

THE GLOBAL ENVIRONMENT MONITORING SYSTEM

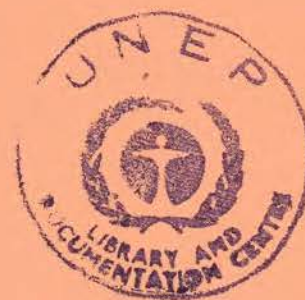
GEMS
SAHEL SERIES
NUMBER 7

NAIROBI
1988

Inventory and Monitoring of Sahelian Pastoral Ecosystems

ANNEX 7:

WOODY VEGETATION IN THE SAHEL



UNITED NATIONS ENVIRONMENT PROGRAMME
FOOD AND AGRICULTURAL ORGANISATION
GOVERNMENT OF SENEGAL

SAHEL SERIES

1. Introduction to Sahelian Pastoral Ecosystems Project
2. Rainfall in the Ferlo (Sahelian Region of North Senegal) since 1919
3. Use of Light Aircraft in the Inventory and Monitoring of Sahelian Pastoral Ecosystems
4. Sampling the Sahel
5. Monitoring Pasture Production by Remote Sensing
6. Inventory of Water Resources in the Ferlo
7. Woody Vegetation in the Sahel

THE GLOBAL ENVIRONMENT MONITORING SYSTEM

GEMS
SAHEL SERIES
NUMBER 7

NAIROBI
1988

Inventory and Monitoring of Sahelian Pastoral Ecosystems

ANNEX 7:

WOODY VEGETATION IN THE SAHEL

**UNITED NATIONS ENVIRONMENT PROGRAMME
FOOD AND AGRICULTURAL ORGANISATION
GOVERNMENT OF SENEGAL**

Executive Summary:

The GEMS Sahel Series is a product of the Pilot Project for the Inventory and Monitoring of Sahelian Pastoral Ecosystems. This project was set up to demonstrate and assess the GEMS methodology for ecological monitoring in a West African pastoral ecosystem.

The present document, the seventh in the series, reviews the status and trend of the woody plant cover in the Sahel. The history of the climate of the Sahel is used to place the recent droughts in context. Changes in the ecology of the woody plant in the Sahel due to man's activities are examined and compared with the changes brought about by alterations in climate. Possible ways of rehabilitating the woodlands of the Sahel are discussed, and particular emphasis is placed on the need to involve the rural population in decisions and projects, and on the need to make legislative changes appropriate to current conditions. The document includes recommendations for future research and action designed to reverse the deforestation currently afflicting the Sahel.

In support and illustration of some of the trends reported in the literature, the document presents data from case studies of three areas in the Ferlo.

Global Environment Monitoring System Program Activity Centre
Sahel Series No 7

Provisional title:
Woody vegetation in the Sahel

Author: M. Sharman

Target audiences: Government of Senegal
Government of other sahelian countries
Reafforestation projects
Range managers
Ecological monitoring projects
Remote sensing projects

Objectives:

- (1) Review of the problem of woody plants in the Sahel
- (2) Case studies in Senegal:
 - (a) Examination of population dynamics through analysis of dimensions of woody plants in two parts of the Ferlo
 - (b) Examination of factors affecting numbers of various species on the crest of a dune
 - (c) Examination of a 25ha plot in north Senegal monitored after a seven year interval

"For every child a tree"

- Title of UNEP Project (1982)

The reduction of tree cover ... is the most telling symbol of desertification in the Sahel... To fight against this ecological disaster, we must recognise that man is responsible: the trees die because we kill them.

Rochette (1986)

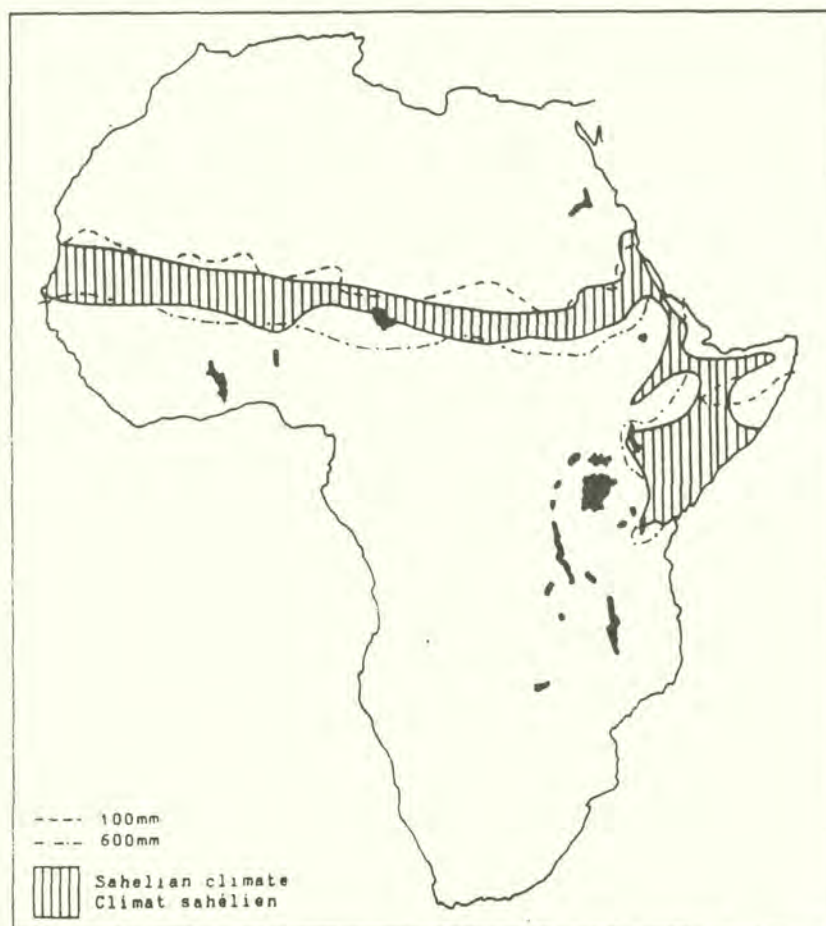
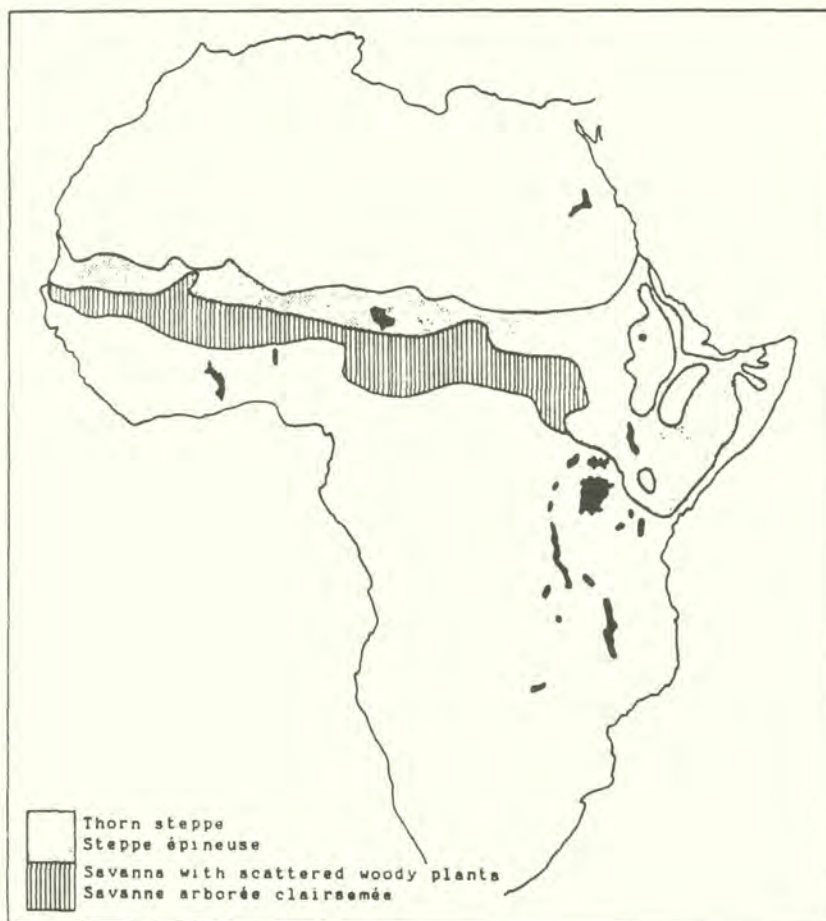
We felled mixed natural forests of this area and planted Eucalyptus. Our handpumps have gone dry as the watertable has gone down. We have committed a sin.

- Forest Ranger in the Nainital Tarai, Uttar Pradesh.
(quoted in Desertification Control Bulletin 13:30)

In the Sahel, life depends, in the end, on the tree.

Dommergues (1986)

Frontispiece: The sahelian zone



Source: Van Chi-Bonnardel R. (1973)
L'Atlas de l'Afrique. IGN, Paris
Editions Jeune Afrique. Paris

Contents

- 1 Introduction
 - 1.1 Objectives of this document
 - 1.2 Definitions
 - 1.2.1 Plants (after Baumer 1983)
 - 1.2.2 Landscapes (after Baumer 1983 and Lapedes 1974)
 - 1.2.3 Processes
 - 1.2.4 Sahel
 - 1.3 Countries in the Sahel
 - 1.4 Brief description of the ecology of the Sahel
- 2 Vegetation of Sahel
 - 2.1 Ecology of woody plants
 - 2.2 Properties of sahelian plants
- 3 History of the climate of the Sahel
 - 3.1 Severity of the recent drought
- 4 History of Man in Sahel
 - 4.1 Changes in human ecology
 - 4.2 Wildlife
 - 4.3 Livestock
 - 4.4 Agriculture
 - 4.5 Improvement in transport
 - 4.6 Cities
 - 4.6.1 Domestic fire
 - 4.7 Extinction of species: extinction of a way of life
 - 4.8 Conclusion: the consequences of environmental changes
- 5 Drought and the woody plants
 - 5.1 Effect of drought
 - 5.2 Effect of drought and famine on rural economy
- 6 Production of woody plants
 - 6.1 Sustainable use of woody vegetation: The cold equations
- 7 Rehabilitation
 - 7.1 Range improvement
 - 7.2 Reforestation and Plantations
 - 7.2.1 Costs and areas
 - 7.3 Agroforestry
 - 7.4 Shelterbelts
- 8 The rôle of humans in the rehabilitation of the Sahel
 - 8.1 Education
 - 8.2 Rural support
 - 8.3 Political factors: legislation
- 9 Research
 - 9.1 Genetics
 - 9.2 Stoves
 - 9.3 Research into tree populations
 - 9.4 Ecological monitoring: the GEMS approach
 - 9.4.1 Satellite data
 - 9.4.2 Low-level reconnaissance flight data
 - 9.4.3 Observations in the field
 - 9.4.4 The woody plants near Vindou Thiengoli and Amali
 - 9.4.5 The woody plants on the Dune de Mbidi
 - 9.4.5.1 Size classes
 - 9.4.5.2 The population structures of woody plants
 - 9.4.5.3 Frequency of various species on the Dune de Mbidi
 - 9.4.5.4 Trends in numbers along the dune
 - 9.4.5.5 Associations among species
 - 9.4.5.6 Effects of boreholes, fields, settlements and

- firebreaks
- 9.4.5.7 Conclusion
- 9.4.6 The enclosure at Fété Olé
 - 9.4.6.1 Method
 - 9.4.6.2 Results
 - 9.4.6.2.1 Distribution of woody species at Fété Olé
 - 9.4.6.2.2 Changes in populations of woody species
 - 9.4.6.2.3 Use of standing dead plants as an indicator of annual mortality
 - 9.4.6.2.4 Influence of type of terrain on distribution of woody plants
 - 9.4.6.2.5 Changes in dispersion pattern between 1976 and 1983
 - 9.4.6.2.6 Changes in complexity of community between 1976 and 1983
 - 9.4.6.3 Conclusions
- 10 External Aid
- 11 Discussion

Preface

From the available data it seems probable that the numbers of domestic stock in the Sahel have reached levels equal to those of the decade before the catastrophic drought of 1968-72. At the same time the condition of the rangeland has improved only slightly, if at all, from its degraded state immediately after the drought. Furthermore, in parts of Africa, extension of agriculture has meant that pastoralists no longer have access to some of their former pastures. If the future of pastoral peoples is to be assured, the condition of rangelands must be preserved and if possible improved. Unfortunately the protection of the pastures poses well-nigh intractable social and complex ecological problems. The ecological problems alone cannot be solved unless the dynamics of the ecosystem are understood, and understanding can only be achieved by approaching the ecosystem as a functioning whole. To this end, the United Nations Environment Programme's Global Environment Monitoring System (GEMS) set up the Pilot Project for the Inventory and Monitoring of Sahelian Pastoral Ecosystems, which was executed by FAO as part of the global network of GEMS monitoring projects.

Objectives of the sahelian monitoring project

There were two major objectives. Firstly, the project was to adapt the standard GEMS ecological monitoring methods to the inventory and monitoring of sahelian pastoral ecosystems. Thus data were to be collected from observations made at three levels (on the ground, from the air, and from satellites), using methods designed to encourage a systems approach in their presentation and use. Secondly, the project was to collect data which would improve understanding of the renewable resources in the world's arid lands.

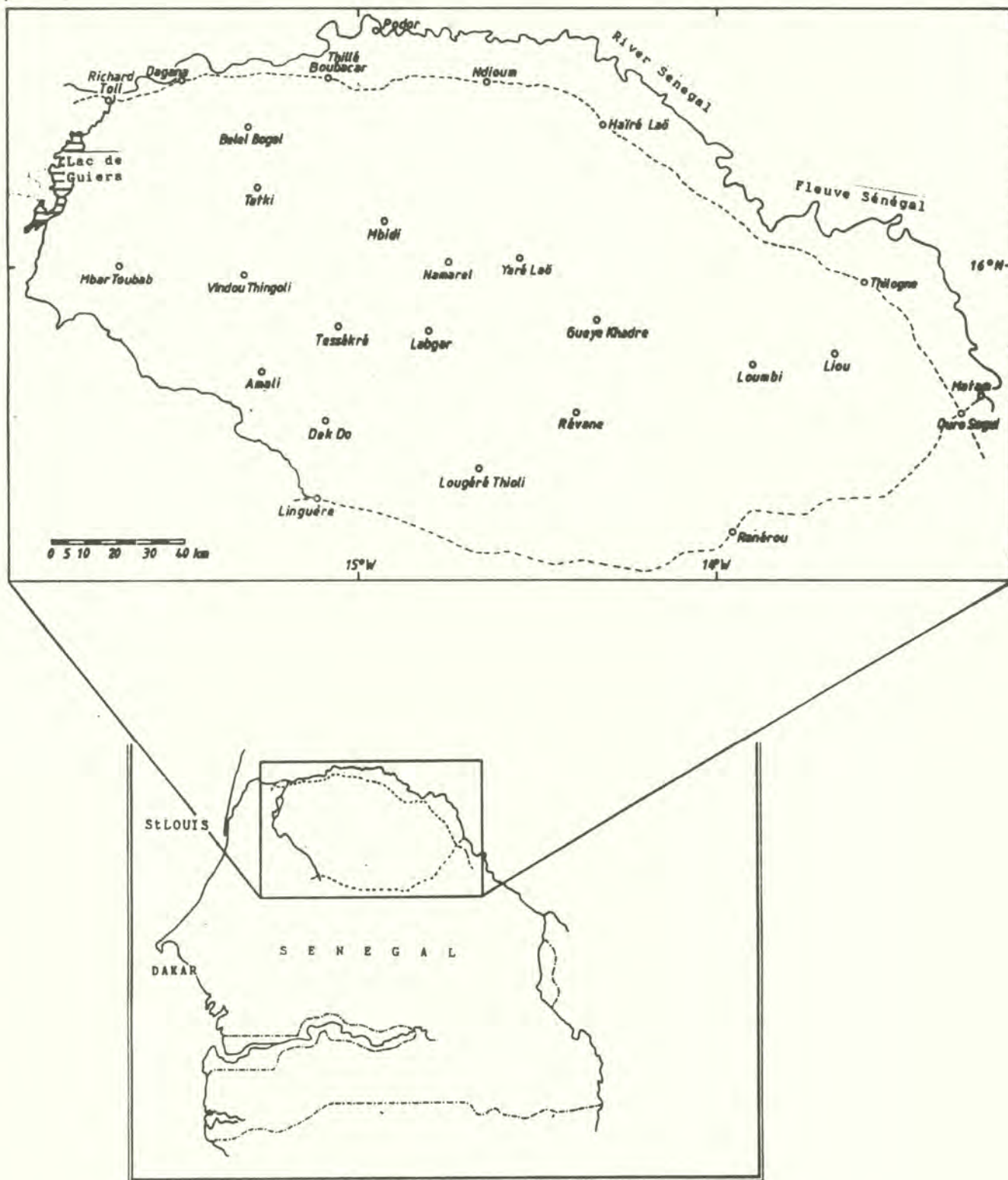
Choice of test zone

The ecology and economy of the north of Senegal is typically sahelian, and the area faces many of the ecological problems that confront the Sahel elsewhere. The zone chosen as a test area for the project, some 30,000 sq km of low-lying pastoral land (Figure 1), is bordered to the west by the shallow Lac de Guiers, to the north and east by the River Senegal, to the southwest by the fossil valley of the Ferlo, ending at Linguere, and to the south by the road between Linguere and Matam (on the River Senegal). This area corresponds roughly with that known traditionally as the Ferlo du nord, or north Ferlo. In the GEMS Sahel Series the test zone is known simply as the Ferlo.

Objectives of this document

This report reviews the status of woody plants and the trend of their populations in the Sahel, and presents data from the Ferlo, in the north of Senegal, in support of some of the trends reported in the literature. It also contains recommendations for action to reverse the deforestation of the Sahel.

Figure 1: Location of the test zone of the Pilot Project



=====

1 Introduction

Since its inception in 1972 the United Nations Environment Programme has attempted to make people aware of the need to protect forests, to stop damaging or killing trees needlessly, and to promote reforestation projects around the world.

Nevertheless, in May 1984 UNEP's Governing Council reported that there had been a "general failure to formulate national plans to combat desertification". Good intentions had foundered on over-ambitious schemes and the inability to surmount the difficulties abounding in the formulation, let alone the implementation, of integrated projects. Large-scale, capital-intensive projects have not resolved the problems. Far from having been able to halt desertification, mankind has lost ground.

1.1 Objectives of this document

This document reviews the status and trend of the woody plant cover in the Sahel. In support of some of the trends reported in the literature, it presents data from case studies of three areas in the Ferlo, the test zone in north Senegal of the Pilot Project for the Inventory and Monitoring of Sahelian Pastoral Ecosystems. For further information about the Project, see GEMS (1986a), and for a summary description of the Ferlo, see Le Houérou (1986a).

This document includes recommendations for future research and action designed to reverse the deforestation currently afflicting the Sahel.

1.2 Definitions

1.2.1 Plants (after Baumer 1983)

A tree is defined as a single-stemmed ligneous plant at least seven metres tall when adult.

A shrub is a multi-stemmed ligneous plant less than seven metres in height. A dwarf shrub is normally less than 1.2m tall when adult. A small shrub may grow to be 3m tall as an adult, and a tall shrub is from 3 to 7 metres tall.

1.2.2 Landscapes (after Baumer 1983 and Lapedes 1974)

A landscape with scattered trees is woodland, while one with scattered shrubs is sometimes called shrubland and sometimes bushland. Dwarf shrubland is a landscape with scattered dwarf shrubs.

Savanna is a landscape characterised by widely scattered or bunched bushes and small trees growing in grassland. Savannas experience a pronounced dry season.

=====

Steppe is made up of short grasses growing bunched or sparsely distributed, with widely scattered low shrubs. Steppe contains much bare ground.

1.2.3 Processes

Some authors distinguish between "desertification", the change in climate towards a drier regime, and "desertization", the degradation of an environment independently of any change in the climate. This distinction is made to bring out the responsibility of man in the degradation of the environment. While intellectually satisfying, the distinction is in practice of limited use, since it is nearly always difficult to isolate causes of degradation.

For reasons of euphony in French, Le Houérou (1976a) prefers the term "désertization" to "désertification". Most English speakers find "desertization" awkward, and in this document "desertification" is used to mean the extension of typical desert landscapes and landforms to areas where they did not occur in the recent past, irrespective of the cause of that spread. Patches of desertification occur throughout the fragile lands of the Sahel wherever land is overused, and is not limited to the rim of the desert. In recent years desertification has affected tens of thousands of hectares in the Sahel (Le Houérou 1976a).

1.2.4 Sahel

There are no universally accepted limits or terms for the various climatic and vegetation zones that make up the Sahel. A tabular summary of definitions by various authors is given in GEMS (1986a). Because of the close association of various ecological communities with the annual rainfall, isohyets are frequently used to define the limits of the Sahel.

In its widest definition the Sahel is often taken to be that zone lying to the south of the Sahara and to the north of the sudan biome, that is, the land which lies between the 100 and 500mm or 600mm isohyets. This strip, some 100 to 600 kilometres wide, is generally defined to consist of three parallel belts of vegetation such that the tree savanna of the Sahel proper lies between the 200 and 400mm isohyets, with the grass steppes of the sahel-sahara to the north and the shrub savanna of the sahel-sudan to the south. The area of the Sahel is estimated to be between 1.5 and 2.5 million square kilometres (Boudet 1986, Le Houérou 1986).

1.3 Countries in the Sahel

In West Africa, the Sahel extends over about 2 million square kilometres, and makes up about 7% of Burkina Faso, 27% of Senegal, 32% of Chad, 39% of Mauritania, 40% of Mali and 50% of Niger (ACOS 1984). These six countries, together with the Gambia and Cape Verde, have formed the Comité inter-Etats de Lutte contre la Sécheresse au Sahel

=====

(CILSS, the Permanent Interstate Committee for Drought Control in the Sahel).

While a considerable part of Sudan, Ethiopia, Somalia and Kenya also exhibit similar vegetation, landscapes and landuse, and experience similar rainfall regimes, the arid lands of these countries are not normally included in the term "Sahel". However, for the purposes of this and other GEMS Sahel Series reports, the term is used to mean the ecologically identifiable belt of thorn savanna stretching across Africa from the Atlantic to the Red Sea and the Indian Ocean (see Frontispiece).

The climate and ecology of the semi-arid lands of north-west India are similar to that of the Sahel (Goudet 1986), while the ecology of the semi-arid lands on the northern rim of the Sahara is clearly different (Le Houérou 1977).

1.4 Brief description of the ecology of the Sahel

Soils are generally iron-rich, and in the north are sandy, in the south gravelly. Much of the sands of the Sahel are composed from ancient ergs, vast inland "seas" of dunes, relics of past transgressions of the Sahara to the south of its present limits.

Vegetation is sparse, rarely covering more than 20-40% of the ground, even in areas that are not degraded. It consists principally of shrubs, undershrubs and annual grasses. With this much cover wind erosion from areas of naked earth is balanced by sand deposition around the bases of perennial plants (Le Houérou 1976a). In the lateritic areas tall shrubs and small trees make up dry woodland, many of whose species are drought-deciduous.

Acacia thorn savanna characterises the sahelian subzone. Woody plants typical of the sandy soils of the subzone include *Acacia tortilis/raddiana*, *Acacia senegal* and *Commiphora africana*. On the silty soils in this subzone can be found *Acacia ehrenbergiana*, *Balanites aegyptiaca*, *Boscia senegalensis* and *Cordia sinensis*. *Acacia seyal*, *Acacia laeta* and *Ziziphus mauritiana* are also typical of the subzone.

Further south, in the sudano-sahelian subzone, the savanna is dominated by Combretaceae. On sandy soils typical woody plants include *Combretum glutinosum*, *Guiera senegalensis* and *Sclerocarya birrea*. The shallow soils over hardpan support *Combretum micanthrum* and *Pterocarpus lucens*, while woody plants common on the other soils of the subzone include *Acacia seyal*, *Combretum nigricans*, *Combretum aculeatum*, *Combretum ghazalense*, *Adansonia digitata*, *Sterculia setigera*, *Grewia bicolor* and *Bombax costatum*.

Land use is principally pastoral, and traditionally transhumant. Most livestock rearing in the countries bordering on the Sahel takes place in these woody regions of semi-arid lands, partly because the southward expansion of livestock is limited by the tsetse fly (Laurent 1986).

Increasingly, intermittent rainfed agriculture is attempted in the area, especially in the south and in more humid interdune hollows. Given the unpredictability of the rains, crops frequently fail.

2 Vegetation of Sahel

The Sahel grades from open steppe in the extreme north, through bush steppe, to wooded savanna in the south. In the southern part of the Sahel, between the 300mm and 600mm isohyet, woody plants cover between 3% and 10%-20% of the surface. The species composition of the grass layer changes annually, and that of the woody plants changes frequently with the changing environment (Penning de Vries 1982).

2.1 Ecology of woody plants

Sahelian woody plants often have a deep central tap root, which may be as much as 25 metres long. The other roots are equally long, but are arranged horizontally, often going no deeper than 20 centimetres, so that they collect water from a wide superficial area around the tree (Boudet 1986). Woody plants are thinly spread on the dune crests and slopes, and densely clumped in depressions, their density corresponding to the capacity of the ground water to support them.

In the north the photosynthetic efficiency of grass in the open is about 0.3%. Under woody plants it rises to 1.4% (Le Houérou 1980). Under natural conditions this normally means that by comparison with open areas, grass production under trees is much greater (Bille 1978), and remains greener longer (Hiernaux and Diarra 1978). However, since trees and grasses are in direct competition for water, the supplementary growth of the grass layer beneath trees is only made possible by humid local conditions. In many areas the reserve of water in the soil is so small that the annual grasses use it completely and woody plants cannot then survive the dry season. This results in vast steppes empty of woody vegetation in very dry areas (Bremner 1982a).

In areas of higher rainfall, trees benefit the livestock by providing forage during much of the dry season. Unfortunately for the livestock, much of the protein in the forage is rendered unavailable by high levels of tannin (Bremner 1982a), but without this protection the woody plants would come under increased pressure, and, certainly, suffer increased mortality.

Trees flush and bud even before the rains begin (Giffard 1974) and begin to produce new biomass as soon as the rains start. They go on producing up to the end of the rains. Since water limits growth almost everywhere in the Sahel, productivity can be greatly influenced by local water balance and plants benefitting from runoff produce far more than those nearby (Bremner 1982a). In the south, where nitrogen and phosphorous limit production (Penning de Vries 1982), local water flow presumably plays a lesser role, confined to the distribution of these elements, in determining productivity.

=====

The heat and drought during the dry season is often intensified by the Harmattan, a hot dry wind, frequently laden with dust and sand, blowing from the desert. This harsh climate has exerted a high selective pressure on the plants of the Sahel, leading to the present formation of species resistant to dessication. Their adaptations are various and may take the form of thick leaf cuticles (Table 1a) and small stomata, of drought-dehiscent leaves, of deep central taproots and coronas of widely-spreading superficial roots, or of many other designs for survival. Many plants protect themselves from herbivory by producing tanins or toxins, or mechanically by spines or with silicone spicules in high concentrations in the leaves. Among the annual grasses, many are adapted to early germination and rapid maturity, and most have seeds which do not necessarily germinate at the first opportunity, thus ensuring the seedstock across several years of poor rains.

The rainfall and soil requirements of nineteen of the more common and ecologically important species of the Sahel are listed in Appendix 1.

2.2 Properties of sahelian woody plants

In the Sahel, woody plants feed both people and their livestock. Many species are also excellent sources of firewood or charcoal, and provide fuel for cooking. Some provide construction materials for housing, tools and fences, and the roots and bark of others are used to make string. Many species have medicinal properties worth investigating.

Thus, of the 40 woody species growing in the Ferlo, roughly 35 are eaten to a greater or lesser extent by the livestock. Leaves or flowers of 5 species, the fruit of 9, and the gum of 2 are eaten by humans, while 21 are considered to have medicinal properties. Ten species produce commercially useful wood, and 3 species are commercially important for reasons other than their wood (Giffard 1974).

Appendix 1 lists the properties of 19 woody species found in the Sahel. As a partial indication of the wide range of uses found for sahelian plants, Table 1b shows eight species with a surprising variety of useful properties.

Apart from their direct use to humans and livestock (Table 1c shows the forage value of several species), woody plants also help to buffer the environment against change brought about by external agents. They act as windbreaks, helping to reduce wind erosion, stabilise dunes, and reduce evaporation from free water surfaces. Their branches provide shade and protect the soil from the direct impact of rain.

It is therefore no exaggeration to say that in the Sahel, the well-being of pastures, livestock, and the pastoralist himself all depend on the health of the woody plants.

3 History of the climate of the Sahel

Early merchants, travellers and explorers were struck by the greenness of the Sahel. Their evidence, and many archeological clues, show that the sixteenth, seventeenth and eighteenth centuries were wetter than the nineteenth or twentieth. Evidence from the heights of lakebeds suggest that the present century may be the driest in more than 1000 years (ACOS 1984).

Nonetheless, on a larger scale, there has been little significant change in the climate of the Sahel in the last 2500 years. This period has been characterised by alternating dry and wet periods on which have been superimposed relatively rapid erratic variations. These "rapid" variations consist of runs of generally moist or dry years which frequently last for one or two decades (ACOS 1984). Dry years are more common than wet ones, especially in the north of the zone, and climatic variability and drought are characteristic of the region (GEMS 1986b, Le Houérou 1976b). Although they are a natural and recurrent feature of the climate, the dry periods severely depress the carrying capacity of the rangelands.

3.1 Severity of the recent drought

Since 1968 the Sahel has suffered nearly two decades of poor rains, with a brief period of relief in the mid 1970s. In this period, there have occasionally been rainfall deficits of 200mm, causing the often irreversible degradation of many populations of woody plants (Goudet 1986).

This drought is comparable with at least six previous droughts since 1400, and indeed the existing evidence suggests that such droughts may strike as many as three times a century (ACOS 1984).

What was perhaps climatically unusual in the drought at the end of the 1960s was its juxtaposition with the relatively high-rainfall years of the 1950s, during which farmers and herders alike exploited lands which in more normal years would be considered marginal. When the drought returned not only did tens of thousands of people and several million head of livestock starve, but the environment sustained considerable damage from the excessive demands placed on it (ACOS 1984, Grainger 1982).

4 History of Man in Sahel

The Sahel was inhabited by hunter-gatherers at least 600 000 years ago. For hundreds of thousands of years the major use of the land by man did not change. More recently, hunting, herding, agriculture, charcoal burning, fire, and the destruction of forest have accelerated so that today no area of the Sahel, no matter how remote, has been left undisturbed (ACOS 1984). The widespread disappearance of woody vegetation in the pastures of the Sahel has been perhaps the most visible symbol of the failure of the world-wide campaign to stop the destruction of forests.

Table 1a: Index of sclerophylly

Boscia senegalensis	1.24
Balanites aegyptiaca	0.82
Guiera senegalensis	0.53
Acacia senegal	0.31
Sclerocarya birrea	0.20
Commiphora africana	0.18

The degree of sclerophylly of a plant is the ratio of the dry weight of a leaf to its surface area, and the higher the sclerophylly the more resistant is the plant to dessiccation (Poupon 1980).

Table 1b: Properties of eight selected sahelian species (ACOS 1984)

Species	Property or use
Aloe barbadensis	pharmaceuticals and cosmetics
Balanites aegyptiaca	kills bilharzia snails and water fleas
Cissus quadrangulus	pest control
Acacia seyal	gum
Prosopis juliflora	gum
Calitropis procera	hydrocarbons
Euphorbia spp	hydrocarbons
Spirulina platensis	edible alga rich in protein

Table 1c: Analysis of major forage species (Baumer 1983): Leaves

	% Dry Matter	% Crude Protein
Acacia raddiana	17.9	17.2
Acacia senegal	88.5	18.2
Acacia seyal	43.8	15.6
Adansonia digitata	91.0	9.6
Balanites aegyptiaca	48.3	40.8
Boscia senegalensis	53.5	25.5
Grewia bicolor	84.2	7.4
Pterocarpus lucens	42.4	19.4
Ziziphus mauritiana	47.1	13.2

=====
The reduction of the woodlands itself threatens the future of the remaining trees, since the removal of woody plants renders the environment more vulnerable to the effects of climatic change.

The dry years have not been entirely responsible for the reduction in woody cover. The imbalance between man and his environment is also largely implicated (Goudet 1986).

4.1 Changes in human ecology

Population data for the area are not reliable (Table 2a), but the human population in the Sahel seems to be increasing at about 2.3% per year. By extrapolating from Le Houérou's (1976b) figure of 5 per square kilometer, the 1986 rural population density in the Sahel can be calculated at 6.3 per square kilometre.

In recent years, there has been increasing pressure on the rural population to find sources of revenue external to their traditional pastoral economy. One of the most obvious has been wood, which can be gathered or cut and sold. In part this need for cash has come about as a result of the increase in rural populations and in the numbers of livestock, with an accompanying decrease in productivity per head as the rains have failed. Maintaining some of the least adaptive aspects of traditional livestock management and abandoning others has further decreased the capacity of the rural inhabitants to survive without external sources of revenue. Finally, in most countries there have been moves to centralise land-management, principally for the production of meat for urban communities.

Thus, apart from the recent temporary climatic changes, there have been both quantitative and qualitative changes in the human ecology of the Sahel which profoundly affect the woody plants. Changes in the climate bring about generally reversible changes in the vegetation. Changes brought about by man's activities tend to be longer-lasting (Breman et al 1982).

4.2 Wildlife

Wildlife and livestock are adapted to eat different plants, and different parts of plants. Some plants depend on various species of wildlife to eat their fruit and transport the seed to other areas. The passage through the gut primes the seed, making it more likely to germinate. The onslaught against wildlife populations by excessive hunting and habitat destruction has reduced the rate at which vegetation regenerates, largely by the disappearance of ruminants and birds needed to prime and transport seeds.

The absence of predators in the forests means that thickets once avoided by herders and their animals can now be freely exploited, with the result that woody plants in these once protected areas suffer the same fate as those in more open areas.

Table 2a: Human populations in sahelian countries

Country	Capital	Date of estimation			Growth Rate(%) est.1985	Most recent census
		1979	1982	1985		
Ethiopia	Addis Ababa	31.8	32.9	33.7	2.7	1976
Sudan	Khartoum	17.9	20.2	20.8	2.2	1983
Mali	Bamako	6.5	7.1	7.7	2.5	1976
Burkina Faso	Ouagadougou	5.6	6.5	6.7	1.8	1975
Senegal	Dakar	5.5	6.0	6.5	3.5	1976
Niger	Niamey	5.2	5.9	5.9	2.8	1977
Chad	Ndjamena	4.4	4.6	4.9	2.3	1964
Somalia	Mogadisho	3.4	4.5	5.5	4.5	
Mauritania	Nouakchott	1.6	1.6	1.8	2.0	1976
Gambia	Banjul	0.6	0.7	0.6	0.9	1973
Cape Verde	Praia			0.3	1.4	1970
Total		82.5	90.0	94.6	2.30	
Excluding Ethiopia, Sudan and Somalia		29.4	32.4	34.6	2.28	

Sources: 1979 estimation: Mendez (1981) citing World Bank Atlas 1980
 1982 estimation: ILCA (1984) citing World Bank Atlas 1984
 1985 estimation
 estimated 1985 growth rate } Gèze et al. (1985)
 date of most recent census }

Table 2b: All humans and livestock for whole Sahel (in millions)
 (Source: Dickey 1983)

	1950	1968	1974	1977	1983
Human population	15.2	23.2	26.6	28.4	33.4
Livestock (TLU)	11.5	24.3	19.5	21.2	24.9

=====

A major source of protein for the rural population, especially in the dry season, is now gone (ACOS 1984). This means that the population must depend more than ever on the products of the livestock, for immediate consumption or for sale to buy cereals.

4.3 Livestock

The distant history of the exploitation of the sahelian rangelands by livestock of the area is obscure; it is only certain that cattle herds were known in the Sahel from about 6000 years ago. Contrary to the common assumption, from that time to the present millennium, a cattle economy was only intermittently important in the Sahel (ACOS 1984).

From the thirteenth to the nineteenth centuries A.D., herders were vulnerable to raiders, and cattle herds were largely absent from the Sahel. Camels were almost the only livestock in the region. During this troubled period the vegetation could regenerate and the lands recover.

With political stability at the beginning of the twentieth century came renewed exploitation. Cattle were reintroduced to the Sahel, and from the early 1940s to the late 1960s cattle numbers in the western Sahel are said to have quintupled (Gallais 1979). The rainfall was normal or high in these three decades, and the annual rate of growth of the herds is thought to have been between 5% and 6%, some 5 times that recorded between 1974 and 1978, when herds increased as the pastures received moderate rainfall in the middle of the drought.

In the last two decades before the great drought of the 1970s, the installation of boreholes in certain parts of the Sahel (see, for example, GEMS 1986e) allowed livestock numbers to increase rapidly, threatening the many old and unmanaged populations of woody plants, whose regeneration was already feeble (Hamel 1986).

As pastoral populations grow, the numbers of their livestock tend to increase at about the same rate. In the Sahel as a whole, including urban populations, the ratio has remained fairly constant at about 3 TLU tropical livestock units (TLU) for every 4 humans (Dickey 1983). In purely pastoral economies, each person needs about 3 to 4 TLU to survive (Le Houérou 1976b).

Present animal populations are far beyond carrying capacity (Le Houérou 1976a) especially in dry years (Le Houérou 1980).

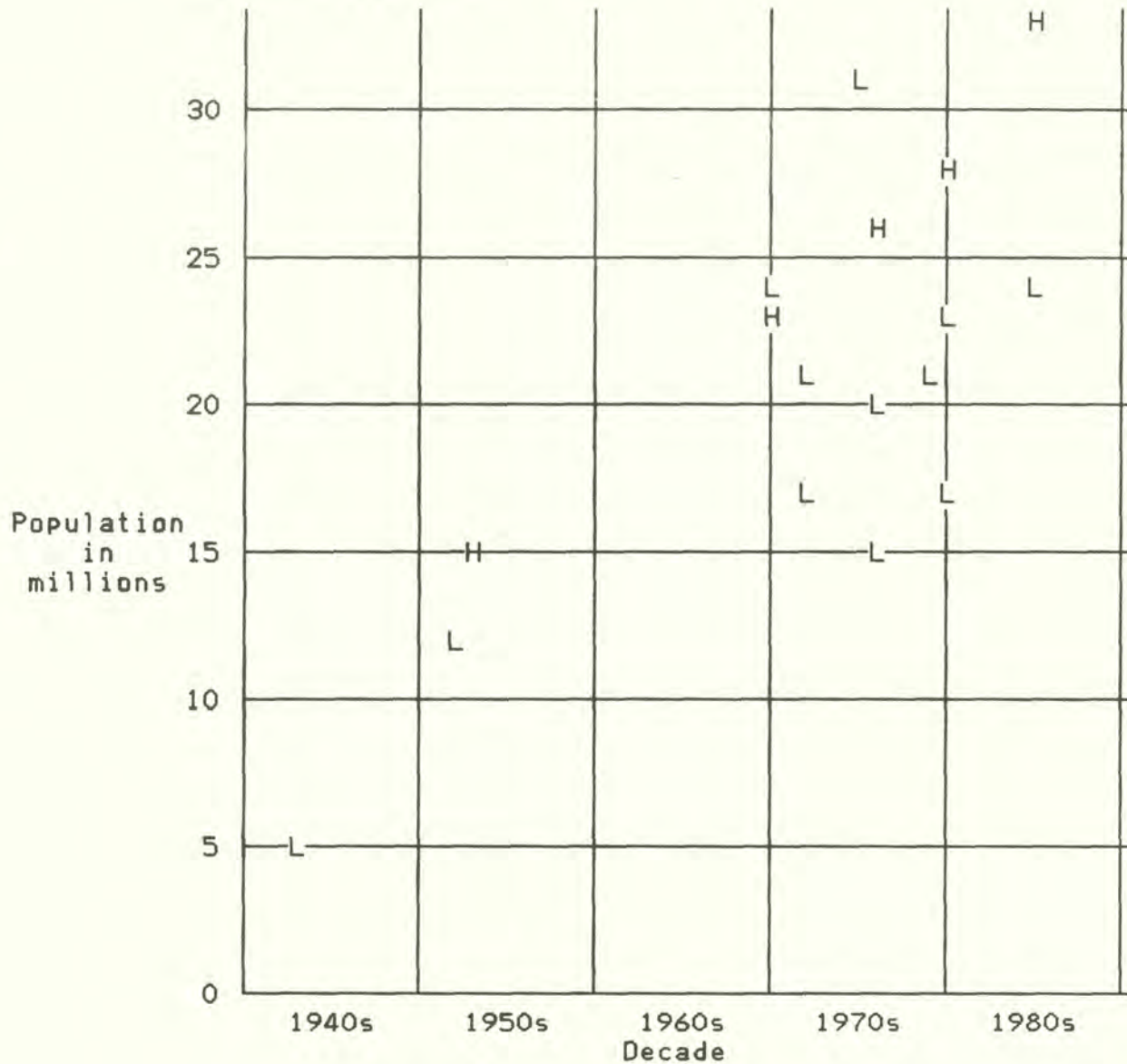
Estimates of the number of head of livestock in the Sahel (Table 3) vary even more widely than do human population figures (Figure 2). There are now thought to be some 25 million TLU in the Sahel (Dickey 1983). The domestic species making up this figure are thought to be some 13.7 million head of cattle, 51.5 million smallstock, 4.1 million dromedaries, and 2.4 million donkeys and horses.

In drought years in the Sahel the livestock removes the aerial parts of the grass-layer plants well before the end of the dry season. Even if the rains return before further damage occurs to the plants, the loss of the grass layer encourages erosion, sealing of the soil and increased

Table 3: Cattle numbers (in thousands) by country

	Source: Gallais 1979				Le Houérou 80	
	1940	1970	1974	1978	1950	1973
Sudan					5260	15200
Chad	933	4630	3250	3600	3807	4100
Mali	1174	5300	3640	3800	3471	3700
Niger	754	4200	2200	2850	2239	3000
Mauritania	850	2100	1175	1200	812	1900
Senegal	440	2615	2318	2500	916	1750
Burkina Faso	491	2900	2300	2600	865	1600
excl Sudan	4624	21745	14883	16550	12110	16050
incl Sudan					17270	31250

Figure 2: Evolution of human and livestock populations in the Sahel (various sources)



Key: H estimated size of human population
L estimated size of livestock populations

Estimations of the number of livestock in any sahelian country are inexact. This is illustrated in particular by the wide range of values quoted for the mid 1970s (from 15 to 31 million).

runoff, with the result that ground water is reduced (Boudet 1986). If, on the other hand, the rains do not come, the removal of the grass layer forces the animals to survive by feeding on the woody plants. In some areas the livestock may be sufficiently hungry to eat shade trees in settlements and even the living trunks of baobabs (Rochette 1986). Away from settlements the livestock concentrate in areas where pastures are still good and woody plants still living. This concentration of grazing and browsing pressure rapidly removes the remaining grass layer, young branches and seedlings (which also suffer from trampling), and exceeds the capacity of the woody plants to produce fodder (Boudet 1986). If excessive livestock pressure is not removed, many species stop producing seed and regeneration ceases.

The resulting progressive loss of the woody vegetation further increases wind erosion. The intense trampling near thickets of woody plants leads to destruction of the upper soil horizons by compaction or pulverisation, depending on the soil. With the onset of the rains the soil surface is sealed, and much of the water runs off into depressions. In places this causes water tables to be temporarily higher during the wet season, which may salinize the upper soil. In general, however, decreased infiltration leads to an increase in evaporation, a reduction in the replenishment of subterranean water reserves, and further stress on the remaining woody plants. These stressed plants are less resistant to the assaults of man and his livestock (Rochette 1986).

In some parts of the Sahel the cattle are left to wander and forage where they will. Many of them remain in the pastures day and night, coming to water every second or third day. Unweaned calves are kept in the villages until the herd has left, so that the milking cows will return to suckle their calves and be milked. The following morning they are then led into the pastures from the settlement and left to forage for themselves. This system of range non-management, and other facets of poor herd control, has greatly increased the ecological impact of the livestock. It is particularly damaging for woody plants; any hope of developing the woody plant cover is subject to the chance arrival of a herd of domestic stock (Goudet 1986).

If cattle damage the environment, sheep and goats are by no means exculpated. The camel has some significant advantages over other livestock, among which is the reduced environmental impact that it has on degraded pastures (see Field 1979 and Stiles 1983 for reviews).

Bad though it is, the influence of livestock on woody plants is less devastating than are man's actions in support of the animals (Breman et al 1982). In particular, herders cut woody plants for temporary pens and for fodder. Perhaps in the past herdsman would prune in such a way that the tree survived, but today the young shepherds have less training and more urgent need, and cut excessively, leading to the weakening or death of the tree (Rochette 1986). The practice of pruning trees to excess, which is especially prevalent in dry years, has led to the wholesale removal of woody cover over vast areas (Le Houérou 1976b).

4.4 Agriculture

=====

In the last few hundred years agriculture has rarely been practiced in the Sahel, since lands to the south were far more favourable to growing crops and population densities were sufficiently low for there to be no need to attempt what is still a highly risky enterprise. Recently, at the same time that livestock numbers have increased, there has been a steady encroachment on pastoral areas by marginal, rain-fed agriculture

It is difficult to quantify even the current expansion of agriculture, since the area cultivated varies from year to year as new fields are cleared in wetter years and old ones abandoned to the dust and weeds in the years of poor rains. Very few areas north of the 400mm isohyet are cultivated, except near the rivers Senegal, Niger, Logone, Chari and Nile.

Fields are now thought to cover some 5% of the land in the south of the Sahel, between the 400 and 500mm isohyet, where population pressure and the demand for crops have meant that the best grazing lands are steadily taken over by agriculture, and that the livestock are increasingly concentrated on mediocre, more easily overexploited pastures (Le Houérou 1976b, ACOS 1984). Rochette (1986) estimates that in this part of the Sahel, 3000 square kilometres are cleared for crops each year, on average, in the tragic slash-and-burn system of wandering agriculture.

This high-risk agriculture starts with the wholesale removal of vegetation cover, including the woody species. In areas where cereals such as millet are grown, the farmers automatically cut down all the trees in the fields, because, they say, the quelia needs them to roost in. Careful selective pruning just before the harvest would serve the same ends. The pruned branches could be kept until near the end of the dry season, when their dried leaves would serve to feed the livestock (Boudet 1986). In areas which are to be planted with cotton, farmers clearfell their land in the partly mistaken belief that the trees will compete with the crop (Rochette 1986).

Most woody plants surrounding the settlements are then rapidly consumed in construction and by cooking fires. Agriculture in the Sahel, "having consumed space, then preys upon it" (Marchal 1982).

From the day that they are cleared, the presence of fields means the absence of local fodder species. Throughout their existence fields promote the erosion of the soil, especially by wind in the dry season, and by water at the start of the rainy season. Since little fertiliser (manure) is used in the fields, the fragile soils are further impoverished by the crops, and in the long term, soil fertility declines (Breman et al 1982). As the fields become less productive, and are finally abandoned, unpalatable weed species invade (Le Houérou 1976a), and the impoverished soil produces poor fodder for years to come.

4.5 Improvement in transport

The influence of roads on the environment, even in the most remote areas, is easily appreciated as one passes the bags of charcoal stacked

ready for transport to nearby towns. Settlements have been established along the new roads and railways, and the surrounding forests have been exploited and destroyed to satisfy local needs. Even classified forests and the more distant woodlands, now "served" by new roads and tracks, are not exempted. Large areas of classified riverine forest, especially of *Acacia nilotica*, along the banks of the Senegal and Niger have been lost, often for charcoal (GEMS 1986d), with the result that erosion of the banks and the flood plains has increased (ACOS 1984). Seedlings stand little chance of maturing in these circumstances.

4.6 Cities

Each year the urban population in the Sahel grows by between 4.9% (according to Kurian 1982) and 5.7% (according to Laurent 1986). This is roughly twice the rate of increase (2.3%) of the population of the area as a whole. Certain cities have exhibited spectacular growth rates. For example, Nouakchott had 2000 inhabitants in 1957. Twenty years later it was 67 times more populous, having increased on average by 23% per year in the interim. In the 34 years from 1945 to 1979 the population of Niamey was multiplied by 43 - a mean annual increase of nearly 12%.

4.6.1 Domestic fire

Estimates of the annual fuelwood consumption in arid and semi-arid areas of Africa range from 300 kilogrammes per person, or about 0.4 cubic metres (Foley and Moss 1983), up to 1100 kilogrammes, or roughly 1.6 cubic metres (Le Hou  rou 1976a). Most authors give 0.5 cubic metres as the lower limit on annual consumption per person, corresponding to a daily consumption of approximately 1 kilogramme per person (eg Goudet 1986, Poupon 1986 etc).

Whatever the exact figure there is complete agreement that wood from local trees is by far the most important source of domestic energy in the Sahel (ACOS 1984, Foley and Moss 1983, Poupon 1986 and many others), and that the consumption of wood for cooking is overwhelmingly more important than the use of wood for building, which accounts for less than 10% of the demand (Laurent 1986). In some more humid areas, clearance of woodland for cultivation is the single major source of deforestation, removing more than ten times as many trees as are taken for firewood. This is not the case in the Sahel, where cultivation is severely limited by lack of rain.

Given that the demand for wood is so closely linked to the size of the human population, it will probably follow exactly the increase in population in the area. This means that in the Sahel, demand for wood will increase by about 2.3% per year.

Firewood is inconveniently bulky and heavy. Towns require charcoal. The preparation of charcoal, which has gone on for at least 2500 years, now depends largely on living, or recently killed trees. It has led to the widespread removal of *Acacia tortilis*, and to profound changes in

=====

the ecology of the Sahel (ACOS 1984).

Firewood costs roughly 25 CFA per kilogram, or roughly 17500 CFA (\$35) per cubic metre. Charcoal costs about 35-60 CFA (¢7 to ¢12) per kilogram. Although this may mean that the price of a meal is shared equally between the food and the fuel, costs are nevertheless lower than they would be if the real cost of growing the wood had to be paid by the consumer, and not just by the environment (Laurent 1986).

The fuel needs of such towns and cities as now exist are so much greater than that of villages and settlements of pastoralists that the same solutions cannot conceivably be applied to them. A plantation capable of supplying the needs of a village could be seeded, tended, protected and harvested by the villagers themselves. The same cannot be said for a city such as Niamey, with its population of half a million, or of Dakar, which, together with its satellite city of Pikine, now shelters nearly a million people.

The towns of the Sahel are now surrounded by aureoles of deforested land. Khartoum was once (1955) set in an acacia forest. Today it stands in a desert extending for 90 kilometres in all directions (Boisgallais 1986). Ouagadougou and Niamey are in the centre of similar deserts (Rochette 1986). Dakar gets its wood mainly from the Casamance, a region whose forests come by truckload some 300-500 kilometres to the city each day (Rochette 1986, Hamel 1986, Poupon 1986).

4.7 Extinction of species: extinction of a way of life

Faidherbe, leading an expedition through north Senegal in the 1860's, was obliged to cut his way through the dense vegetation (Barral 1982). Today the same area has about 2%-5% tree cover (GEMS 1986d). Even within living memory, the face of the Sahel has changed almost beyond recognition. Other accounts of journeys in the Sahel, old photographs, and the oral traditions of the people of the area all describe a past in which the vegetation and the wildlife of the Sahel resembled biomes now far to the south (Barral 1982). Morel and Morel (1983) show that in as little as twelve years various bird species have disappeared from the area, to be replaced by others from the north, with a simultaneous reduction in their densities and total biomass. Aerial photographs show that in the 1950s, woody plants covered wide areas of the Sahel that are now denuded (Boudet 1986).

The extent of the deforestation of Senegal has been quantified. In 1964 28% of the vegetation of the country could be described as open woodland, and 31% savanna. By 1983, these two vegetation classes covered respectively 3% and 5% of the country (Boisgallais 1986). This corresponds to a regular removal of 11% of the remaining open woodland and 9% of the savanna each year. In fact, of course, the proportional rate of removal is likely to have increased rather than remained constant over this period.

Areas that could be described as pastureland are thought to have

=====

diminished by 25% throughout the Sahel since the start of the 1968 drought (ACOS 1984).

Of particular note, great forests of *Acacia senegal*, the tree which produces gum arabica, were once found in Mauritania, from which it has now almost entirely disappeared (ACOS 1984). In 1971 Senegal exported 6000 tonnes of gum arabica. A year later only 500 tonnes were exported, and production has remained low ever since (Fleury 1983). At the same time the populations of *Acacia laeta*, a tree producing an inferior but nevertheless economically important gum, have also been devastated. The pastoralists once depended on the gum from these species as a source of revenue (Goudet 1986).

At 34 one-hectare sites in the Ferlo, woody plant densities dropped in the course of three years from a mean of 438 to 376 individuals per hectare (Boudet 1977). In a single year of drought (1972) *Acacia senegal*, *Commiphora africana* and *Guiera senegalensis* were particularly badly affected in the north of Senegal (Poupon and Bille 1974).

The introduction of firearms and the ensuing excessive hunting has reduced the wildlife of the area, once an abundant major source of protein for the local inhabitants, to a tiny remnant. In the Ferlo, an area of some 30000 square kilometres, their populations can be numbered in the dozens rather than the hundreds (GEMS 1986d), and probably include only warthog (*Phacochoerus aethiopicus*), aardvark (*Orycteropus afer*), striped jackal (*Canis adustus*), redfronted gazelle (*Gazella rufifrons*) spotted hyaena (*Crocuta crocuta*), and a relict population of ostrich (*Struthio camelus*).

Constant selective grazing, especially by cattle, has helped to eliminate nearly all species of perennial grasses. Today the grasses of the Sahel are almost exclusively annuals.

Bushfire plays a major part in the ecology of the Sahel. The ecology of fire in the African savanna has been studied principally in the pastures of Eastern and Southern Africa. Here, perennial grasses exhibit fire flush, providing livestock with tender green shoots in the dry season. The grasses compete with shrubs for water, and too-frequent fire can under some conditions cause the invasion of rangelands by fire-resistant bush.

In the steppes of the Sahel, annual grasses die at the end of the growing season, and fire flush is therefore impossible. Hot grass fires, the apparently inevitable companion of livestock rearing, sterilise seeds, destroy seedlings and sometimes adult woody plants, eliminating all fire-fragile species, and hence greatly reduce and simplify the vegetation. They consume fallen branches, remove nitrogen from the soils and release it to the atmosphere, and otherwise damage the ecology of the soil (Bremner et al 1982).

In Africa alone, bush fires are thought to destroy 80 million tonnes of fodder each year (Le Houérou 1976b). This wastes food for livestock, in a land where even in drought the animals die of hunger and not thirst. At the same time it forces the livestock off the burnt, useless areas,

=====

to graze and browse on unburned areas, increasing the load that these pastures must support.

In sum, in the past century the area has experienced a high rate of extinction of species of both animals and plants. This reduction in the diversity of the area, and especially the disappearance of species of ecologic, economic or alimentary importance, directly menaces the long-term survival of the system, since species diversity helps to maintain a dynamic equilibrium and prevent the collapse of the ecosystem (ACOS 1984).

Should this reduction in species diversity among woody plants continue, much of the remaining bird and insect life will also disappear. In the north the removal of woody plants will result in vast sandy plains whose grass cover will become steadily less able to stabilize the dunes. In the south, exposed lateritic hardpan will become more widespread and the area will gradually lose all capacity to support either livestock or man. While the stability of the environment would therefore tend to increase if the woody plant cover were to be restored, deforestation compromises the alimentary future - and even the present - of the Sahel (Boisgallais 1986).

4.8 Conclusion: the consequences of environmental changes

Livestock helps to suppress woody vegetation permanently, especially in areas where man also uses the woody plants, but is not the only cause of degradation (Bremen et al 1982).

If human and livestock distributions corresponded to that of the woody plants in the Sahel, we might expect that very nearly all the available foliage, especially that within reach of the animals, would be consumed, and much of the annual production of wood removed. These distributions do not, of course, coincide; in fact there is some evidence that while livestock and human population densities are somewhat correlated in pastoral regions, they are both negatively correlated with woody plant cover (GEMS 1986d). Some areas are therefore hardly used at all while others are heavily over-exploited. In Poupon's (1986) expressive phrase, the people of the Sahel are eating into their capital of woody plants.

The marketing of livestock removes them from the system; it also exports soil fertility. More directly, livestock mechanically disrupt soils, although they have limited impact on sandy soils.

Selective cutting and grazing tend to remove the more useful species first, before the complete destruction of the woodland. A change in species composition away from palatable and towards unpalatable species, and a simultaneous reduction in the percentage cover by woody plants, result in a diminution of the potential production of the area (Vanpraet and Van Ittersum 1983).

5 Drought

5.1 Effect of drought on the woody plants

Although the quantity of rain falling in the year influences the species composition of the pastures, its distribution in time is equally important. Steady rainfall favours southern species, while long dry spells favour northern ones. A series of dry years can eliminate not only southern perennial grasses and those southern annual grasses with long growing cycles, but also southern woody species (Cissé and Breman 1982).

Repeated dry years result in the diminution and the disappearance of superficial and subterranean water sources, and, given the need of woody plants for water throughout the dry season (Breman 1982a), the sudden and simultaneous death of whole populations of woody plants. The loss of the canopy provided by woody plants makes it difficult for the grass layer plants to survive (Boudet 1986), and with the removal of all or part of the herbaceous layer the soil suffers accelerated wind and water erosion. In areas with surviving woody plants the removal of soil exposes roots and reduces the food potentially available to them, further threatening their lives. Even without the action of livestock, therefore, the environment suffers considerably as a result of the unfavourable climate.

The drought hit *Pterocarpus lucens*, *Acacia raddiana*, *Commiphora africana* and *Euphorbia balsamifera* particularly hard, with 50%, 30%, 20% and 10% (respectively) of their pre-drought populations in the north of the Sahel dying before the short-lived respite in 1978. Further south the trees which suffered most severely from the drought were *Terminalia avicennoides*, *Pterocarpus lucens* and *Combretum glutinosum*, with mortality rates of 85%, 50% and 35% respectively (Breman et al 1982).

The reactions of adult trees to changes in their environment are sometimes carried over into subsequent years. For example, severe defoliation in any one year may lead to a halving of the wood production in that year and a residual loss of 25% in the following year (Piot 1983). The environment may therefore continue to suffer from earlier episodes of overgrazing even after the climatic conditions improve.

Most of the irreversible steps towards desertification thus occur discontinuously during droughts when vegetation is under heavy grazing pressure and has no chance to regenerate. Intermittent periods of high rainfall may mask the general trend.

5.2 Effect of drought and famine on rural economy

In times of drought, famine does not strike indiscriminately at rich and poor people alike. There are proportionately many times more deaths in families with low incomes, just as there are in countries with low incomes, than there are in those with high incomes (ICIHI 1985). During the famine in the 1970s the poorer livestock owners in the Sahel were forced by hunger to give away their animals at knock-down prices.

Richer herdsmen and urban merchants could easily afford to buy these animals, with the net result that there was a marked shift of the ownership of livestock from the small herdsman to urban merchants (ICHI 1985, SODESP 1982).

When the drought ends, therefore, and as agricultural and pastoral production revives, poor people do not necessarily stop starving. They may have been obliged to give up their means of making a living. These destitute people, like Africa itself, reap the consequences not just of the weather, but of poverty.

6 Production of woody plants

There have been few studies of the productivity of natural formations, but the existing data suggest the following rough estimates:

The density of woody plants on a healthy steppe in the Sahel is usually between 100 and 400 individuals per hectare. This corresponds to between 1000 and 8000 kg of above ground biomass (Le Houérou 1980). The accessible annual wood production of the Sahel (that is, the production of the semi-arid lands of north Africa, excluding 5%-10% contributed by the maghrebian countries north of the Sahara) is of the order of 260 million cubic metres (Laurent 1986).

While it is difficult to evaluate the woody production of stems and branches, it is a great deal harder to evaluate leaf production, and still harder to evaluate the production of foliage useful to livestock, because the time at which the leaves are eaten depends upon the species and the state of the pastures. Furthermore, the position, and especially the height, of the leaf on the plant plays an important part in determining whether or not it will be eaten. The problem is still further complicated because otherwise inaccessible leaves may be cut down by the herder.

As a rough guide, and given an "average" rainy season, the annual production of leaves is about one third to one half of the annual woody production. At the height of the growing season leaves make up 2-6% of the above-ground weight of the tree. Small branches contribute 8-20%, and the main branches and the trunk 75-90%. The larger the tree, the smaller is the relative contribution of the leaves and small branches (Bremner 1982a).

With less than 400mm per year, the annual production of forage by woody plants is very low, of the order of 50 to 60 kg/ha. Above 400mm, woody plants produce roughly 1.5 kilograms/hectare more for each extra millimetre of rain (Bremner 1982a), but production rarely goes above 500 kilogrammes per hectare per year (Le Houérou 1976b), and it is more usual to expect a hectare to produce between 80 and 300 kilograms of forage, including leaves, twigs and fruits, every year (Le Houérou 1980, Kane and Dutrieux 1983).

6.1 Sustainable use of woody vegetation: The cold equations

Of course, not all of the biomass produced by a plant can be removed without damaging or killing it. In the Sahel, roughly 1.5% of the standing volume can be taken off each year without damaging the tree (Poupon 1986), that is, something under half of the annual production.

A square kilometre of natural woodland in the Sahel produces, at best, about 50 to 100 cubic metres of wood per per year (Table 4). Each rural inhabitant of the Sahel consumes at least 0.5 cubic metres of wood per per year (section 4.6.1), thus using equivalent of the total production of 0.5 to 1.0 hectares of natural woodland annually. By 1985, the human population was growing at the rate of 2.3% per year, and had reached some 94.6 million (Table 1a). The annual needs in fuel wood of the peoples of the Sahel are now the equivalent of the total annual production of about 0.87 million square kilometres of natural woodland. In terms of sustainable yield, these figures double, as we have seen, to about 1.7 million square kilometres.

The proportion of the diet of livestock that is made up of woody plants depends in part on the animal species and in part on the season - consumption increases with the length of time into the dry season. For the more numerous domestic species, over the course of the year about 20% of the diet of cattle, 25% of that of sheep, and 60% of that of goats is taken from woody plants (Blancou et al 1977, Sharman and Gning 1983). Assuming that each TLU eats 6.25 kilograms of dry matter per day, or about 2.3 tonnes per year, the animal population of the Sahel consumes of the order of 11 million tonnes of fodder from woody plants each year. These figures suggest that livestock consume the total forage produce of some 0.4 to 1.4 million square kilometres each year.

Spread evenly over the whole 2.5 million square kilometres of the area, this combined demand could be met by between two thirds and all of the total production of the woodlands of the Sahel. As has already been pointed out (section 4.6.1), the demand is of course not evenly spread, and in the more populated areas offtake from woody plants is greater than annual production, leading to ineluctable deterioration of their potential production (Hamel 1986). There is thus a glaring imbalance in the production and the consummation of wood in many parts of the Sahel. Often the harvest of wood involves cutting whole living branches, or even whole crowns (Rochette 1986), thus mutilating or killing the trees. Le Houérou (1976) estimates that in the long term, and given the growth and regeneration typical of the woody plants of the Sahel, each person destroys the equivalent of all the woody plants growing in about one fifth of a hectare each year. This means that in 1976 the woody cover equivalent to that covering some 67 thousand square kilometres is destroyed every year. By 1986 this figure must be approaching 90 thousand.

Despite this alarming state of affairs, there is no evident shortage of wood or charcoal in the cities (Laurent 1986); the resource is not being husbanded. Instead, the patrimony of the forest is being mined.

Even the excessive collection of dead, fallen branches or trees has adverse effects on the environment. Fallen logs help, however slightly,

Table 4: Annual productivity of natural woodlands and plantations
(cubic metres per hectare)

Biome vegetation	Type of woodland			
	Natural		Plantation	
	min	max	min	max
Sahelo-sahara Sahel	0.05	0.1		1.5
bush steppe	0.10	0.5		
Sudano-sahelian tree savanna	0.50	1.0	1.5	3.0
Sudano-guinean open forest	1.00	1.5	5.0	6.0
dense forest	2.00	4.0		

Source: Laurent (1986), Goudet (1986)

=====

to prevent further deterioration in the soil surface, and as they slowly rot, nutrients are returned to the soil.

7 Rehabilitation

A strategy for the rehabilitation of the Sahel must succeed in protecting the fragile and nutrient-poor soils, where possible restoring and improving soil fertility, and protecting trees, probably by reintegrating them into production systems and into land use planning. For the sake of the stability of the ecosystem there is a need to preserve as wide a spectrum of woody plant species as possible, and that the Sahel has recently experienced the disappearance of many species (section 4.7), management should be directed at least in part at preserving species diversity (ACOS 1984). These aims are inter-related (ICHI 1985).

In the north Sahel, and throughout the Sahel on skeletal soils, the struggle against desertification is probably lost; the degradation is irreversible. All that can now be done is to attempt to protect the environment near population centres, partly by encouraging the frugal use of water from superficial aquifers and the careful protection of the remaining natural woody cover (Boudet 1986).

In much of the central Sahel there is hope of limited rehabilitation of the pastures. On deep sandy soils, once the cause of degradation is removed regeneration is often rapid, and degraded ecosystems can be rehabilitated (Le Houérou 1976b). In areas where the soil is severely compacted, subsoil ploughs could be used to encourage infiltration. The effect of such ploughing is short-lived and should be undertaken just before the rains. In selected areas runoff could be reduced by building small barriers from stones and logs, and infiltration encouraged by scooping shallow basins or troughs out of the top of the soil. At the same time, livestock could be kept out of deforested areas near human habitation during the growing season and the early dry season in order to allow woody plant seedlings to establish themselves (Boudet 1986).

In the extreme south of the Sahel, where mean annual rainfall exceeds 500mm, the environment can survive major changes in vegetation cover without permanent damage (Breman et al 1982). Rehabilitation consists largely of protecting chosen areas of woodland from exploitation for several years to allow recovery and regeneration.

7.1 Range improvement

Actions designed to improve the condition of the pastures are known collectively as range improvement. Also grouped under this term are actions designed to increase the productivity of the system. Unfortunately, all too often, "range improvement" has meant the installation of boreholes in areas where there was previously no surface water.

=====

In the north of the Sahel, where the mean annual rainfall is less than 300mm, woody plants cover roughly 3% of the land. Where there are few or no water points the vegetation is stable and relatively undisturbed, but permanent water points radically alter the balance between vegetation and livestock. All areas within reach of water are pastured (Breman et al 1982), and boreholes have made it possible for concentrations of livestock in the dry season to be at densities 3 or 4 times the carrying capacity of the land (Le Houérou 1976b). In Somalia, after the drought of the 1970s, there was in general very little range deterioration, except around those areas where "range improvement" projects - that is, boreholes - had been established (Box 1983).

"Range improvement" has also been used to describe great irrigation schemes near the major rivers of the Sahel, which clear thousands of hectares, often far beyond the strict necessity. Even small and medium irrigation schemes sometimes exhibit this unreasoning impulse to clear-fell trees (Rochette 1986), thus becoming the cause of range destruction.

A third example of "range improvement" gone awry is the plantation of inappropriate woody plant species in reforestation projects, which turns tree planting, which was to have been the cure, into an added cause of desertification. For example, some eucalyptus species threaten to become an ecological menace in water-deficient regions of India, because, in years with less than 1000mm of rain, they create deficits in soil moisture which kills indigenous woody plant species by robbing them of vital ground water (Shiva and Bandyopadhyay 1986).

Clearly, range improvement must be seen as part of management policy designed to spread sustainable grazing over the pastures, and should be undertaken only when it is designed to fit in with the ecological, social and economic characteristics of the land (Box 1983). One of the first requirements for any range improvement project in the Sahel is for greater control of foraging livestock (ACOS 1984), without which the tree cannot be integrated into the production systems of the Sahel (Goudet 1986).

7.2 Reforestation and Plantations

On their own, reforestation programs are of little or no use. They should always be part of larger conservation efforts, and should really be called "revegetation" rather than reforestation (Weber et al 1977).

Plantations are principally needed for firewood. Ideally, plantations should be centred on the village and family-based, so that each family has responsibility for, and rights over, clearly defined plots in the plantation (Goudet 1986). At the village level, it is possible to establish several stands which together provide a continuous supply of firewood by poldering the trees in a given stand every twelve to twenty years, and rotating through the stands. With this scheme, a village of 500 people would have to manage a series of stands amounting to roughly 500 hectares (Laurent 1986, Goudet 1986).

=====

The manual written by Weber et al (1977) is highly recommended for much practical advice on siting and establishing nurseries and plantations, choice of species and for its illustrated and annotated list of West African woody plant species. However, the conditions in the Sahel are, unfortunately, not favourable for plantations. In particular, the soils are generally poor, and plantations need soils good enough for cultivation, which is to say, the best soils available; this is, not unnaturally, difficult for the rural populace to accept. Furthermore, restoration of the woody plant cover can only be achieved by decreasing the offtake in forage, gum, and firewood (Bremen 1982b), which means that the rural populace must be deprived of part of a source of livelihood if the woodlands are to recover.

7.2.1 Costs and areas

In the Sahel, some \$11.2 million were invested in woodland-related projects between 1972 and 1982 (Weber 1983). Little of this money was invested in the effective management of existing forests; most went on fuelwood plantations (ACOS 1984), many of them monospecific. In the Sahel as elsewhere, monospecific plantations are inadvisable, for well-documented reasons too numerous to discuss here (Goudet 1986).

This \$11.2 million allowed for the reforestation of some 160 square kilometres (ACOS 1984), that is, some 0.005 to 0.01 of one percent of the Sahel. Over the 10 year period (1972-82), an average of 16 square kilometres were reforested each year, at an estimated initial cost of \$70000 per square kilometre. One hectare of eucalyptus plantation costs between \$500 and \$700 to plant and bring to maturity, 5 or 7 years later (Goudet 1986).

Clearing trees and cutting branches is a daily event in most rural areas, while planting trees is unusual. Thus, at the moment, about ten times as much land is cleared as is planted each year (Rochette 1986), and the rate at which the forest is lost will easily outstrip the rate at which new plantations are established for the foreseeable future (ACOS 1984). The Club du Sahel estimates that the "efforts deployed for reforestation ... are 50 times too small" (Grainger 1982).

7.3 Agroforestry

The ancient practice of planting trees and crops in the same field is now called "agroforestry". The complaints of the farmers that trees compete for water and nutrients with the crops and harbour pests, especially birds, may be in part true, for some species of tree. However, their crops will almost certainly benefit from the shelter and shade provided by trees, and a judiciously chosen species will enrich rather than deplete the soil. The chosen species of tree should be drought-resistant and multipurpose, and, since farmers need practical economic incentives to plant trees, preferably yielding some product that can be translated into cash.

=====

The requirement that the products of the tree can be converted into cash is never to be overlooked. Cultivating trees is a long and labour-intensive business. In many cases, a dilemma is faced by the family which wishes to plant a tree - the person who looks after it cannot leave on the annual migration to look for temporary jobs, and there is therefore less money for the family (Clément 1986). A tree which can produce forage, fruit and other products is particularly attractive.

Acacia senegal is of particular interest in agroforestry schemes because it not only produces gum arabic, which can be marketed, but also gives browse, wood for both tools and fire, and charcoal; its flowers are used by bees for honey, its bark produces tannin, and its long surface roots not only can be used to make fibre but also help to stabilise the soil and maintain soil ecology. Farmers may spontaneously plant this sort of tree, provided that there are no legal uncertainties about ownership and exploitation rights (ACOS 1984).

Reforestation along the edges of fields could be brought about by using the accumulated faeces of smallstock, which are kept in pens at night. Their droppings accumulate to such an extent that the floor of these parks are sometimes more than a metre above the surrounding ground. The seeds of many sahelian woody plants germinate better after passage through the gut of a ruminant. These faeces could be taken to protected areas and dug into the ground to encourage the germination of palatable woody species (Boudet 1986).

7.4 Shelterbelts

A shelterbelt is a large windbreak made of suitably massive trees, combined with smaller species which prevent the tunnelling of wind under the lower branches of the biggest trees. The effectiveness of a shelterbelt depends on how dense the vegetation is. Each belt should be constructed of a mixture of local species chosen so as to give both height and density to the wall, and to provide a variety of plant products that can be continuously exploited (ACOS 1984).

On the downwind side of a shelterbelt wind speed is reduced and hence wind erosion and potential evapotranspiration also diminish. The shade helps to reduce soil temperature, which coupled with a slight increase in atmospheric humidity, increases the efficiency of rainfall. This is further improved if the shelterbelt is so positioned as to reduce runoff and water erosion, with a resulting improvement in soil structure, initially manifested as an increase in permeability and in the capacity of soil to retain moisture. The combined effect on the soil, over the course of the years, is to increase the organic matter in the soil, and to encourage the revitalisation of the soil flora and fauna. With the improved biological activity of the soil, the productivity of the ecosystem increases (Le Houérou 1976b).

Shelterbelts promise to contribute to rehabilitation programmes and in the stabilisation of agricultural and livestock production in the Sahel. However, if a shelterbelt is to do its job, livestock must be kept away. This is an impossible requirement if livestock are not herded (ACOS

1984), and imposes a great strain on the integrity of the herdsman even when herds are controlled, especially in times of dearth.

8 The rôle of humans in the rehabilitation of the Sahel

The woodlands and forests of the Sahel are in grave difficulties. It is pointless to attempt to restore them to health or to reintroduce trees to deforested areas by specific, short-term actions. An integrated, sustained programme of environmental rehabilitation is unavoidable. This programme will involve the establishment of new organisations, new links between established organisations, new techniques, and bold new legislation (Hamel 1986). It will demand all the goodwill, energy, responsibility and imagination of everybody concerned.

8.1 Education

Before we can hope to stop deforestation at least three psychological barriers must be overcome.

Firstly, for many rural people, forests are synonymous with backwardness. For these people, clearing woodlands for cultivation appears to be progressive.

Secondly, wood has long been considered a free, and therefore worthless, resource. Since they are used to the idea that trees are a "gift of God", the rural population does not always realise sufficiently early that the trees are overexploited. When they do realise, it is often too late; there is by then a pressing need to plant new trees in what has become an unsuitable, degraded environment (Clément 1986).

Thirdly, governments and aid agencies are often not particularly attracted to ecological development, because, unlike more conventional development projects such as boreholes, dams and dispensaries, to the casual onlooker rangeland which has recovered its health provides no visual result to show the worth of their investments (Bruhjell 1985).

To start with, the rural population must be reminded that the tree can be a direct or indirect source of revenue, and should not just be regarded as a source of leaves or fruits gathered from natural woodland (Goudet 1986). Subsequently, they must be educated in the causes and effects of the degradation of the environment (Clément 1986).

Primary school is the ideal place to start the necessary process of education. What better way to restore the tree to a position of respect in the minds of the rural inhabitants of the Sahel than lessons about the tree and the soil in a school shaded by healthy trees, scrupulously looked after, grown from a nursery run by the children themselves? The children could also be encouraged to plant and care for shade trees, and trees bearing sought-after fruit, such as the lime or lemon, near their houses.

=====

The rural population will understand that cutting down trees is not necessarily wrong or destructive, but they must be taught that deforestation comes about when exploitation is unplanned and reckless. Conversely, planting trees must never be seen as the only way of combatting the degradation of the environment. Trees and forests must not be protected for themselves but because they are seen to be part of good land-management practice and part of the means by which the land can be improved (Clément 1986).

8.2 Rural support

Nothing lasting can be done to protect and improve the woodlands without the willing cooperation of the countryman (Clément 1986). The heart of the problem is therefore to create a new rural dynamism. People must be party to resolving their own problems and in devising schemes leading to their solution. Too often in the past development projects have been conceived and planned out of context, have used staff who were not integrated into the community, and left the rural inhabitants aside as helpless spectators rather than giving them their share of responsibility (Rochette 1986).

Talking to people about rehabilitating the environment will have no effect on their willingness to cooperate unless they can make the link between the degradation of the environment and the deterioration of the quality of their lives. They must be persuaded of the real and immediate benefits that their work will provide them. However, the technique of bribing them by giving goods in exchange for services is doomed if they can make their cooperation conditional on such material "aid" - as they most certainly will (Clément 1986). As an example, it is worth quoting Grainger (1982:52), writing about a dune-fixation project in Niger: "In 1983 CARE will stop paying the wages of villagers who now guard the trees from camels and goats.... CARE hopes that the villagers will continue to guard the trees on their own, but admits that they probably will not."

People are motivated to the extent that they can see immediate benefits, and will cooperate to the degree that the results of their work will help to meet their needs. Production of woody plants then becomes the result of the will, the understanding, and the vested interest of the rural population (Clément 1986).

Village-level projects, organised and run in cooperation with the villagers, often help considerably to reduce their dependance on the outside for food. Thus, for example, in a village in the Department of Podor in Senegal a group of women set up a collective vegetable garden and a small reforestation programme. After three years, they were selling the surplus of their garden to neighbouring villages, and had noticed that the trees were not only a long-term investment but were already acting as a windbreak, helping to keep the soil moist, and shading the vegetables from the direct rays of the sun (Boisgallais 1986).

=====
The techniques used to rehabilitate the woodland must be simple and easily applied by the rural population, and where possible should be based on traditional knowledge and practices. Traditional values should also be appealed to in order to reinforce the individual responsibility towards his or her community. Those responsible for the dissemination of these techniques must understand not only the local ecology but also the psychology of teaching new methods to older people (Clément 1986). Furthermore, projects that are seen to help poor people may be met with hostility by the more powerful members of the rural community, and skills of diplomacy and persuasion will also be needed.

The government would also have to train local experts, giving them the necessary skills and knowledge, and providing the technical means and the initial plant stock, adapted to local conditions and needs, and the solid political support necessary to encourage village-level developments to sustain their efforts (Dommergues 1986, ICIHI 1985). At the same time, it would have to give to the population the responsibility for the protection, the management, and the exploitation of the trees, both in plantations and in natural woodland (Clément 1986).

Thus, in summary, if reforestation projects are to have any significant impact, the forestry services must abandon their monopoly. The rural population must be given the power to make decisions, and must have access to the necessary technical means and the finance for the job, with the assurance that they will be the beneficiaries of the scheme (Clément 1986).

8.3 Political factors: legislation

There are no miraculous solutions to these long-term problems, and it is illusion to believe that the rural populations will of their own accord assume responsibility for the protection, management and replanting of trees (Clément 1986). If village-level reforestation is to work, changes must be made in the laws, especially those concerning rural land use.

It is necessary to legislate so that the owner is made responsible for the movements of his herds and so that land can be temporarily withdrawn from the onslaught by livestock in order to give the pastures the opportunity to recover (Boudet 1986).

The person who cultivates a tree must know that he or she will benefit from the results of his or her labour, whether this be firewood or fruit. Village-level reforestation schemes should not be started until the ownership of the products of the trees has been clearly defined (Goudet 1986, Wane-Condé 1986).

Frequently it is only those who own the land who can envisage and undertake the necessary long-term investment which will allow them to grow trees (Clément 1986). However, in some regions of the Sahel, even farmers own the land will refuse to grow certain species of tree - those which are protected by law - because if they want to exploit them, and

=====

especially if ever, in the future, they want to cut them down, they will have to prove that they planted them and undertake a long and costly series of steps for permission to do so (Clément 1986).

Unfortunately, the political will to carry out the necessary reforms is often lacking, largely because urgent conflicting economic demands must also be met (Boisgallais 1986). Protecting the forest is therefore not yet a serious national policy in many of the countries at risk.

This does not imply that there are no laws designed to protect the woodlands, but until recently forestry legislation has been marked principally by a concern to protect the forest from the rural population. As a result, the rôle of the forestry departments of sahelian countries has been almost entirely that of forest police, whose job has been mainly to exclude farmers and pastoralists from the designated woodlands, and only secondarily, to plant and tend trees.

Since the laws give exclusive rights over woodlands to the forestry services, most reforestation projects are carried out by them, although they are generally understaffed and underfinanced and cannot fulfil even the tasks of exclusion and protection. As a result the plantations, which are often of exotics, are too few in number, too costly and produce too little to satisfy the needs of the population (Rochette 1986), and are in any case little concerned with the needs of the rural population, and even less by the need to integrate the tree into the rational exploitation of the rural environment. The chronic lack of finance of the forestry services and the lack of interest by the local population, which, when involved at all, has been seen merely as cheap labour, has meant that reforestation projects are often only poorly followed up and feebly maintained. Many reforestation projects, after a few years, have been destroyed by fire, insects, or the depredations of the local population (Clément 1986).

The idea of planting trees and managing forests for the benefit of the rural population demands radical changes in the aims, practices and personnel of most forestry departments. To start with, the relationship between the villager and the forestry departments must be profoundly altered. The major effort in this respect is in the retraining of the personnel of the forestry departments.

There is an urgent need for more women foresters, who are more likely than are men to be able to encourage the women in the country to collaborate. In the villages, women have shown themselves to be more receptive than men to the ideas of planting trees because they are the ones who at present suffer most acutely from the lack of wood (Clément 1986).

A subsidiary effort should go into training a local representative of the rural population to act as an intermediary between the forestry department's staff and the local people, with the job of helping to explain the aims of the projects to the locals, and explaining their needs to the forestry department.

9 Research

9.1 Genetics

Reforestation will succeed only if the trees chosen are hardy and adapted to the conditions they will have to endure. Principally, given the poverty of the soils, the plants must be capable of fixing atmospheric nitrogen. One such plant already in wide use on the coasts of Senegal is *Casuarina equisetifolia* (Dommergues 1986). Some work is being done to find bacterial inoculations which could be given to the roots of trees to enable them to fix nitrogen. Other laboratories are trying to select for particular strains of trees, a difficult task given the generation time of woody plants.

9.2 Stoves

Since the population depends to such a large extent on wood for fuel, it would seem that a cooking stove that gave a reduction of even 10% or 20% in the use of firewood would have a significant effect on the rate at which forests disappeared (Ament and Joseph 1980). In the laboratory it is quite clear that properly designed stoves are more efficient than are their traditional counterparts (Foley and Moss 1983). With the aim of encouraging the use of efficient and environmentally sound stoves, Ament and Joseph (1980) have prepared an enthusiastic and practical guide to building fuel-efficient, and culturally acceptable cooking stoves.

Foley and Moss (1983) provide a sobering review of new wood burning stoves, whose conclusions, more pessimistic than those of Ament and Joseph (1980), form the basis of the following comments.

Firstly, there is no support for the frequent claim that new designs save 50% of fuel. Some stoves do indeed save fuel initially, some do not, and little is known about the majority of cases or the longer term.

In some field trials in households using new stoves, the better designs save more than 30% firewood, even though the dampers were not correctly used. The Ban ak Suuf stoves in Senegal showed a mean saving of 26% over traditional fires.

In other field trials, new stoves were just as fuel-hungry as open fires. For example, in trials in Burkina Faso and Senegal it was found that each family consumes 2.4 to 3.0 kilograms of firewood per meal with a traditional fire. One new design (banco) used between 1.6 and 2.6 kilogrammes, barely an improvement on the open fire, while others (Nouna and Kaya) used between 3.9 and 7.0 kilogrammes, decidedly worse than an open fire.

Frequently, the new stoves are abandoned by their owners after a brief experimental period. Thus in two studies in Senegal, out of 1500 Ban ak Suuf stoves, between 4% and 5% were abandoned by their owners each month over the first year, and a similar proportion fell into disrepair. This means that the stove has a half-life of 15 or 16 months. If stoves are produced at a constant rate of say N per month, then once the factory

=====

has been in operation for ten years, long enough for nearly all of the oldest stoves to have deteriorated, the total number of functional stoves in any one month is about 22.2*N. If we assume that 10 people eat from the food cooked on a single stove, then in order for half of the population in a country of 16 million inhabitants to eat from a new stove, the factory would have to produce 36000 each month, or more than 9000 each week. This rate of production seems improbable.

The effect of the widespread introduction of stoves is hard to predict. A reduction in demand in cities could be met by the dealers maintaining their selling price while reducing the buying price, possibly obliging the rural cutter to cut more to try to maintain his income, at least until he realises that the market has become unprofitable. If, however, efficient stoves mean that urban dwellers can buy less, but more expensive wood, firewood plantations may become more economically viable.

Even under optimistic assumptions, Foley and Moss (1983) calculate that a successful campaign to get people to use "fuel-efficient" stoves would result in national savings of firewood amounting to only about 5%. Major reductions in deforestation seem unlikely, and much will depend on the role of government in setting prices, enforcing market controls and regulating cutting.

In summary, while some families may find that they use less firewood with a stove of new design, the introduction of new stoves is unlikely to have any noticeable effect on national energy consumption or on deforestation (Foley and Moss 1983). State intervention by raising prices for firewood or charcoal cannot be expected to reduce deforestation. The state should nevertheless create a department whose responsibility is to manage and plan domestic energy use (Laurent 1986).

9.3 Research into tree populations

A crucial element in the study of the Sahel is the evaluation of the status and trend of the woody plants (Piot 1983), for reasons outlined above, and because repeated measures may be made on the same individual over time, and in this way the effects of changes in the environment can be monitored (Vanpraet and Van Ittersum 1983). Knowledge of local trees and forests should be gathered, formalised and improved, the dynamics of the major taxonomic groups should be studied, and a system of calculating woody plant volume from simple easy measures should be perfected (Hamel 1986).

Unfortunately the number of species and their sporadic distribution mean that in a programme of ecological monitoring one cannot rely on statistical sampling to give averages (GEMS 1986f, Piot 1983), and therefore sample plots must be permanently marked and all the trees in the stands within them completely counted.

9.4 Ecological monitoring: the GEMS approach

=====

One of the new techniques which promises to help in the rehabilitation of the Sahel is that of ecological monitoring (GEMS 1982). The standard GEMS technique for ecological monitoring and inventory requires that data be collected from satellites, from the air, and from observations made on the ground, and then integrated in such a way as to provide information on the status and trend of the ecosystem. This methodology was tested in the Sahel by the Pilot Project for the Inventory and Monitoring of Sahelian Pastoral Ecosystems (GEMS 1986a, Le Houérou 1986).

9.4.1 Satellite data

Satellite images and aerial photos should be used to the limits of their potential (de Wispelaere 1981, GEMS 1986c, GEMS 1986d, Hamel 1986). Unfortunately for the purposes of this report, the satellite data collected by the Project were designed to follow the development of the herbaceous layer during the growing season (GEMS 1986c), and the instrument used to collect the data could not differentiate woody cover from herbaceous plants. Data from other satellite-borne instruments which would have distinguished tree cover were not tested by the Project.

9.4.2 Low-level reconnaissance flight data

The observations collected on the woody plant layer during low-level reconnaissance flights over the Ferlo are discussed in detail in GEMS (1986d). In the sandy area of the western Ferlo the clumped woody plants in the interdune hollows were judged to cover between 15 and 20% of the ground. In the gravelly region to the south-west, woody plant canopies covered 20%-40% of the ground, while in the centre of the region, composed of eroded dunes, woody plants were judged to cover 10-20%. To the east of the Lac de Guiers is an area sporadically wooded with local cover up to 40%, but generally closer to 10%. The forests of *Acacia nilotica* which were once found along the River Senegal are today vestigial, occasionally covering up to 40% of the ground, but more commonly less than 10%, and frequently less than 5%. Many charcoal mounds and their scars were seen in these classified forests, the only place in the Ferlo that they were noted.

9.4.3 Observations in the field

Quantitative estimates of vegetation are made with the intention of comparing the vegetation of a given area with that of other areas or with the same area at later date. A subsidiary reason is the study of how changes in some parameter of the vegetation are correlated with changes in habitat.

The Project undertook four studies of woody plants in the Ferlo, of which three are discussed here. The first was a study of the diameters of woody plants in the region near Vindou Thiengoli and Amali, two settlements equipped with boreholes in the south-west of the test zone.

=====

The objective of the study was to examine the past history and likely future of three woody plant species in the area. The second was an inventory of woody plants on the crest of an ancient dune (the Dune de Mbidi) whose objective was to monitor trends in woody species relative to the probable pressure from livestock and human activities. These pressures were assumed to be related to various parameters such as the distance from cultivation or from settlements. The third was a complete inventory of a plot (at Fété Olé) in which the woody plant populations had been previously mapped.

9.4.4 The woody plants near Vindou Thiengoli and Amali

Many complicating factors enter into the relationship between height, circumference and age, especially the extent to which the plant was browsed when young. Nevertheless, when no other information is available, the simplest index to the age of an individual is either its height or its circumference. It is preferable to use height when the circumference of the dominant species is difficult to measure (as is the case with the multi-stemmed *Boscia senegalensis*, for example) but to use circumference when the size of the trees is such as to make the measurement of the height difficult or inaccurate (Vanpraet and Van Ittersum 1983).

The circumferences of individuals of the three species *Balanites aegyptiaca*, *Combretum glutinosum* and *Sclerocarya birrea* were measured and are plotted in Figures 3-5. A population composed of individuals of different ages, if in equilibrium, will show a frequency distribution in which the ratio between any two adjacent age or size classes remains constant for all classes (Piot 1983). The vertical axes on these figures are expressed in a logarithmic scale; on such a scale the heights of the bars of the histogram of a population in equilibrium, as defined by Piot (1983), will fall linearly from left to right.

In this study, the population of *Balanites aegyptiaca* can therefore be said to be in equilibrium, if perhaps slightly under-represented in the smallest class of circumference (Figure 3). By contrast, the curious bimodal distribution of *Combretum glutinosum* (Figure 4) suggests that there was once a far larger population, whose survivors are today found in classes 11 and 12, with circumferences of 51-55 and 56-60 centimetres respectively. The smallest classes (less than 15 centimetres circumference) are apparently under-represented, suggesting a second collapse in the size of the future population of the species. The frequency distribution of *Sclerocarya birrea* suggests that no regeneration at all has taken place for many years (Figure 5), and that before this complete cutoff, regeneration had steadily declined. With the passing of the present population of adult trees, the species will disappear from the landscapes of the south-west Ferlo - unless, that is, efforts are made to protect the seedlings from dessication and destruction by livestock.

9.4.5 The woody plants on the Dune de Mbidi

Figure 3: Frequency distribution of classes of circumference of *Balanites aegyptiaca* in the Vindou-Amali region:

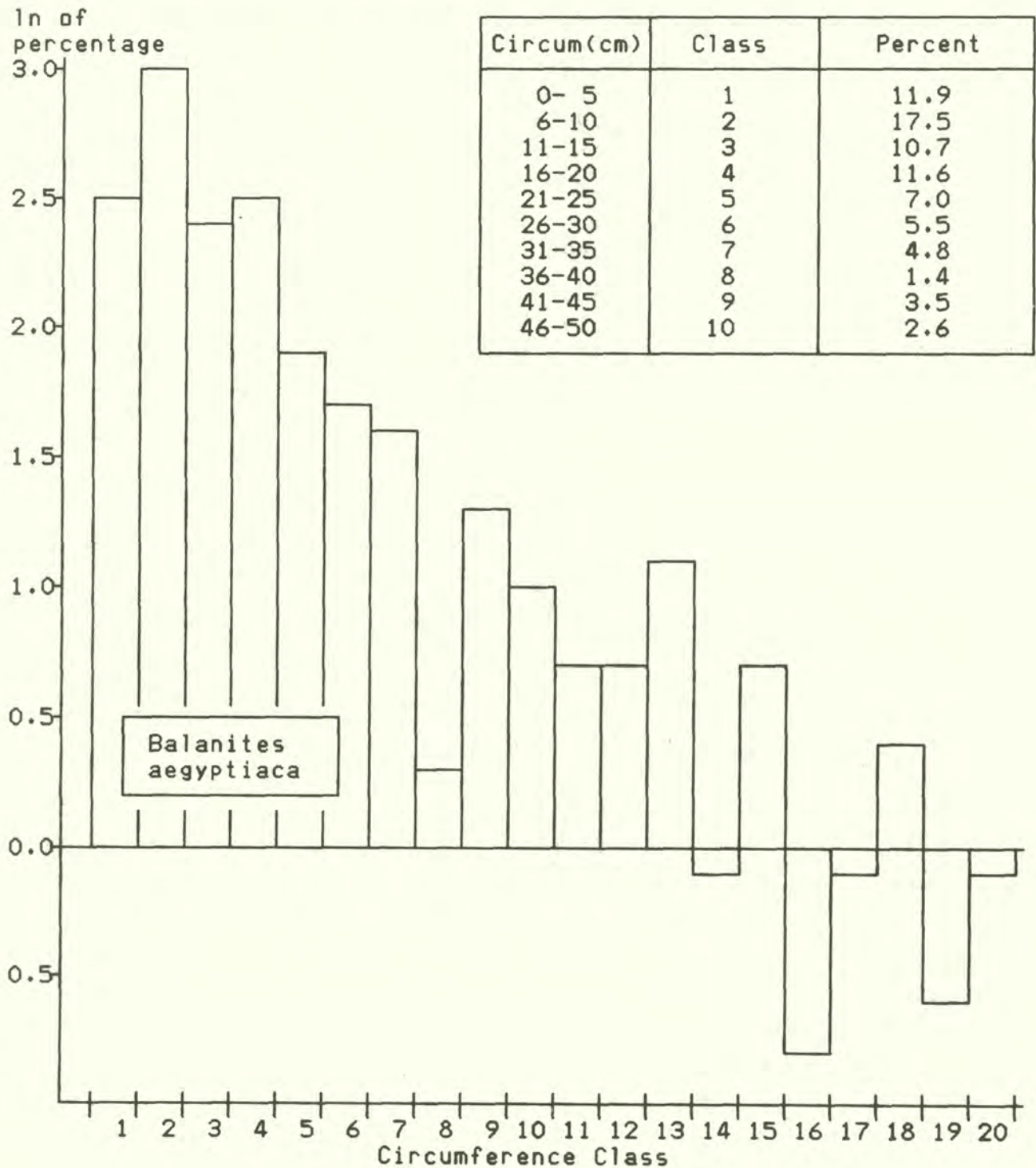
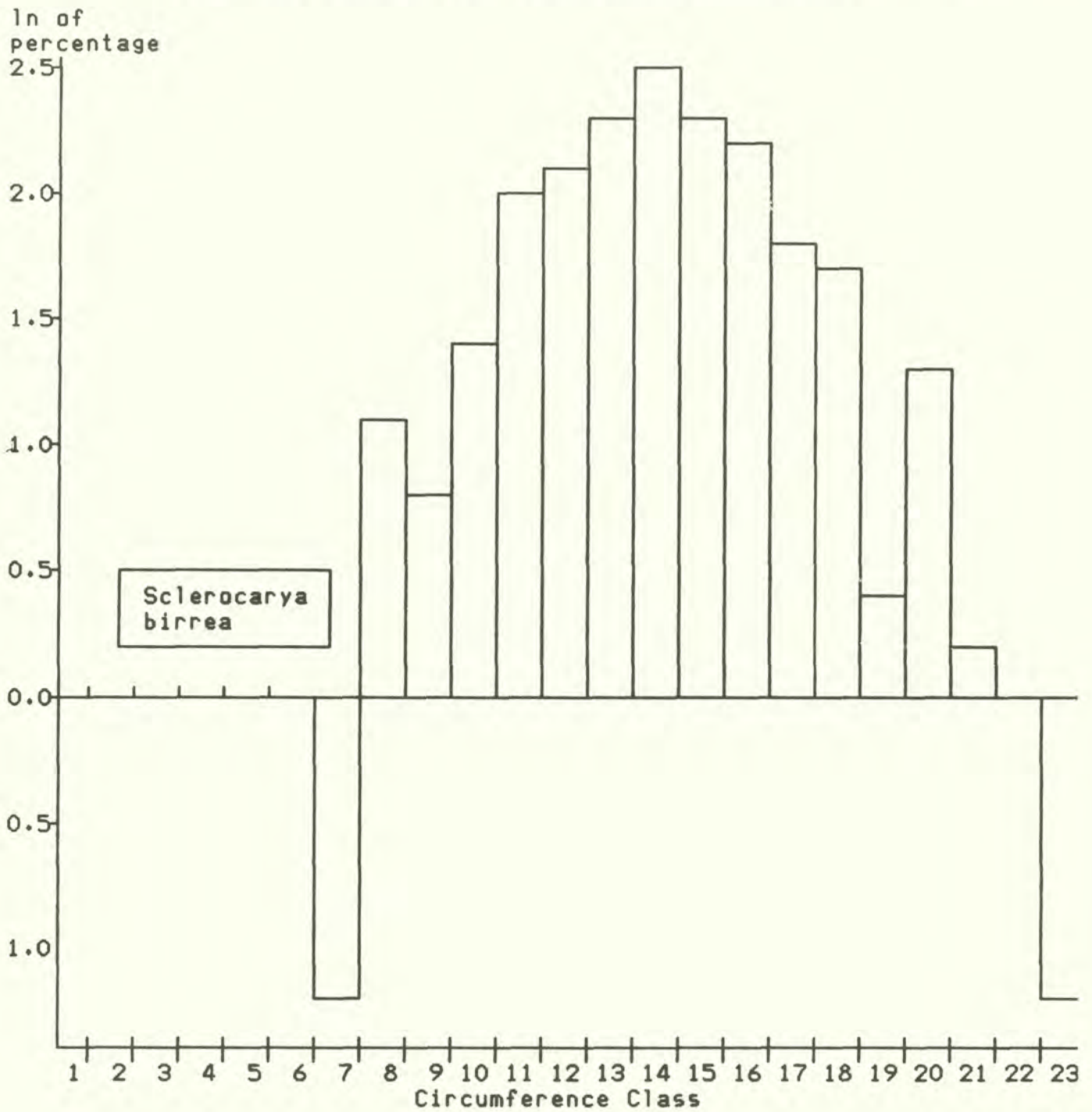


Figure 5: Frequency distribution of classes of circumference of *Sclerocarya birrea* in the Vindou-Amali region:



=====

The location of the stations on the dune relative to two boreholes and various human settlements and fields are shown in Figure 6. The numbers of woody plants counted at each station is given in Table 5.

9.4.5.1 Size classes

Of the five woody species present in sufficient numbers for testing on the Dune de Mbidi, only *Boscia senegalensis* shows a distribution which is anything like in equilibrium (Figure 7). *Balanites aegyptiaca* seems to be regenerating ever more feebly, and unless the environment changes in its favour, this species seems to be unlikely to survive on the dune crest. *Guirea senegalensis* is apparently also likely to decline in numbers. The bimodal distribution of *Acacia senegal* hints at an earlier catastrophic period for the species, followed by a good recovery, but currently its prospects for regeneration are poor (Figure 8). As for *Sclerocarya birrea*, it shows the same disastrous frequency distribution on the Dune de Mbidi as it does in the region around Vindou Thiengoli and Amali.

9.4.5.2 The population structures of woody plants at both study sites

On both the study sites the species that are palatable to livestock were found to be suffering particularly badly, in that they showed little or no regeneration and a high mortality (Vanpraet and Van Ittersum 1983). However, the species which were still showing healthy frequency distributions had high indices of sclerophylly, that is, they were particularly resistant to dessication (Table 1).

The proportion of plants that were dead or moribund was found to be closely related to the density of the species; species already at low densities were dying proportionately more rapidly than are those that were still at relatively high densities (Vanpraet and Van Ittersum 1983).

These changes have reduced and will continue to reduce the spectrum of species in the area. This reduction will almost inevitably be accompanied by a reduction in the productivity of the region (Vanpraet and Van Ittersum 1983).

9.4.5.3 Frequency of various species on the Dune de Mbidi

It is apparent at first glance at Table 5 that *Boscia senegalensis* is numerically dominant at most of the stations, with up to 733 individuals recorded (the median number of individuals is 258; the interquartile range is from 164 to 335). *Balanites senegalensis* is also occasionally numerous, with as many as 169 individuals per hectare, but it is most commonly present at fewer than 100 stems per hectare (median 40, interquartile range 8-92). Other species are far less numerous, with *Acacia senegal* having 63 individuals in one sample, but with a median of 2 (interquartile range 0-6).

Figure 6: Stations on the Dune de Mbidi

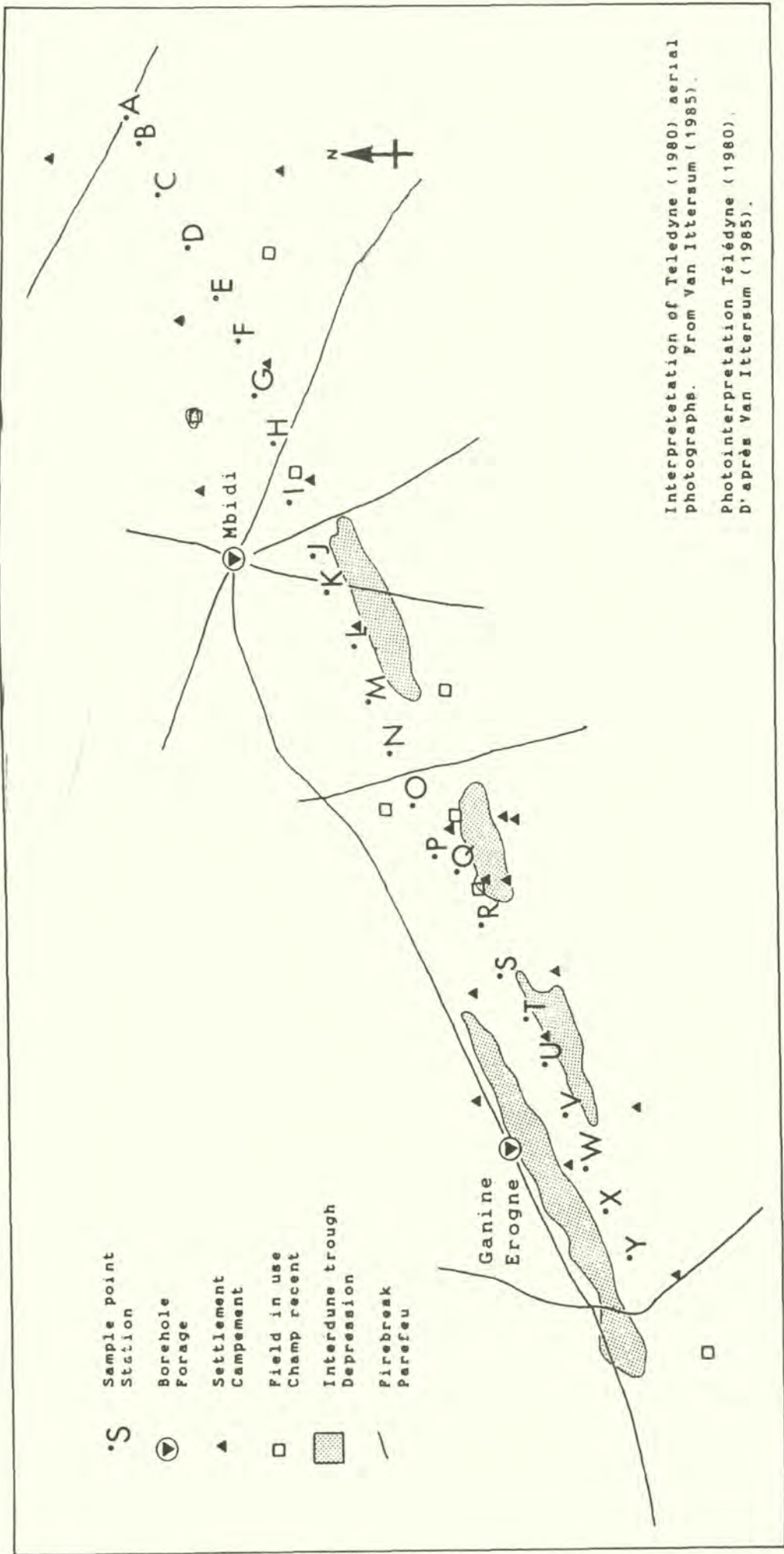
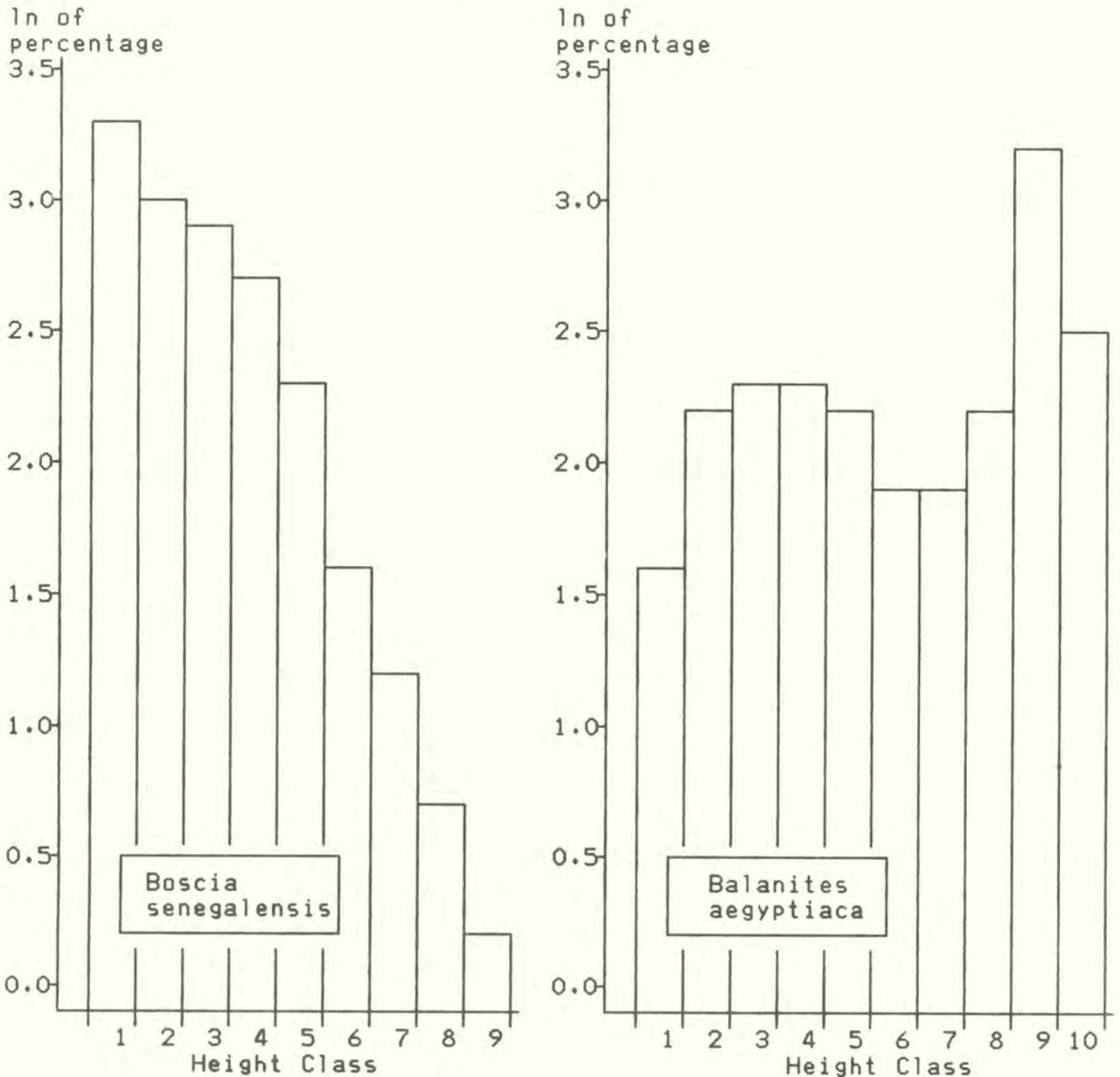


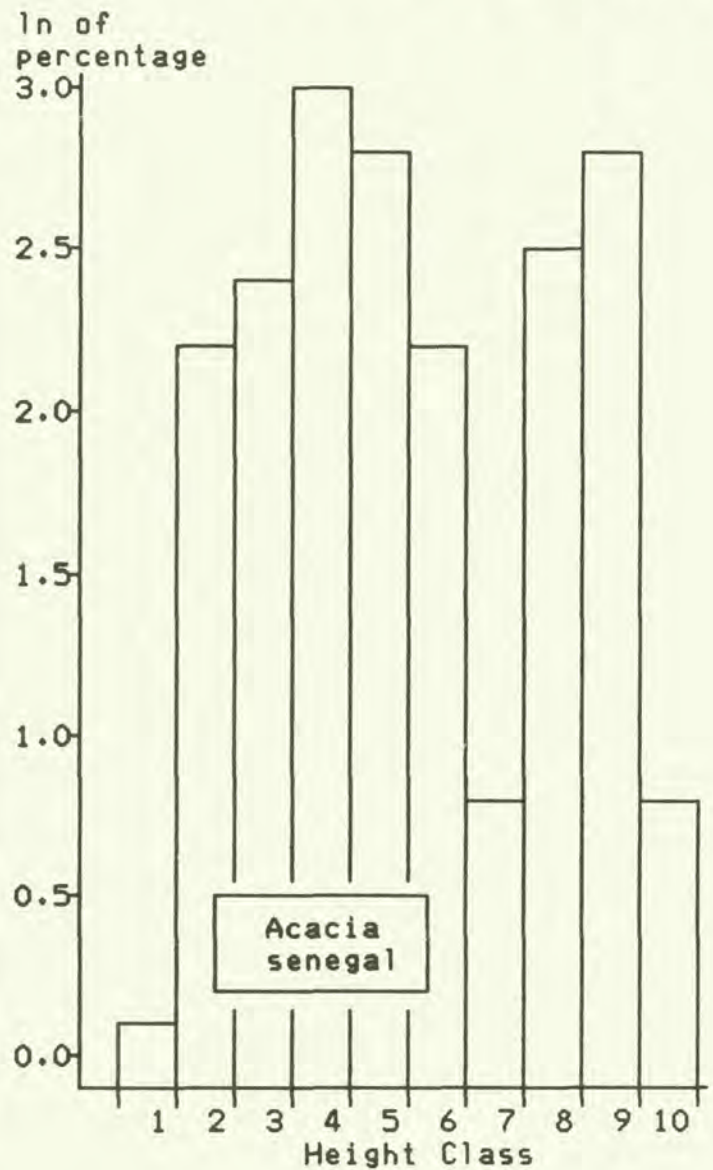
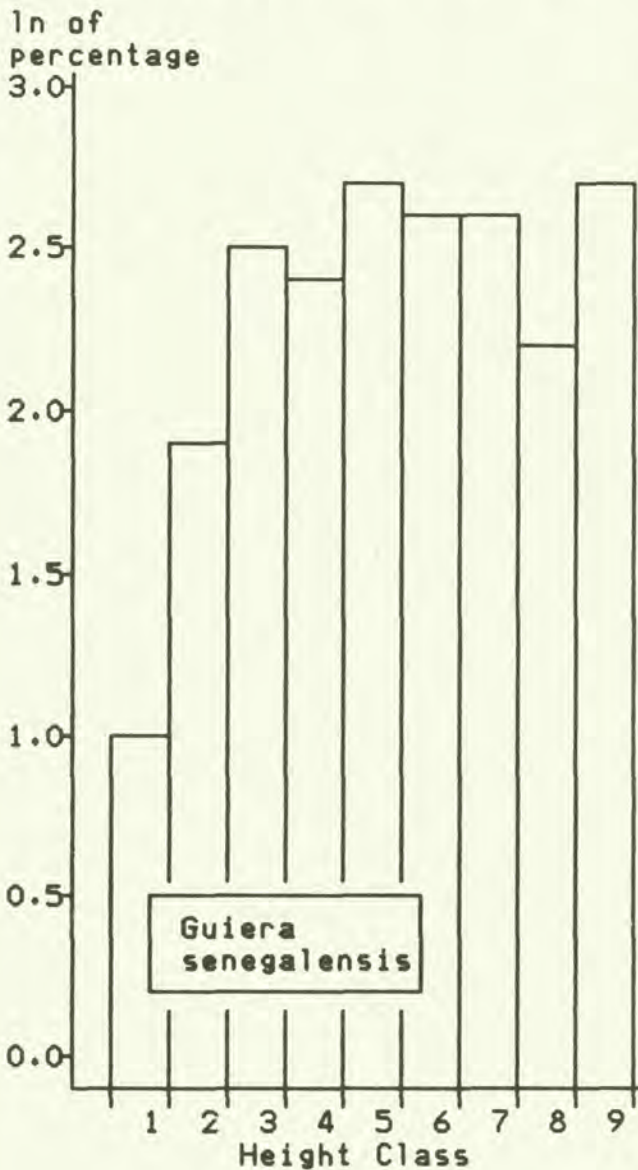
Figure 7: Frequency distribution of height classes of *Boscia senegalensis* and *Balanites aegyptiaca* on the Dune de Mbidi



On this sort of plot, if the successive size classes of species contain a number of individuals which is a constant proportion of the number in the previous class, the top of each bar lies on a descending straight line (cf *Boscia*).

Figure 8: Frequency distribution of height classes of *Guiera senegalensis* and *Acacia senegal* on the Dune de Mbidi

Class	1	2	3	4	5	6	7	8	9	10
<i>Guiera senegalensis</i>	2.9	6.9	12.7	11.0	14.7	12.9	13.9	9.0	15.9	%
<i>Acacia senegal</i>	1.0	9.0	11.4	19.4	16.2	9.3	2.3	11.6	17.2	2.3 %
<i>Sclerocarya birrea</i>	0	0	0	0	0	0	0	0	20.0	80.0 %



Note: the frequency distribution for *Sclerocarya birrea* is not drawn, since only two classes contained members.

Table 5: Number of individuals of various woody plant species counted at 25 1-hectare stations along the Dune de Mbidi

Station	Species										
	1	2	3	4	5	6	7	8	9	10	11
A	0	1	267	8	0	5	0	9	3	0	8
B	0	4	297	2	0	6	0	16	0	1	29
C	6	4	364	6	0	2	0	54	1	2	26
D	1	40	366	8	0	0	1	53	1	2	57
E	11	169	273	11	0	0	0	2	1	0	91
F	5	91	146	12	0	0	0	1	1	0	130
G	2	56	56	2	2	0	0	0	0	0	118
H	3	25	201	6	0	0	0	0	0	0	55
I	0	16	226	8	0	0	0	0	0	0	78
J	2	52	70	1	0	0	0	0	1	10	76
K	6	58	130	0	0	1	0	0	0	0	80
L	63	134	263	1	1	0	0	0	2	6	87
M	1	58	258	4	0	0	0	0	0	0	104
N	13	75	234	1	0	0	0	0	0	0	102
O	4	92	178	3	0	1	0	0	0	0	154
P	0	18	306	5	0	0	0	0	0	0	210
Q	27	20	222	1	0	3	0	0	0	0	193
R	2	9	304	1	0	3	0	1	2	0	79
S	0	127	151	2	0	0	0	0	0	0	115
T	3	97	258	2	0	0	0	0	1	0	53
U	0	70	140	0	1	2	0	0	0	0	74
V	0	1	535	1	0	1	0	0	0	0	37
W	1	8	694	0	1	2	0	1	5	4	36
X	1	38	692	1	4	3	1	0	16	0	41
Y	2	17	733	1	0	1	5	13	18	0	46

Key to column headings:

- 1 *Acacia senegal*
- 2 *Balanites aegyptiaca*
- 3 *Boscia senegalensis*
- 4 *Calotropis procera*
- 5 *Combretum glutinosum*
- 6 *Commiphora africana*
- 7 *Grewia bicolor*
- 8 *Gueria senegalensis*
- 9 *Sclerocaria birrea*
- 10 *Ziziphus mauritania*
- 11 Dead trees

After *Boscia*, standing dead trees dominate the landscape (Figure 9). At one site, there were 329 living woody plants and 210 dead ones. The median number was 78 (interquartile range 43-109).

9.4.5.4 Trends in numbers along the dune

There were few obvious trends along the dune in the numbers of individuals of the various species. Only one, that of *Calitropis procera*, was statistically significant ($p < 0.001$), with a decline in numbers from the eastern end of the transect (stations A-F) to the western end (stations Q to Y).

Other species showed some tendency towards systematic differences in numbers along the dune; thus *Balanites aegyptiaca* tended to decrease from east to west, with the notable exception of its frequency at the first four stations on the line.

For several species the numbers present at stations A, B, C and sometimes D, and W, X, Y and sometimes V, seemed to diverge radically from the other stations on the line. This is doubtless because these stations were not squarely on the crest of the dune, but on slopes or in depressions (Figure 6). The numbers of dead woody plants tended to be lower at these extreme stations than they were on the crest of the dune.

9.4.5.5 Associations among species

There was a statistically significant trend for very high numbers of *Boscia*, and relatively high numbers of *Commiphora* to occur in quadrats containing few *Balanites*. *Boscia* and *Sclerocarya* were positively correlated, but the correlation depended entirely on stations W, X and Y.

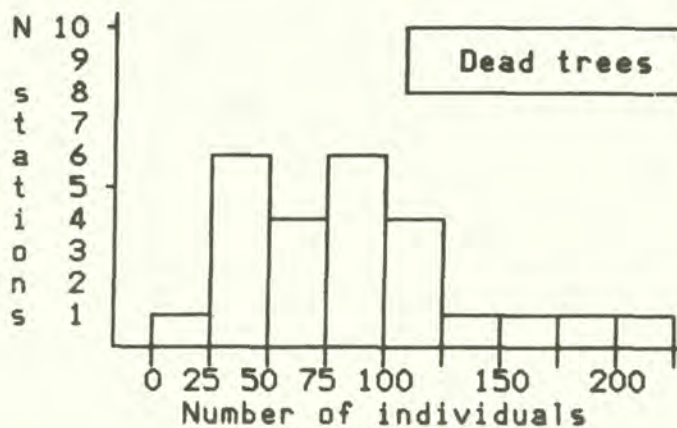
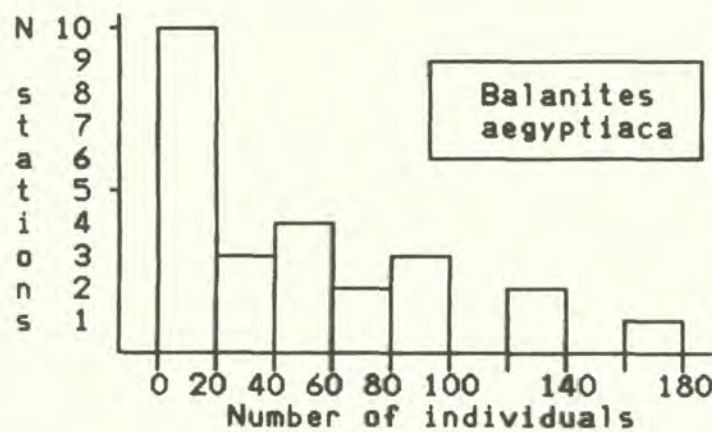
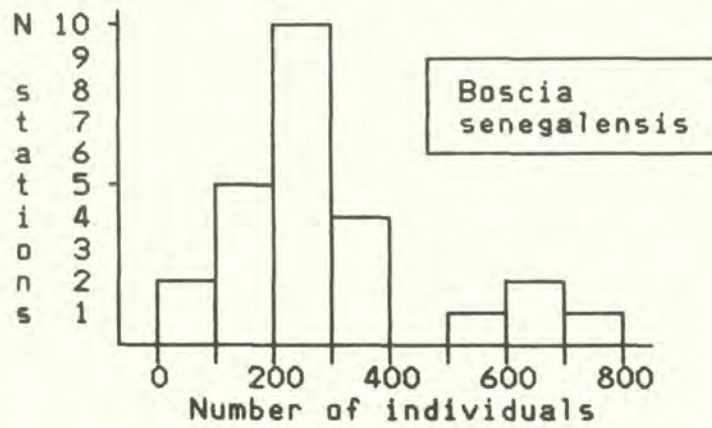
Balanites tended to be more numerous on the dune crest than on the lower-lying ground, while *Boscia* preferred the latter to the former ($p < 0.01$ in both cases).

9.4.5.6 Effects of boreholes, fields, settlements and firebreaks

The stations nearest to the boreholes were U, V and W, and I, J and K. The ones most remote from the boreholes were O, P and Q and A, B and C. There is therefore some difficulty in interpreting trends given that stations A, B, and C, and U, V and W also fall in different ecological zones and therefore bias the results.

When all the stations were taken together, no significant trends were seen in the numbers of woody plants and the distance of the station from the nearest borehole, field, settlement or firebreak. With the exclusion of stations V to Y, *Boscia senegalensis* shows a strong tendency ($p < 0.001$) to increase in numbers as the distance from the nearest borehole increases. With the exclusion of stations A to D, the number of dead trees also increases with increasing distance from the

Figure 9: Frequency distributions of *Boscia senegalensis*, *Balanites aegyptiaca* and dead woody plants on the Dune de Mbidi



=====

nearest borehole, presumably in part because the wood is rapidly collected from areas near boreholes.

9.4.5.7 Conclusion

The study is inconclusive for most species; there seems to be little or no direct influence of human use or pressure of livestock detectable by these techniques. This is perhaps because the distance from a focus of human activity is not a good measure of use of the pastures, or because the impact of humans and their livestock is fairly evenly spread over the sorts of distances considered.

It is also possible that ratios between species might change in a systematic manner with increasing distance from human activity, but this possibility was not investigated, since the Project had no a priori expectations which could be tested.

9.4.6 The enclosure at Fété Olé

In 1974 ORSTOM (Poupon 1980) carried out a complete inventory of woody plants in an enclosure near Fété Olé (N 16°14' W 15°08'). This research provides us with maps of four woody species (*Balanites aegyptiaca*, *Acacia senegal*, *Commiphora africana* and *Grewia bicolor*) and an invaluable opportunity to examine the direction and extent of changes in a relatively undisturbed community of woody plants over nearly a decade.

The Project inventoried and mapped the woody species in the enclosure in 1983 when the fence was still in place, although not everywhere intact.

9.4.6.1 Method

For the purposes of the survey the enclosure, 500m on a side, was divided into 25 north-south strips, each 20m wide. Each strip was then divided into 20m sections and the position within the resulting 20x20m block of each woody plant of the four species concerned (*Balanites aegyptiaca*, *Acacia senegal*, *Commiphora africana* and *Grewia bicolor*) marked on a specially-prepared field map. The most common species (*Boscia senegalensis* and *Gueria senegalensis*) were not mapped, but the number of each species in the block was counted. The state of health of each individual (good, one-third dead, two-thirds dead, standing dead, fallen dead) was noted, as was the height class (grouped by 25cm) of its topmost twig. Individuals whose height was greater than 2m were classed together.

The landform of the area plays a role in the distribution of the woody plants which is evident to the observer in the field. The type of terrain in the enclosure was mapped into five categories by ORSTROM (summit of dune, upper slope, middle slope, base of slope, depression) which were also used by the Project for this analysis. The landscape and soils of the enclosure are described in detail by Poupon 1980). The area is sandy and nearly flat, with only

4m of difference between the highest and lowest point. The dune crests are not aligned, one running from the north-west to just south of the centre of the enclosure, and another running south along the north-eastern edge (Figure 10).

For the four species for which it was possible (*Balanites aegyptiaca*, *Acacia senegal*, *Commiphora africana* and *Grewia bicolor*), the location of each stem was mapped. For the purposes of the analysis the maps drawn up by ORSTOM and by the Project were then divided into 100 50x50m blocks. The size of block was chosen because errors in the placement of the lines dividing the blocks were likely to have been of the order of 1-2m, giving aerial errors in the comparisons between the years of up to a maximum of about 15%. Smaller block size would have led to difficulties in the interpretation of the results.

The number of living individuals of each species in each block was counted and the resulting 8 digital maps filed on computer. A further 4 digital maps were constructed for standing dead woody plants in 1983, and finally a digital terrain map was made up by consideration of the landform occupying the greater part of the area of each 50x50m block.

Since Poupon does not present data on either *Guiera senegalensis* or *Boscia senegalensis* on which maps could be based, a finer grid size, 20mx20m, was used for plotting these two species. A corresponding terrain map was also filed. The finer grain of these maps is useful in the visual comparison of plant distribution with landform.

There are some slight discrepancies between the numbers of stems plotted on Poupon's (1980) maps and the published numbers. Where possible the data from the maps has been used. There are also some differences between Poupon's and the Project's data in the proportion of the quadrat scored as belonging to each landform. This is certainly due to differences in the techniques used to measure the areas. In the analysis that follows, all densities have been calculated using the Project's figures for landform areas.

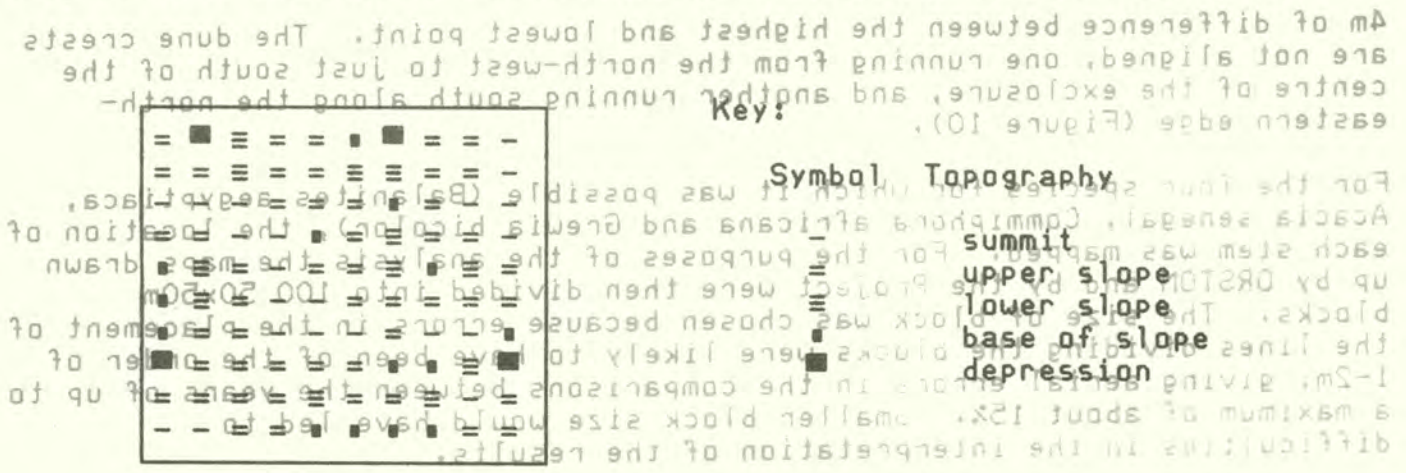
In the sections that follow the plant species are referred to by their generic name.

9.4.6.2 Results

9.4.6.2.1 Distribution of woody species at Fété Oie

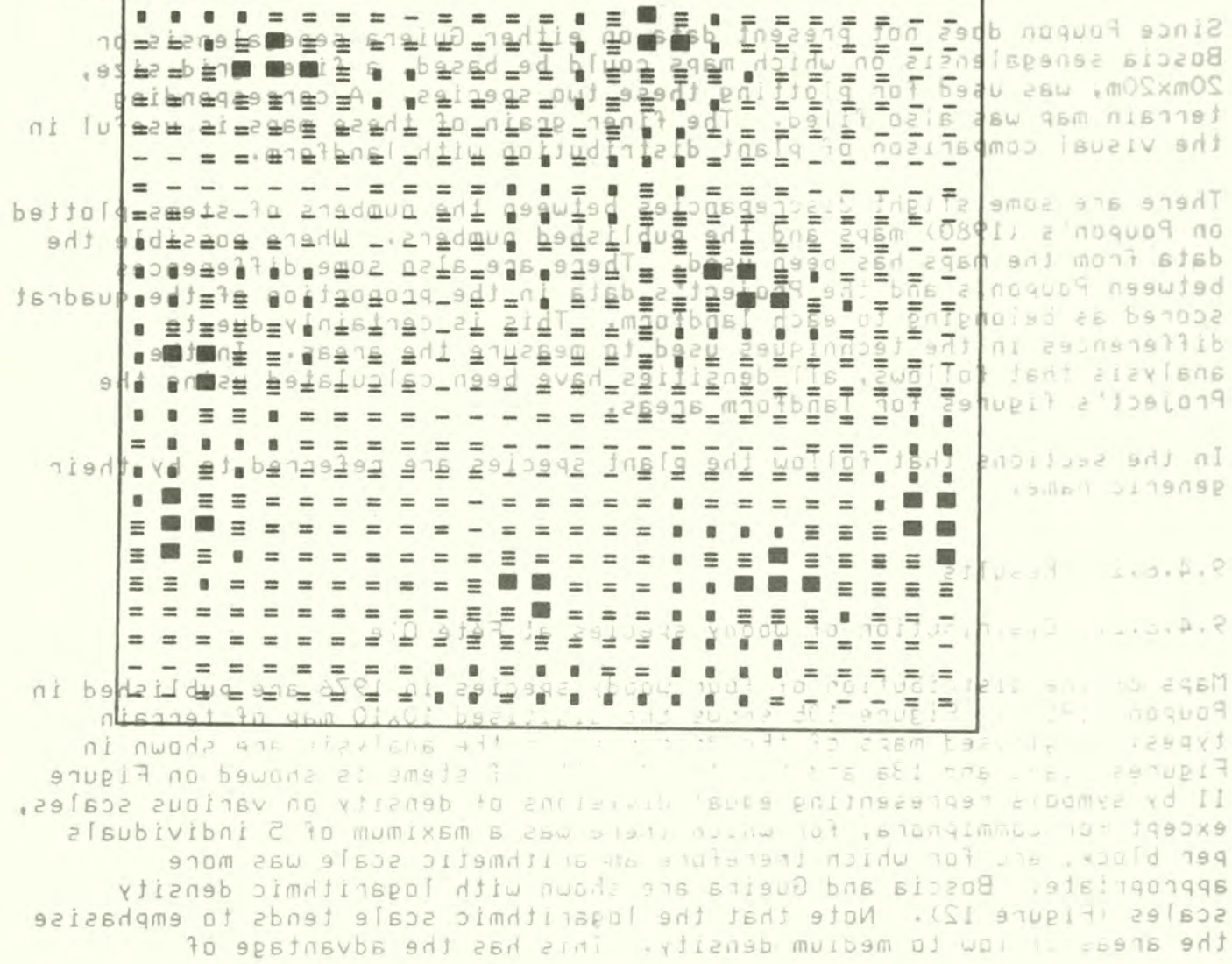
Maps of the distribution of four woody species in 1976 are published in Poupon (1980). Figure 10b shows the digitised 10x10 map of terrain types. Digitised maps of the data used in the analysis are shown in Figures 11a-d and 13a and b. The density of stems is showed on Figure 11 by symbols representing equal divisions of density on various scales, except for *Commiphora*, for which there was a maximum of 5 individuals per block, and for which therefore an arithmetic scale was more appropriate. *Boscia* and *Gueira* are shown with logarithmic density scales (Figure 12). Note that the logarithmic scale tends to emphasise the areas of low to medium density. This has the advantage of

Figure 10a: Terrain in the enclosure at Fété Oié: 50x50 meter grid



The number of living individuals of each species in each block was counted and the resulting digital maps filed on a computer. A further digital map was constructed for standing dead woody plants (Figure 10b). The terrain map was made up by consideration of the landform occupying the greater part of the area of each 20x20m block.

Figure 10b: Terrain in the enclosure at Fété Oié: 20x20 meter grid



Since Poupon does not present data on either *Guiera senegalensis* or *Boscia senegalensis* on which maps could be passed, a size of 20x20m was used for plotting these two species. A corresponding terrain map was also filed. The finer grain of these maps is useful in the visual comparison of plant distribution with landform.

There are some slight discrepancies between the numbers of stems plotted on Poupon's (1980) maps and the unpublished numbers. Where possible the data from the maps has been used. There are also some differences between Poupon's and the Project's data in the proportion of the quadrat scored as belonging to each landform. This is certainly due to differences in the techniques used to measure the areas. In the analysis that follows, all densities have been calculated using the Project's figures for landform areas.

In the sections that follow the plant species are determined by their generic names.

2.4.2. Results

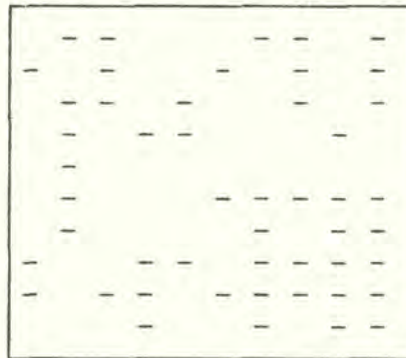
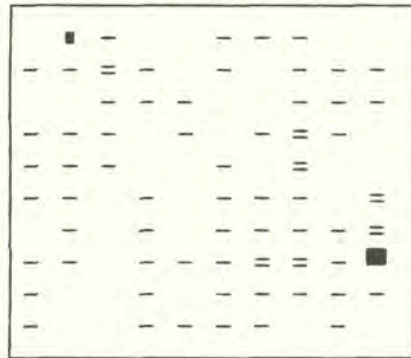
2.4.2.1. Distribution of woody species at Fété Oié

Maps of the distribution of four woody species in 1978 are plotted in Figure 10. Figure 10a shows the terrain map of Fété Oié and Figure 10b shows the distribution of the four species. The analysis is shown in Figures 10c and 10d. The analysis is shown on Figure 10e. The symbols representing each division of density on various scales, II by symbols representing each division of density on various scales, except for *Commiphora*, for which there was a maximum of 2 individuals per block, are for which there are arithmetic scale was more appropriate. *Boscia* and *Guiera* are shown with logarithmic density scales (Figure 12). Note that the logarithmic scale tends to emphasize the areas with low to medium density. This has the advantage of

Figure 11a: Distribution of Acacia in the enclosure at Fété Olé

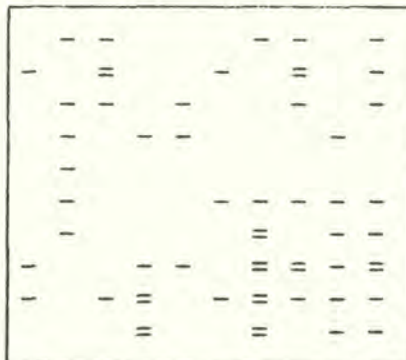
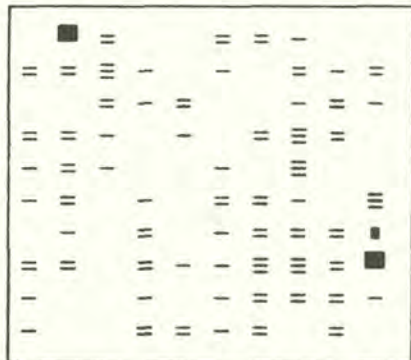
...in 1976

...in 1983



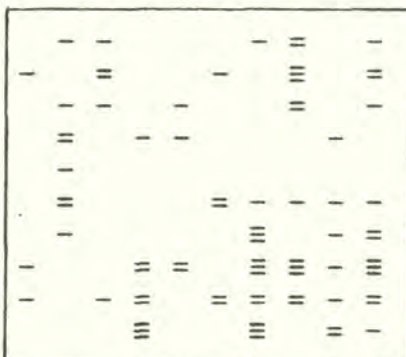
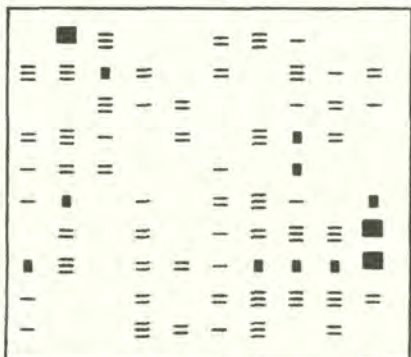
Arithmetic scale

Symbol	No of stems
-	0
-	0 to 12
=	12 to 24
≡	24 to 36
■	36 to 48
■	48 to 60



Square root scale

Symbol	No of stems
-	0
-	0 to 2
=	2 to 10
≡	10 to 22
■	22 to 38
■	38 to 60



Logarithmic scale

Symbol	No of stems
-	0
-	1
=	1 to 3
≡	3 to 8
■	8 to 22
■	22 to 60

Percent frequency of individuals per square

1976:

1983:

	Class							Class					
	A	B	C	D	E	F		A	B	C	D	E	F
Arith	33	58	7	0	1	1	Arith	51	49	0	0	0	0
Root	33	25	33	6	1	2	Root	51	39	10	0	0	0
Log	33	16	22	17	9	3	Log	51	26	16	7	0	0

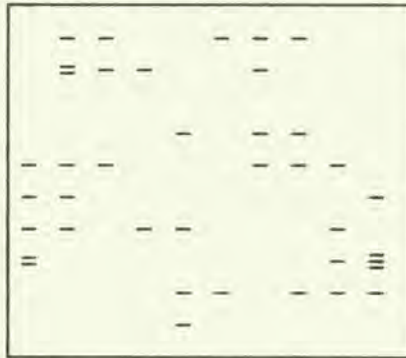
Class A = 0. The number of individuals in classes B-F are defined by the scales given above.

Figure 11b: Distribution of *Grewia* in the enclosure at Fété Olé

...in 1976

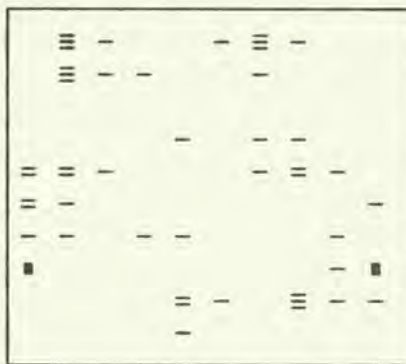
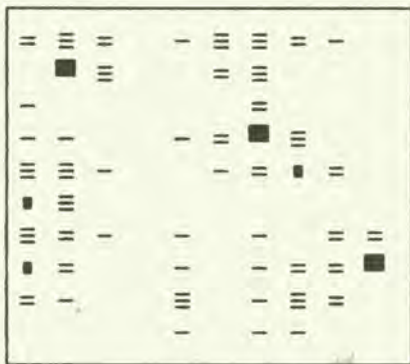


...in 1983



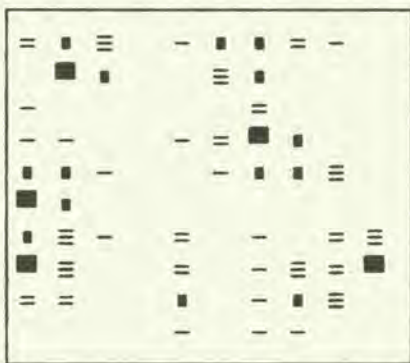
Arithmetic scale

Symbol	No of stems
-	0
-	0 to 10
=	10 to 20
≡	20 to 30
■	30 to 40
■	40 to 50



Square root scale

Symbol	No of stems
-	0
-	0 to 2
=	2 to 8
≡	8 to 18
■	18 to 32
■	32 to 50



Logarithmic scale

Symbol	No of stems
-	0
-	1
=	1 to 3
≡	3 to 7
■	7 to 19
■	19 to 50

Percent frequency of individuals per square

1976:

	Class					
	A	B	C	D	E	F
Arith	48	37	10	2	2	1
Root	48	18	16	12	3	3
Log	48	15	10	8	14	5

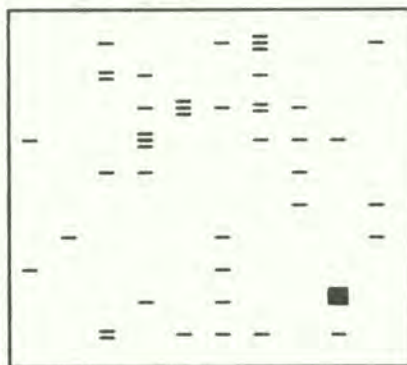
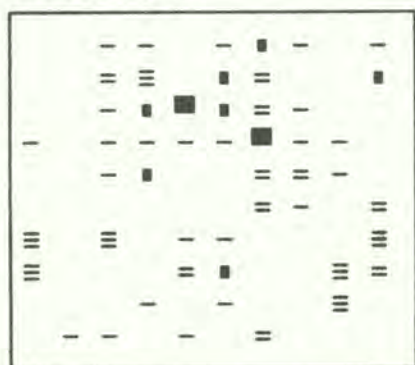
1983:

	Class					
	A	B	C	D	E	F
Arith	65	32	2	1	0	0
Root	65	24	5	4	2	0
Log	65	17	9	3	4	2

Class A = 0. The number of individuals in classes B-F are defined by the scales given above.

Figure 11c: Distribution of *Commiphora* in the enclosure at Fété Olé
 ...in 1976

...in 1983



Arithmetic scale	
Symbol	No of stems
-	0
=	1
≡	2
■	3
■	4
■	5

Percent frequency of individuals per square

1976:

	Class					
Arith	A	B	C	D	E	F
	50	24	10	7	7	2

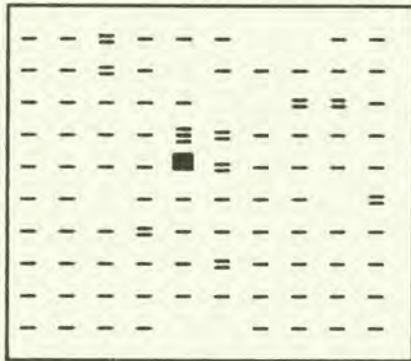
1983:

	Class					
Arith	A	B	C	D	E	F
	65	28	3	3	0	1

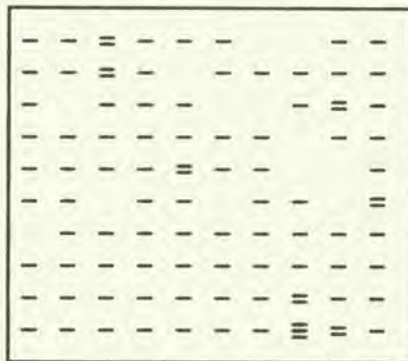
Class A = 0. The number of individuals in classes B-F are defined by the scale given above.

Figure 11d: Distribution of Balanites in the enclosure at Fété Olé

...in 1976

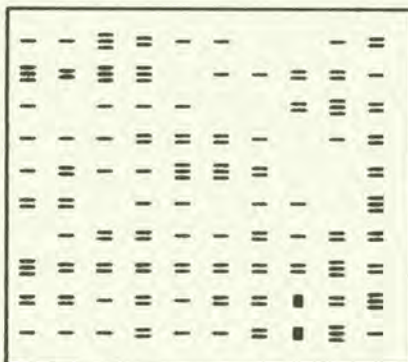
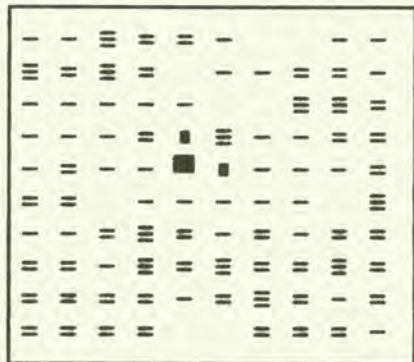


...in 1983



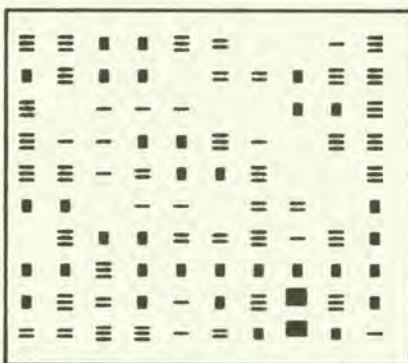
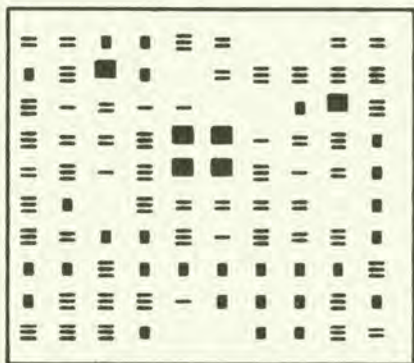
Key:

Arithmetic scale	
Symbol	No of stems
-	0
-	0 to 32
=	32 to 64
≡	64 to 97
■	97 to 129
■	129 to 161



Key:

Square root scale	
Symbol	No of stems
-	0
-	0 to 6
=	6 to 26
≡	26 to 58
■	58 to 103
■	103 to 161



Key:

Logarithmic scale	
Symbol	No of stems
-	0
-	1
=	1 to 4
≡	4 to 13
■	13 to 45
■	45 to 161

Percent frequency of individuals per square

1976:

Class

	A	B	C	D	E	F
Arith	9	80	9	1	0	1
Root	9	37	39	12	2	1
Log	9	8	19	30	28	6

1983:

Class

	A	B	C	D	E	F
Arith	13	79	7	1	0	0
Root	13	36	37	12	2	0
Log	13	14	12	26	33	2

Class A = 0. The number of individuals in classes B-F are defined by the scales given above.

Figure 12a: Distribution of *Boscia* in the enclosure at Fété Olé: 1983

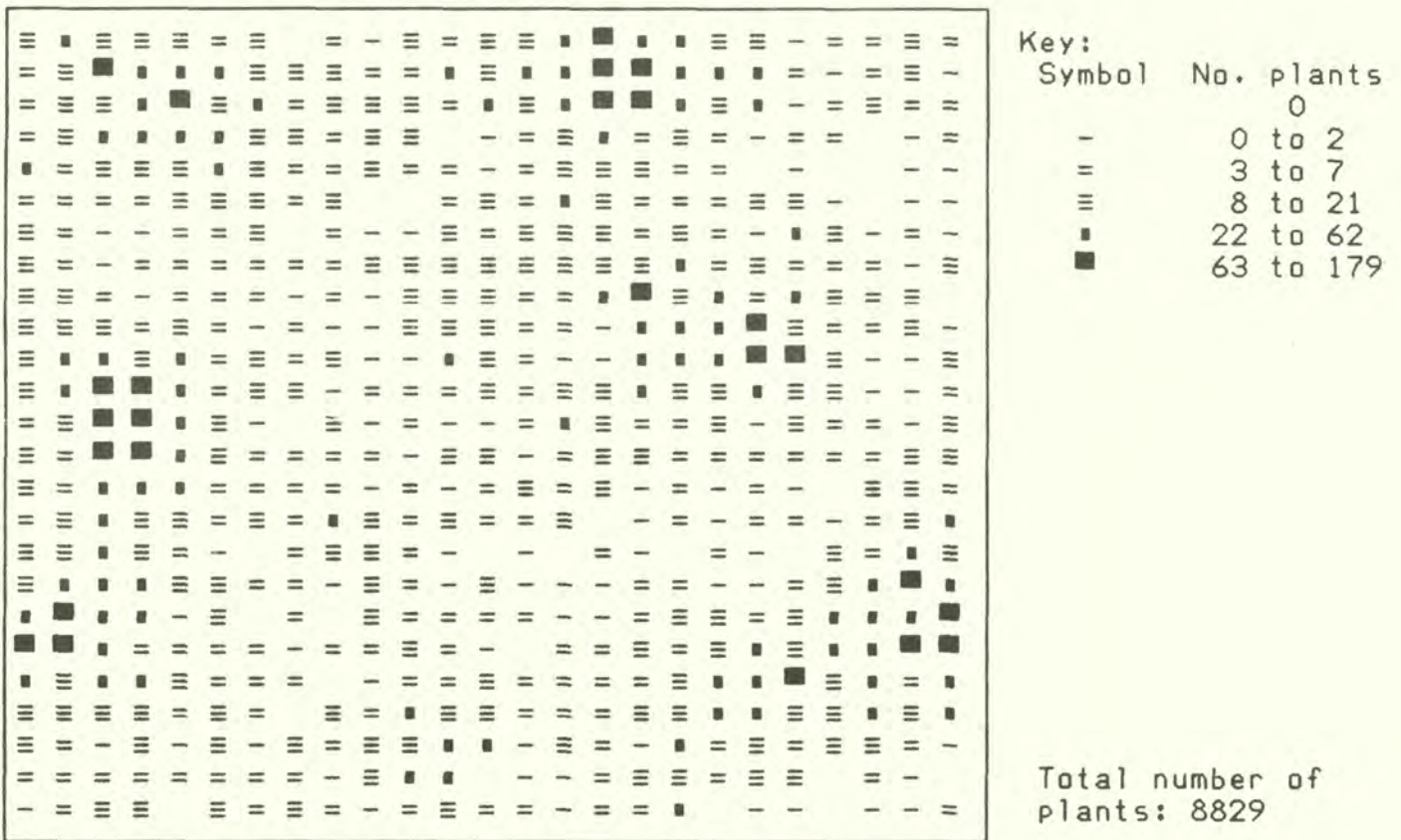


Figure 12b: Distribution of *Guiera* in the enclosure at Fété Olé: 1983

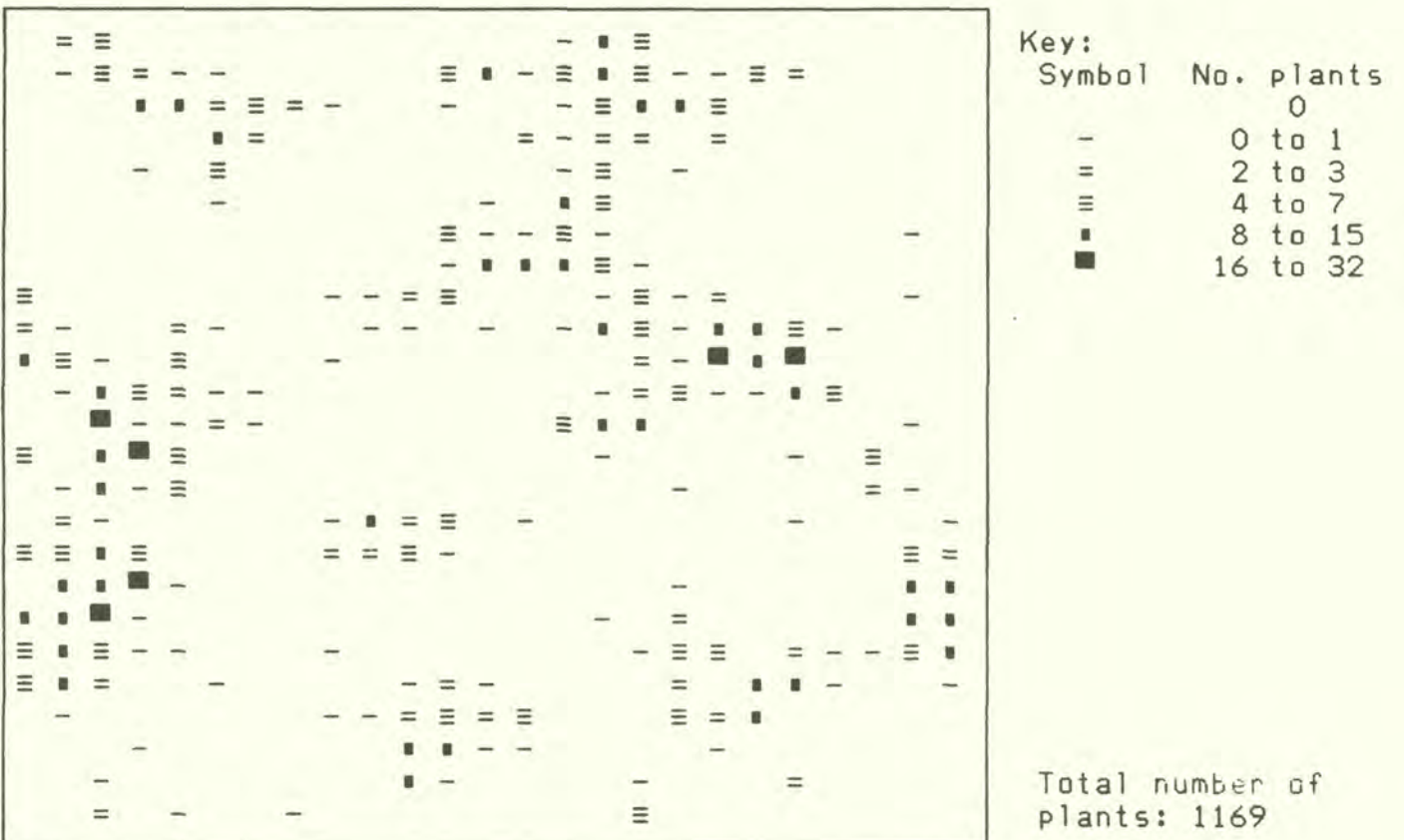
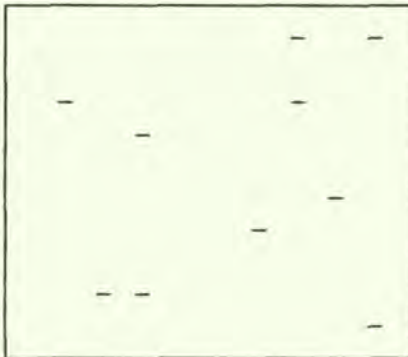


Figure 13a: Change in population of Acacia between 1976 and 1983:

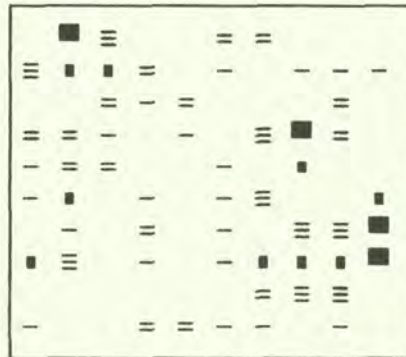
	-38	-4				-3	-3	+1		+1
-4	-8	-18	-2			-1		-1	-1	-1
	+1	-3	-1	-2				+1	-3	
-3	-3	-1	+1	-1			-7	-21	-2	
-1	-2	-2				-1		-15		
-1	-8		-1			-1	-5		+1	-14
	-1		-3			-1	+1	-5	-4	-21
-9	-7		-1			-1	-11	-10	-9	-56
		+1	+1				-3	-5	-5	
-1			-3	-3		-1	-1		-1	+1

The mean change in number of stems per square was -3.34 ± 7.78
 The value of t is -4.294 ($p < 0.001$)

...increase



...decrease



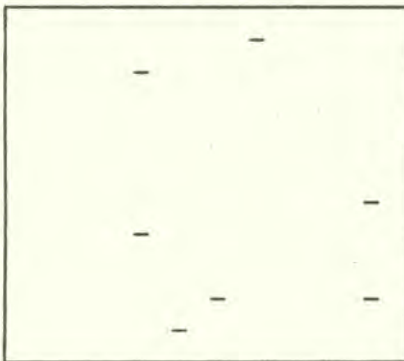
Logarithmic scale
 Symbol No of stems
 - 0
 = 1
 ≡ 1 to 2
 ≡ 3 to 7
 ■ 8 to 20
 ■ >20

Figure 13b: Change in population of Grewia between 1976 and 1983:

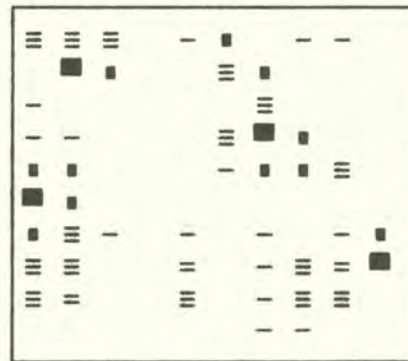
-3	-5	-5		-1	-11	+1	-1	-1	
	-26	-13	+1		-4	-12			
-1						-3			
-1	-1				-3	-32	-12		
-13	-8				-1	-7	-12	-4	
-20	-8								+1
-8	-4	-1	+1	-1		-1		-1	-7
-3	-4			-2		-1	-5	-2	-26
-3	-2			-6	+1	-1	-3	-3	+1
				+1		-1	-1		

The mean change in number of stems per square was -2.87 ± 5.89
 The value of t is -4.894 with probability $p < 0.001$

...increase



...decrease



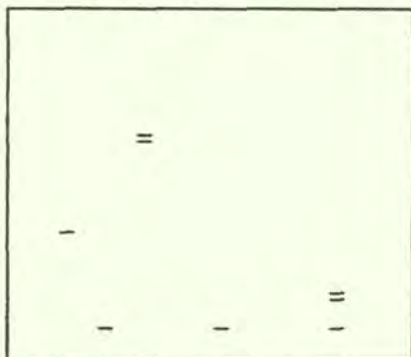
Logarithmic scale
 Symbol No of stems
 - 0
 = 1
 ≡ 2
 ■ 3 to 6
 ■ 7 to 19
 ■ >19

Figure 13c: Change in population of Commiphora between 1976 and 1983:

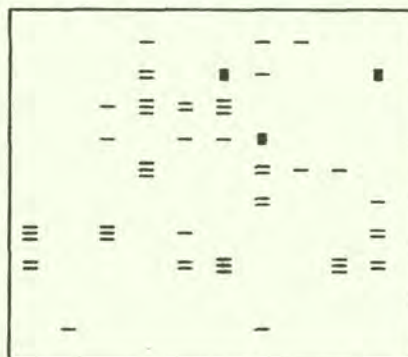
			-1			-1	-1		
			-2		-4	-1			-4
		-1	-3	-2	-3				
		-1	+2	-1	-1	-4			
			-3			-2	-1	-1	
						-2			-1
-3	+1	-3		-1					-2
-2				-2	-3			-3	-2
								+2	
	-1	+1			+1	-1		+1	

The mean change in number of stems per square was -0.55 ± 1.18
 The value of t is -4.646 with probability $p < 0.001$

...increase



...decrease



Arithmetic scale
 Symbol No of stems
 0
 - 1
 = 2
 ≡ 3
 ■ 4

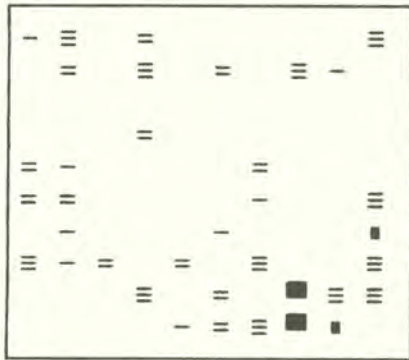
Figure 13d: Change in population of Balanites between 1976 and 1983:

+1	+4	-3	+2	-2				-1	+4
-1	+3	-7	+8		+2	-2	+7	+1	
	-1	-2					-13	-8	
-1	-1	-1	+2	-71	-45		-4	-5	-2
+2	+1		-2	*	-35	+3	-1	-2	-4
+2	+2		-4	-1	-2	+1			+6
-6	+1	-7	-19	-5	+1		-1		+12
+11	+1	+2	-2	+2	-16	+5			+6
-1		-6	+7		+3	-21	+41	+8	+11
-6	-7	-7	-5	+1	+3	+9	+61	+36	-1

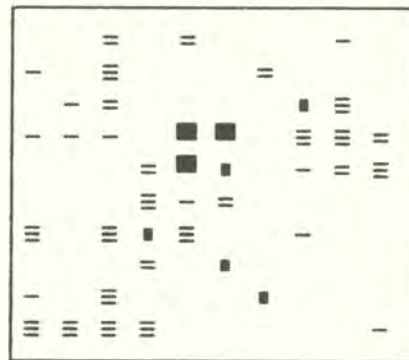
*-121%

The mean change in number of stems per square was -1.80 ± 17.97
 The value of t is -1.002 (ns).

...increase



...decrease



Key:

Symbol	No of stems
-	0
-	1
=	1 to 3
≡	4 to 11
■	12 to 40
■	>40

=====
transmitting more information than would an arithmetic scale, but tends to reduce the visual impact of the change in densities between the two inventories.

9.4.6.2.2 Changes in populations of woody species

It is immediately apparent that the populations of *Acacia* (Figure 13a), *Grewia* (Figure 13b) and *Commiphora* (Figure 13c) have suffered a remarkable loss in the intervening 7 years. The situation for *Balanites* (Figure 13d) is not so clearcut; some areas within the enclosure have suffered high mortality, but others have shown increases in density. Problems of inaccurate localisation of stems may account for some of the changes noted, but this concerns few of the stems inventoried, and the general trends are clear. With the exception of *Balanites*, almost no redistribution of woody cover, in the sense of an invasion of new areas by a species, has taken place.

Although they were not been mapped in 1976, Poupon gives measures of density of *Boscia* and *Guiera* on the different land types. From these figures it can be shown (Table 6a) that the populations of both species have become considerably less dense over the intervening period. Note that the figure in the last column represents the percentage reduction of each year's standing crop (ie annual compound decrement).

9.4.6.2.3 Use of standing dead plants as an indicator of annual mortality

An inventory was made in 1983 of the number of dead plants of each species still standing. From this inventory and the preceding data, it can be seen (Table 5b) that the relationship between the long-term rate of mortality per year and the numbers of standing dead plants is far from clear. In order to use the proportion of standing dead plants as an indicator of rate of mortality, it would therefore be necessary to examine the species-specific length of time that a dead woody plant is likely to remain standing. Such a study would have to take into account the actions of fire, termites and humans, and is unlikely to be of great benefit to a monitoring programme.

9.4.6.2.4 Influence of type of terrain on distribution of woody plants

To the observer in the field, the landform visibly influences the distribution of the plant species. This is perhaps specially true of *Boscia*, for which the human eye can readily make out strong similarities in pattern in Figure 12a, a distribution map of *Boscia* in the enclosure, and Figure 10b, the digitised map of terrain types.

The effect of landform on density is in all cases statistically highly significant (analysis of variance, $p < 0.001$ in all cases), as is the effect of landform on the change in densities between the two years ($p < 0.001$ in all cases), except in the case of *Balanites*. Each of the

Table 6a: Mean change in number of individuals per hectare per year

Species	Density per ha		Change per ha	mean change per ha per yr	
	1976	1983		absolute	as % reduction
Boscia	492*	353.2	138.8	19.8	4.6
Guiera	235*	46.8	188.2	26.9	20.6
Balanites	56.7	49.6	7.1	1.0	1.9
Acacia	17.0	3.6	13.4	1.9	19.9
Grewia	17.1	5.6	11.5	1.6	14.7
Commiphora	4.1	1.9	2.2	0.3	10.4

*Data from table on page 68 of Poupon (1980). Other data from maps in his annexes.

=====

Table 6b: Comparison of proportion of standing dead with mean annual mortality

Species	% mortality mean per year	No of standing dead as % of population
Boscia	4.6	-
Guiera	20.6	19.2
Balanites	1.9	7.6
Acacia	19.9	9.9
Grewia	14.7	49.3
Commiphora	10.4	4.0

=====
species has tended to suffer proportionately more in the wetter areas, with the exception of *Balanites*, which has tended to shift its distribution off the crests of the dunes and into the depressions.

9.4.6.2.5 Changes in dispersion pattern between 1976 and 1983

Clapham, quoted in Greig-Smith (1983) provides a variance:mean ratio test designed to describe the degree to which the dispersion pattern of a population of plants departs from a random distribution, that is, the degree to which the plants are clumped or regularly dispersed. This test (Table 7a) shows that the dispersion of all the species was statistically significantly contagious in both years, but in all cases except *Commiphora*, the populations had become less clumped or contracted in 1983 than they were in 1976 (Table 7b). This arises presumably as a direct consequence of each species losing proportionately more individuals in areas of high density than in areas of low density. However, this finding runs directly contrary to the frequently-quoted tendency of plant populations differentially to lose outliers as they retreat into restricted clumps where survival is still possible.

9.4.6.2.6 Changes in complexity of community between 1976 and 1983

If all the plant species had been plotted to the same grid, Shannon's Index (Greig-Smith 1983) could be used to examine the degree to which the landscape had become ecologically more or less uniform between the two inventories. As it is, it can be applied to that part of the community excluding *Boscia* and *Guiera*. In both 1976 and 1983 the heterogeneity of the community, considering the other four species alone, depended strongly on the landform, increasing monotonically as one moved off the dune crests into the depressions (analysis of variance, $p < 0.001$). This observation would certainly remain true were the other two species included. For every landform, the community remaining in 1983 tended to be more homogeneous than it was in 1976; once again, were *Boscia* and *Guiera* included in the analysis, the observation would certainly remain true.

9.4.6.3 Conclusions

There has been a dramatic loss of woody plants at Fété Ole between 1976 and 1983. There is every reason to believe that this loss is continuing, and that these changes are representative of events elsewhere in the Ferlo, and probably throughout the Sahel. Although the enclosure was imperfectly protected in the years after the ORSTOM study, and has certainly been used to graze livestock, it was originally chosen for its relative remoteness from the nearest mechanised water-point, so as to reduce as much as possible the effect of livestock and human activities. The changes that have taken place, therefore, are likely to be considerably less marked than in those areas of greater exploitation. It is therefore certain that in a very short interval the pastures of the Sahel have become generally less protected by woody cover, and that the community of woody species remaining has become less and less diverse.

Table 7a: Degree to which distribution of woody plants differs from random (Greig-Smith p61)

Species	1976			1983		
	var/mean	Disp.	Prob	var/mean	Disp.	Prob
Acacia	15.883	1572	0.001	1.689	167	0.001
Grewia	16.620	1645	0.001	10.117	1001	0.001
Commiphora	1.794	177	0.001	1.451	143	0.005
Balanites	31.508	3119	0.001	16.509	1634	0.001

All four species show highly significant statistically contagious distributions.

=====

Table 7b: Test of degree of change in dispersion (Greig-Smith p65)

Species	Clumping index		omega (Ω)	signif. change?
	1976	1983		
Acacia	14.883	0.689	-1.120	yes
Grewia	15.620	9.117	-0.248	no
Commiphora	0.794	0.451	-0.106	no
Balanites	30.508	15.509	-0.323	yes

=====

Even if reduced rain rather than increased exploitation is the principal reason for this dramatic change, we must act rapidly to ensure that the current and future demands made on this enfeebled ecosystem do not exceed its capacity to regenerate, or, at very least, its capacity to resist the apparently inexorable drive towards a sparse monoculture of *Boscia*, and, eventually, desert.

10 External Aid

Ultimately, only Africans can devise solutions to the problems of Africa (ICIHI 1985). But can the rest of the world simply stand by? Africa needs, more than ever before, massive aid from external sources, directed especially to herders and small farmers. Because the problem is of such a size, it is greater than any international aid can cope with on its own, and demands greater technical input than is available. Only a concerted and continual effort on the part of the affected populations can seriously make a difference (Clément 1986). Thus although the resources for a new rural initiative must come principally from aid donors outside the continent, external aid should no longer be regarded as an indispensable prerequisite for all forestry programmes (Wane-Condé 1986).

Since the famine in the mid-seventies aid in the sahelian countries has reached \$2 thousand million, more than \$44 per person. However, only 24% of aid has gone towards agriculture, and less than 1.4% to forestry projects. Of this agricultural and forestry aid, less than 40% went to projects in the field, and the rest went to urban support projects (Grainger 1982). Although successful livestock management is essential for coping with desertification (ICIHI 1985), less than 5% went to the livestock sector.

Of the finance that went towards the fight against desertification, four-fifths went to preparatory or support projects, while one fifth went into corrective field action. Even here, the emphasis was placed on measures to increase production rather than arresting desertification (ICIHI 1985). Clearly, in view of the gravity of the situation, ways must be found to increase either the amount or the proportion of aid going directly to rural livestock, reforestation and forestry projects.

The rural populations must help to identify the problems which will be tackled and the resources that will be needed for the rehabilitation of their environment. Donor and recipient governments must trust their capacity and help them help themselves on the difficult path to self-sufficiency (ICIHI 1985). External sources can provide sustained technical assistance, including the facilities and funds for the training of those who are to be responsible for spreading the understanding of the techniques and of the need for them. It can also help by supporting continual education, especially through the various communications media, including audio-visual propaganda for the tree (Clément 1986).

=====
11 Discussion

The conclusions are clear. Firstly, if there is a productive future for the Sahel it lies in pastoralism. Agriculture can only lead to increased pressures on the land. Secondly, if the present trends are not reversed, the forest will disappear from the Sahel to satisfy, temporarily, the needs of man (Rochette 1986). Thirdly, what is happening in Africa today can very well happen in other parts of the globe tomorrow. If man continues to use resources without thought for the future, and to fight against nature instead of cooperating with it, the kind of problems now facing Africa may, in years to come, also face the other continents (ICHI 1985:14).

In the Sahel the crisis of the woodlands arises because for many years the area has suffered from the pressure of livestock and bad management, during an extended dry period, which has tended to concentrate the livestock on surviving pastures (Boudet 1986), and from the rapidly increasing demands for fuel wood and charcoal. Additional pressure on the tree in the south of the Sahel has come from the uncontrolled clearance of fields for agriculture.

Up to the present, reforestation projects and measures for the protection of the environment have been unable to cope with the problem of desertification in Africa (Wane-Condé 1986). However, there is still great hope that deforestation and desertification can be stopped by the efforts of the rural population, whose competence and knowledge of pastoralism must be integrated into modern range management practices, acting jointly with the forestry services, government action and the help of their foreign partners (Johnson 1980, Rochette 1986).

New programmes should be designed to work even if the current drought should turn out to be permanent (Hamel 1986), but donors and Governments must beware of finding themselves in an endless search for more and more basic data in the attempt to define realistic, ecologically sound plans for development (ACOS 1984). It is less and less a question of "what to do", "how to do", nor even of "determined to do", but increasingly urgently "do"; that is, act immediately on vast areas for a long time (Clément 1986). The alternative, as we have seen too often in the past, is famine, with the accompanying breakdown of the local environment and society that threatens wider social stability and government structures (ICHI 1985).

Our present attitude toward the environment is scarcely more sympathetic than is that of the maladapted parasite towards its host. The parasite draws its life from the unwilling host, which sickens and weakens. If the host eventually dies, the parasite dies with it, unless it finds a way to move on to another victim.

The tree has long been recognised as the friend of mankind, and attacks on trees have always been seen as hostile acts. Thus, in the Middle Ages in Europe, cutting trees was an act of despoilation in time of war: "Enguerrand III, called 'the Great'... was accused of having pillaged the lands of the diocese of Reims, cut down its trees, seized its villages..." (Tuchman 1978). More recently, there have been at least

=====

four wars since the Second World War in which defoliants have been used as weapons directed at forests belonging to the enemy (Robinson 1979).

It is now time that we learned that attacks on trees are acts hostile not only to our fellow man, but to the environment in which we all live. Perhaps this generation will discover whether in the Sahel man will save his host, the woodland, from his hostile, parasitic behaviour; or whether he will bring the trees "ad Triarios" - to their last stand.

Appendix 1: The following list of sahelian woody plants is drawn substantially from Baumer (1983) with the addition of some information from Weber et al (1977). The plants listed here are chosen largely for their ecological value to the pastoral peoples as forage or wood.

Acacia albida (see *Faidherbia albida*)

Acacia ehrenbergiana

Synonymy/close relative: *Acacia flava*, *Acacia seyal*

Growth form: small shrub 2-4m

Water requirements: less than 300mm

Forage: most important browse species in its environment. Camels, sheep and goats.

Potential for plantation: unknown

Preferred soils: coarse, stony soils, clays covered by gravel

Uses: bark makes ropes, branches line wells

Acacia laeta

Synonymy/close relative: *Acacia trintigniani*

Growth form: tree

Water requirements: 300-600mm

Forage: poor. Fruits eaten by camels and sheep.

Potential for plantation: unknown

Preferred soils: rocky; also found in compacted sandy soils and on shifting sands over laterite

Uses: charcoal for drying hides; mediocre gum; good firewood; stem bark used for ropes; root bark used for sewing; medicinal properties; magical properties

Acacia nilotica

- Synonymy/close relative: *Acacia arabica*, *Acacia scorpioides*,
Mimosa nilotica
- Growth form: spiny shrub or small tree; usually 3-5m, but up to 20m
- Water requirements: 250-750mm, but also in any area with adequate ground water
- Forage: pods, leaves and twigs consumed by camels, sheep and goats, even when fallen
- Potential for plantation: from seed; seedlings develop fast; weeding advantageous. Natural regeneration poor.
- Preferred soils: fine textured soils; heavy clay
- Uses: wood used for tools, carts, posts, poles; fences for livestock pens; live fences and windbreaks; excellent firewood; good charcoal; bark and pods for tanning; gum for dyes; medicinal properties
-

Acacia senegal

- Synonymy/close relative: *Acacia verec*
- Growth form: depends on rainfall: 120-300mm, a bush, otherwise a tree of 3-6m, occasionally up to 9m
- Water requirements: 120-750mm (mostly 200-500mm)
- Forage: leaves and pods eaten by sheep, goats, camels. Despite legislation herdsmen often lop branches to feed livestock
- Potential for plantation: natural regeneration easy when protected from grazing. Planting from seed without fertilizer. Seedling must be weeded. Plantations must not be too dense.
- Preferred soils: deep sandy soils; stabilized sand dunes; abandoned fields; also on shallow clayey soils
- Uses: gum arabic; live fencing; tannin from bark; tool handles; building poles; lining wells; good firewood; good charcoal; roots used for twine; nitrogen fixation
-

Acacia seyal

- Synonymy/close relative: *Acacia stenocarpa*; *Acacia boboensis*
- Growth form: small tree up to 12m
- Water requirements: 400-800mm; very resistant to soil dessication
- Forage: very good; sheep and goats eat leaves and pods. Herdsmen lop branches; in times of shortage of other forage, livestock eat bark
- Potential for plantation: propagation from seed as for *A. senegal*
- Preferred soils: loamy-clay or clay
- Uses: gum; forage; firewood

Acacia tortilis

- Synonymy/close relative: *Acacia raddiana*, *Acacia spirocarpa*
Growth form: tree up to 20m
Water requirements: 100-1000mm; very adaptable, resistant to drought
Forage: good: sheep and goats eat leaves and pods on smaller individuals. Fallen pods also eaten by horses and donkeys. Herdsmen lop branches of larger trees.
Potential for plantation: poor germination in vitro, improved by passage through ruminant gut. Shade and irrigation necessary for seedling
Preferred soils: very adaptable
Uses: multiple: forage; construction; firewood; excellent charcoal; inferior gum; shade; soil stabilization; fishing spears on Lake Chad; construction of saddles; roots used for framework of huts; medicinal properties
-

Adansonia digitata

- Synonymy/close relative:
Growth form: large tree up to 25m
Water requirements: 250-1100mm
Forage: poor
Potential for plantation: seedlings do not germinate well and do not survive in presence of livestock. Natural regeneration extremely limited.
Preferred soils: various; acid or calcareous, clays, sands and stony soils
Uses: pulp of fruit rich in vitamin C, and is eaten fresh or cooked; smoke from burning pulp used to keep insects away from livestock; husk used for making soap; hollowed-out trunk used as reservoir or food store; fibre from bark for ropes and rigging, mats and paper; leaves are cooked fresh and dried; leaves, pulp and seeds have medicinal properties. Wood is useless.

Balanites aegyptiaca

Synonymy/close relative:

Growth form:

Water requirements:

Forage:

Potential for plantation:

Preferred soils:

Uses:

tree up to 10-12m

200-900mm. Will survive in drier areas if it has access to groundwater

leaves appreciated by sheep, goats, cattle and camels; fallen leaves by camels and sheep; shoots and fruit by all livestock; flowers and fruit by humans

soaked and sun dried seeds germinate easily

varied; heavy soils near ponds or underground water; rocky screes; deep sandy soils,

especially those which occasionally flood

hard, heavy, fine-textured wood can easily be worked and resists insects; many uses for light woodworking and heavy carpentry; fruit is appreciated by humans; kernels of fruit yield edible oil; many medicinal and insectivorous properties; fruit and bark yield toxins for fish which are harmless to humans

Boscia senegalensis

Synonymy/close relative:

Growth form:

Water requirements:

Forage:

Potential for plantation:

Preferred soils:

Uses:

Boscia octandra

undershrub or shrub, 1-2m; may grow to 4m

100-300mm; very tolerant to drought

occasionally consumed especially in bridging period

none

arid soils; rocky, lateritic, clay stony hills, stabilized dunes, sand-clay plains; compact soils, termite mounds, hollows.

acid fruit soaked for a week for human consumption; sundried and powdered leaves can be cooked; medicinal properties.

Combretum aculeatum

Synonymy/close relative:

Growth form:

Water requirements:

Forage:

Potential for plantation:

Preferred soils:

Uses:

small climbing shrub

100-600mm

leaves and fruit highly sought-after by livestock. High tolerance to browsing.

high germination rate, easy growth from seeds

various; sand on laterite; lateritic cliffs; rocky soil; near ponds

forage; fruits palatable; root used as purgative

Combretum glutinosum

Synonymy/close relative:

Growth form: depending on rainfall; shrub in Sahel, evergreen tree, 10m tall, in Sudanian zone

Water requirements: 200-1000mm

Forage: leaves (both on plant and fallen) eaten when other forage is scarce

Potential for plantation: unknown

Preferred soils: various; preferably sandy; also clay-sands, laterites and sandstones.

Uses: dense wood used for tool handles and mortars; good firewood; ash used for fixing dye; medicinal properties; root produces dye.

Combretum micanthrum

Synonymy/close relative: *Combretum album*, *Combretum rainbaulti*, *Combretum floribundum*

Growth form: bushy shrub up to 4m

Water requirements: 300-900mm

Forage: cattle eat fallen leaves

Potential for plantation: unknown

Preferred soils: non-cultivable land; very dry soils, lateritic soils, sandstones, clays and crystalline rock debris

Uses: medicinal properties; firewood; stems used for poles; branches for poultry baskets and grain stores

Commiphora africana

Synonymy/close relative: *Heudelotia africana*, *Balsamodendron africana*

Growth form: shrub, 3-7m

Water requirements: 200-400mm

Forage: young shoots, available at end of dry season, relished by camels and smallstock

Potential for plantation: easy to multiply by cuttings

Preferred soils: various

Uses: wood used for troughs, bowls, beads; living plants used as fences; fragrant bark used to perfume clothes; medicinal properties

Faidherbia albida

- Synonymy/close relative: *Acacia albida*, *Acacia gyrocarpa*, *Acacia saccharata*
Growth form: tree, 20-25m
Water requirements: 350-500mm, but also found in very dry areas near ground water close to surface. Has high water requirement.
Forage: sheds foliage in rains, keeps it through dry season. Leaves, pods and fruit are excellent fodder, appreciated by livestock.
Potential for plantation: Seeds germinate better after passage through ruminant gut. With sufficient rain, germination and seedling establishment easy. Seedlings easily destroyed by livestock in natural pastures, and cannot grow in areas with less than 450mm unless water provided.
Preferred soils: sandy or silty-sandy; drainage lines and depressions; will also grow in clays
Uses: highly valued in conservation; very useful fodder plant; improves soils giving better harvests of crops and grasses (but not groundnuts); shade; wood easy to work and though not strong, used for many small household items and occasionally in building and for canoes; branches for fences; bark contains tannin; pods eaten by man in times of dearth.
-

Grewia bicolor

- Synonymy/close relative: *Grewia salvifolia*
Growth form: shrub or small tree up to 8m
Water requirements: 200-1500mm
Forage: fairly good; leaves eaten at end of dry season
Potential for plantation: unknown
Preferred soils: varied; from rocky screes to clay depressions
Uses: leaves used in cooking; berries for a drink; medicinal properties
-

Guiera senegalensis

- Synonymy/close relative:
Growth form: bush or small tree 3-5m
Water requirements: 300-600mm
Forage: appreciated by camels
Potential for plantation: poor germination but cuttings grow readily
Preferred soils: sandy; fallow fields
Uses: good firewood; medicinal properties

Pterocarpus lucens

Synonymy/close relative: *Pterocarpus abyssinica*
Growth form: shrub or small tree up to 12m
Water requirements: 100-700mm
Forage: at beginning of rainy season, leaves relished by livestock. Fallen leaves also sought.
Potential for plantation: unknown
Preferred soils: dry, rocky screes or lateritic soils; heavy soils in depressions
Uses: wood easy to work; leaves cooked; medicinal properties; bark used in tanning.

Ziziphus mauritiana

Synonymy/close relative: *Ziziphus jujuba*
Growth form: shrub or small tree 5-6m
Water requirements: 200-800mm
Forage: leaves and fruits much appreciated by livestock
Potential for plantation: germination fairly good, grows easily but slowly
Preferred soils: sands; sandy depressions; rocky; cultivations; near dry river beds
Uses: spiny branches used for temporary livestock pens; fruit edible; pulp of fruit fermented, dried and macerated in water to produce a drink rich in Vitamin C; wood very hard, but works easily and takes polish; used for bed frames; medicinal properties

Bibliography

Although it is now rather outdated, the extensive bibliography of 1510 titles assembled by Le Houérou (1976c) is still without peer for the student of the arid lands of Africa and south-west Asia. The more recent ACOS (1984) contains a bibliography of 100 titles which usefully supplements the earlier work.

For an up-to-date assessment of the state of the tree in the Sahel the attention of the reader is drawn to the collections of articles in:

Aménagement et Nature 81: L'arbre et la forêt. Menaces et l'avenir.
II: Afrique tropicale sèche

from which much of the information in this document has been drawn.
=====

ACOS (Advisory Committee on the Sahel) (1984) Environmental change in the West African Sahel. Board on Science and Technology for International Development. National Research Council. Washington DC.

Ament K.S. and S. Joseph (Eds) (1980) Wood conserving cook stoves: A design guide. Volunteers In Technical Assistance (VITA) Publications. 3706 Rhode Island Avenue, Mt. Rainier, Maryland.

Barral H. (1982) Le Ferlo des Forages: Gestion ancienne et actuelle de l'espace pastoral. ORSTOM. Direction Générale de la Recherche Scientifique et Technique. Dakar

Baumer M. (1983) Notes on trees and shrubs in arid and semi-arid regions. EMASAR Phase II. Plant Production and Protection Division, Food and Agriculture Organisation of the United Nations. Rome.

Bille J.C. (1978) Woody forage species in the Sahel: their biology and use. Proceedings of the First International Rangelands Conference Pp 392-395.

Blancou J., H. Calvet, D. Friot et J. Valenza (1977) Composition du pâturage naturel consommé par les bovins en milieu tropical: note sur une technique d'étude nouvelle. Recherches sur l'élevage bovin en zone tropicale humide. Bouaké. Côte d'Ivoire.

Boisgallais A-S. (1986) O.N.G. et opérations triangulaires: L'arbre et l'autosuffisance alimentaire. Aménagement et Nature 81:21-24

Boudet G. (1977) Contribution au contrôle continu des pâturages tropicaux en Afrique occidentale. Revue de l'Elevage et de Médecine vétérinaire des Pays tropicaux 30(4):387-406

Boudet G. (1986) L'arbre et l'élevage. Aménagement et Nature 81:25-26

Box T.W. (1983) Social and economic implications of range improvement. Pp 1-2 In: Clawson W.J. Range Improvements Today and Tomorrow. Thirty-sixth Annual Meeting of the Society for Range Management. Albuquerque.

Breman H. (1982a) La production actuelle des pâturages naturelles en relation avec des facteurs naturels et des facteurs anthropiques: La productivité des herbes perennes et des arbres. Pp 284-296 In: Penning de Vries F.W.T. et M.A.Djièye (Eds) La productivité des pâturages sahéliens. Une étude des sols, des végétations et de l'exploitation de cette ressource naturelle. Centre for Agricultural Publishing and Documentation. Wageningen.

Breman H. (1982b) L'aménagement des pâturages: L'amélioration des pâturages. Pp 468-470 In: Penning de Vries F.W.T. et M.A.Djièye (Eds) La productivité des pâturages sahéliens. Une étude des sols, des végétations et de l'exploitation de cette ressource naturelle. Centre for Agricultural Publishing and Documentation. Wageningen.

Breman H., I.B. Cissé et M.A. Djitéye (1982) La production actuelle des pâturages naturelles en relation avec des facteurs naturels et des facteurs anthropiques: Exploitation, dégradation et désertification. Pp 352-386 In: Penning de Vries F.W.T. et M.A.Djièye (Eds) La productivité des pâturages sahéliens. Une étude des sols, des végétations et de l'exploitation de cette ressource naturelle. Centre for Agricultural Publishing and Documentation. Wageningen.

Bruhjell J. (1985) Voices from the desert. United Nations Environment Programme. Nairobi

Cissé A.M. et H. Breman (1982) La phytoécologie du Sahel et du terrain d'étude. Pp 71-83 In: Penning de Vries F.W.T. et M.A.Djièye (Eds) La productivité des pâturages sahéliens. Une étude des sols, des végétations et de l'exploitation de cette ressource naturelle. Centre for Agricultural Publishing and Documentation. Wageningen.

Clément J. (1986) Enjeux et stratégie d'une nouvelle politique forestière: La silviculture paysanne. *Aménagement et Nature* 81:11-16

Darkoh M.B.K. (1986) Combating desertification in Zimbabwe. *Desertification Control Bulletin* 13:17-28

De Wispelaere G. (1981) Système de production d'élevage au Sénégal. Etude et cartographie de l'évolution de la végétation par télédétection. 2ème campagne. Institut d'Elevage et de Médecine Vétérinaire des pays Tropicaux (IEMVT). Maisons Alfort.

Dickey J. (1983) Denombrement des animaux et rendement actuels en regard des possibilités de pâturage au Sahel. In: Vanpraet C.L. (ed) Méthodes d'Inventaire et de Surveillance continue des Ecosystèmes pastoraux sahéliens: Application au Développement. Ministère de la Recherche scientifique et technique, République du Sénégal. Pp 391-399.

Dommergues Y. (1986) Peut-on sauver la végétation ligneuse en Afrique tropicale sèche? *Aménagement et Nature* 81:31-32

Field C. (1979) Preliminary report on the ecology and management of camels, sheep and goats in northern Kenya. UNESCO's Integrated Project

for Arid Lands. Technical report E-1b. United Nations Educational, Scientific and Cultural Organisation. Nairobi.

Fleury J-M. (1983) Acacias at home on the range. Mazingira 7(1):68-69

Foley G. and P. Moss (1983) Improved cooking stoves in developing countries. Energy Information Programme Technical Report No 2. Earthscan. 10 Percy Street. London

Gallais J. (1979) La situation de l'élevage bovin et le problème des éleveurs en Afrique occidentale et centrale. Les Cahiers d'Outre-Mer 32(126):113-138

GEMS (1982) Desertification monitoring and assessment within GEMS. Desertification Control Bulletin (UNEP) 6:14-20

GEMS (1986a) Introduction to the Sahelian Pastoral Ecosystems Project. Global Environment Monitoring System Sahel Series No 1. UNEP/FAO.

GEMS (1986b) Rainfall in the Ferlo (Sahelian region of north Senegal) since 1919. Global Environment Monitoring System Sahel Series No 2. UNEP/FAO.

GEMS (1986c) Monitoring pasture production by remote sensing. Global Environment Monitoring System Sahel Series No 5. UNEP/FAO.

GEMS (1986d) Use of Light Aircraft in the Inventory and Monitoring of Sahelian Pastoral Ecosystems. Global Environment Monitoring System Sahel Series No 3. UNEP/FAO

GEMS (1986e) Inventory of water resources in the Ferlo. Global Environment Monitoring System Sahel Series No 6. UNEP/FAO

GEMS (1986f) Sampling the Sahel. Global Environment Monitoring System Sahel Series No 4. UNEP/FAO

Gèze F., Y. Lacoste, A.G.A. Valladao, T. Pequot (1985) L'état du monde. Edition 1985. Annuaire économique et géopolitique mondiale. Editions la découverte. Paris.

Giffard P.L. (1974) L'Arbre dans le paysage Sénégalais. Centre Technique Forestier Tropical. Dakar.

Goudet J-P. (1986) Aménagement des forêts naturelles et reboisement en Afrique tropicale sèche. Aménagement et Nature 81:33-36

Grainger A. (1982) Desertification. How people make deserts, how people can stop and why they don't. Earthscan. 10 Percy Street, London.

Hamel O. (1986) Recherche et développement. L'arbre et la désertification en Afrique tropicale sèche. Aménagement et Nature 81:27-31

Hiernaux P. et L. Diarra (1978) Rapport annuel. Section écologie. International Livestock Committee for Africa. Bamako.

ICHI (Independent Commission on International Humanitarian Issues) (1985) Famine: a man-made disaster? Pan Books Ltd. London.

ILCA (International Livestock Centre for Africa) (1984) ILCA Annual Report. PO Box 5689, Addis Ababa. Ethiopia.

Johnson D.L. (1980) Desertification and nomadic pastoral development. Pp 75-86 In: Bartlett E.T. The Man and the Biosphere Program in Grazing Lands. First International Rangeland Congress. Denver, Colorado.

Kurian G.T. (1982) Encyclopedia of the Third World. Facts on File. New York.

Lapedes D.N. (1974) (Ed) McGraw-Hill Encyclopedia of Environmental Science. McGraw-Hill.

Laurent D. (1986) Ressources forestières et besoins en bois dans les pays africains de zone sèche. Aménagement et Nature 81:7-11

Le Houérou H.N. (1976a) The nature and causes of desertization. Arid Lands Newsletter 3:1-7. Office of Arid Lands Studies. Tuscon.

Le Houérou H.N. (1976b) Nature et desertisation. Consultation CILSS/UNSO/FAO. Sur le rôle de la foresterie dans un programme de rehabilitation du Sahel. Comité permanent Interetats de Lutte contre la Sécheresse dans le Sahel. FO:RAF/305/3.

Le Houérou H.N. (1976c) Contribution à une bibliographie écologique des régions arides de l'Afrique et de l'Asie du sud-ouest (Végétation, pâturages, élevage, agriculture, nomadisme et désertisation). Nouvelles Editions Africaines. Dakar-Abidjan.

Le Houérou H.N. (1977a) Man and desertization in the Mediterranean region. Ambio 66:363-365

Le Houérou H.N. (1977b) Rangeland production and annual rainfall relations in the mediterranean basin and in the African sahelo-soudanian zone. Journal of Range Management 30(3):181-189.

Le Houérou H.N. (1980) The rangelands of the Sahel. Journal of Range Management 33(1):41-46

Le Houérou H.N. (1986) Inventaire et surveillance continue des écosystèmes pâturés sahéliens. Rapport technique rédigé pour le compte de la FAO et du PNUE. FAO/UNEP technical report.

Marchal J.Y. (1982) Facteurs climatiques limitants et calamités agricoles en régions de savanne: Yatenga, Pays Mossi, Haute Volta. Herodote 24:68-94

Mendez R. (1981) Combating desertification in the sudano-sahelian region. Desertification Control Bulletin (UNEP) 5:2-8

Morel M-Y. et J. Morel (1983) Treize années de comptages d'oiseaux dans un quadrat de steppe arbustive dans le Ferlo. In: Vanpraet C.L. (ed) Méthodes d'Inventaire et de Surveillance continue des Ecosystèmes pastoraux sahéliens: Application au Développement. Ministère de la Recherche scientifique et technique, République du Sénégal. Pp 169-176

Penning de Vries F.W.T. (1982) La production potentielle des pâturages sahéliens. Pp 84-86 In: Penning de Vries F.W.T. et M.A.Djièye (Eds) La productivité des pâturages sahéliens. Une étude des sols, des végétations et de l'exploitation de cette ressource naturelle. Centre for Agricultural Publishing and Documentation. Wageningen.

Piot J. (1983) Etude et suivi de la couverture ligneuse en milieu sylvo-pastorale. In: Vanpraet C.L. (ed) Méthodes d'Inventaire et de Surveillance continue des Ecosystèmes pastoraux sahéliens: Application au Développement. Ministère de la Recherche scientifique et technique, République du Sénégal. Pp 223-242.

Poupon H. (1980) Structure et dynamique de la strate ligneuse d'une steppe sahélienne au nord du Sénégal. Travaux et documents de l'ORSTOM. Paris.

Poupon H. (1986) La place de l'arbre dans les écosystèmes sahéliens. Aménagement et Nature 81:2

Poupon H. et J.C. Bille (1974) Recherche écologique sur une savanne sahélienne du Ferlo septentrional, Sénégal. Influence de la sécheresse de l'année 1972-1973 sur la strate ligneuse. La Terre et la Vie 28:49-75

Robinson J.P. (1979) The effects of weapons on ecosystems. UNEP Studies Volume 1. United Nations Environment Programme. Nairobi.

Rochette R. (1986) Deforestation et désertification au Sahel. Aménagement et Nature 81:3-6

Sharman M.J. et M. Gning (1983) Comportement du cheptel au Ferlo - résultats des suivis quotidiens. In: Vanpraet C.L. (ed) Méthodes d'Inventaire et de Surveillance continue des Ecosystèmes pastoraux sahéliens: Application au Développement. Ministère de la Recherche scientifique et technique, République du Sénégal. Pp 209-222

Shiva V. and J. Bandyopadhyay (1986) Desertification in India: trends and countertrends. UNEP Desertification Control Bulletin 13:29-33

SODESP (Société de Développement de l'Élevage dans la zone Sylvo-Pastorale) (1982) Etude de factibilité de projet de création de la filière de Linde. Annexe I: Etude socio-économique de la zone de naissance de Guèye-Kadar. Ministère du Développement. Dakar.

Stiles D.N. (1983) Camel pastoralism and desertification in northern Kenya. UNEP Desertification Control Bulletin 8:2-8

Tuchman B.W. (1978) A distant mirror. The calamitous 14th century. Penguin Books. Harmondsworth.

Van Ittersum G. (1985) Dune de Mbidi. Photointerpretation Télédyné (janv 1980). In: Vanpraet C.L. (Ed) Méthodes d'inventaire et de la surveillance continue des écosystèmes pastoraux sahéliens. Rapport technique terminal. (Diffusion restreinte: Restricted distribution). AGP. Food and Agriculture Organisation. Rome.

Vanpraet C.L. et G. Van Ittersum (1983) Considérations sur des analyses dimensionnelles de quelques espèces ligneuses de la zone sylvo-pastorale au Sénégal. In: Vanpraet C.L. (ed) Méthodes d'Inventaire et de Surveillance continue des Ecosystèmes pastoraux sahéliens: Application au Développement. Ministère de la Recherche scientifique et technique, République du Sénégal. Pp 243-249

Wane-Condé C. (1986) Participation: Stratégie et moyens pour une participation effective des populations à la défense et à la réhabilitation des arbres. Aménagement et Nature 81:17-20

Weber F. (1983) Désertification: bilan - programme forestier CILSS. Club du Sahel.

Weber F.R., F.J. Holman and V.C. Palmer (1977) Reforestation in arid lands. Volunteers In Technical Assistance (VITA) Publications. Manual Series Number 37E. 3706 Rhode Island Avenue, Mt. Rainier, Maryland.