular movements represents a form of rotational grazing which is eminently suited to the Kalahari conditions (Campbell, 1971a; Campbell & Child, 1970; Child, 1970b, 1971a).

Hunting is considered vital in the Kalahari for the supplies of meat, skin and hides (v. Richter, 1969) even for the newcomers with cattle (Campbell, 1971a, b). Any significant changes in wildlife populations and distribution are likely to affect the amount of protein supplies and possibly the cash incomes of the indigenous population.

It has been estimated that the expansion of demarcated village areas and livestock ranches will be extended over some 16,000 km^2, which is about one-third of the Western State Lands. This expansion will interfere both with the game movement and the hunting areas of nomads and villagers (see Fig. 8.7.8). The numbers of selective grazers and water-dependent species have been reported to decline such as springbok and wildebeest populations (Child, 1971a).

Land use pattern and planning for development of the Kalahari

Pastoralism in the Kalahari has a relatively short history and up to the 1930s was characterized by migratory and scattered grazing determined by the rainfall pattern. The first herdsmen in the Kalahari in the beginning of this century became accustomed to wildlife hunting in addition to livestock rearing (Campbell & Child, 1970; Campbell, 1971a), which was of utmost importance during times of scarcity or in drought situations.

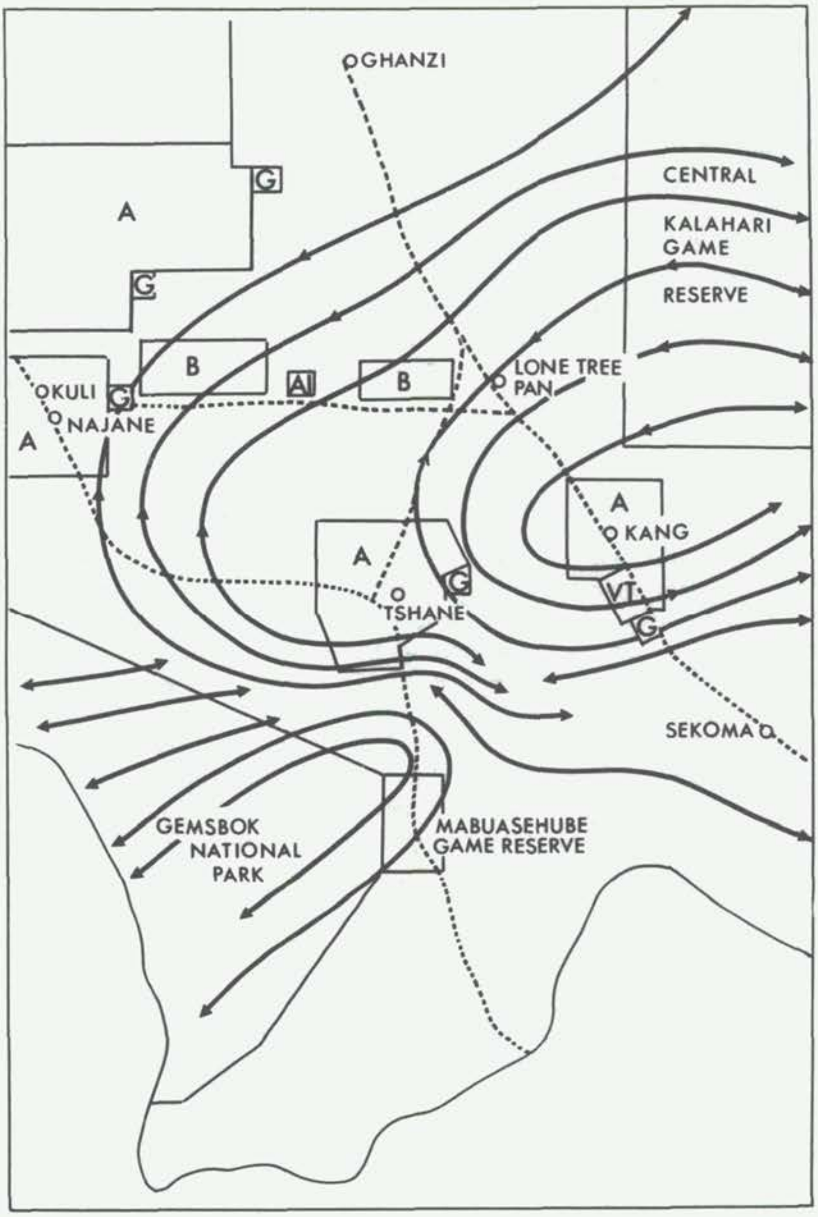

Figure 8.7.8. Sketch map depicting approximative wildlife movements in the Western State Lands (Dept. of Wildlife and National Parks, 1972). (Based on information by Dept. of Wildlife and National Parks, from Zumer-Linder, 1972b.)

A = Demarcated village areas
B = Breeding ranches (planned)
G = Growing-out ranches (planned)
AI = Artifical insemination camp
VT = Quarantine camp

On a larger scale, grazing has been opened in the Kalahari by the relatively recent development in the 1950s of watering points. Livestock tend to concentrate in the vicinity of permanent boreholes. This restricted mobility has gradually transformed the Kalahari pastoralists into permanent settlers (Devitt, 1971).

Some 2300 boreholes were drilled up to the 1970s by the Government and even more than that by private investors (Jennings, 1969). The habitat surrounding the borehole is characterized by an area of heavily trampled, desiccated ground (Martens, 1971). The reduction of grass cover shows a pattern of widening rings, gradually improving with distance from the borehole. Advances in technology have thus contributed to short-term gains at considerable environmental costs rather than to the evolution of methods of continuous production. The present institutional structure is not well adapted to the requirements of sustained grazing (Devitt, 1971; Fosbrooke, 1970a, 1971a, 1971b; Child, 1971a, 1971b).

Over most of the eastern region on the Kalahari edge, where 80 % of Botswana's population lives, the productive capacity of the lands has been seriously reduced. Here, the population subsists largely on arable crops, but only limited areas can provide reasonable yields under natural rainfall (Pike, 1971; Gibbon, 1974), in addition to which is the fact that the pastures are largely overgrazed. Significant changes for the worse occurred in the intrinsically most productive areas of Botswana which were naturally the first to be settled (Child, 1970a; Fosbrooke, 1970a, 1972a, b). These changes have led to the progressive use of less and less productive areas which were rejected in the past. In spite of low human density, a shortage of land is now becoming evident (Child, 1970a, 1971b).

The failure to maintain soil fertility by an adequate system of land use is the root cause of the present situation. The process of degradation is self-perpetuating – man overcultivates, causing decreased fertility of arable land, and then the cattle take over and denude the area of grass cover. Finally, only the woody vegetation (if not burned or cut down) is left, on which only goats can survive, very often followed by abandonment of the land by man (Fosbrooke, 1970b, 1972a, b).

In 1971, a conference on sustained production from semi-arid areas was organized in Gaborone with the main objective of bringing together politicians, economists, rangers and conservationists in order to reach an agreement on the future land use policy of the Kalahari (Proc. Conference, 1971). Land use practices and problems associated with the grazing of marginal lands were elucidated from various angles, yet the gap between the decision-makers and conservationists became broader and deeper (Zumer-Linder, 1971, 1972a).

The future solution for Botswana as presented by economists was briefly, to increase livestock production (livestock represents 90 % of Boswana's exports) in the following way:

> "Livestock offers the best opportunities for increasing the rural product . . . . Kalahari represents Botswana's major underutilized resource for rural development. It is only by opening up new land that it will be possible to solve the problems of the overgrazed areas." (Mettrick, 1971.)

Accordingly, big ranching schemes have been developed for the Western State Lands of the Kalahari, which cover about one-tenth of Botswana, in order

> ". . . to relieve the pressure on eastern areas . . . it is planned to redistribute live-

stock to the underutilized areas of the country through the settlement schemes and the provision of additional watering points." (National Report for the Conference on the Human Environment in Stockholm, 1972).

During the preparation period for the planned livestock project in the early 1970s a great deal of uncontrolled drilling for water occurred in the Western State Lands. Rapidly increasing sizes of herds, located at the new boreholes, contributed to an accelerated overgrazing in spite of exceptionally good rainfall years. This initial activity of ranching schemes developed contrarily to what had been hoped to be achieved according to the project plans. The bigger cattle owners were undoubtedly favoured by the latest events, as stated by Thomson (1971), who refers to the existing large disparities in income and wealth in the Kalahari:

> "It seems to be an increasing tendency for wealthier farmers from the east of the country to run cattle posts in the underutilized areas of Kalahari."

According to Blair Rains & Yalala (1972):

> "On historical grounds, the Bushman should have the first consideration in any proposals for the development of those parts of the Kalahari which have become his home. They have a unique culture . . . The future of the Bushmen will be watched with interest from the outside world."

The hunting and gathering as an anachronism from the days of sparse population and endless territory is breaking down quickly under present changes (Biesele, 1971). Bushmen, as inheritors of the oldest African culture, would have either to limit themselves to the Bushmen Game Reserve, with an even harsher environment than most of the Kalahari, or to give up their traditional way of life.

Since the direction of future development still remains with the decision-makers, the following questions, brought up at the Conference in 1971, still have to be answered: Have the politicians gathered enough information to make a proper decision which will influence many generations and the future of the Kalahari? Are the short-term gains justified at the expense of long-term destruction?

If severe deterioration of the environment results from the livestock industry development, then it will be too late to turn the Kalahari into a game reserve, because the lack of grazing will lead to the disappearance of most grazing animals (Martin, 1971; Child, 1971a, b).

Failure in attempts to stabilize and develop the critical marginal lands will be tragic. Success in developing stable forms of land use will ensure a continuing renewable resource base and will provide a great example for other African countries to follow.

How to achieve sustained production in the Western State Lands is at present not known. It will be one of the main tasks of the international livestock production project to devise the proper management practices in an environment of severe limitations. An Australian expert (Newsome, 1971), who was consulted on the development of livestock schemes, described livestock farming in the Kalahari as a gamble if the unpredictable climatic conditions and the variation of resource availability were not taken into account. Dependence on one single source of income under such circumstances is dangerous and a one-sided impact on grazing resources is often detrimental. Any kind of successful management system will have to take into account:

- high capital investment (boreholes, water reservoires, firebreaks, fencing)
- control of stocking rate and supervision of grazing areas

- high managerial skill to tackle difficult situations
- flexible management system with special measures during drought periods
- variable management of the veld adjusted to the variability of natural resources
- infrequent grazing, with some areas reserved as "emergency areas", varying the time and degree of grazing. The heavier the grazing, the shorter must be the grazing time
- awareness on the part of cattle owners of need for control and offtake
- training in management practices and cattle herding.

Management for maintaining the natural productivity in a difficult environment will not be easy and cannot be done cheaply.

Geographically, the Kalahari has always been called a desert, yet is classified botanically as bush or tree savanna and called locally a sweetveld, sourveld, bushveld, thornveld or sandveld. The future way of handling these areas will determine the proper naming of a "true desert" or a "grassed savanna". The responsibility lies with all of us, and the success or failure of the development of the Kalahari might be regarded as a test case in an international context.

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Chapter 9

REHABILITATION OF DEGRADED ARID LANDS

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Introduction and climatic modifications

Since desertization is a man-induced phenomenon, aggravated by climatic circumstances (periodical prolonged drought), any requisite measures for halting further irremediable loss of productivity land and for restoring desertized land to productivity must necessarily interfere with human behaviour and land-use management.

However, it is questionable whether intervention on the physical plane, with results such as, artificially induced rain, sea- or brackish-water desalinization and irrigation can partially or totally halt desertization and rehabilitate desertized areas.

Halting desertization in arid areas in technologically advanced countries such as the southern United States or central Australia is no problem, owing to the very low densities of population. However, in the North African, Near and Middle Eastern arid zones, the problem is entirely different owing to the pressure and sharp growth rate of the respective populations (doubling every 20–25 years, i.e., increasing 16-to 32-fold per century). In central Australia a rancher lives on 10,000 to 1,000,000 hectares whereas in climatically similar areas a Tunisian, an Algerian, or a Syrian has to take out his living from 10 hectares (and sometimes less) of nonirrigated land.

The cures for desertization have been known for a long time: they consist of the reverse processes, that is, biological recovery or biological revival (Fr. *remontée biologique*) of environmental conditions, naturally or artificially induced.

Much research effort has been devoted to cloud seeding in several countries, but with dubious results. Cloud seeding produces rain only under very special conditions. According to experts, the desired rain would probably have fallen anyway, but somewhere else. However, some local successes have been obtained in producing rain on a specific catchment basin in order to fill a dried-out reservoir, etc. In other words, it is possible to influence the distribution of rain in space but not the total amount of rainfall.

Cloud seeding presupposes water-bearing clouds and a rather moist atmosphere – conditons which are generally absent in the areas under study. Moreover, any man-induced modification of regional climates cannot be envisaged in the foreseeable future. The causes of climatic fluctuations are extremely complex and are far from being understood; in addition they involve enormous amounts of energy, far beyond the reach of present-day technology. The effect of vegetation on the overall water balance of the earth is negligible, since almost all the water in the atmosphere comes from the oceans and lakes, and one cannot hope to influence rainfall by means of green belts or other "miracle solutions" such as the "Saharan internal sea" which, incidentally, is physically impossible to realize, given the difference in level (30 m) and the distance from the sea (300 km); the slope would have to be at least five times steeper to allow water to flow and compensate the 20×10^9 cubic metres corresponding to annual evaporation in the 10,000 km^2 of this "would-be sea". The whole question of weather and climate modification has recently been reviewed (Glantz & Parton, 1975).

Biological recovery

Biological recovery consists in the reverse processes of the degradation of ecosystems, viz., increase in biological activity, biomass, plant cover, organic matter, and soil micro- and macroorganisms; higher fertility; better water intake and turnover; and lower evaporation and runoff – in short, improved functioning of deteriorated ecosystems. This overall process is also termed de-desertization.

Biological recovery may be attained in various, complementary ways under natural, seminatural, or artificial conditions.

Natural recovery

Natural recovery consists in biological improvement of ecosystems via protection from intruders (in general, man and his livestock). This protection may be total, such as when an area is fenced off and people and domestic animals are not admitted (exclosure). Natural ecosystems usually respond to this treatment by allowing increased development of producers (vegetation) and then of consumers (animals). Hence a greater production of organic matter is induced which, in turn, increases biological activity in the soil, thereby improving soil structure, permeability and water intake. The entire ecosystem is thus affected.

The speed of response varies greatly with local conditions. It depends on the entropy of the system, that is, the stage of deterioration of vegetation and soil and also on the respective sizes of degraded and undegraded areas adjacent to a given zone. It depends also on vegetation, stability and resilience, that is to say, its ability for recovery after disturbance.

Stability, resilience, and entropy depend on many biological and nonbiological conditions, such as, seed availability, whether a given dominant species propagates by seeds or not, soil permeability and depth, and water storage potentialities. However, as a rule, biological recovery is slower when the climate is more arid, the soil shallower or more toxic, the vegetation more degraded, and the entropy higher.

Biological recovery was found to be excellent in exclosures set up in the 1950s on deep, sandy soils of Mauritania north of Adrar, under about 80 mm of average annual precipitation (Monod, 1951; Naegele, 1959; Adam, 1967). The same was found in an area protected for 79 years at Nefta (southern Tunisia), where a 2–3 m high shrubby vegetation covering 30–50 % of the ground sharply contrasts with the adjacent sandy reg where vegetation covers 0.1 % to 1 % and is 1–5 cm high; the average rainfall in this area is about 80 mm and the soil is deep, with very coarse sand overlaying a gypsym pan. Similar results were observed in Kabao, (southern Tripolitania, 120 mm) and in Sidi Toui (southern Tunisia, 100 mm), after 12 and 20 years respectively of protection. However, in this last site, in a 1000 hectare exclosure, recovery on shallow soils (barren limecrust or limestone from geological outcrops) was almost nil (Le Houérou, 1958, 1962) whereas on sandy soils the recovery was considered satisfactory.

Vegetation greatly improved in biomass and ground cover in the Great Kevir area in Iran (rainfall 60 to 80 mm) after 12 years of total protection, in spite of the very poor soil (saline, gypseous, alkaline clay) but seems to have reached a state of equilibrium.

Numerous field observations on biological recovery have been made in many arid zones all over the world, but precise quantitative data on the evolution of ecosystems as a whole are generally lacking. Many books and reports on range management show very suggestive photographs of range vegetation on both sides of a fence in protected and unprotected areas. However, very few – if any – tell the detailed story of what happened to the ecosystem and how it happened (the present writer is not without blame).

Protection for recovery may also be partial. In some cases, domestic animals are admitted on a temporary basis once vegetation has improved. The areas thus managed are then considered as emergency grazing reserves to be used in drought periods. There are infinite combinations between total protection, standing buffer reserves and rotational grazing. After 2–3 years of total protection, biological recovery often results in a spectacular increase in primary production. Current figures show a 300–500 % increase (Rodin & Vinogradov, 1970; Le Houérou, 1971).

In some cases a totally protected area might produce up to 10 times as much as the adjacent degraded areas in the same plant community.

Seminatural recovery

In many cases, natural recovery may be speeded up by artificial measures, such as: scarification, pitting, contour terracing, oversowing, water-spreading techniques, and fertilization. These techniques aim at helping natural vegetation to recover by increasing water and/or seed/nutrient availability; they greatly help biological recovery to take off and may save many years.

Artificial recovery

In this case, the whole ecosystem is transformed artificially either by ploughing and seeding with plant species which may or may not belong to the native vegetation (autochthonous or exotic).

These species may be sown or planted (shrubs and trees) with or without the following: irrigation or watering, fertilization, water conservation techniques, etc.

Artificial recovery entails:

i. planting of drought-resistant fodder shrubs and trees
ii. planting of woody species for fuel
iii. sand-dune stabilization
iv. creation of windbreaks and shelterbelts
v. reclamation of saline or alkaline land.

Fodder shrubs and trees. It has been shown that several fodder shrubs and trees may be successfully established and economically exploited in areas receiving as little as 150 mm of annual precipitation in the Mediterranean arid zone. Extensive work on this subject has been carried out in Tunisia, Israel, Iran, Chile, South Africa, the United States, Brazil (NE), Mexico, and elsewhere.

The main groups of species used are listed in Table 9.1.

Table 9.1. Fodder shrubs and trees to be economically exploited in areas receiving as little as 150 mm annual precipitation in the Mediterranean zone.

Saltbushes
Atriplex nummularia
Atriplex halimus
Atriplex canescens
Atriplex lentiformis
Atriplex semibaccata
Atriplex glauca
Atriplex vesicaria

Acacias
Acacia albida (W. Africa)
Acacia aneura (N. Africa, Sudan)
Acacia ligulata (N. Africa)
Acacia cyanophylla (N. Africa, Near East)
Acacia salicina (N. Africa)
Acacia victoriae (N. Africa, Near East)
Acacia nilotica spp. *indica* (India, Pakistan and Somalia)
Acacia senegal (Sahel, Sudan)

Mesquites
Prosopis juliflora (N. Africa, Mauritania, Senegal)
Prosopis chilensis (N. Africa)
Prosopis africana (Sahel)
Prosopis tamarugo (Chile)
Prosopis cineraria (Pakistan, India)

Cactuses
Opuntia ficus indica var inermis (N. Africa, Brazil, S. Africa, Madagascar, Mexico, Texas)
Opuntia inermis (Brazil, S. Africa, USA)
Opuntia fusicaulis (S. Africa)
Opuntia robusta (S. Africa, Mexico)
Opuntia streptacantha (Mexico)
Nopalea cochenillifera (Brazil, Mozambique, Mexico)

Saxaouls
Haloxylon aphyllum (USSR, Iran)
Haloxylon persicum (USSR, Iran)

Tree Salsola
Salsola richteri (USSR)
Salsola paletskiana (USSR)

Calligonum
Calligonum arich (N. Africa)
Calligonum azel (N. Africa, Iran)
Calligonum comosum (N. Africa)
Calligonum arborescens (USSR)
Calligonum caput medusae (USSR)
Calligonum polygonoides (Iran)

However, very little has been done in this respect in the African arid zone south of the Sahara (with the exception of *A. albida* in Senegal). Although the native flora of the dry African tropics comprises many very palatable and nutritious species, their biology and potentials have not yet been studied. Examples of such plants are:

Maerua crassifolia	*Cadaba farinosa*
Ziziphus mauritiana	*Cadaba glandulosa*
Combretum aculeatum	*Boscia minimifolia*
	Acacia sp. pl.

Tree plantation for fuel: rural afforestation. Firewood is an acute problem in most of the arid and semi-arid zones of the developing world. Cities and villages are surrounded by ever growing areas of woodless land, extending in many places up to a radius of 100 km or more.

One of the possible answers to this situation is what has been called "village forestry" or "rural afforestation", that is, the planting of fast-growing trees in adequate sites providing good growing conditions, so as to meet the requirements without deteriorating the environment.

After decades of experimentation, foresters now have a sound knowledge of wood production potentials in various arid and semi-arid zones.

The main species usable for firewood are listed in Tables 9.2 and 9.3.

The same species could be used as windbreaks and shelterbelts around villages, water points, irrigated perimeters, etc. However, the drier the climate the more carefully the plantation sites should be selected. There is no mystery – the simple fact is that good growth requires deep, fertile soils having a good water budget and hopefully benefiting from inflowing waters or deep water tables. Such sites exist in relatively large regions in the arid zones; the wood production potential of those areas (sometimes 10 to 15 $m^3\ ha^{-1}\ yr^{-1}$) is rarely utilized.

Sand-dune stabilization. Sand-dune stabilization techniques are well known and practised even in areas receiving less than 150 mm of rainfall (in Iran, for instance).

The species used are listed in Table 9.4.

Sand-dunes have been stabilized over large areas in the arid zones of North Africa (Morocco, Tunisia, Libya), Iran, Pakistan, India, Sudan, and other countries.

Improving the soil water budget. Simple expedients for water conservation, such as, scarifying soils having a sealed surface may greatly increase the water intake and hence the development of natural or introduced vegetation; this would also ensure the take-off of biological recovery. The same applies to water catchment and spreading techniques which are not different from those used for centuries in the Near East and North Africa.

Making better use of saline soils and waters. Saline soils and waters occur in large areas in almost all arid zones. They could be better used by utilizing salt-tolerant forage species, such as, *Atriplex* and *Kochia*. Such species, which make excellent, protein-rich forage, can utilize waters having salt concentrations close to that of seawater (electrical conductivity of 30 to 40 mmhos) (Franclet & Le Houérou, 1971; Malcolm, 1972).

This has been achieved on thousands of hectares of salt land – in Tunisia (*Atriplex halimus, A. nummularia, A. vesicaria, A. glauca*), Chile (*Atriplex atacamensis, A. repanda*), Iran (*Atriplex canescens, A. lentiformis*), Israel (*Atriplex halimus, A. nummularia*), the

Table 9.2. Trees for fuel in the Mediterranean arid zone

Tamarix	
Tamarix aphylla	
Tamarix stricta	
Tamarix nilotica	
Gumtrees (Eucalyptus)	
Eucalyptus microtheca	*Eucalyptus occidentalis*
Eucalyptus oleosa	*Eucalyptus salmonophloia*
Eucalyptus brockwayi	*Eucalyptus stricklandi*
Eucalyptus torquata	*Eucalyptus flocktoniae*
Eucalyptus salubris	*Eucalyptus lesoueffei*
Eucalyptus dundasii	*Eucalyptus gomphocephala*
Eucalyptus sargentii	*Eucalyptus eudesmioides*
Eucalyptus gongylocarpa	*Eucalyptus kingsmillii*
Eucalyptus woodwardi	*Eucalyptus gillii*
Eucalyptus intertexta	*Eucalyptus gracilis*
Eucalyptus sideroxylon	
Acacias	
Acacia farnesiana	*Acacia horrida*
Acacia senegal	*Acacia raddiana*
Acacia victoriae	*Acacia tortilis*
Acacia peuce	*Acacia aneura*
Acacia ligulata	*Acacia sowdeni*
Acacia cyanophylla	*Acacia salicina*
	Acacia cyclops
Argantree	
Argania sideroxylon	
Pinetrees	
Pinus halepensis	
Cypress	
Cupressus sempervirens	
Cupressus arizonica	
Casuarina	
Casuarina equisetifolia	*Casuarina cunninghamiana*
Casuarina tenuissima	*Casuarina stricta*
Russian olive	
Eleagnus angustifolius	
Schinus	
Schinus molle	
Schinus terebinthifolia	
Parkinsonia	
Parkinsonia aculeata	

Table 9.3 Trees for fuel in the tropical arid zone.

Tamarix	
Tamarix aphylla	
Tamarix nilotica	
Tamarix stricta	
Gumtrees (Eucalyptus)	
Eucalyptus microtheca	*Eucalyptus camaldulensis*
Eucalyptus creba	*Eucalyptus tereticornis*
Eucalyptus rudis	
Acacias	
Acacia nilotica spp. *indica*	
Acacia albida	
Acacia senegal	
Mesquite	
Prosopis juliflora	*Prosopis chilensis*
Prosopis africana	*Prosopis cineraria*
The Neem	
Azadirachta indica	
Various	
Dalbergia sissoo	*Cassia sisamea*
Khaya senegalensis	*Anogeissus leiocarpus*
Albizia lebek	*Parkia clappertoniana*
Euphorbia balsamifera	

Table 9.4 Species used for sand dune fixation

Tamarix		
Tamarix aphylla		
Tamarix stricta		
Acacias (see above)		
Gumtrees (Eucalyptus) (see above)		
Egyptian cane	*Saccharum spontaneum*	
Balsam euphorb	*Euphorbia balsamifera*	
Castor bean	*Ricinus communis*	
Saxaoul	*Halyxolon persicum* (less than 100 mm)	
Calligonum	*C. azel, C. arich, C. arborescens, C. comosum, C. polygonoides*	
Perennial grasses such as:		
Panicum antidotale		*Aristida pennata*
Panicum turgidum		*Aristida kareliana*
Pennisetum dichtomum		
Legumes shrubs such as:	*Retama raetam*	
Other sand-adapted shrubs could be tested, such as:		
Leptadenia pyrotechnica		*Salvadora persica*
Ochradenus baccatus		*Genista saharae*

United States (*Atriplex canescens*), and Australia (*Atriplex nummularia, A. vesicaria*).

In Australia, large areas of scalded land (i.e. eroded, saline, former agricultural land) have been reclaimed by planting saltbushes and bluebushes, especially in New South Wales (Knowles, 1954), making it possible to initiate biological recovery processes. Other salt-tolerant forage species using drainage waters have been utilized such as (Le Houérou, 1969a, b):

Hedysarum carnosum	*Melilotus alba*
Sporobolus airoides	*Festuca arundinacea*
Sporobolus helvolus	*Puccinellia distans*
Trifolium fragiferum	*Paspalum vaginatum.*

Rational range and water management

Rational management means that:

i. stocking rates are adapted to the carrying capacity of the range
ii. water availability must be adequate to the needs corresponding to the carrying capacity in the dry season
iii. the range and the water are effectively owned by definite groups of people or by individuals, that is, accessibility to range and water is restricted to rightful claimants
iv. the range is used, hopefully, on a rotational pattern using differential grazing techniques and is partitioned off by firebreaks
v. marketing facilities are provided.

These aims may be attained in many different ways. In Syria, about 600,000 hectares of steppe land are used by grazing cooperatives where stock numbers are controlled, some rotation practised, and fattening operations organized, involving about 300,000 sheep (Draz, 1974).

In Algeria, forty grazing cooperatives of 10,000 hectares each have been established in the steppe zone, using rotation grazing, fencing, and restricted access to water (Chellig, 1975).

Cooperative ranches and grazing associations have been established in Kenya over large areas with various degrees of success (Pratt, pers. comm.). Grazing associations using differential grazing have also been established in Somalia (Hartley, 1972).

Several private or state-owned ranches with individual areas ranging from 6000 to 100,000 hectares have been established in the Sahel: Dahra and Doli in Senegal, Toukounous and Ekrafan in Niger (the latter has been popularized during the Sahel drought since it appeared as a green island, after burning, on satellite imagery; MacLeod, 1974).

Here the limiting factors, again, are not of a technical nature; the problem is social and political; it is a problem of government and organization. Pastoralists are not necessarily unwilling to accept modern technology; their adherence to it may be obtained through various incentives and motivations and temporary food assistance to help them to accept the new living conditions.

The government and administrations should help them organize themselves; this is the duty of sociologists and politicians. However, one of the main limiting factors is the shortage of trained extension personnel. Range-management specialists are extremely few in Africa and in the Near and Middle East.

The role of fire has to be considered in relation to management. It is estimated that bush fires annually remove 80 million tons of forage from the African dry savannah range resources (Wickens, 1962), equivalent to the nine-month diet of 25 million cattle (calculated on an intake of 6 kg dry matter per day and a consumption rate of 50 %). The beneficial effects of rational management on range and livestock productivity as well as in the prevention of bush fires are unanimously recognized.

Good management is to use temporary surpluses during rainy years. Forage production by far exceeds livestock consumption capacity, especially in lowland depressions and natural water-spreading areas.

Such temporary surpluses may be mowed, converted into hay, and kept as feed reserve for the dry season. This has been done over limited areas in Tunisia, Senegal, and Niger. There is no reason why the method could not be extended. This forage is otherwise wasted by deterioration in feed value, by trampling, and finally by being blown away during the dry season. This is the case, for instance, with *Sorghum aethiopicum* or *Shouwia purpura* pastures in the Sahel or *Eruca vesicaria* or *Hedysarum carnosum* pastures in North Africa.

Complementary actions to improve economy and the environmental situations

Complementarity of pastoral and farming areas

Arid zones are essentially pastoral areas; they are bordered to the north or to the south by semi-arid farming areas. Two spheres of interest are in permanent competition: the farmers seek more land to crop and the pastoralists look for feed for their cattle during the dry season. These conflicting interests could be merged in a harmonious way through diversification of crop production in the semi-arid zone by rotating field crops and forage crops or temporary pastures (which moreover, would contribute to restoring soil fertility).

Those fodder crops are:

i. **in the Mediterranean:**
Berseem, Persian clover, alfalfa, subclover, medic, vetch, Wimmera rye grass, sulla *(Hedysarum)*, forage peas, oats, barley.

ii. **in the tropics:**
legumes such as stylo (*Stylosanthes humilis), Dolichos lablab, D. biflorus*, cowpea (*Vigna sinensis*) and grasses such as buffalo grass (*Cenchrus ciliaris, C. setigerus*), fodder millet (*Pennisetum thyphoides*), blue panic (*Panicum antidotale*).

These forage crops are successfully grown between the isohyets of 400 mm and 800 mm both north and south of the tropics. Irrigated areas could make it possible to fatten and finish young and culled animals respectively from the range areas and also to build up fodder reserves for the drought periods. Again, it is a matter of planning, organization, and extension.

New sources of energy

Some countries have taken specific measures for relieving the pressure from the human population on woody species in arid zones. Algeria and Libya, for instance, make butane and propane bottle refills available at the cost price of US$ 3.00 per bottle of 15 kg.

Purchase of the material, containers, heaters and ovens is highly subsidized. The whole system is very popular, relieving, as it does, women and children of several hours a day of painstaking effort for fuel gathering. Solar energy devices have also been designed but not popularized enough as yet, for instance, in India and in the Niger Republic. The use of solar energy for domestic heating is far from being widespread, although several systems have been developed which function perfectly and economically (Israel, India, Niger).

Government initiatives obliging large-scale consumers of fuel, such as, bakers and managers of public baths to use modern fuels – subsidized, if need be – would also help a great deal in the fight against desertization.

Much more use could also be made of wind energy in water pumping and in providing electricity to small communities.

However, solar and wind energy cannot totally replace conventional forms – when the sky is overcast and the atmosphere still, one is left helpless. However, they would save a good deal of conventional energy since sunshine in arid zones is usually over 3000 hours yr^{-1} and wind, if not constant, is also fairly frequent, especially harmattan in the Sahel.

The necessity for dual installations sharply increases the installation costs (which are quickly amortized later) and this is why these two non-conventional sources of energy are not used more.

Education and training

Education and training are too often patterned on Western models, which are not quite suited to arid zones and are too bookish (if not too theoretical).

In other respects students incline to liberal and administrative professions, which are more comfortable and better paid than technical jobs in fields such as agriculture, forestry, and research.

The number of competent ecologists and range-management specialists in Africa and the Near and Middle East is infinitesimal in relation to the needs. A recent meeting (April 1975) on the subject in Sfax, jointly organized by Unesco, FAO, and UNEP, concluded that the five countries of northwest Africa immediately need at least 200 specialists in range ecology and management, whereas the present strength of such specialists is hardly one-tenth of this figure.

However, there is no difficulty in the way of the governments to encourage students to take up scientific and technical jobs via the provision of scholarships, and to offer good employment prospects and incentives for fieldwork.

It is obvious that as long as the legal, medical, business and administrative professions enjoy enormous privileges, as they usually do in many countries, scientific and technical careers will have little attraction for the young.

Ecological research, natural resources evaluation

A considerable amount of knowledge on arid zones has been built up over the past twenty to thirty years. Numerous ecological studies and surveys, as well as range, agricultural and forestry experiments have been carried out. This knowledge generally enables development projects to be implemented with confidence. Research should be carried out, however, on the following subjects:

- definition of range types and measurement of their productivity
- monitoring of range trends
- reseeding of degraded pastures in arid zones with native and introduced species (entails applied physiological and genetic research)
- domestication of wild fodder shrubs and trees whose richness in protein, vitamins, and trace elements are the salvation of herds during dry seasons
- use of native shrubs and trees as windbreaks, shelterbelts and for sand-dune stabilization. The biology and potential use of most of these highly specialized and adapted species are not known
- more studies on surface-water resources, water harvesting conservation, and spreading techniques, and in general better use of runoff
- rational use of some native woodlands such as the doum palm (*Hyphaene thebaica*) in the Sahel, the *Atriplex, Tamarix*, and *Betoum* in the Mediterranean area.

Monitoring and project evaluation

Monitoring is concerned both with natural undeveloped areas where ecological trends ought to be identified, and if possible quantified, and with development projects for evaluating the change in the environment induced by the development process. Monitoring should use both remote sensing (aerial photographs and satellite imagery) and ground checking.

Satellite imagery (of the ERTS type) which is available regularly over a number of years can also yield extremely helpful information of fundamental importance in determining the size of land-management units. The variables to be monitored are mainly vegetation (composition, cover, etc.), erosion, soil loss, sedimentation, land-use and migration patterns, and human and animal populations. Development projects not only need to be monitored but also to be periodically evaluated, preferably by outside appraisers with the help of the development agencies.

This evaluation should in particular be concerned with:

- demographic and social changes
- range conditions and trends
- changes in soil (erosion, sedimentation, salinization)
- livestock performance
- water balance and water tables
- pests and diseases
- economic results.

The objective of monitoring and evaluation is to identify and correct faults, and possibly, to take advantage of them in further development or in planning new programmes.

Settlement of nomads and groups practising transhumance

Nomadism and transhumance are constraints imposed by the ecological conditions in arid zones. The climate is such that plant growth and production are too irregular in time and space to allow year-round feeding of livestock. When the forage and/or the water available are exhausted, people and herds have to move to other areas where fresh supplies are available.

Hence, settlement of nomads and groups practising transhumance entails two possible strategies:

a. the feed supply for livestock in periods of scarcity is ensured either artificially by irrigated fodder crops or by concentrates (or both), by different grazing systems, or by planning fodder shrubs and trees as feed reserves. In one way or another the assured supply obviates the necessity for migration in search of pasturage
b. nomadic populations turn to other activities: irrigated farming, trade, handicraft, tourism, industry, civil service, army, etc.

The settlement of nomads is generally encouraged by the respective governments. Attempts at organizing nomadism – such as, the provision of nomadic schools – have been successful to a certain extent, but do not seem to have been widely extended.

In some countries, such as, Syria and Algeria, settled grazier cooperatives have been established over fairly sizeable areas. These cooperatives need areas which are large enough to balance the effect of patchy rainfall on range production. This is also the case with modern range exploitation in the arid zones of the USSR, Australia, the USA and elsewhere, usually covering tens of thousands and sometimes several hundred thousand hectares.

Obstacles to development

The main obstacle to the development of arid zones is the lack of a global policy taking into account and integrating all the various facets of this difficult task, or the lack of will or power to enforce such a policy.

The basic cause of arid land degradation and desertization is the increase in human and livestock populations whereby the population densities grow beyond the carrying capacity of the land under the present system of exploitation.

This situation could be improved in several complementary ways:

- population control
- emigration
- rational use of the land.

It might be interesting to ascertain why successful implementation of these measures has hitherto not been generally possible, that is, to determine the obstacles to development.

Population control

Population control has been attempted in several countries with little success (excluding China and Japan). The reasons are manifold: basically, the lack of education and motivation on the part of the people concerned, and the inadequacy of the methods (including education and advertisement campaigns) in relation to the mentality and traditions of the populations involved.

Emigration

Emigration has been a great help to many countries, but it is not without its drawbacks. For instance, the money sent home by emigrants is often used for buying tractors, allowing of vast areas to be cleared of natural vegetation and thus accelerating the desertization process (Le Floch & Floret, 1972; Le Houérou *et al.*, 1975).

Emigration permits a residual population density of over 100 persons per square kilometre in areas with 100–200 mm of rainfall and without irrigated agriculture. A density of this magnitude very quickly results in a "mineral landscape" where almost all perennial plants are removed.

Rational use of the land

Rational use of the land is the result of numerous conditions interacting in a very complex way:

Education: As mentioned above, the number of trained ecologists, conservationists, and range specialists is extremely small in relation to the needs. It is obvious that unless adequate numbers of trained specialists are available at all levels, any large development plan is doomed to fail. It is certainly not the foreign experts – however competent and numerous they may be – who can affect any large-scale development plan.

Research and survey: Inadequate research and survey sometimes hinder development, especially when land capabilities and carrying capacities have not been determined. In such cases, development schemes initiated on the basis of inadequate data may be hazardous. It is very often the case, however, that adequate data is available for initiating development, but that the information is not integrated, or that some very important aspects have been overlooked, especially those concerned with the social sciences.

One recommendation has emerged from almost all recent meetings: the need for coordinating and integrating the natural and social sciences with engineering and other aspects. This is especially emphasized in programmes such as MAB and EMASAR.

Development planning: This point is closely connected with surveying. Planning should always result from an integrated survey: however, this rarely occurs. In most cases, planning is carried out after partial and sectorial pre-investment studies where generally only climate, water, and soils are taken into consideration. Important considerations, such as, vegetation, rangelands and their productivity, and social factors, such as, the technical level of farmers or herdsmen, land tenure, traditions and motivations of the local population concerned are simply ignored. Since development has to be achieved through the local populations, it is not realistic to plan any action without their agreement and involvement. Although this might seem to be plain common sense, hardly deserving comment, it is surprising how often it is overlooked in the planning process.

Legislation and organization: Many countries lack modern range legislation. Rangelands are exploited under traditional customary legislation, which is no longer in line with the present forms of society or exploitation. In other cases, existing legislation is not enforced, especially where it places restrictions on cultivation entailing particular erosion hazards, on woodcutting, etc.

This state of affairs is usually due to the lack of a clear-cut governmental policy or of the will and power to enforce it where it exists.

However, policies and law-making are not enough in themselves, without being backed up by an efficient organization for enforcement. In many countries there is, for instance, no range service powerful enough to coordinate all actions on rangelands and their development, research, survey training, water development, land tenure, health services, marketing, etc. A strongly structured organization is required, represented at regional and local levels and able to help local populations to organize themselves to move from a traditional subsistence economy to a production-profit oriented system. This transition is a very difficult one, but is made necessary by the growing economic and demographic pressures of the present.

The establishment of a well-structured organization, able to deal efficiently with extension and development, presupposes a well-defined policy and numerous well-trained personnel at all levels. Here the discussion returns to point "education", and the vicious circle of underdevelopment is closed.

Guidelines for development

Any development in arid zones should be based upon:

- a realistic acceptance of the following ecological facts:
  a. low and erratic rainfall
  b. unpredictable recurrence of periodic drought
  c. uncertain and irregular production
  d. low potential per unit of land area, hence the necessity for large land-management units
  e. unstable and fragile ecosystems
  f. erosion and salinization hazards
- an adequate knowledge of economic criteria and social attitudes
- availability of good pre-investment studies providing a sound evaluation of the carrying capacity of the land in relation to various development strategies and investment inputs.

Training

In most of the recent international meetings, especially those devoted to range conservation and management, training has been rated as the top priority. As mentioned before, one can hardly envisage any large-scale development without proper training of numerous specialists at all levels and in the various disciplines involved. Training should include learning how to work in interdisciplinary teams. Specialists in fields, such as, ecology and range mangement – of paramount importance for arid zones – are usually slighted, when in fact rangelands generally represent over 80 % of the land surface in arid zones.

Moreover, the training is all too often of inferior quality, besides beeing too academic and too bookish, and not adapted to the conditions prevailing in the country.

Therefore, particularly ecology and range management ought to be taught in the countries (or the regions) concerned, using local examples. Students trained abroad in different (socio-economic, if not physical) environmental conditions can often not properly adapt what they have learned to conditions in their own countries. Students trained abroad are often employed, on returning home, in jobs other than those for which they were trained.

Another aspect of training is the need to attract young people of good calibre to technical careers relating to arid land development. It would be a comparatively easy task for the governments concerned to make these careers attractive by offering appropriate salaries and other incentives to fieldwork. In fact, however, the contrary turns out to be the case: urban or bureaucratic life is made much more attractive to youth, and this, of course, is of little help in real development.

Prior to joining the central administration, technicians and administrators should spend several years in actual fieldwork so as to obtain knowledge of real development problems at that level.

Government policies and administrative setups

Planning and execution: Before any large-scale development is possible, a clear governmental policy has to be defined and a firm political commitment made.

Development is a very complex matter involving many governmental as well as non-governmental services and agencies. The first need is good coordination at the planning level (frequently found) and subsequently at the execution level (frequently lacking).

One single agency should normally be responsible for the coordination of all actions taken in a specific domain. For example, in range areas, all forms of development implemented by other departments or agencies – that is, actions taken in matters of water development, communications, marketing, housing, etc. – should be coordinated by the Range Department (both at central and local levels). Conversely, in irrigation development schemes, the water development authority should draw upon other agencies for the execution of those parts in the plan in which it has no competence.

In other words, each department should have coordinating powers strong enough to command the support of other relevant departments and of the local administration for the execution of its own development projects.

Marketing: The major problem in the marketing of livestock products is the extreme irregularity in the supply which leads to an excess in the market at some periods and a deficit for long periods. Improved range conditions and herd management would, via the more uniform feed supply, somewhat regularize the market through more regular off-take selling. However, some measures could further improve the situation:

- improved network of routes and holding grounds with feeding and veterinary services
- improved credit facilities for traders and pastoralists
- new outlets for livestock in fattening schemes and foreign markets
- improved purchasing power in agricultural and urban areas
- subsidies on a sliding scale of prices to encourage the sale of livestock during off-peak periods and at the beginning of drought periods before the animals damage their environment
- price policies encouraging good quality meat and differential prices between meat cuts.

Credit facilities: Range development, forage crops, and fodder shrub plantation have been encouraged by granting special credit facilities and subsidies. Such grants should naturally be made whenever possible.

Legislation: Legislation designed to control land use has rarely been enforced in the past and legislation designed to prevent overgrazing has usually not worked either. Much of the legislation dealing with land use has been designed for agricultural rather than for pastoral areas, and further legislation should be directed toward enabling range users to improve their current form of management – for example, to secure land tenure, to prevent trespass or disturbance and, if need be, to retain preventive safeguards against range destruction.

Whenever possible, range users should be involved directly in the preparation and enforcement of their own legislation, thus ensuring closer relations between the government and pastoral people.

Fiscal policies: In principle it is desirable that range areas contribute to the general revenue of the country. However, a variety of situations are encountered in practice. For example:

- rangelands belong to the state
- rangelands are the property of the users, whether legally or by customary right
- the country is mostly arid and has few other assets than range livestock
- the country enjoys a more balanced agricultural economy and range areas are of marginal importance
- the country is oil-rich.

One principle should be followed, however, viz., that any taxation raised in the range areas should primarily be devoted to financing services for these areas.

Taxes may be imposed per head of livestock or per head of the human population or per unit of land area (in this case, on groups of individuals having land rights). In all cases, the rate charged per unit should be calculated on a sliding scale, related to the potential of the land, so as to discourage overuse of the resources.

Payment for services (maintenance of wells, boreholes, marketing facilities) should not be regarded as taxation revenue, and the money so raised should be used for maintaining the services.

Conclusions

The remedies for desertization are numerous and interdependent. Technically, desertization can be halted; there is no question about it, and many desertized areas can be restored to production. However, the cure can only be administered if there is a strong political will and the power to do so (which in turn presupposes political stability), since the measures which need to be adopted closely interfere with the daily life of the population concerned.

Such interference consists in population control, transfer to other areas or activities, enforced emigration, education, and control of land and water use. These are usually very touchy political issues that many governments are reluctant to tackle.

The example of Iran – where about 10 million hectares of protected arid rangelands are steadily improving for wildlife or sheep-raising and where three million hectares of dunes have been stabilized and are progressively being brought to production – shows clearly that desertization can definitely be halted if the decision-makers, jointly with those having political and economical power, really so wish.

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Chapter 10

CATTLE INSURANCE BLOCKS – AN ALTERNATIVE TO GROUP RANCHES

A. HJORT

Introduction

A number of strategies for coping with uncertain climatic conditions have been presented in Chapter 3. People inhabiting marginal dry-lands tend to make use of different ecological zones and to disperse their economic resources over a large area as a precaution against local drought and generally with the aim of maintaining a permanent minimum level of subsistence, even in times of disaster.

In a pastoral subsistence economy, the most important strategy consists in splitting the herds up in different areas. Each subherd must be big enough to provide for the needs of those tending it and also of their dependents. The total herd must be big enough to stand the losses incurred during an average dry season or during a recurring epidemic. Diversification is also a practical necessity for adequate management of a herd comprising animals of different ages, sexes and species, varying in their requirements of grazing and management.

A household with many young men available for herding can keep a large number of animals and many subherds. The odd animal which, for practical reasons, does not fit into an individual's own subherds, may be lent to friends or relatives and herded by them, thus contributing to a wider communal sharing of risks and resources.

The problem of overgrazing

In conditions where grazing is adequate, the strategy on the part of a household of keeping a great number of large stock, primarily for milk production, leads to a low meat offtake. Slaughtering for meat is confined to male animals at times when milk production is not adequate or when meat is needed for ritual purposes, such as a circumcision ceremony or marriage. In areas where cattle and camels are kept on a large scale for milk production, sheep and goats provide most of the meat as well as some extra milk. Small stock are not discussed in this chapter as the herding of large stock is more complex and imposes constraints on the management of small stock in economies where both categories are important for food production.

Cows and female camels are also kept on after their fertility declines (at the age of around 10 and 20 years respectively), so long as there is still some small chance of their producing young (Dahl & Hjort, 1976). Slaughter and sale mainly involve male animals, and old female stock only to a limited extent.

The complex role of pastoral cattle is discussed in Chapter 5. As regards the ecological aspect, the role of cattle or camels can be likened to an insurance system, since large stock provide economic security in difficult times. A likeness can also be made with a banking system, since any surplus is invested in acquiring more animals. Where diversity of animal species has not sufficed to protect a particular household from, say, a drought disaster, various systems of redistribution may be employed. These have been mentioned in Chapter 5, *viz.*, stock-friend networks, raiding the cattle of neighbours, redistribution via gifts to ritual leaders, or exchange.

These redistribution methods may work for a household so long as a disaster is local, that is, so long as the whole area is not depleted of animals.

Fig. 10.1 illustrates the complexity of a pastoral herd management in relation to an existing social system. The calculation is based on Goldschmidt (1969) and the author's own field notes from northern Kenya. The selected "cow lineage" has a time depth of about 30 years. To sketch a possible return a curve showing "relative availability" is added. This is only intended to illustrate different access to animals in different positions. The circulation of cattle is illustrated later in Fig. 10.2.

Thus from the point of view of an individual household, three kinds of disaster may be distinguished; those that kill all the animals of the household grazing in one area, but where the household can still rely on the remaining animals; those that kill most of the animals of the household but where redistribution methods enable the household to survive; and those that kill most of the animals in the area so that the total number of herds is too small for the population to live on.

These types of disasters are illustrated in Fig. 10.2, where the herds of four households are marked with circles and the kinship network of the households is sketched. Let us assume that the heads of households 2–4 are stock-friends of X, the head of household 1. In a local drought, household 4 loses some of its animals but it can still rely on the remaining stock – an illustration of the first kind of disaster.

If many of the livestock of household 2 die, it will have to contact its stock-friends to borrow animals so as to safeguard the consumption needs of its members. Thus X being one of the stock-friends of household 2, will have to contribute some stock. This illustrates the case of a local drought where redistribution principles are effective enough for the household to survive in the pastoral economy.

The figure illustrates that in the case of the major drought so many domestic animals are afflicted that the total number left in X's stock-friend network is inadequate. Only household 3, among X's stock-friends, has some animals left but the number is not adequate.

The factor of social distance may also play a part. Thus, X would probably be able to put stronger pressure on households 2 and 3 than on household 4, as they are closer relatives.

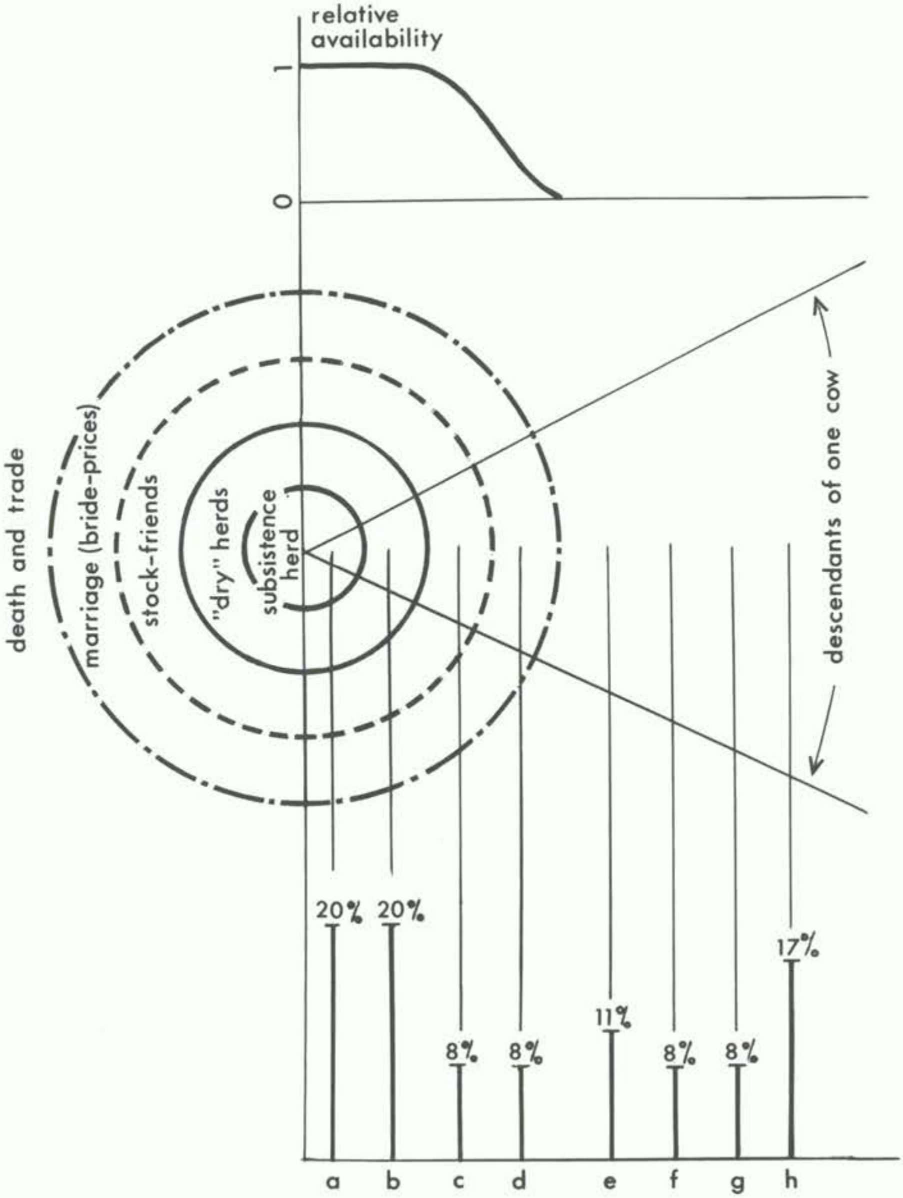

Figure 10.1. An example of the distribution of cattle from the same female progenitor at a particular point of time. The bars indicate fictive fractions of the descendants of one particular cow: a = in subsistence herd, b = in "dry" herds, c = given to stock-friends, d = given as bride-price, e = sold for cash, f = slaughtered ritually, g = stolen in cattle raids, h = dead (naturally and by disease). See the text for a discussion of the figure.

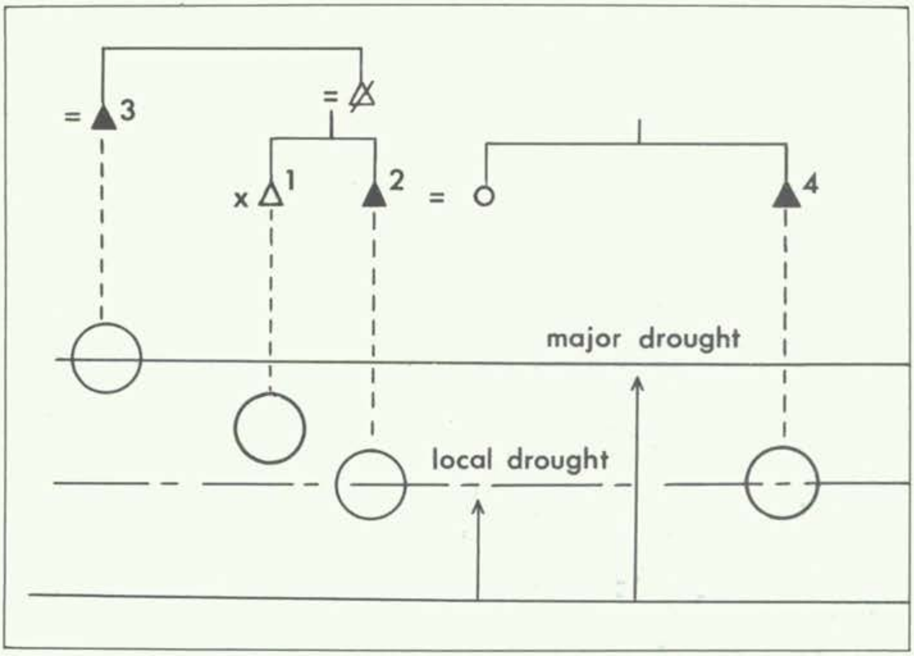

Figure 10.2. Drought and redistrubtion of domestic animals. The triangles in the kinship diagram indicate males, the small circles females. Marriage is denoted by =. The large circles attached to the four stock-friends denote the herds of the corresponding households.

The above perspective – which is relevant for how the pastoralists themselves would categorize the problem of drought – may help in outlining realistic development projects, whether they are intended to reclaim degraded grazing areas, to increase the economic output of a pastoral economy or to introduce complementary economic activities in a cash economy. The case in Chapter 8.6 shows how group ranches may be employed in an already established set of precautionary measures, or rather why this still remains necessary. Let alone a reduction in the total number of livestock in the area, the effect of the group ranches in Kenya so far has been a more rapid increase than would have occurred had the group ranches not been established. However, this fact is in itself not an argument for the impracticability of group ranches. The major point is, as Halderman (1972) emphasizes, that the ranches must be ecologically viable.

Yet, given that serious overgrazing exists in an area, a satisfactory way of establishing stock control needs to be found. It must be emphasized, however, that a major reason for overgrazing is the expansion of farm lands into the best grazing lands. The effect is that the land available for pastoral herd management diminishes and its quality is impaired. Occasionally the new farmland may be situated along river courses which creates great difficulties for the pastoralists to get access to water during dry periods. The next issue is what possibilities exist to establish stock control with popular support. Another one is how alternative economic activities within an area should be linked with pastoralism. As indicated previously, the major problem here is that the monetary surplus is often invested in the pastoral economy for economic and social reasons (the banking aspect), causing the total number of livestock to increase drastically and the ownership to become stratified along new lines. Henriksen (1974), for example, puts forward a general proposal for restricting the monetary surplus to the economic niche where it is produced, or at least for preventing it from entering the pastoral economy. However, it is difficult to see how such a proposal could be implemented with popular support and without connotations of colonalism.

Yet another problem is to delimit pastoral grazing areas from farmlands in such a way as to create satisfactory conditions for grazing. Pastoralism is the only land use possible in many marginal dry-lands. If such regions are not to become completely deserted, they must provide adequate grazing during dry periods and also in times of locally recurring droughts. Reserve areas must be set aside where livestock can be taken during such periods. At present, farming areas are tending increasingly to encroach upon the pastoralists' best grazing areas. Governments often encourage this state of affairs in view of the higher GNP (gross national product) likely to accrue from increased cash-cropping. A common argument against such a policy is that it involves many hidden costs which are not revealed unless a general cost-benefit analysis is carried out. Many problems are involved here – not the least being that of an expanding capitalistic economy – often intensifying regional economic differences within a country. For example, Mensching & Fouad Ibrahim (1975) recently suggested in the case of central Tunisia that pastoralism rather than plough cultivation should be encouraged as one necessary step towards land rehabilitation.

Assuming that some areas can be used only for animal husbandry, that these are combined with sufficient reserve grazing grounds and that increasing overgrazing is at hand, the problem may be stated thus: How can the local population succeed in destocking without running the risk of starving in an acute crisis at any of the three levels mentioned earlier. As stated above, one central point for discussion must be the insurance aspect of the various distribution mechanisms and how they can be developed and made more efficient. Another important point is the banking aspect and how the economic surplus, whether generated by herd growth or cash incomes, can be invested and used for the future security of the pastoralists against disaster and impoverishment.

The approaches presented in Chapter 8.6 are relevant to the present discussion as much effort has been expended in Kenya in trying out different ranching methods. Experiments with group ranches based on clan land have involved great difficulties on such central issues as how to demarcate a suitable piece of land and how to organize the decision-making process within each group. Even if many pastoral groups tend to graze within a certain tract of clan land, the flux can be great and strict boundaries do not exist in reality but are rather situational. Again, given the choice, a household would sometimes wish to graze cattle outside the area inhabited by relatives. Other factors such as local grazing, size and composition of different herds (particularly age structure), conditions of herds, available manpower, etc., influence migratory patterns and need further consideration. This means that no clear-cut boundaries will develop, but rather a statistical probability of finding members of one specific clan within one specific area at any given time.

Decision-making within the group ranches has also been problematic. The conflict between a traditional system of authority – where elders have the right to develop their arguments at length before a decision is reached – and the authority of an elected board for the ranch has not been satisfactorily solved; see Chapter 8.6.

The other experiment of interest here is the establishment of grazing blocks, that is, areas intended for grazing solely during dry periods. These have been put forward as alternatives to group ranching in drier areas.

An alternative ranching system

The demarcation difficulties concerning group ranches among the Masai of Kenya were discussed by Halderman (1972). He concluded:

> "If strict measures are established in order to control movement between group ranches it is probable that serious problems will arise. Since the ecological conditions on the presently proposed group ranches vary considerably, it will be necessary for the members of the ecologically poorer ranches to frequently request grazing on the better ranches; and these requests may be refused if the members of certain ranches wish to preserve their own grazing . . .".

Development of group ranches on the best grazing land in semi-arid areas might lead to a risk of preventing all pastoralism outside these ranches as there might not be sufficient grazing during dry periods. The following theoretical model of an insurance block – intended to take account of the present land use system – is presented as an alternative or supplementary solution to group ranches. It must be emphasized that this is done as an exploratory discussion to bring out some central features. More research is needed before specific suggestions can be made or lines of action taken in an empirical situation.

Some of the household domestic animals would graze in cattle insurance blocks. The sites selected should have reliable grazing. They might even be situated on the periphery of pastoral areas where low productivity farming could also be carried out. The blocks need not necessarily be based on kinship or even be run on a cooperative basis. Instead, they could be organized like the present Livestock Marketing Division in Kenya, which is a body under the Ministry of Agriculture that purchases cattle from nomadic people and grazes them for some months within a reserved area for fattening and for treatment of disease. The idea would be, basically, to follow the banking idea by keeping animals not needed for household consumption within selected grazing blocks; at the same time, the insurance aspect would be paid due attention: if animals in a household's herd died, it would be possible at any time to take new livestock from the cattle insurance block so as to keep the herd sizes constant. In this way it might prove possible to develop a number of grazing blocks within a prevailing form of pastoral land use. A ranching scheme of this kind would be particularly beneficial in such marginal dry-lands where a major shift to conventional ranching is not possible owing to climatic conditions. The scheme could be supplemented with rotational ranching where possible. It could probably be eleborated upon so as to be more realistic than other suggested solutions, which aim at restricting areas to kinship groups for grazing and creating a large number of former pastoralists who must be employed elsewhere (see e.g. Henriksen, 1974).

A first step along the lines of the present suggestion would be to define a certain maximum number of livestock per household depending on the number of its members, and to confine the remaining livestock for herding within the cattle insurance blocks. This maximum limit must be set high from the beginning, exceeding minimum subsistence limits by a good margin. This would take into account the fact that the nomads cannot be expected to have confidence in the new scheme before they have seen it working safely but will rather want to keep their own insurance margin.

The maximum limit should not only be devised to provide for the present needs of each household but also to accommodate the setting up of new household units occasioned by the natural course of family growth and development. Even though this might be regarded as a system of government control and taxation, some such solution is necessary in conditions of ecological degradation. Needless to say, local backing is decisive for any destocking project. If control of cattle insurance blocks were entirely in the hands of the local population, it would be possible for them to increase gradually their share of domestic animals in the scheme. Theoretically, it would even be possible to herd all extra animals (those not needed for household consumption at a particular period of time) inside such cattle insurance blocks. To aim at making this part of the scheme from the start would, however, most likely mean that the project would never take off.

The removal of animals from a local area for trade purposes would be partly channelled via cattle insurance blocks, which would only need to keep an emergency reserve against local droughts or epidemics from which households could replenish their livestock. A certain proportion of domestic animals contributed by individual pastoral households – calculated on the basis of local conditions – should be kept in order to support existing redistribution principles. This scheme would work similarly to the traditional stock-friend network.

If the animals delivered to the cattle insurance blocks were predominantly male, they would be traded for female stock. When afflicted by drought or an epidemic, households would then have access to productive stock since these animals could be young females, provided that the major subsistence interest were in milk. The rest of the animals, predominantly males and old females, would be traded, thus attaining the overall goal of limited destocking and maybe also of a positive change in age and sex structures of the herds in the particular area. Some job opportunities would also be created, together with a possibility for improving the health standard of the stock in the area (building dips and introducing other veterinary facilities). Furthermore, the gains from an increased offtake could be partly reinvested into the area via the cattle insurance block in, for example, local dairy industries based on produce from herds inside and outside the cattle insurance blocks, thus generating more job opportunities.

A system of restricting the number of domestic animals for each household within an area would also – at least partly, have the advantage of countering investments of monetary surplus into the pastoral economy. Today it is often highly profitable for former pastoralists, now employed within a capitalistic sector, to invest their savings in large stock in their home areas. The result is often both an increased number of animals and a stratification between this new category of herd-owners and those restricted solely to a pastoral economy. Alternative investment possibilities might be created perhaps within established cattle insurance blocks, and in local trade and handicraft.

In theory, at least, the suggestion would strengthen the insurance aspect of herds of large stock. The main goal of the cattle insurance blocks would be to offer households one possibility of obtaining replenishment stock in times of difficulty. Again, if local control proves efficient, the insurance blocks could even become the major source of replenishment livestock. In this respect the proposed system of grazing blocks could be well adapted to already existing forms of land use and even supplement them substantially. This is roughly illustrated in Fig. 10.3, which shows a possible change in social networks resulting from the establishment of a cattle insurance block such as that suggested. The areas of the block in the figure are intended to be roughly proportional to the number of stock rather than to reflect a geographical distribution of cattle. From a herd management point of view, a cattle insurance block substitutes some of the stock-friends of the individual household.

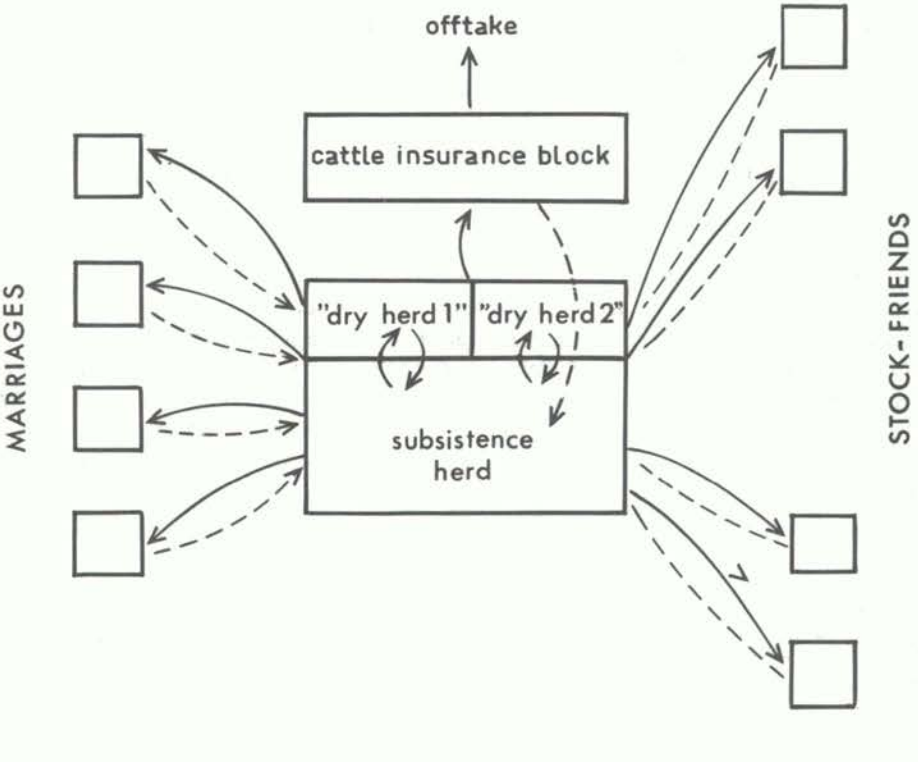

Figure 10.3. The flow of cattle in social networks including a cattle insurance block. The figure illustrates possible changes resulting from the introduction of a cattle insurance block, where this partly takes over the tasks of stock-friends.

If it were possible to introduce circulation of animals between a cattle insurance block and its surrounding areas, further benefits could be attained. The introduction of a special health service for livestock in the cattle insurance blocks would lead to improved health conditions overall in the region. This would reduce mortality rates, leading possibly to higher offtake, and perhaps also to increased milk production.

A further improvement would be to introduce storage of fodder where possible. Another improvement would be to change the age structure in the area in favour of younger animals if it were possible to show that the new cattle insurance blocks constituted a safe system enabling herds to restock after disasters.

There are many difficulties involved in the present suggestion, mostly in relation to mobilizing popular support. Generally, it might be necessary to have several grazing blocks in a specific area with a fairly small number of households attached to them. The administration systems must be efficient enough so that the local people would venture to participate in this new economic system even if overgrazing were an acute problem in the area. Any central government is often held in great distrust, maybe with a few exceptions. The present proposal for sufficiently decentralized cattle insurance blocks perhaps allows of effective local control.

Will individual household be able to exchange livestock, when entitled to do so, without difficulty at the cattle insurance block, or will they have to pay bribes? Will they be able to exercise their own choice or will they have to accept whatever animal is given to them? How great is the danger that the proposed cattle insurance blocks will, like water holes, attract people from the periphery? Would raiding occur against the cattle insurance blocks? These are central issues that need a satisfactory solution if the pastoral households are to be in a position to support such a ranching project.

Starting from the fact that a pastoral economy is milk-oriented rather than meat-oriented, the proposals put forward in this chapter provide some answers on a fairly theoretical level to problems such as the following:

1. How should ranching be organized to allow of destocking in overgrazed areas?
2. How could the monetary surplus from cash incomes be prevented from having disastrous effects on an ecologically sensitive pastoral economy?
3. Can the present trend of desertization of many marginal dry-lands owing to overgrazing and resultant mass out-migration be stopped?

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Chapter 11

COMPLEMENTARY ACTIVITIES FOR THE IMPROVEMENT OF THE ECONOMY AND THE ENVIRONMENT IN MARGINAL DRYLANDS

H.N. LE HOUÉROU & B. LUNDHOLM

Introduction

A number of complementary activities for improving the economy and combatting rangeland degradation in arid areas are briefly discussed below: greenbelts, irrigation and runoff farming, small-scale industry, tourism, fisheries and game utilization. The last two of these sections are authored by B. Lundholm, the others by H.N. Le Houérou. The following initial general word of caution seems appropriate:

> "There is a contradiction in many attempts to develop complementary subsistence activities in order to relieve pressure on pasture. The effects have sometimes been the opposite, namely grazing pressure has increased. The critical aspect of such schemes is not only how high an income they provide for people involved in them but, most important, what people can do with this income besides consuming it.
> If there are no investment opportunities in the complementary subsistence sector, it is most likely that the increased returns from this sector are invested in livestock, i.e. although there may be a flow of personnel from the pastoral sector to other sectors, there may be a flow of capital in the other direction. Unless opportunities and constraints are introduced which stimulate other investment policies, the effect of development in other sectors may just serve to increase environmental degradation in the grazing areas." (G. Haaland, pers. comm.).

Greenbelts and desertization

The establishment of greenbelts along desert margins – one of the many solutions proposed for halting further loss of productive arid land – is often advocated and large projects are planned or are under way towards this end.

An attempt will be made here to answer the questions of what effect greenbelts may have on regional, local and microclimates and whether they may be an efficient means of stopping desert creep.

The establishment of greenbelts along desert margins is based upon two main assumptions:

i. that desert creep is due to the extension of aridity from the desert into arid land, proceeding as waves of aridity propagating a more or less regular and continuous front – that is, it is an external cause generated in the desert itself;
ii. that establishing a solid continuous barrier of greenbelt through tree planting would control this progressing wave of aridity by stopping dry winds, reducing erosion, increasing rainfall and reducing runoff and evaporation, and improving water intake.

However, these assumptions are mere speculations, since there is no evidence in any arid zone, showing that:

i. desertization is generated in the desert itself;
ii. greenbelts would have any effect on local or regional climate.

Desertization is generated locally, and on a discontinuous pattern, in arid zones through the mechanisms mentioned, viz.,

- overgrazing
- overcultivation
- fuel gathering
- hazardous water development
- hazardous irrigation projects.

Desertization should therefore be tackled in the areas where it occurs by restoring the permanent plant cover so as to halt wind and water erosion.

The greenbelt effect

Much research and experimentation has been devoted to this subject over the past few decades in arid as well as in non-arid zones. The results of these experiments are very consistent, especially in arid zones.

- There is no evidence indicating that greenbelts or forest plantations can increase rainfall, and this is not surprising, since over 80 % of the moisture in the atmosphere comes from the oceans and – to a small extent, from intertropical rain forests. The amount of water entering the atmosphere from arid zone greenbelts could only be infinitesimal.
- Potential evapotranspiration itself could not be affected on the regional scale either, since this is largely governed by the amount of solar energy received per surface unit. This amount depend in turn, on latitude and cloudiness.
- The same holds for air and soil temperature. Rainfall, potential evapotranspiration and temperatures are governed by the overall energy balance of the earth and the general circulation of the atmosphere. The effect of any forest plantation on these factors can only be negligible.

To my knowledge, all geophysicists, climatologists, ecologists and other scientists are unanimous in declaring that, in arid zones, reafforestation cannot have any significant effect on the regional climate.

However, on a limited local scale, greenbelts – and reafforestation in general – have a strong effect on the microclimate.

Experiments carried out all over the world show that windbreaks and shelterbelts substantially reduce wind speed at a distance of 2 to 5 times the height of the trees windward, and 20 to 30 times that height leeward. At 10 times that distance windward, and 100 times leeward, the effect is nil or negligible. The width and the length of the belts have practically no effect on their protective action.

Inside the belt itself, however, there is a marked protective effect in:

- reducing wind speed and hence advective energy flow and actual evapotranspiration
- reducing wind and water erosion
- reducing runoff
- reducing soil temperature
- increasing the organic matter content in the soil and hence improving soil structure, water intake, efficiency and biological activity (microflora, micro- and macrofauna) – that is, increasing the overall fertility, productivity and turnover of the ecosystem.

Since greenbelts cannot have a significant effect on regional climatic conditions, it is hard to see how they could be useful in combatting desert creep. Comprehensive reafforestation of man-made deserts or of areas threatened by desertization is, for many reasons, simply unrealistic and unthinkable.

The cost of reafforestation in arid zones is of the order of magnitude of $100 to $200 per hectare at the minimum (except in some very special cases where direct sowing is possible). Assuming that the areas threatened by desertization (between the 100 and 300 mm isohyets) in Africa, the Near and the Middle East are, at least, of the order of magnitude of 50 to 100 million hectares, the minimum investment necessary would be between 5 and 20 billion dollars for a maximum return of 5 to 10 dollars per hectare per year.

Such reafforestation implies total protection from grazing and other present uses for a period of 10 to 20 years. It also raises the question of what alternative solution for a living can be offered to the millions of people living in these areas.

Reafforestation has been successful in arid zones and is perfectly feasible under certain specific conditions – on deep sandy soils, along the stream network, on sand dunes, in depressions benefiting from runoff or in those having a water table. However, reafforestation has generally failed on the shallow soils which cover most of the arid zones for the very simple reason that such soils cannot store enough water to meet the transpiration requirement of trees. A minimum of about 500 kg of water is needed to produce 1 kg of dry matter. Therefore, in order to produce a minimum quantity of 1000 kg of dry matter per hectare, the soils should be able to store at least 100 mm of water (assuming a loss of 50 % by direct evaporation, runoff and drainage) during the short rainy periods. Most arid-zone soils do not have this storage capability, and therefore are not suitable for reafforestation or the establishment of greenbelts. Moreover, in some arid zones like the Sahel, where environmental conditions are particularly harsh (9 to 10 months of dry season every year, air moisture below 30 % for several months), all reafforestation trials have so far failed wherever the rainfall is below 400 mm.

Since greenbelts do not seem to be a realistic possible solution in halting desert creep, what alternative solution can be offered?

The best way to restore desertized areas to productivity is to ensure adequate protection of soil surface from wind and water erosion and to promote biological recovery (see Chapter 9).

In conclusion, it should be emphasized that there is no miracle remedy but that a set of interdependent means of action – comprising the plantation of a network of greenbelts on adequate sites, followed by proper management techniques – constitute part of the strategy in the struggle against desertization.

However, greenbelts would be extremely useful in protecting irrigated areas, villages, roads, reservoirs, etc., but planting solid strips of trees along desert margins without subsequent management organization is a myth which is doomed to costly failure.

Irrigation

In most cases, arid zones exhibit two totally different types of agricultural exploitation, lacking any link or connection: irrigated farming on the one hand, and extensive pastoralism on the other. These two systems could and should be complementary: the extensive herding serving for breeding purposes and the irrigated farms acting as forage producers and allowing fattening/finishing operations.

The example of some arid states of the southern USSR, as well as limited experiments in other countries, shows that this coordination is technically workable and economically feasible. It is a matter of organization.

The advantage from the standpoint of fighting desertization is obvious: part of the herd is removed from the natural pasture, thus reducing pressure on rangelands and allowing them to regenerate.

This type of complementarity is practiced over about 20 stockraising cooperatives in the Syrian steppe and involves about 300,000 sheep. It is also enforced on huge areas of the Karakul breeding states of Uzbekistan and Turkmenistan in the USSR (Nichaeva & Prikhod'ko, 1968; Nichaeva, 1969). The system has been working on a limited surface of 30 hectares of irrigated forage and 8000 hectares of steppe in the Tamidt station of southern Algeria (200 mm) for over 30 years. It is estimated that about 200 million hectares are under irrigation at present and that a potential exists for 200 to 270 million more (Buringh *et al.*, 1975). Most of these irrigated and irrigable areas are in desert, arid, or semiarid zones, which altogether represent about 5000 million hectares or 36 % of the earth's surface (Fig. 11.1).

In other words, irrigation involves at present less than 4 % of arid land and may perhaps reach the figure of 9 % in the remote future. Be that as it may, 90 % of arid land will never benefit from irrigation and will have to be reclaimed by other methods. On the other hand, irrigation programmes have significantly contributed to desertization over large areas in North Africa, Egypt, Syria, Iraq, Iran, Pakistan, and India through salinization and alkalinization resulting from faulty technology. It is suspected that the same mistakes caused the decline of some early irrigation-based civilizations in the Euphrates-Tigris valleys.

For irrigation projects, both large and small, in arid and semiarid areas, a number of hazards are particularly critical. One is salinization of the irrigated soils, as mentioned above. Another kind of hazards is sediment deposition in reservoir and irrigation channels and a third is changes in water table which might be disastrous to agriculture. Of importance are also the negative effects upon public health. These are characterized as follows by Greene (1966).

Figure 11.1. Pump irrigation at Kufra oasis, Libya. Each circle is watered from a 560 m long pipe, supplied with 76 litres of water/second and moving one turn in 24 hours. Very high costs and limited fossil groundwater supplies are two difficulties connected with similar projects. Air photo, S. Leijonhufvud.

"Introducing irrigation into an arid region greatly increases the density of population. Because of this, benefits to agriculture are unhappily offset by increased incidence of disease, mainly due to inadequate arrangements for disposal of human excreta. From this cause arise bacterial infections producing bacillary dysentry and cholera; protozoal infections producing amoebic dysentery; infections by parasitic worms including *Ascaris* (round worm), *Ancylostoma* (hookworm) and *Schistosoma*, the vector of bilharzia. A great educational and administrative effort is needed to convince people that these diseases can be controlled by improved sanitation and are not a necessary consequence of irrigation. There is also need for research on methods of sanitation other than water-borne sewage, which should not be regarded as a complete solution of the problem. Irrigation may also provide breeding places for mosquito that spread malaria and other diseases. Nearly complete control has been established in various places by coordinated use of appropriate measures, attacking larval and mature forms of the mosquitos and eliminating sources of infection. Here again there is need for a closely knit and wellinformed community so that measures of control may be uniformly effective."

The volume edited by Stanley & Alpers (1975) is a general reference work on man-made lakes and human health.

Water supply through desalinization

Desalinization techniques are perfected now and currently used to produce fresh water for human and animal consumption. However, the cost of such water is still too high for agricultural purposes. In the cheapest cases (nuclear energy power plants) the cost is about US$ 0.10 per cubic metre and sometimes 10 times this amount. Since at least 0.5 m^3 water is needed to produce one kilo of dry matter, the cost of one kilo of dry matter is thus US$ 0.05 at the minimum; and therefore, for the time being, this source of water is still too expensive for agricultural purposes and can only be used to grow luxury products, such as out-of-season strawberries, which, of course, have little to do with desertization. However, in the near future, water desalinization is a serious prospect (US$ 0.05 per m^3) although it will require very large plants powered by nuclear energy, which in turn calls for huge investments that, in the foreseeable future, can only be afforded by countries rich in oil or minerals. It will, however, be of little help to the land-locked countries of the Sahel. Desalinized water would not aid in the struggle against the desert unless this water were more widely used than the present conventional irrigation water.

Irrigation by pumping groundwater from deep aquifers in arid areas is also at present too expensive to be a realistic alternative in poor countries.

Runoff farming

Runoff farming was prosperous in Palestine during the Israelite period 1000–600 B.C., during the Nabatean period 300 B.C.–A.D. 100 and under the Roman and Byzantine rule A.D. 100–A.D. 635. The same authors have shown that successful runoff agriculture is still technically possible in the northern Negev at the present time, in an area receiving only 80 mm of average annual precipitation (Evenari *et al.*, 1961, 1967, 1971). See Fig. 11.2.

The same techniques of runoff farming, as practised at the present time, were already in use probably earlier than 1000 B.C. before the "Qanat revolution", at the border of Iran, Afghanistan and Pakistan (B. Spooker, pers. comm.).

Such runoff agriculture, probably dating back to the pre-Roman (Phoenicean) period, is still thriving in Tripolitania (Djebel Nefousa) and in central and southern Tunisia (Sousse, Matmata, Gafsa), where ten million olive trees are cultivated by means of runoff farming techniques (Le Houérou, 1958).

In Beni Ulid, in southwestern Libya, for instance, there are beautiful, centuries-old olive groves in an area where precipitation does not exceed, on the average, 70 mm per year but where a large catchment basin concentrates runoff floodings. This system has been working apparently without discontinuation for almost 2000 years.

This type of runoff farming seems to be ignored elsewhere in arid zones, although its potential probably makes it equal to irrigation farming in terms of areas thus reclaimable (in all probability 3 % to 5 % of the arid zones).

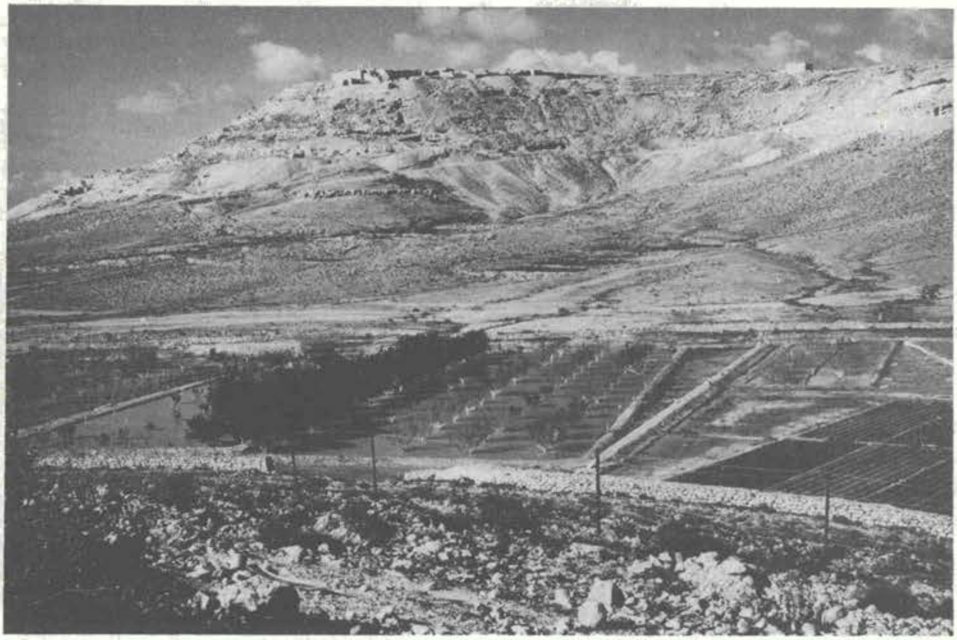

Figure 11.2. Run-off desert farming at Avdat in Israel. Almond trees and other crops are standing in temporary run-off water after a local rainstorm. Ancient run-off terraces in centre of picture, and ruins of Roman town of Avdat on skyline. Photo A. Rapp, 1974.

Utilization of agricultural and industrial by-products and stratification of the livestock industry

Many stock-producing countries export – sometimes at very low prices – groundnut cake, cottonseed, bran, pulp, molasses from the sugar industry (which is sometimes just thrown away) and brewery draff. Slaughterhouse refuse is just wasted.

As shown in experiments carried out in several countries, such as Kenya, Mali, Nigeria, Cameroon and Senegal most of those items can obviously be used in fattening operations. However, large-scale organization of feedlots still has to come. The beneficial effect of such practices on rangelands and in the struggle against desertization are evident:

i. part of the herd is taken away from the pasture, thus relieving the pressure on the range and making more feed available to the breeding herd
ii. psychologically, pastoralists move towards a marketing economy where livestock no longer consitute a status symbol.

Promotion of tourism and the cottage industry

Most of the countries north and south of the Sahara, and the Near and Middle East possess touristic treasures which are not fully or economically utilized. Promotion of these resources would create numerous jobs. Examples from developed countries, such as the United States, Spain and Israel show that tourism is a major asset in developing arid zones. In the African and the Near and Middle Eastern countries, there are traditional handicraft industries of high artistic value, which are not brought to the notice of potential buyers and, sadly, in some cases this traditional know- how is being lost. Here is a potentially important job opportunity, which would enable people to be transferred from the overpopulated pastoral sector.

Fisheries

In Chapter 3 of this work Hjort describes the importance of fish in the subsistence economy of the Nuer people of the Sudan. During the dry season fish constitutes the main source of protein. Important fisheries in rivers and lakes similarly occur in many areas near the southern border of the Sahara – for example, the Senegal River, the Niger River and its tributaries, Lake Chad, and the headwaters of the Nile. In normal years these waters produce about 300,000 tons of fish annually for trading. With an additional subsistence consumption of between 30 to 60 %, the total amounts to between 400,000 and 500,000 tons annually (Allsopp, 1974). The 300,000 tons used for trading purposes may be compared with the 1,400,000 tons produced annually in the inland fisheries in the whole of Africa, this being almost equivalent to the inland fish production of North and South America, Europe and the USSR taken together (Allsopp, 1974).

The Senegal River fisheries have a normal annual production of 37,000 tons with 12,000 fishermen; the Niger fisheries produce 130,000 tons with 80,000 fishermen, and Lake Chad produces 100,000 tons using 210,000 people as well as 20,000 full-time fishermen (Allsopp, 1974). Production in the Sudan was 23,000 tons (Medani, 1974).

Inland fisheries are not only important for internal consumption but for export as well, fish being the second largest export commodity both in Mali and Chad.

Allsopp (1974) has reported on the effects of the Sahelian drought disaster on the inland fisheries. Fish production in Mali was reduced to 30 % of normal, while Lake Chad was reported as being a third of its normal size.

> "In short, the effect of the drought has been comparable to an extensive overfishing of the resources. The full degree of overfishing is unknown and the composition of the residual ichthyomass in regard to their ecological niches and reproductive capacities cannot be immediately determined in the absence of baseline data. How quickly the remaining stocks can recover will only be determined by a close monitoring of the catch results from various places, and even a curtailment of fishing effect so as to allow the re-establishment of fishable populations in the customary known fishing grounds." (Allsopp, 1974.)

It is of interest to compare this situation with that in the Sudan, as both areas have suffered a prolonged drought. In the Sudan the through-flowing Nile renders the area less drought-susceptible than the Sahelian water basins. See Table 11.1.

Table 11.1 Fish catch in the Sudan. (After Medani, 1974.)

Year	Catch tons	Year	Catch tons
1964	19,300	1970	22,200
1966	20,000	1971	22,200
1968	21,500	1972	22,200
1969	21,500	1973	23,000

It is thus obvious that the fisheries in the Sudan are not influenced by a drought situation – that is, in this area fish are a drought-independent protein source.

Fisheries are important in the arid zone south of the Sahara, a consideration that must be taken into account when an evaluation of the natural resources is made. Fishing must be integrated into any comprehensive study on the possibilities of feeding human populations, and not only the present but the future potentialities must be taken into account.

There are five different types of inland fisheries in this region: river, floodplain, lake, man-made lake, and so called "aqua cultures". A description of these different types and their future possibilities for increased productivity and contribution to the economy follows below.

Allsopp (1974) describes floodplain fisheries as follows:

> "The normal cycle is of seasonal flooding when the river overflows and covers the flat lands which are otherwise dry. During the flood there is a bloom of vegetation and thus a period of flood-fallow when algae and higher aquatic plants as well as a variety of other aquatic life prevail. During the intermittent dry or unflooded period the land is used agriculturally for rice or other food crops near to habitations or for nomadic grazing and cattle pasturage".
>
> "Fishes occur in these permanent waters and their breeding generally coincides with the rains or rising waters so that the eggs, fry and other juveniles are spread in the extending waters over the flood plain. The period of flooding is of importance to breeding and survival and also for the transfer of nutrients from the terrestrial to aquatic ecosystems. The fishing is done during the dry period."

Allsopp (1974) regards these fisheries as underexploited. In the Niger basin the present normal catch is 130,000 tons, but the potential is estimated at 200,000 tons annually, the same case applying in Sudan.

Medani (1974) writes:

> "The Mashar area of the River Sobat and the Sudd region, extending for thousands of square kilometres, offer suitable habitats for fish. These fisheries support at present a small-scale, sun-dried salted fish industry. This industry, however, can be increased manifold."

The lake fisheries of Lake Chad are well organized and up to the Sahelian drought showed considerable improvement in the living standards of the fishing communities as well as an increased regional trade (Allsopp, 1974).

Man-made lakes of varying sizes are now being created in the African arid regions. These can be used for fish production to a much higher extent than now. Lake Nubia (Lake Nasser) may be taken as an example. The 1973 catch was only 500,000 tons, but the potential 1980 catch is estimated at 5,000,000 tons (Medani, 1974). The use of the large man-made lakes for fish production calls for special attention; research, improved techniques, improved facilities and trained fishermen are required.

Small dams for irrigation or watering purposes pose special problems. Some dry out temporarily, which means that systems for rapid restocking with fast-growing species need to be established. These problems are very similar to those encountered by proper aqua-culture (fish farming). Payne (1975) has pointed out the enormous possibilities which this now improved technique offers. Of particular interest are the improved yields obtained when polycultures are used. "For example, young carp stocked alone at 5000 per hectare in experimental ponds in Egypt yielded 377 kg per hectare under natural conditions. When stocked with *Tilapia*, a quarter of that number, the carp yield was 411 kg per hectare and the *Tilapia*, 300 kg per hectare". It is particularly important to adapt the new methods to the climatic conditions of the arid zone.

One of the great biological problems in the tropical world is to find an animal – preferably a fish – which can utilize the primary production of the macrophytes (*Eichhornia, Salvinia, Azolla,* etc.) which now infest many tropical waters.

Game utilization

In the section dealing with adaptations in the arid ecosystems it was pointed out that the populations of large animals were adapted to the variable environment through nomadic migrations. There is also reason to assume that these populations – in certain areas, at any rate – have adapted to a coexistence with man. In the beginning, when man first emerged as a hunter, some kind of confrontation occurred. The disappearance of many large mammal species is contemporary with this, and some scientists have talked about the "Pleistocene overkill'. However, in recent times before the European exploitation of Africa, man and the game populations were in balance. It may also be assumed that man has a regulatory effect on the game populations. This may be one of the reasons for the difficulties in maintaining balance in national parks without man.

Game is still important in the African subsistence economy. Game meat is a substantial part of the diet. Riney (1971) mentions that in Ghana, wildlife is the source of 65 % of the protein consumed in rural areas and that the value of game meat in 1966 in southern Nigeria was not less than $ 50 million. In the Kalahari area, the bushmen are completely dependent on game, which is also a major constituent of the diet of other tribes in the area.

Lundholm (1952) has suggested that game farming might be a way of utilizing marginal areas in southern Africa, where – contrary to the situation in northern Africa – no nomadic tribes occur. The idea was not to replace cattle and sheep with eland and springbok, but to use wildlife for food production in areas where ordinary farming was impossible. The use of game in central and East Africa was investigated and extensive field work carried out by Petrides (1956), Darling (1960), Dasmann & Mossman (1962), and Talbot (1963). This pioneer work has been followed by a large number of investigations and papers dealing with the subject.

There are many arguments for the use of wildlife as a protein source. The wild animals are probably better adapted to the ecosystems than introduced domestic animals. The native animals are more flexible in water requirements, they utilize the plant cover better, they have a larger biomass than cattle, and they are more resistant to diseases. One detail which has not yet been fully evaluated is the difference in meat quality. Game meat has less fat and – even more important from a human health angle in relation to arterial diseases – less saturated and monosaturated fatty acids (Crawford, 1968). Lawton (1975) has reviewed the present situation in this field and points out that game farming schemes in East Africa have had limited success, but nowhere has it been possible to maintain a sustained yield. The MIT report (Matlock & Cockrum, 1974), quoting Kyle and Gogan, points out that the theoretical off-take rate from wild ungulates is estimated to 10 % to 18 % but that in practice this figure has to be reduced to 6 % to maintain herd size. From southern Africa there are reports on successful projects: South Africa (Asibey, 1974; Pollock, 1969), Rhodesia (Johnstone, 1974).

From an ecological point of view, the productivity of game populations might be high. The question, however, is whether man can use this productivity in an economic way. There are at present many problems facing game farming. First, there are the difficulties of harvesting. Free-living animals must be killed, bled, and transported to a place for processing. The species forming large herds might be easier to handle than species living singly, in pairs, or in small herds. The harvesting might be very expensive when it cannot be made by "sportsmen", as is the case in many places. The costs are high for collecting the animals or the meat, especially in dry areas with low productivity. Another difficulty relates to marketing. It might be very costly to build up a network for proper marketing, especially since this would have to be done in competition with beef marketing.

It has been suggested that African game meat should be sent to the big overseas markets in the developed countries. However, exportation is at present impossible because of hygienic requirements. Local veterinary control of game meat is not adequate to permit importation into Western countries. It is even doubtful if transport between African countries could be sanctioned. The hazards of rinderpest and foot and mouth disease are cause for special concern.

The disease factor is important in any consideration of game farming and/or cattle farming. In some cases the game might be a reservoir for diseases of domestic animals. The disease might be spread by a vector, as in trypanosomiasis, by soil, as in botulinism or anthrax, or by direct contact infection, as in rinderpest or foot and mouth disease. In these cases, mixing of game and cattle must be prevented. In other cases diseases of domestic animals might threaten the game populations. This is especially the case when the natural immunity in the wild populations has been lowered.

Even if the prospects for game farming in arid areas are not very promising from a short-term point of view, recourse to research and development should help in overcoming the difficulties. As previously pointed out, in areas with higher rainfall and higher productivity, the game populations are larger, which makes handling cheaper, and thus the potential for future utilization better.

The utilization of wildlife as a source for new domestic animals might be a long-term solution to some of the problems. However, such research must be allowed sufficient time if it is to produce results. This research should be directed to areas where wildlife resources still exist. It might be very difficult to introduce new wildlife into areas where it has previously been exterminated. In such areas the ecosystems might be too changed to allow an easy introduction.

From an economic point of view the wildlife might be used as a means of attracting tourism. This has proved to be very promising for many parts of Africa. In order to promote this it would probably be of economic importance to restore wild animals in areas where they have been exterminated. Tourism might offer a possibility for conserving some of the rich animal life in Africa.

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Chapter 12

NEEDS OF ENVIRONMENTAL MONITORING FOR DESERT ENCROACHMENT CONTROL

A. RAPP

Introduction

A clear overview of the extent of desert encroachment which occurred in connection with the recent Sahelian-Sudan drought has not been obtained. Nor do we know to what extent and how soon soil and vegetation can recover after severe degradation in pre-Saharan environments. Next time a prolonged drought strikes, we will unfortunately not be much better prepared for the disaster if the lessons of 1968–73 are not learned and remembered.

Prescriptions for combatting desertization should be based on a correct diagnosis of the ills afflicting the ecosystems involved. The type, extent and rate of desertization and also of recovery have to be surveyed and monitored as a basis for sound and effective action in desert encroachment control.

It is for this reason that the pre-Saharan countries need international help to begin the monitoring, within selected reference areas, of environmental shifts in the desert boundary zones. The monitoring of blowing dry-land soil dust is another type of urgently needed environmental check. These two kinds of monitoring are discussed below.

Monitoring of desert boundary shifts

The surveying and monitoring of ecological shifts in the desert boundary zones were recommended in an earlier report from SIES (Rapp, 1974). A three-level survey approach was suggested using data and observations from ground checks and from aircraft and satellites. References were made to examples from the Gabès region in Tunisia, where local desert patches formed by deflation or sand deposition in steppe vegetation or by dunes advancing into oasis vegetation appeared clearly on satellite images of Landsat-1 (or ERTS-1) in black-and-white copies of band 5 (*op.cit.* Figures 15 and 17). Other examples of similar cases appearing on Landsat-images have been shown and discussed,

– for example, the "green polygon" of cattle-ranch areas in the Sahelian zone of Niger (MacLeod, 1974) and the green Sinai border zone facing the pale and desertized Gaza strip (Otterman *et al.*, 1975).

The contrast between dense vegetation and bare desert surface appears very clearly both in aerial photographs and in satellite image. However, desert boundaries are generally not sharp lines, but wide zones of gradual transition. It is therefore difficult to define their exact position in any particular year, and still more difficult to map the shifts of desert boundaries. Perennial vegetation, trees and brush are the best indicators of persistent shifts of desert boundaries. Annual grasses reflect the distribution of local rainfall patches. Annual vegetation is thus a poor indicator of persistent changes of desert boundaries.

Wickens (1975) has underlined the difficulty of making reliable comparisons of vegetation in arid lands over different years without very thorough descriptions of biota and sites:

> "Reports of the vegetation by most travellers are usually confusing; identifications, apart from a few common species, are generally unreliable. Habitat descriptions are invariably misleading due to imprecise terminology." (*Op. cit.*)

Monitoring of desert boundary shifts can best be done along well-defined transects, which include reference plots of thoroughly documented vegetation and landforms, such as dunes or deflation patches and their condition.

Discussion of an example from the Sudan

The map by Lamprey (1975) is probably the most thorough attempt made so far to map and reconstruct desertization over a large area by a combination of ground check and aerial survey. The interpretation of the evidence is, however, open to discussion, as shown by the following example. In the IUCN Bulletin (1976) it is stated that "the Sudan's desert is marching south slightly faster than 5 km a year". This annual rate was calculated from information in the above-mentioned 1975 report, *viz.*, that the southern boundary of the desert has shifted southwards about 90–100 km in the period 1958 to 1975.

If desert encroachment occurred as a regular annual advance of a sand front, monitoring would be easy. It is, however, likely that the desert boundary shift is a very discontinuous process and that possibly the 100 km move southwards occurred in one or two long jumps towards the end of the 1968–1973 drought.

Besides, it is the author's opinion that the following general description of desert encroachment in the IUCN Bulletin (1976) is open to criticism:

> "Sand encroachment, moving ahead of the onward march of the desert, is also serious. Sand from the extensive Libyan desert and the Jebel Ayan Plateau is being blown southwards on a broad front by the steady northerly winds."

Desertization occurring south of a continuous desert boundary – for example, in the Kheyran area north of Bara, Sudan is due to local deflation and local dune movements. This was at any rate shown to be the case in the village of El Bashiri, where a local dune stabilization programme which started in 1970, had successfully stopped the movement of dunes even during the years of drought culmination.

The above discussion is included in order to illustrate the need for systematical environmental monitoring of shifts in desert boundary zones, to provide better knowledge of the actual processes of desertization versus recovery, and of how both can be brought under control.

The map and the report by Lamprey (1975) on desert encroachment reconnaissance in the northern Sudan underline the usefulness of large wadis with belts of trees as reference lines for monitoring of shifts in desert boundaries. The report also underlines the need for reference to reliable maps or descriptions for purposes of comparison.

> "The southward shift can be readily appreciated in the vicinity of the Wadi-Milk in northern Kordofan" . . . . "A striking piece of evidence of the southward drift of sand on a large scale is the covering of the bed of the Wadi Howar by loose sand over its whole length . . . the area in the immediate vicinity of the Wadi Howar and the Wadi itself had become sandy desert except that many of the old *Acacia tortilis raddiana* trees were still standing and alive" . . . .

These two quotations from Lamprey's report and his description of the extensive die-off of trees in the *Acacia senegal* woodlands along the 14th parallel underline the usefulness of tree vegetation for monitoring shifts of desert boundaries and ecological changes near the desert boundaries. The Sudan seems to offer favourable topographical and hydrological conditions for such large-scale monitoring.

In addition to the aerial surveys, a network of areas for pilot projects related to desert encroachment was examined. They were selected from a series along the ecoclimatic gradient from the 400 mm isohyet in the south to the 50 mm isohyet in the north (Lamprey, 1975).

Recommendations for environmental monitoring of eco-zone transects

Ground checks should be repeated annually at the same season. They should include inventories of the actual state of natural and human resources of the area and of land use. By combining ground checks of small sample areas with inspections from aircraft and analysis of available satellite images, the findings of ground surveys can be extrapolated to larger areas, preferably transects across ecological zones (ecozone transects).

Environmental monitoring of shifts in desert boundaries should not only consist in registration of changes in vegetation and landform patterns, but should be geared to action for desert encroachment control by improved land use. Therefore it will not be enough to survey and map changes in vegetation or movements of dunes, etc., but it will be necessary to investigate the reasons behind the changes in order to understand how control measures can be applied. A number of reference areas included in each monitoring transect should be used for annual collection of data on natural resources, human resources and land use.

The data base for each representative site should include the following information.

1. Daily records of rainfall, wind, temperature, humidity and dust storms from observations at a nearby synoptic weather station.
2. Annual reconnaissance information on the condition of natural resources, plotted on maps or air photographs: observations on soils and erosion, the availability of surface water and groundwater, vegetation and wildlife.
3. A demographic survey of the population of the area and of migrations.
4. Annual censuses of livestock numbers and composition of herds. This is a particularly important point. Failing to keep track of livestock numbers is a classical problem in planning in developing countries.

5. Surveys of actual land use: grazing, cultivation, wood collection, burning and other activities of man with an impact on the environment.

In brief, a planned land use for counteracting desertization requires a reliable base of data on the existing resources and of how they have been utilized earlier. On this basis a strategy for improved land use can be worked out which has to be adapted to local ecological and social conditions in order to be successful.

Monitoring of soil dust from deserts and dry lands

Wind erosion is a serious threat to soils in dry lands with inadequate vegetational cover for protection. Finer soil fractions (silt, clay and organic matter) are removed as dust and carried away by the wind, leaving sand, gravel and other coarser particles behind.

> "This sorting action not only removes the most important material from the standpoint of productivity and water retention, but leaves a more sandy, and thus a more erodible soil than the original . . . In the extreme, the sands begin to drift and form unstable dunes which encroach on better surrounding lands." (FAO, 1960.)

Of these two types of soil degradation, sand drifting and dune encroachment is a striking feature, which is easier to demonstrate than the more diffuse and widespread loss of fine-grained soil dust carried long distance as an aerosol high up in the air. It is surprising how limited our knowledge is about this process. which is probably responsible for a much more outspread degradation of dry-land soils than the better known and more studied migration of sand dunes. The environmental impact of dust storms in desert margins is threefold: **erosion** and loss of productive topsoil, **transport** of dust in the air causing air pollution and possible changes in albedo and other climatic variables, **deposition** of wind-borne dust either as loess covers on land with possible increase in fertility of soil or deposition in the sea or lakes with impact on the water ecosystems and bottom sediments.

Examples of previous monitoring and observations

The sampling and analysis of airborne dust from Africa has been performed since 1965 at a ground station on the east coast of Barbados Island in the Caribbean, and completed by sampling from aircraft. The dust clouds have also been followed on satellite images during their one-week long journey from West Africa across the Atlantic.

A network of dust monitoring stations is now bering established in West Africa and one on the island of Tenerife (J.M. Prospero, pers. comm.). On the basis of the measurements in the Caribbean it was calculated that 25–37 million tons of African soil dust was carried by the winds across the longitude of Barbados in the summer of 1969 (Prospero & Carlsson, 1972). In addition, large quantities of dust are deposited on the floor of the Atlantic, as can be shown in sediment cores (Parmenter & Folger, 1974) and by actual observations of fallout. Thus, Nehring (1975) measured 0.6 g m^{-2} hr^{-1} of dust depositon in the Atlantic near Cape Blanc during 5–6 March 1973. The "summer dust" is brown to reddish in colour. The area of origin of most of the airborne dust over the Atlantic during the summer season is considered to be the interior Sahara west of the Ahaggar mountains (J.M. Prospero, pers. comm.). However, it is an open question as to how much of the summer dust comes from the pre-Saharan margins, hence is a loss of productive topsoil.

A second major path of African airborne dust is the winterly course of black to grey dust coming from burnt areas of the Sahel and adjoining lands, carried by the harmattan winds and continuing over the Atlantic in a wide zone immediately north of the equator (Fig. 0.3). The quantity, type and origin of this dust have not been closely investigated. Other major flow paths of African dust northwards and eastwards have been described by Yaalon & Ganor (1973), who have also conducted monitoring of dust deposition over Israel for four years. They report that severe dust storms can transport several million tons of dust and they measured rates of dust deposition of 0.3–0.4 $g\ m^{-2}\ hr^{-1}$ (Yaalon & Ganor, 1974) during storms.

Recommendations for monitoring of blowing soil dust

A particular effort should be made to begin monitoring of soil dust losses from pre-Saharan and other dry lands as compared with dust from true deserts. This can be done by an improved technique of monitoring and identifying the types of dust and by correlating information from different types of observations.

1. Long-distance aerosol transport should be measures at a few specialized base-line monitoring stations, similar to those being operated on Barbados and Tenerife.
2. Synoptic meteorological observations of dust stoms and other conditons of high dustiness should be utilized from the largest possible number of regular weather stations in arid and semi-arid lands, and analyzed in combination with information from weather satellite images.
3. A few special stations for the monitoring of short-distance transport of soil dust should be established near source areas (deflation patches). Analysis of the relations between vegetation cover, land use, soil factors, wind speed and blowing soil should be performed on the basis of data from these stations.
4. The mechanisms and patterns of wind erosion should also be analyzed by geomorphological surveys of deflation patches, dunes and other eolian ground patterns, considering the factors mentioned under point 3 (vegetation, land use, soil factors).
5. Combined with the above-mentioned four types of observations, measurements of deposition of airborne soil dust should be made, using standardized methods of dust deposition collectors and analysis.

A methodological study of points 2–5 above will be included in a pilot project planned by SIES.

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Chapter 13

CAN DESERTIZATION BE STOPPED? SUMMARY AND RECOMMENDATIONS

H.N. LE HOUÉROU & A. RAPP

Desertization is the result of two sets of factors operating either singly or in combination. These factors are: 1) severe, prolonged drought 2) man's overexploitation of drylands. The desert boundary zone is not static but can shift over periods of years. In periods of extremely low or ill-distributed rainfall (such as the Sahelian drought years of 1968–1973), the desert boundary can shift into surrounding lands. In other periods of favourable rainfall and low pressure of exploitation, the desert boundary may shift back again, provided the degradation of vegetation and soil has not been irreversible. By manipulating the vegetational cover in the marginal drylands, man can influence desertization and strengthen or weaken the swings of the desert boundaries.

The vegetational recovery of desertized areas has been demonstrated in many cases – for example, in so-called exclosures or areas fenced off against intrusion, where regrowth has occurred, except where the soil is too shallow.

Halting desertization in technologically advanced and rich countries, such as Australia and the USA is, in principle, no problem owing to the low densities of rural population. However, high population pressure in the desert margins of developing countries in Africa, Asia and the Americas makes the problem quite different. Unless the pressure of exploitation can be reduced, either by out-migration or successful family planning, no long-term solution to the problem of avoiding recurrent famine can be envisioned.

Even if man's present situation in the dry zones is not bright, it must be stressed that these areas are important from the standpoint of global resources. The arid and semi-arid ecosystems are well adapted for the use of man. The problem is to give support to man and beast during critical periods. Nomads and large wild animals overcome critical periods by seeking out sparse patches of grazing over vast areas. Pressure from over-exploitation and artificial boundaries have degraded the areas which may be used and have increased the risk of disasters.

It is said that we have adequate knowledge of the processes causing desertization and of the technology of restoration of desertized areas, but our knowledge of the structure and functioning of dry ecosystems is generally poor. Research has an important role to play in helping us to find ways not only of restoring desertized areas but also of improving and converting them into ecologically adapted systems of higher productivity. More information about the linkage between the ecological and socio-economic systems is urgently needed. Even the very best desert technology is useless if it cannot be adapted to social and economic reality.

Priorities in measures for combatting desertization

Awareness of the drought hazard

The authorities must be aware of the fact that years of drought will recur in the future. The lessons from the Sahelian famine must be remembered and measures taken to diminish the hazards of future droughts.

Planning with a view to minimizing future drought hazards

Ecological principles for halting and combatting desertization should be given the highest priority in the land use planning of marginal drylands. Sectoral interests in producing special agricultural crops, meat, charcoal, etc. must be held back and combined into integrated plans for long-term and diversified use of the land. Social, political, economic and ecological constraints should all be recognized and considered.

Planning for land consolidation and ecologically sound land use must be based on reliable data on the natural and human resources of the areas concerned. Hence inventories and surveys of human, livestock, land, water and vegetation resources must be carried out to provide a data base for planning. Without a reliable cattle census, for instance, no rational land use planning is possible. The relevent national and international organizations should immediately prepare plans for relief and assistance in case of future drought catastrophes.

Repeated evaluations from monitoring of the impact of land-use projects on man and environment are necessary as a tool to recognize and correct negative effects. The environmental monitoring should utilize information from surveys on three levels: ground, air and space.

The twin dependences on rainwater (or surface water) for food production and well-water (groundwater) for drinking make an area sensitive to drought. The exclusive dependence on groundwater need not pose any unexpected problem as long as the water exploitation is well guided by competent groundwater hydrologists. Exclusive dependence on rainwater can be feasible if the nomads and their herds have freedom of movement. There are several ways of conserving water, even as drawing irrigation water from the sandy riverbanks instead of directly from the river, creating shallow reservoirs for storing water and using the storage capacity of the sandy sediments for avoiding evapotranspiration.

Grazing as a major form of land use

The predominant land use in dryland areas is grazing. This is also the only traditional way of utilizing the highly variable vegetational resources of these vast areas.

Overgrazing, overcultivation, excessive wood-collection and bush burning are practices which cause much degradation of dry rangelands and contribute to desertization. These forms of overexploitation must be counteracted. Biological recovery of desertized lands can occur by natural regrowth during years with normal or favourable rainfall and under protection from heavy grazing and other exploitation. Recovery can be speeded up by artificial planting – fodder shrubs and trees, woody species for fuel, woodlots, windbreaks, shelterbelts, etc. – and by sand dune fixation, and reclamation of saline or alkaline land. Haymaking, grazing reserves, controlled temporary grazing and use of irrigated farmlands for livestock feeding can release much grazing pressure on rangelands and improve the overall livestock production system through better stratification of these systems. As regards the possibilities of using these areas for grazing, there is a great difference between subsistence pastoralism and range management based on a market economy. A possible method of compensating for animal losses during droughts in subsistence pastoralism is suggested in this volume in the chapter entitled "Cattle insurance blocks – an alternative to group ranches".

Improved roads, marketing facilities and abattoirs are other means towards attaining rational utilization of rangelands. Unplanned provision of water holes, and cattle vaccination without subsequent offtake of cattle, have contributed to overstocking and desertization in many areas of the Sahelian zone.

Reorganization of Sahelian rural territory should aim at rationalizing and improving the transhumance system, and reducing the distance traversed to about 10 km between the rainy-season and the dry-season pasturelands. Each year the surplus animals should be removed from the land, placed on the market or sent to re-breeding centres. Young Sahelian steers could be utilized by developing the use of draught oxen in areas suited for cultivation

Complementary activities for decreasing the pressure on grazing lands

Compared to livestock raising, agriculture has limited potential in most arid and semi-arid areas. However, long sustained yields of farming crops can be obtained where flood-retreat agriculture and runoff irrigation are possible. The land use of floodplains in dry areas should be planned with particular care to allow of stock rearing combined with agriculture, thus reducing grazing pressure from surrounding rangelands.

On the northern Saharan margins and particularly in the Near East, tractor cultivation of marginal drylands is a very serious threat leading to desertization. Some countries are counteracting this practice by legally enforcing cultivation limits – a commendable measure, provided such regulations can be successfully enforced.

Tree planting in ecologically suitable localities, together with other forms of vegetational improvement, is essential for combatting desertization as well as for fulfilling present and future requirements of fire-wood and fodder. However, greenbelts are of little use if they are not combined with further sound management practices.

Other complementary activities of importance for decreasing the pressure on grazing lands are the development of fisheries, wildlife, handicraft, tourism and small-scale industries.

If there are no investment opportunities in the complementary subsistence sector, it is most likely that the increased returns from this sector will be invested in livestock. Hence, efforts at developing other sectors may have a feedback of increasing numbers of cattle and degradation of rangelands.

Expensive methods are not practical solutions

Artificially induced rainfall and desalinization of seawater or brackish water for irrigation are expensive and highly sophisticated methods. They will probably not be of practical interest in halting desertization, except in specific, restricted areas of high economic importance.

Importance of political decisions and integrated action

Halting of desertization and restoration of degraded land requires a strong political will and the power to implement necessary measures. It also requires close cooperation with the local population and employment offering an alternative to emigration.

> "A careful improvement of Sahelian territories taking into account all the physical and human factors is the only possible solution at the present time. Even so, it will not be possible to remove entirely anxiety about drought, the threat of famine or the poverty of the inhabitants." (Dresch, 1975.)

It is, however, important that the restoration of the degraded lands should not be achieved at the expense of keeping the pastoralists down in poverty at an abject standard of living. The inhabitants of the dry areas have the right to development and an improved quality of life.

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