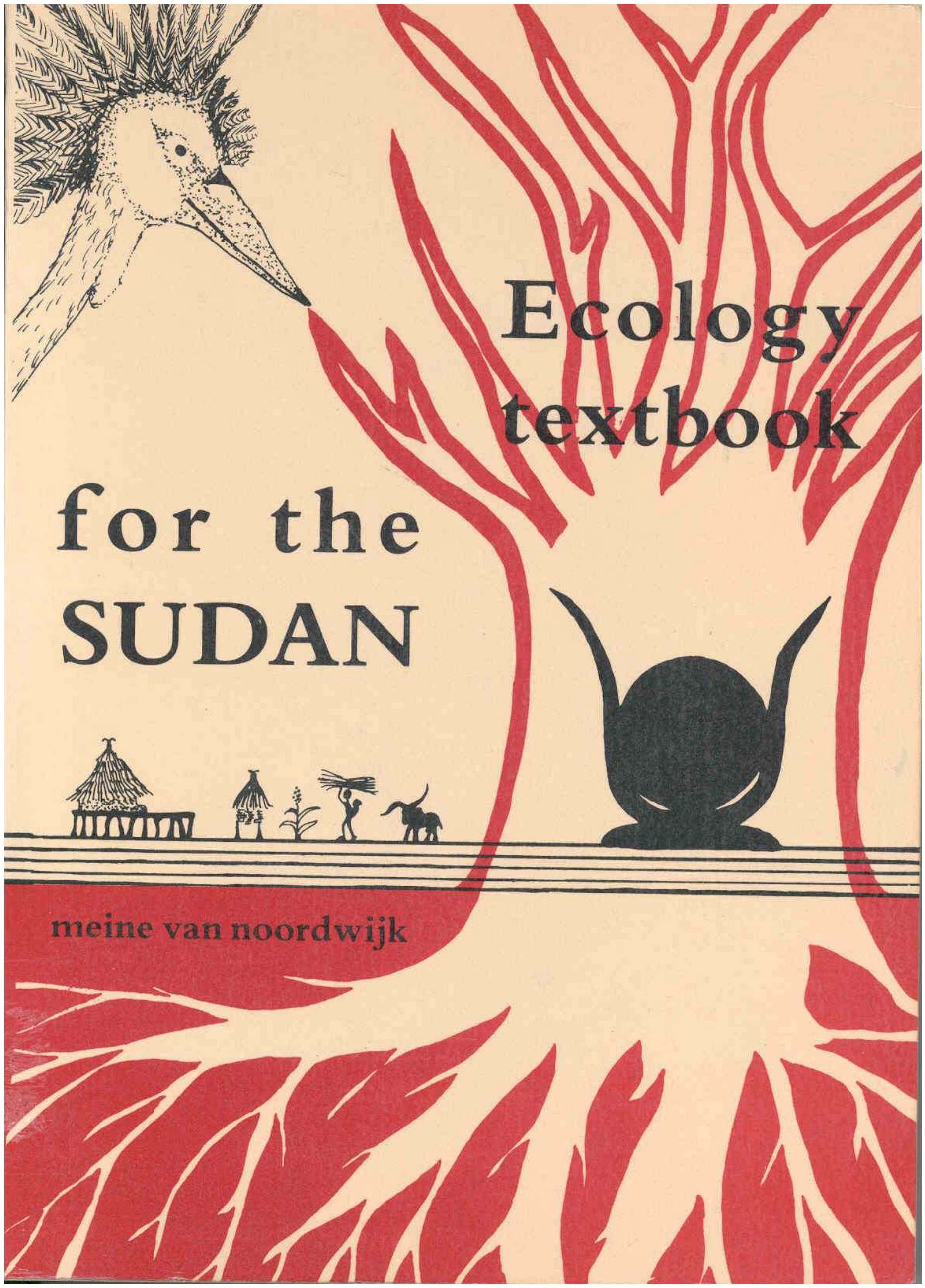
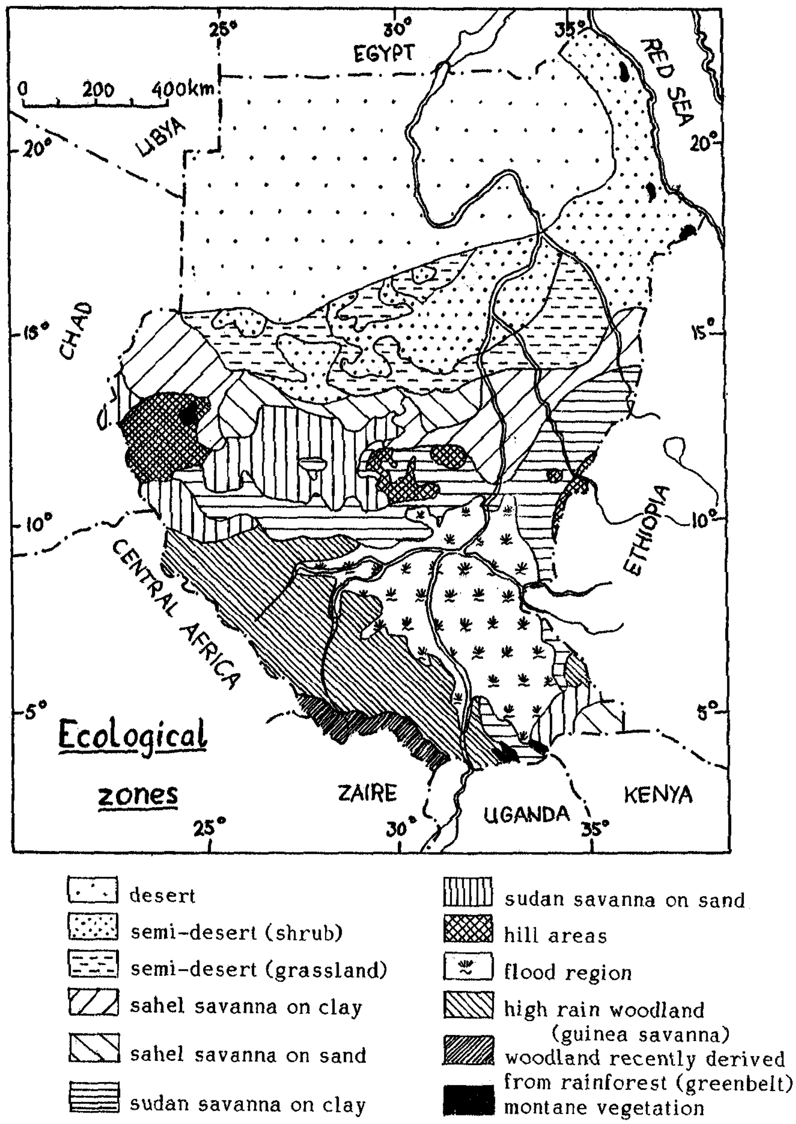
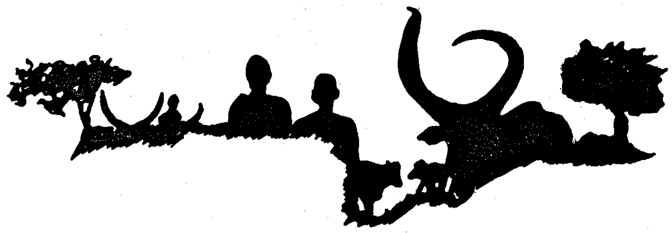

Ecology textbook
for the SUDAN
meine van noordwijk


Ecological zones
0 200 400km
EGYPT
LIBYA
CHAD
RED SEA
ETHIOPIA
CENTRAL AFRICA
ZAIRE
UGANDA
KENYA
25°
30°
35°
20°
15°
10°
5°
desert
semi-desert (shrub)
semi-desert (grassland)
sahel savanna on clay
sahel savanna on sand
sudan savanna on clay
sudan savanna on sand
hill areas
flood region
high rain woodland (guinea savanna)
woodland recently derived from rainforest (greenbelt)
montane vegetation

Ecology textbook for the Sudan



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marja de vries
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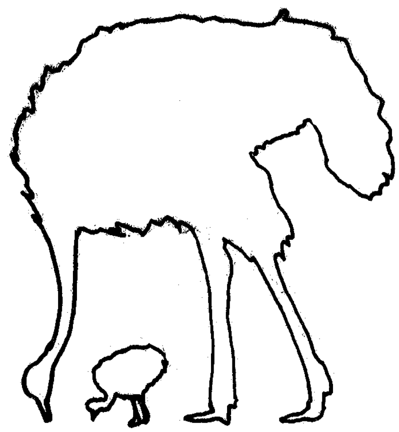
the author

1984 first edition



Ecology textbook for the Sudan

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Joan Looyen (page 8, 47, 48, 96, 137)
the author (others)

Foreword

This book gives an introduction to basic principles of ecology in a Sudanese context, using local examples. Ecology is presented as a way of thinking about and interpreting one's own environment, which can only be learned by practising, by applying these ideas to one's specific situation.

Some people are 'ecologists with their heads', considering ecology to be a purely academic, scientific subject; some are 'ecologists with their hearts', being concerned about the future conditions for life on our planet Earth; others are 'ecologists with their hands', having learned some basic principles of ecology by trial and error in traditional agriculture, fisheries etcetera.

Education of 'ecologists in their mind', combining the positive sides of the three approaches mentioned, can be seen as essential for the future of a country such as the Democratic Republic of the Sudan, with its large environmental potential for positive development, along with great risks of mis-managing the natural resources.

The first half of this book (chapter 1-5) deals with ecology as a biological science, studying the relationships between plants, animals, soil and climate. The second half (chapter 6-9) deals with 'human ecology': use and mis-use of the environment by humankind. These aspects are traditionally 'treated as part of geography or general agriculture, but they build on many of the ideas of the first part.

This book has been set up as a textbook for introductory ecology courses in universities, agricultural schools, teacher training institutes, etcetera. It will be important background material for biology and geography teachers at secondary school level. The text consists of two levels: the normal print gives the main line of argument and can be read independently of the smaller print, which adds further details and more examples. The main text can be used at secondary school level, but does not fully coincide with the present, official school syllabus in the Sudan. I hope some people will take up the challenge of making a simpler version, in both Arabic and English for use as a school textbook, along with updating the official syllabus. So far no textbooks have been available dealing with the subject in a comparable way. The excellent African ecology textbooks for A-level by Ewer and Hall (see references) are more complete and extensive, but of course they contain few Sudanese examples and have a more experimental, scientific approach.

Specific information on the Sudanese environment is scarce, partly out of date and often not easily accessible outside University Libraries. Through is book I have tried to make this information available in a more direct way, adding some results of two year ecology-courses in Juba University. Learning the language of ecology is not possible without some of the jargon and technical terms. These have been avoided where possible, but still, the reader may come across many new terms. Technical terms in **bold** print are listed in the glossary (chapter 11). A special problem is created by use of the names for plants and animals. Scientific names as such are of limited use in a country where keys for identification are hardly at all available. I have tried give synonyms in local languages where-ever I could find these, but my of them are based on the old flora by Broun and Massey, so they may incorrect. By giving many illustrations in the text and in the appendix I hope confusion about the names will be reduced.

Many people have contributed to this book, from the initial conception in September 1980 to the proof edition of December 1981 and to the present version. First of all Dr. Ken Knox, at that time senior lecturer Zoology in Juba University, contributed, as well as three students of the College of Education: Abdelrahim Ahmed Salim, Ismail Ishag and Remigius Idroga. Without many of the students of Juba University this book could never have been written, as they were essential in the teaching/learning experience of blending ecological theory with Sudanese realities. Robert Lubajo, Martin Ring Malek, Abdelrahim Ahmed Salim and Abdelrahim Ahmed El Khidir deserve special mentioning, as they introduced me to their part of the country and helped in describing the respective examples in is book, as well as becoming friends. Mentioning a few names does not mean that I forgot the many others with whom I shared interesting experiences. Through the Dean of the College of Natural Resources and Environmental Sciences, Dr. Peter Tingwa, I would like to thank the University administration for the interest shown and the encouragement given. 'Excellence and relevance' is the motto of Juba University. I hope is book can contribute to at least the relevance of Sudanese education.

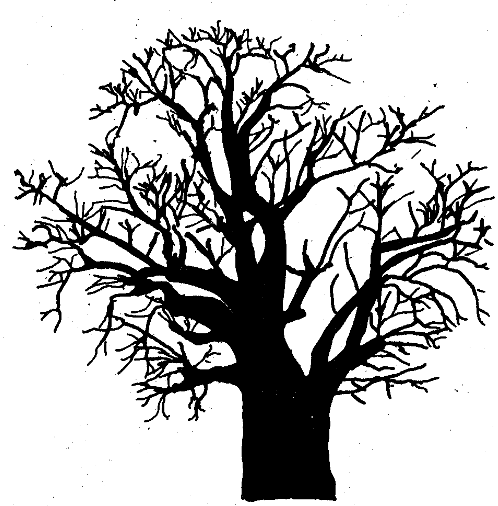
Several people gave critical comments after reading the proof edition: my former colleague Mr. David Knox, Mr. Scopas Dima, Dr. Henk Breman, Joan Looyen, Maria van Noordwijk and Prof. Stortebeker all helped in improving the text. With several colleagues in Khartoum and Gezira University I had fruitful discussions and I want to thank them for the interest shown.
Kast Olema Daniel and Marja de Vries prepared the illustrations for the proof edition in a friendly cooperation. Joan Looyen helped considerably in transforming the many illustrations added later, into a presentable form. Siska, Brord, Henk and Henrik of the Grafische Kring Groningen produced the printed version of this book in a cooperative way, for which I want to thank them.

Finally the Dutch Ministry of Foreign Affairs, Directorate for development cooperation, through the Dutch Embassy in Khartoum, agreed to donate one thousand copies of this book to universities, schools and libraries in the Sudan. By doing so, they made publication of this book possible. Khartoum University Press and Ecologische Uitgeverij Amsterdam agreed to make the book available in bookshops as well.

Of course I remain responsible for all remaining shortcomings. If you want to correspond about these, my address is: c/o Institute for Soil Fertility, Oosterweg 92, Haren (Gr.), the Netherlands.

Juba/Groningen September 1980 -December 1983

the author.



This digital version has a number of minor, mostly typographical and grammatical corrections. Contact: m.vannoordwijk@cgiar.org

Contents

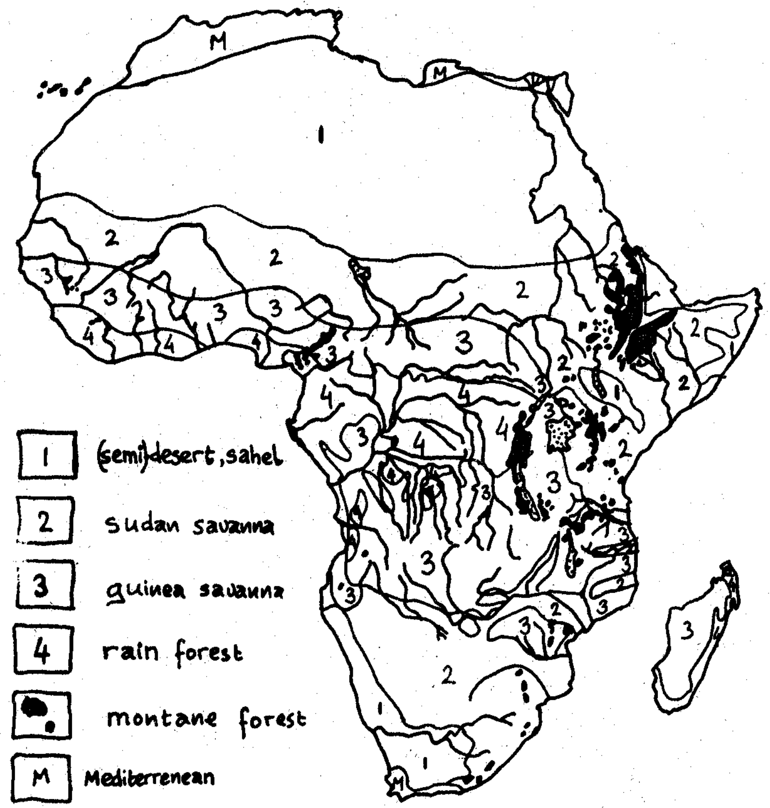
6. Traditional human use of the environment

7. Environmental problems of development

8. Ecological analysis and planning

9. Man and nature

abbrevations used:
A. = Arabic
B. = Bari
D. = Dinka
Sh.= Shilluk
Z. = Azande


1 (semi)desert, sahel
2 sudan savanna
3 guinea savanna
4 rain forest
montane forest
M Mediterrenean

1. Ecological zones of the Sudan

1.1 What is ecology

Ecology deals with the relations between organisms (plants, animals, man) and the environment. Probably such a statement does not make much sense to you, so we will start by considering as examples four organisms, two plants and two animals, which you can probably find nearby: a grass plant, a tree, a snail and a lizard (figure 1.1).

> We can look at the living world around us from many different points of view; some of these viewpoints are part of ecology. Observations in science often have the character of analysis; that means taking to pieces. Although this may be necessary to see enough detail, for a proper understanding it is essential to consider the wholeness as well; if we consider organisms we have to take into account their structure, ('how they are built'), together with their behaviour ('what they do') and function ('what it's good for'). It often helps to imagine a change of role, to think that you are a tree or a lizard yourself and that you have to survive in the environment as perceived by that organism.

A grass plant starts its life as a germinating seed; it forms roots which grow into the soil and which branch many times and in different directions to exploit a large volume of soil; at the same time the plant makes leaves, small ones at first, then bigger ones which expand higher and further away. In this way the plant lives in two completely different environments, the soil and the air, which are both essential to its survival. The growth point where new leaves are formed can be found near the ground surface, where it is protected from grazing, trampling, fire, etcetera. Once the grassplant is established it usually forms a stem, bearing flowers high above the leaves, exposing the flowers to the wind for **pollination.** When the seeds have set and matured, usually towards the end of the rainy season, the life of many grassplants comes to an end. Others make a stock of reserves in their underground parts and survive the dry season resting, to resume growth at the start of the new rains.

Of course there are many different types of grass. Some remain very low near the ground on places where many people walk, others grow very high like bamboo which grows in the forest or they have creeping stems which can extend far into the water from the roots which are attached to the shore. Grasses which flower in their first year and subsequently die are called

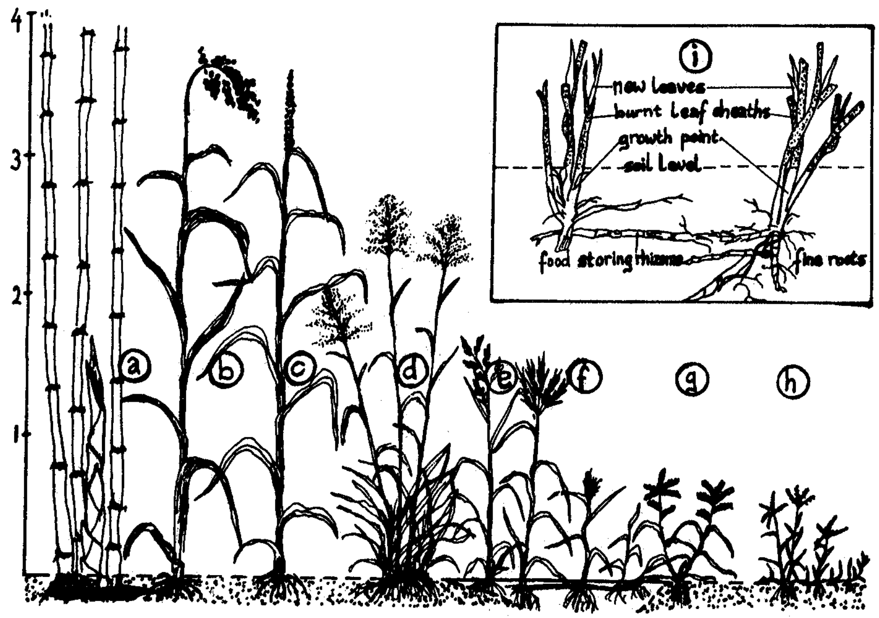


Figure 1.1.A. Some grasses of the Sudan: a. Mountain bamboo (Arundinaria alpina), *up to* 15 m *tall woody perennial, b. Millet or. Dura* (Sorghum), *c. Bulrush millet or Dukhn* (pennisetum), *d.* Panicum maximum, *a tufted perennial, e. Rice* (Oryza), *f.* Vossia cuspidata, *with creeping stem in water, g. Fingermillet* (Eleusine), *h. star grass* (Cynodon dactylon), *a common weed, i. detail of the way in which savanna grasses can survive fire (after various sources).*

annuals. Plants which live for more then one year are called **perennials**. Some grasses are used by man because their seeds are edible: dura *(Sorghum),* dukhn *(Pennisetum),* fingermillet *(Eleusine)* and rice *(Oryza)* to mention a few for which wild relatives can be found in the Sudan as well as cultivated ones. They all belong to the general type of 'a grass', but at the same time they have different relations with their environment, different forms, structures and functions.

By contrast, we will consider a tree. Trees start their growth from a seed as well, but they grow differently because they make a woody stem, woody branches and woody roots. The initial growth of the tree is slower than that of the grassplant, because the tree spends part of its energy on making

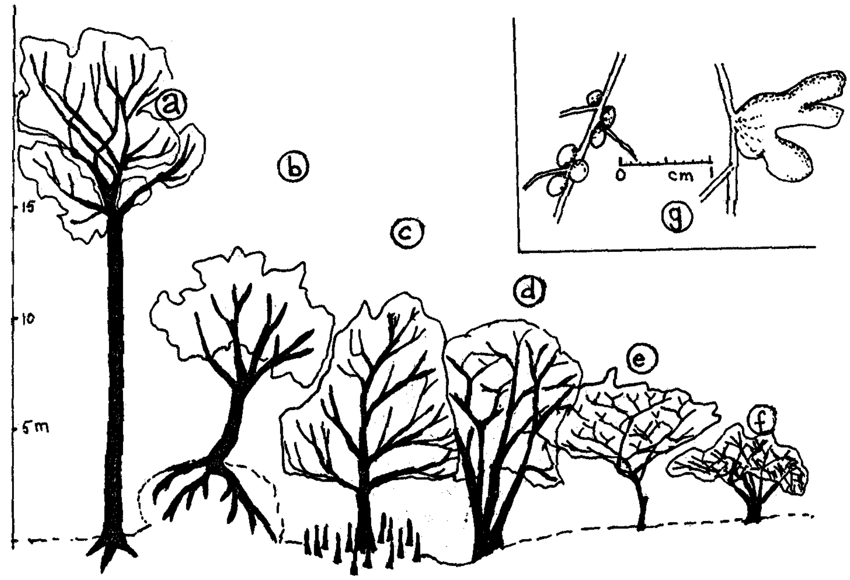


Figure 1.1.B. Some trees of the Sudan: a. Rainforest tree, b. Ficus populifolia; *rooted between rocks, c. Mangrove tree* (Avicennia marina) *growing on the sea coast, d. Sunt* (Acacia nilotica) *growing on river banks, e. Gum arabic* (A. senegal, *Hashab, A.), f.* A. tortilis *(Sayyal (A.)) growing in semi-desert, g. detail of root nodules on* Acacia *roots. (after various sources).*

wood. The young tree will slow down in growth towards the dry season and forms resting buds covered by scales. If the tree survives the dry season, with its risks of drought, fire and grazing, these buds will resume growth in the next year. The woody stem allows the tree to grow above the other plants, provided that the woody roots give enough support. Trees can be blown down by strong wind, but if they are strong enough, they will reduce the speed of the wind locally, and in this way they change the environment for other organisms: less windy, more humid air and shade. Compared to grasses, trees usually wait for a long time before they start to form flowers and seeds. Their **life-cycle** is much longer.

Of course there are many different types of trees. Some will only form small bushes, others become 30-50 m tall. In different environments you will find different types of trees. Near the desert short, thorny bushes are the only types which occur; in the rainforest only tall trees can reach the

sunlight; on rock faces of the mountains and jebels some fig trees with creeping roots can find a hold; along the river some trees can withstand flooding for a long time.
A special group of trees are the *Acacia's* and their relatives. If you wash some of their roots from the soil, you may see little rounded lumps attached to the roots. These swellings are called **nodules** and are inhabited by bacteria, which can only be seen through a microscope. The bacteria are able to fix nitrogen gas from the air and to make it available as nutrient to the plant. The family of plants which have these nodules are called Leguminosae and includes several types of trees as well as beans, groundnuts etc.

In most environments grasses occur as well as trees. Between them, several types of relations exist. One of the most important relations can be seen in the savanna areas, where patches of grass alternate with small groups of trees: In the dry season the grass is often burned by people, for several reasons. Natural fires can break out as well. These fires are hottest on 1-4 m above the ground. The growth points of grasses are low enough to survive the fire usually, while young trees are killed. Full grown trees have a better chance of survival, especially as in their surroundings less grass will grow, because of the shade. Around full grown trees, young trees therefore have a better chance to survive than amidst the grass. The groups of trees can gradually expand into the grass areas, until a heavy fire causes a setback. This is called 'the grass-tree cycle of the savanna.'

Many types of trees are useful to man, in many different ways: they provide edible fruits or edible gum, building poles, sawn-wood or fuelwood; they give shade and reduce the windspeed etc.

Animals differ from plants in many ways. Because they can move their relationship to the environment is different, insofar that they can at every time select the most suitable part of the environment. For their food they are always directly or indirectly dependent on plants.

Our first example, the snail, moves very slowly, so its choice of environment is limited. Still it can hide during the day in cool, moist places and come out during the night to feed. It feeds on plants or on dead animals. By hiding in its shell the snail can try to escape from all kinds of adverse external influences, such as drought, heat and animals which eat

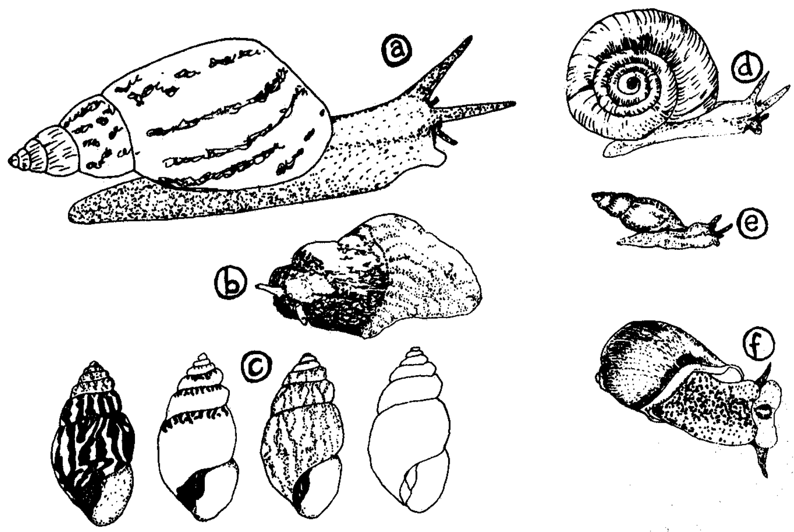


Figure 1.1.C. Some snails of the Sudan: a. Giant land snail (Achatina fulica), *ca* 15 *cm long; b. slug* (Arion), *contracting when in danger; c. four different colour forms of a land snail* (Limicolaria martensiana), *ca* 3 *cm long; water snails which can transfer Bilharzia; d.* Biomphalaria, *e.* Bulinus, *f.* Physopsis *(seen from underneath through an aquarium glass plate; its rasping mouthparts (radula) by which it scrapes of algae etc. can be seen). (from various sources).*

snails. Several of the snail's enemies, however, are able to crush its shell, though with considerable effort. The snail reproduces by laying eggs in a moist, shaded place, which hatch, usually after several weeks, to give rise to young snails, which make a small shell and grow steadily.

Of course there are many different types of snails. Some hardly become two mm's long and live in the upper layers of the soil, between plant litter; others become circa 10 cm long and live in the moist savanna areas; a large group of snails lives in the water, when they feed on waterplants, dead fish, etcetera. The watersnails need special ways to get sufficient air to breathe. Related to the snails are the slugs, which do not carry a shell and are therefore more susceptible to drought.

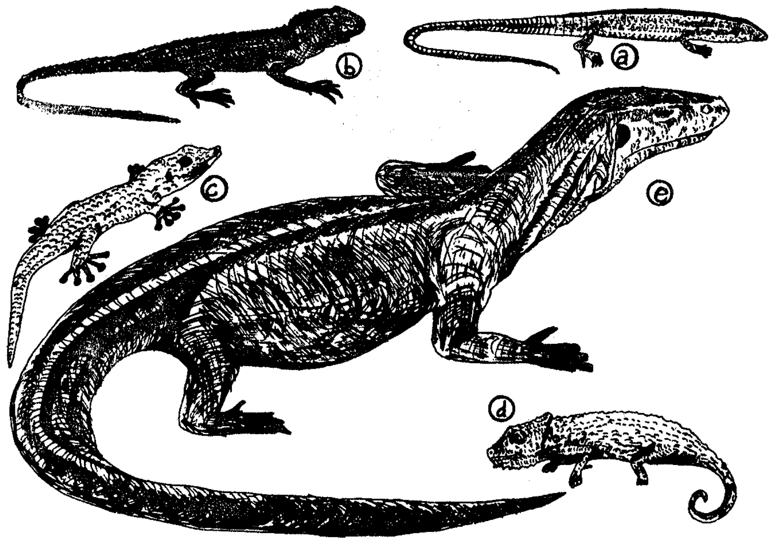


Figure 1.1.D. Some lizards of the Sudan: a. Lizard (Gerrhosaurus), *ca* 25 *cm, b. rainbow lizard* (Agama), *ca.* 30 *cm;* c. *gecko* (Tarentola), *ca.* 15 *cm; d. chameleon* (Chameleo), *ca* 30 *cm; e. monitor lizard* (Varanus), *ca 1.5 m. (after various sources).*

Several snails are important to man. The largest type of landsnail is reported to be edible. Snails can cause considerable damage to crops, especially in the seedling stage. Several watersnails can transfer a disease called **Bilharzia**. This disease only occurs when snails are present. These snails can only occur' when permanent stagnant water is available as well as water plants which can serve as food.

A lizard is much more mobile than a snail; therefore it is better able to select the best part of the environment for all its requirements. But the lizard has no shell, except when in the egg stage, so it is much more exposed to heat, drought and enemies; it only has a hard, leathery skin for protection. The lizard eats insects and other small organisms, but at the same time several birds, snakes and cat-like animals hunt for lizards; the lizard has to search for prey and to hide from other animals at the same time. Its environment is therefore determined to a large extent by other living organisms. Lizards reproduce by laying eggs which are buried in the soil or in other moist places. When the young lizards hatch they have to find their own way, without care from the parents.

Of course there are many different types of lizards. Some are able to survive in hot, very dry environments, others live in a continuously moist forest or are able to swim in water (as the large monitor lizard can). Lizards which live in the grass often have a green and striped skin; lizards which live on tree trunks are generally brownish. The chameleon is a type of lizard famous for its ability to change colour, according to its environment. Some lizards, such as the geckos, restrict their activity to the evenings and nights.

Several lizards are of some importance to man, because they eat mosquitoes and other insects in or around houses. If chemicals such as DDT are used to spray the houses to kill insects, the lizards are often killed as well.

From these examples you may get some idea of 'the relations between organisms and the environment'. Usually an organism deals with several completely different environments at the same time, alternating in the day/night cycle or in the various stages of its life cycle. It needs a way to survive in all these environments. The environment of every organism consists of other living organisms, and non-living elements such as soil, water, air and temperature (or 'energy' or 'fire') (see figure 1.2). The non-living elements can be called **abiotic** factors, the living ones **biotic** factors.
We try to understand the organism as a whole. But still, there are many different aspects. We may consider the general types, such as 'grass', 'tree', 'snail' or 'lizard', but often we have to take the various **species** separately. We may have to consider the various parts of an organism - the roots, leaves and stems of a plant; the head, body, legs and tail of an animal -, but also the various stages of the life cycle - from seed to seed producing plant, from egg to egg producing animal -. Especially when we consider reproduction, the difference between females (♀♀) and males (♂♂) may become relevant.
Instead of the single organisms, we often have to consider the **population** as a whole, that means the group of organisms of the same species which live near enough to each other to mix freely for reproduction. One step further we have to consider all the species (or populations) which live near

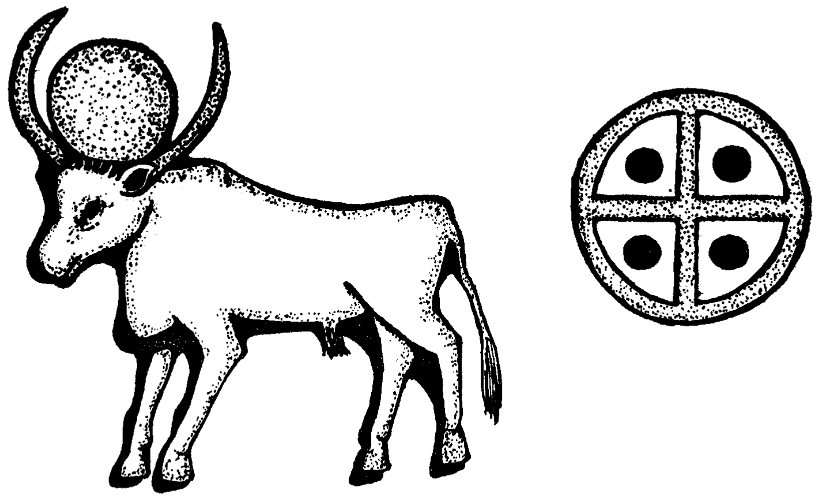


Figure 1.2 *Two ancient symbols representing the major factors influencing life on earth: a. is represented in rockpaintings in the Sahara, estimated to be 6000 years old; it reoccurs in ancient Egypt as symbol of the Earth-goddess Isis and more recently as well (compare cover of this book); the cow or bull stands for the Earth (soil, water, plants, animals), the Sun represents royalty, energy, inspiration; life apparently depends on a combination of the two; b. the pahana symbol of the Hopi indians in North America has a circle, symbolising integrity or wholeness of all life cycles, and a cross representing the four wind directions as well as four basic 'elements' earth, sun, wind and rain. (or.)*

enough to influence each other. This is the level of the **ecosystem**. The ecosystem is formed by all the organisms, as well as all abiotic factors of a given place.

Figure 1.3 symbolizes the ecosystem: plants, animals, man, soil and the climate all influence one another. The climate is the seasonal pattern of rainfall, wind, sunshine, temperature and moisture. As the climate on any place is influenced locally by the presence of mountains, rocks, pools or organisms such as trees, we can use the term **micro-climate** to indicate these small scale differences. All plants living in a certain place are said to form the **vegetation**. The term **flora** is used to describe all the different plant species of a certain area; the term **fauna** is used similarly for all animal species.

Sudan is a large country with a large variation in climate and soils. Consequently, there is much variation in the biotic parts of the ecosystem: the vegetation, flora and fauna. To discuss this variation, it is helpful to distinguish **ecological zones**, within which the ecosystem is roughly the same, e.g. desert, savanna, rainforest. Each ecologica1 zone is characterized by a combination of climate, soils, vegetation and fauna. In this chapter we will discuss climate and soils of the Sudan and then make a division into ecological zones. Chapter two will describe these zones in some more detail. The following chapters deal with the relations between organisms and their abiotic (Chapter 3) and biotic (Chapter 4) environment, while in Chapter 5 the ecosystem as a whole will be considered. The relations between man and the various ecological zones form the subject of the remaining part of this book.

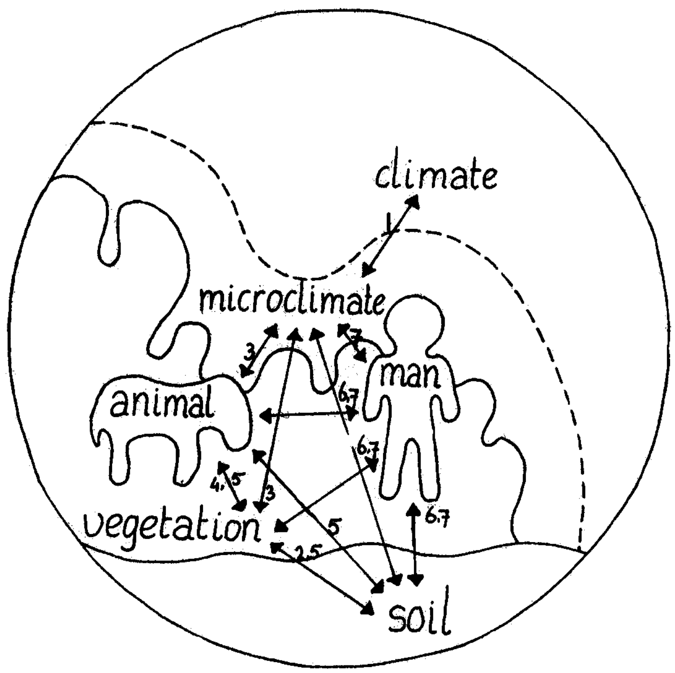


Figure 1.3 *Schematic represention of an ecosystem. It consists of abiotic factors (soil, climate and microclimate) and biotic factors (vegetation, animals, man). All parts of the ecosystem may influence each other, as the arrows indicate. The numbers refer to the chapters where such relationships will be discussed. (or.)*

1.2 Climate

1.2.A. The water cycle

All life depends on the presence of water, so the availability of water is one of the most important abiotic factors. All plants continuously lose large or small amounts of water vapour by their **transpiration**. For animals the loss of water vapour is called **evaporation**. Wet or moist soil and surface water, such as ponds, rivers, lakes, oceans, also lose water by evaporation. Together these processes are called **evapotranspiration.**

The amount of water vapour that air can maximally contain increases with temperature. If air for some reason or other cools down, the amount of water vapour it contains may become in excess of the saturation level, which is lower for lower temperatures. If so, water vapour will condensate into water droplets, which form clouds and may fall down as rain.

These processes are part of the **water cycle** which is depicted in figure 1.4. Rain which falls on the land may infiltrate into the soil or may run off along the soil surface. A certain amount of the infiltrated water can be held in the soil and can be taken up by plant roots; excess water will seep through the soil into the groundwater. **Run-off** water and part of the **groundwater** collects into streamletts, streams, lakes or rivers and finally into the sea. Similarly groundwater may flow in underground rivers, (or **aquifers**) from higher to lower points. In certain low-lying places groundwater can come to the surface again.

> Most of the water which falls on the land as rain is directly used for evapotranspiration (for Sudan circa 95%); the remainder flows into the sea or recharges groundwater reservoirs. In areas receiving more rain a higher percentage of the water is collected in rivers (e.g. the Ethiopian mountains feeding the Blue Nile and the East African areas feeding the White Nile).

Because of their large surface area, the oceans are the major source of water vapour in the air. The flow of water by rivers from the continents into the oceans, is compensated by a flow of watervapour in winds that blow clouds from the oceans to the continents. This in short forms the water cycle.

1.2.B. Rainfall

In the Sudan the amount of rainfall increases from the dry North to the

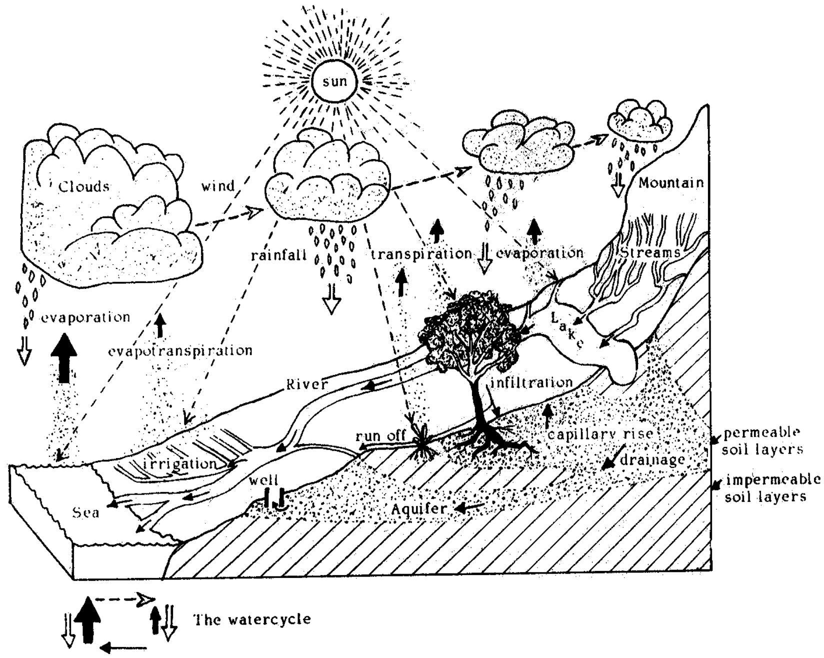


Figure 1.4 *The water cycle*

Water evaporates from the oceans and from the land. Water vapour, is transported by the wind in the form of clouds and rains down to the land and oceans. Rainwater runs of along the surface or infiltrates into the soil. Part of this water can be used by the vegetation for transpiration, The remainder plus the run off feeds streams and rivers, flowing back to the oceans. (after various sources).

humid South. In very general terms this is caused by the domination of the dry Northern and North-Eastern winds and the humid South-Western winds respectively.

The prevailing winds in tropical regions are caused by the heating of the earth by the sun and by the earth's rotation. When the sun is overhead, the intense heating of the earth causes the air above it to rise, because warm air is lighter than cool air. This creates a low pressure belt around the world. Air masses move into this low pressure zone, from the North and South (Figure 1.5). Because of the earth's rotation, these winds are deflected to the west, becoming North-Eastern and South-Eastern trade winds. On crossing the equator the South-Eastern winds become South-Western winds. The low pressure zone directly under the sun where these

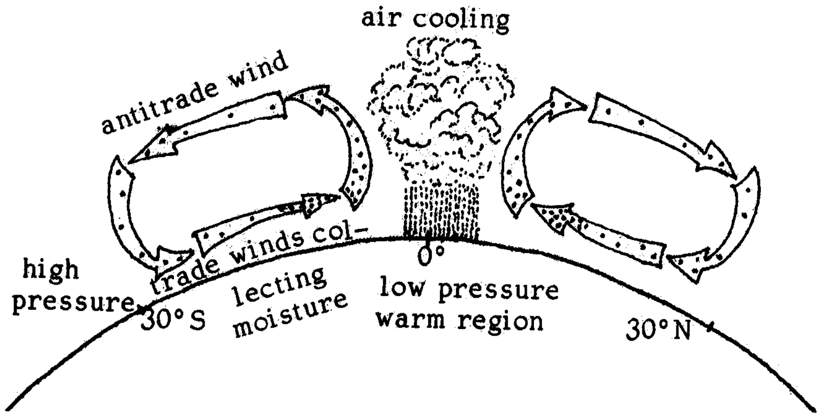


Figure 1.5 *General pattern of air circulation around the equator. (various sources).*

winds come together is called the Inter Tropical Convergence zone or **ITCZ**.

From our point of view on the Earth, the Sun appears to move, not only from East to West during day and night, but also from South to North and vice versa during the year. On 21st of June the sun is overhead on the tropic of cancer (23°N; on 21st of December on the tropic of capricorn (23°S). The ITCZ follows these apparent movements of the sun, but with a delay of about one month. The extreme positions of the ITCZ are reached in July and January. Figure 1.6 shows these extreme positions and the resulting wind directions, for an average year.

The Northern and North-Eastern winds that reach the Sudan bring dry air from the Sahara and the Arabian desert, respectively. In the summer this wind is hot and it only reaches the Northern-most part of the Sudan. In spring and autumn these winds are slightly cooler (although they only gradually cool off in autumn), and they reach further South. In winter these winds can be cool and they may reach well into the Southern Sudan.

The South-Western winds that reach the Sudan from spring to autumn, gradually extending North during summer and retreating during autumn, bring moist air from the Gulf of Guinea and the South Atlantic Ocean. During summer some South- Eastern winds, with moist air from the Indian Ocean, may reach the extreme Southern parts of the Sudan.

Around the Red Sea a local pressure system is important. As the water masses are slower than the surrounding land both in warming up and in cooling off, the air pressure behaves differently. In winter this may result in North-Eastern winds bringing moist air to the Red Sea hills.

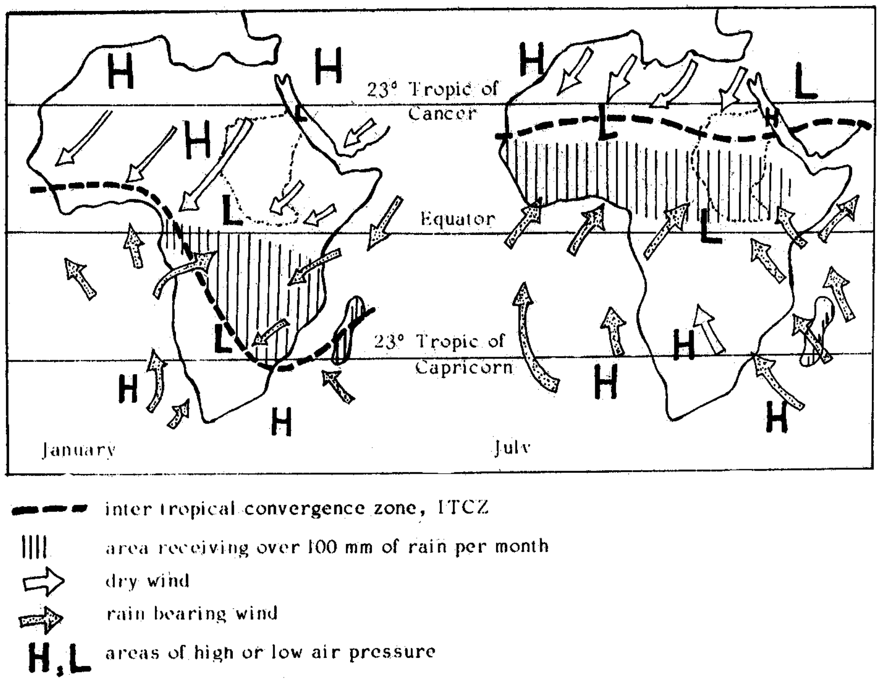


Figure 1.6 *Extreme positons of ITCZ over Africa, in January and July respectively. (after various sources).*

The presence of moist air is not sufficient condition for rain to fall. Thc moisture content has to be above the saturation level before water droplets are formed. Nearly always this is caused by cooling off of the moist air masses. The higher above the Earth, the cooler the atmosphere usually is. Uplifting of moist air masses can therefore lead to rainfall.

There are three common causes for uplifting:

1. under the heat of thc sun, air masses tend to rise;
2. when winds blow over mountains, they are forced to rise,
3. when winds from two directions meet, air masses may mix and some air has to rise.

   In this latter case the cooler air masses win generally stay below and the warmer ones rise. This happens at the ITCZ, as shown in figure 1.7. The moist and relatively cool South-Western winds remain near the surface, wedging under the warm North-East winds.

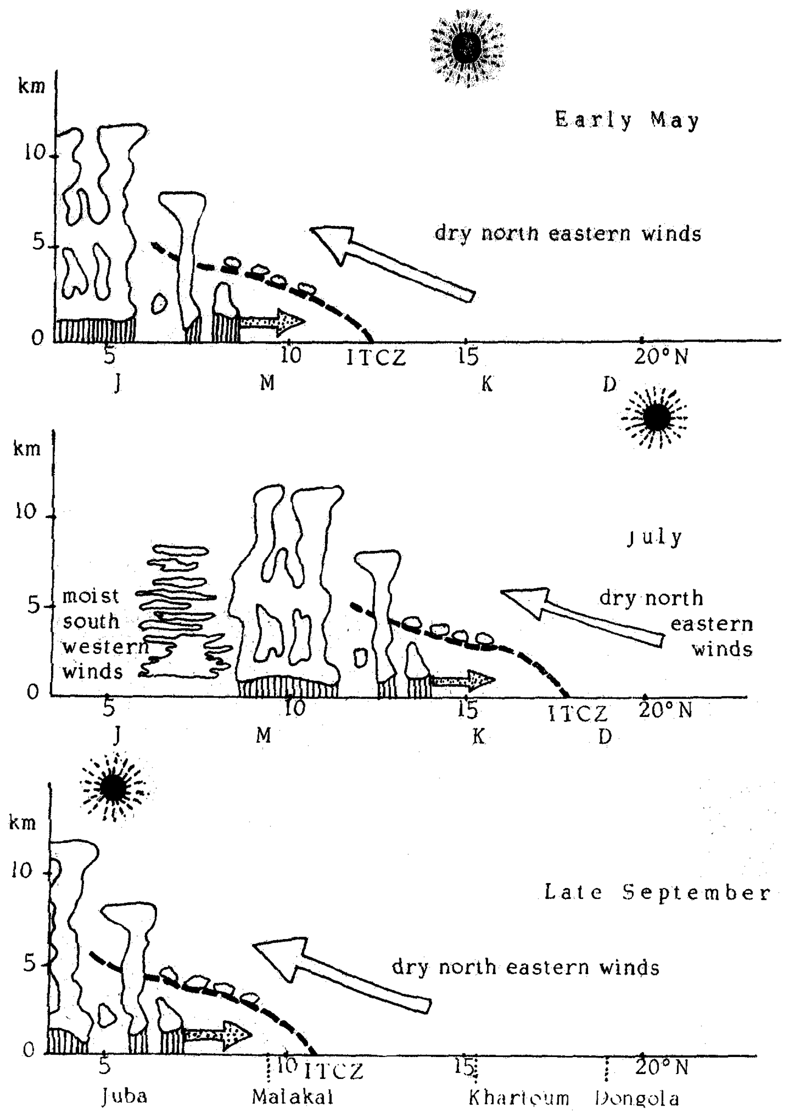


Figure 1.7 Movements of ITCZ over Sudan and the resulting rain pattern. (after various sources)

Thermal uplifting, under the heat of the sun, is the main cause of rainfall in the Sudan. Near the place where the ITCZ reaches the earth's surface, the layer of moist air is too shallow for rain to develop. The main rainfall zone can therefore be found 300-600 km south of the ITCZ. Further south the clouded sky may limit the heating of the earth. On both sides of the equator two rainy and two dry seasons occur. Further away from the equator there is only one rainy and one dry season. In the Southernmost part of the Sudan the transition between these situations can be found. In most years there is a dry spell in July or August, in the middle of the long rainy season. Figure 1.8 shows the variation in duration of the rainy season in the Sudan, as it follows from the movements of the sun and the ITCZ.

Although condensation in over-saturated air is a prerequisite for rain- fall, there are other factors as well which determine whether or not rain will actually start to fall. Some form of instability in the air may be necessary. These mechanisms are not yet clearly understood and here science has so far not been able to make much better predictions than traditional 'rainmakers'.

Figure 1.15 shows the average distribution of rainfall in the Sudan. The largest amounts of rain fall on the Imatong Mountains and on the Sudanese-Zairean border which forms the Nile-Congo watershed. From here rainfall decreases towards the North-East, with- increasing distance to the Atlantic Ocean. Jebel Marra, Nuba Mountains and the Ethiopian foot-hills receive more rain than the surrounding plains.

On the North-Eastern side of the mountains an area of lower rainfall can be seen: the rain-shadow. This is most clearly seen near the Imatong (and related) mountains. Two other areas with a different pattern can be noticed: The Red Sea hills, which receive winter rains in January from the Red Sea, and the Sudd. In the Sudd the air is humid during the whole year. In summer this reduces the heating of the air by the sun and this in turn results in a relatively low rainfall. The high evaporation rate in the Sudd may stimulate rainfall on the North-Eastern side, but the data available are not very clear on this point.

1.2.C. Seasons

Not only the total amount of rainfall in a year is important, but also its distribution over the year. The number of consecutive months with adequate rainfall determines the growth season for natural vegetation as well as crops (except for irrigation). Figure 1.16 and table 1.1 give a classification of the climates of the Sudan based on the number of dry and humid months and on the temperature range.

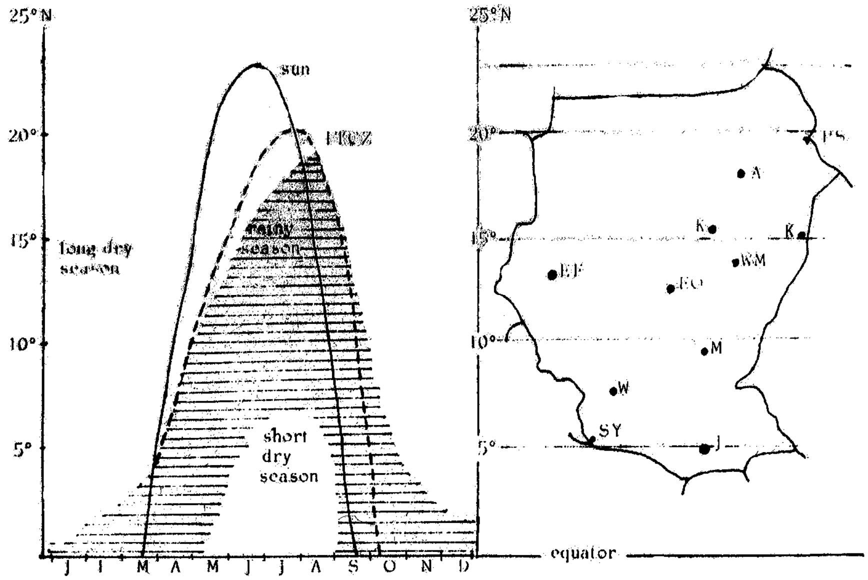


Figure 1.8 Apparent yearly movements of the sun and of ITCZ with latitude, on the northern hemisphere, with the resulting duration of dry and rainy season. (after various sources).

In the Northern parts the seasons differ markedly in temperature. Further South the differences become smaller and eventually the pattern 'is reversed: summer is the hottest season in the north, although the heat may be tempered in the short rainy season, while winter is the hottest part of the year in the south.

The amount of water which is needed for evapotranspiration depends on the amount of sunshine, the temperature and humidity, of the air and the windspeed. In a hot, dry, windy desert environment, with full sunshine, unhindered by clouds, the average transpiration can bc as high as 11 mm/day (or 11 l/m^2 day). Near the Ugandan border with more humid air, partially clouded sky and a lower

Figure 1.9 Climatic diagrams for six stations in the Sudan. The scale of the temperature lines is chosen to correspond roughly with potential evaporation on the rainfall scale; Mean annual rainfall is indicated (data Sudan Meteorological Services).

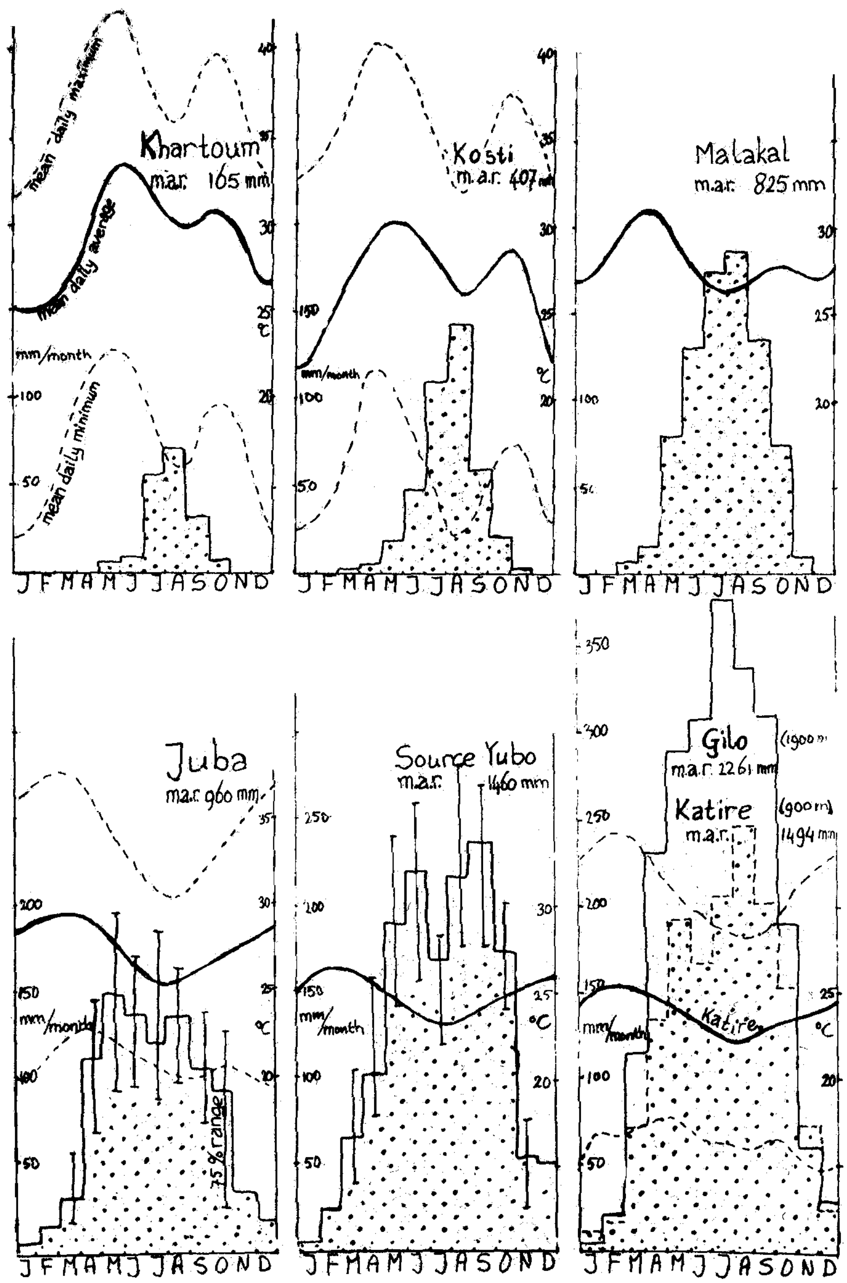

Khartoum
m.a.r. 165 mm
mean daily maximum
mean daily average
mean daily minimum
mm/month
Kosti
m.a.r. 407 mm
Malakal
m.a.r. 825 mm
Juba
m.a.r. 960 mm
75% range
Source Yubo
m.a.r. 1460 mm
Gilo (1900 m)
m.a.r. 1261 mm
Katire (900 m)
m.a.r. 1494 mm
Katire
°C
J F M A M J J A S O N D

Table 1.1. Climatic zones of the Sudan (see fig. 1.16)
1. Symbol; 2. Climatic zone; 3. Number of Humid Months; 4. Number of Dry Months; 5. Length of Growing Season; 6. Average Annual Rainfall (mm); 7. Mean Max. Temp. in Hottest Month (°C); 8. Mean Min. Temp. in Coldest Month (°C).

1	2	3	4	5	6	7	8
D1.1	Desert, summer rain, warm winter	0	12	0	100	42-44	13-15
D1.2	Desert, summer rain, cool winter	0	12	0	100	42-44	8-13
D2	Desert, winter rain	0	12	0	75	42-44	13-18
D3.1	Semi-desert, summer rain, warm winter	0	12	0	100-225	40-42	13-16
D3.2	Semi-desert, summer rain, cool winter	0	12	0	100-225	40-42	8-13
D4	Semi-desert rain	0	12	0	75-225	40-42	18-20
A1.1	Arid, summer rain, warm winter	0	10-11	1-2	225-400	40-42	13-17
A1.2	Arid, summer rain, cool winter	0	10-11	1-2	225-400	40-42	8-13
A2	Arid, winter rain	0	10-11	1-2	225-600	40-42	13-20
A3	Arid, no marked seasons	0	8-9	3-4	550-750	37-38	18-20
S1.1	Semi-arid, summer rain, warm winter	1	9	3	400-750	39-40	13-17
S1.2	Semi-arid, summer rain, cool winter	1-2	9	3	300-600	35-39	8-13
M1.1	Dry monsoon, long dry season, warm winter	3-5	5-7	5-7	750-1000	36-41	17-20
M1.2	Dry monsoon, long dry season, cool winter	3-4	7	5	600-850	38-39	5-13
M2	Dry monsoon, medium dry season	2-3	4-6	6-8	850-1000	36-38	18-21
M3	Wet monsoon, medium wet season	5-7	3-5	7-9	950-1400	34-39	12-10
M4	Wet monsoon, long wet season	7-8	1-2	10-11	1200-1600	34-35	14-19
H1	Highland, short wet season, cool winter	3	7	5	600-1000	36-39	6-8
H2	Highland, medium wet	5-6	3-4	8-9	100-1600	10-17	

temperature during the day, the average transpiration rate is circa 5 mm/day. Inside the Sudd lower values can be found, because of the constant humidity.

Figure 1.9 shows the monthly rainfall distribution as well as the temperature for seven stations. The scale of these graphs is such, that the temperature roughly corresponds with the amount of water required monthly for transpiration, in the same units as rainfall is given. In this way we can judge more exactly how long the growth season will be, when rainfall is adequate to cover the transpirational demand.

When we compare Khartoum, Kosti, Malakal and Juba we can see the general trends in temperature as outlined before. Malakal does not receive much less rain than Juba, but in Malakal the rainy season is much shorter (compare fig. 1.8). Data for Source Yubo, near the Zairean and the Central African border, are given because this is the station with the highest recorded rainfall except for the mountains. The graphs for Katire and Gilo are given to show the effect of altitude: the two stations are only a few kilometer apart, but Gilo is at 1900 m above sea level and Katire at 900 m.

The data given so far are the averages for many years of observation. Of course there is much variation. In figure 1.9 for Juba and Source Yubo the range is indicated within which the rainfall may be expected in three out of four years. It can be seen that this range is considerable. The movements of the ITCZ do not follow the same time course every year. Many other factors contribute to the variation. The total amount of rain per year shows less variation, than the amounts per month. But still the range is considerable.

The further North we come, the higher the uncertainty about rainfall is. In some years the ITCZ reaches further North than on average, with consequently a higher rainfall; in other years the reverse is true. Figure 1.10 shows the likelihood of rainfall for six zones. In a zone with 150 mm of rain on average, the range will be from almost 0 to over 300 mm; in a zone with 900 mm on average, the range will be from 650 to 1150 mm.

1.2.D. Microclimate

Climate differs considerably on a small scale. For example, in the desert the sandsurface can reach 80°C while the air temperature remains at 40°C. In the shade of a tree the air usually is cooler and more humid, while the windspeed and sunshine will be reduced. These small scale variations are called the microclimate. The data given above were all collected in

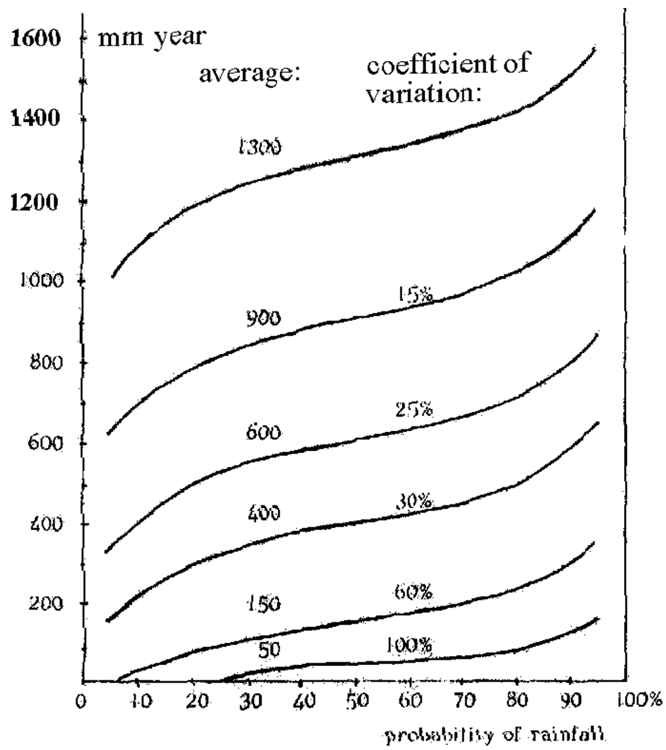


Figure 1. 10 Variation of yearly rainfall for zones of different mean annual rainfall; the probability of rainfall exceeding certain values can be read from this graph. (after various sources).

standardized meteorological stations: inside white boxes with ventilation, 1 m above the ground and not shaded.

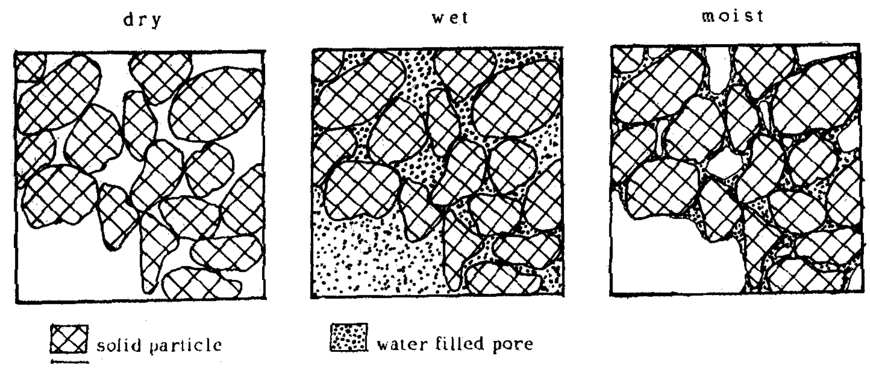
1.3 Soils

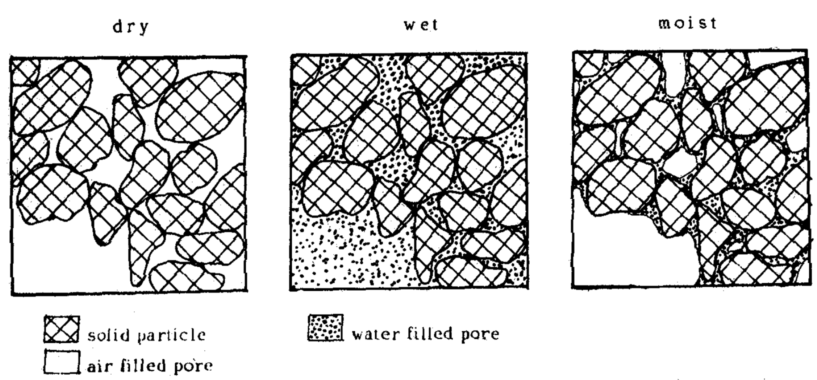
Soils consists of particles and pores. The particles can be large or, small and can be densely packed or more loosely, leaving either small or large pores between them. The pores can be filled with air or water. In a moist soil the small pores are water filled, while the large pores, cracks and channels contain air. Immediately after heavy rain fall (nearly) all pores will be filled with water. Part of this water will seep or drain to deeper soil layers or to the groundwater and only in the smaller sized pores water will be retained (Figure 1.11). Plants needing water daily for transpiration depend on this water retained in the small-sized pores, to bridge the period between two rain showers.

While the smaller sized pores are important for water retention the large sized pores and cracks are essential for drainage of excess water and for allowing air to enter the soil. The roots of most plants and the majority of soil organisms can only function if air is present in the soil to supply oxygen.

From the point of view of the vegetation the five most important characteristics of a soil are the extent to which:

1. water infiltrates into the soil after rainfall or runs off along the surface,
2. excess water drains from the soil after rainfall, allowing air to enter the soil,
3. water is retained in the smaller pores in such a way that plants can get hold of it,





Water infiltration can be rapid, after an initial phase in which air has to escape from the soil. Water drains rapidly and only a relatively small amount is stored in the soil, but all of this water can be used by plants. Capillary rise in sandy soils is very limited, as few small sired pores are available for this process. Plant nutrients are only stored in small amounts in sandy soils.

Clay soils consist of small sized particles leaving many small sized pores between them and very few large pores, except for cracks which are formed under very dry conditions. Water infiltration and drainage therefore is very limited and water often ponds the surface after rainfall or runs off to lower lying areas. Much water is retained in the soil in the small sized pores, but part of this water is hold so strongly by the soil that plants cannot extract it easily. Capillary rise is pronounced in clay soils. Plant nutrients can be stored in large amounts, but, again, these can be hold so strongly that plants cannot extract them easily.

Loam soils, which are intermediate between sandy and clay soils generally have the most favourable characteristics.

Figure 1.12 shows the water balance of the soil. Only a part of the rain water can actually be used by plants:

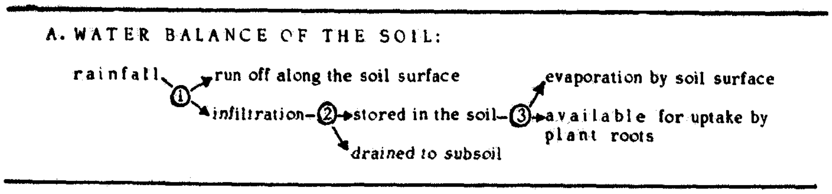
- a part does not infiltrate into the soil and is lost by run off (mainly on clay soils, and initially on dry sandy soils),
- a part is drained to the sub-soil (on sandy soils and especially on soils consisting of stones only),
- a part of the water evaporates from the soil surface and cannot be used by plants (mainly on clay soils where capillary rise keeps the top soil moist for a long time).
- a part of the water is hold so strongly that plants cannot extract it (mainly on clay soils).

In figure 1.12B a numerical example is given for clay, sand and stones as three extreme types of soil. In each case the fate of a small and a large amount of rain is shown.

The distinction between sandy and clay soils is based on the size of the particles that make up the soil. For the particles the following names are used:

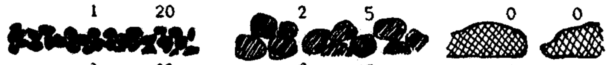
< 0.002 mm clay
0.002 -0.02 mm silt
0.02 -0.2 mm fine sand
0.2 -2 mm coarse sand
>2 mm gravel

When a soil consists for more than 70% of sand particles and for less than 20% of clay particles it is called a sandy soil. With 40-70% of sand and 20-40% of clay particles it is called a loam and with less than 40% of sand and

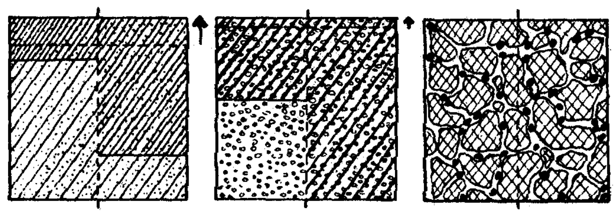


B. EXAMPLES FOR THREE SOIL TYPES:

	clay		sand		stones	
(1) rainfall	10	50	10	50	10	50
run off	1	20	2	5	0	0



	clay		sand		stones	
infiltration	9	30	8	45	10	50
(2) infiltration	9	30	8	45	10	50



	clay		sand		stones	
stored in the soil	9	30	8	20	8	8
drained to subsoil	0	0	0	25	2	42
(3) stored in the soil	9	30	8	20	8	8
evaporation loss at soil surface (capillary rise)	6	6	2	2	0	0
available for plants	3	24	6	18	8	8

Figure 1.12 *Water balance of the soil for explanation see text (or.)*

more than 40% of clay particles it is called a **clay soil**. A simple field test exists to determine to which type a certain soil belongs. Enough fine earth is taken to make a ball of soil about 2.5 cm across and water is dripped on to the soil until it reaches the sticky point, at which the soil adheres to itself but not to the hand. Sandy soils, loams, clay soils and various transitions between them can now be distinguished on the basis of shapes which can now be made from this moist soil. A sandy soil can only be heaped into a pyramid, but from a loamy sand a ball. can be made. If the soil can be rolled to form a cylinder it is a loam (a light or sandy loam if it is a short and thick cylinder; a heavy or clay loam if it is a cylinder of at least 15 cm long). If this cylinder can be bend it is a clay (a light clay when it cracks when making a circle a heavy clay when a full circle can be made without cracks).

Apart from the mineral particles (sand or clay), most soils contain a small amount of **humus**.

Humus is formed from the remains of living organisms by the micro-organisms in the soil. If the soil is exposed to the sun the humus will disappear rapidly by decomposition. For this reason desert soils contain hardly any humus, while soils in a rain forest may contain considerable amounts as long as the soil is shaded. Humus is important, because its presence changes the pore structure of the soil. Humus can stick soil particles together especially on sandy soils, which increases the water retention. Humus also plays a favourable role in temporarily binding plant nutrients, preventing them from being leached to the underground. Humus and the organisms that live in the soil are therefore a very important part of the ecosystem.

The soil on which all life on the land depends usually is only a thin layer on the earth's crust. Soil can be formed from rocks, by a very slow process called **weathering**: rocks can crack and be split by alternating heat and cold, by freezing water, by the action of plant roots and by streaming water. Soil material can be removed very quickly by the action of wind and water, in a process called erosion.

Some of the soils of the Sudan developed locally, by weathering of the rocks present. Most of the soils however consist of material which was first transported and then deposited by wind, rivers or gravity.

Most of the Sudan is flat. The landscape consists mainly of old weathered rocks and large areas where wind and water filled in the existing differences in height with soil material. Only occasionally harder rocks were left as outcrops and on a few places younger volcanic rocks and mountains rise high above the surroundings (Jebel Marra, places near the Ethiopian border). The material deposited by wind and water can consist of both clay and sand particles.

If water flows fast it can carry along quite heavy particles, such as coarse sand, When the current slows down, the heaviest sandy particles will be deposited first and only in stagnant water will the finest clay particles be laid down. When a river enters a lake this usually happens; the sand is left near the lake's entrance, while the clay is spread over a large area. A large part of Central Sudan has been a lake once in geological history and it now consist of clay soils. When soil material is deposited by rivers a more complicated pattern is the result.

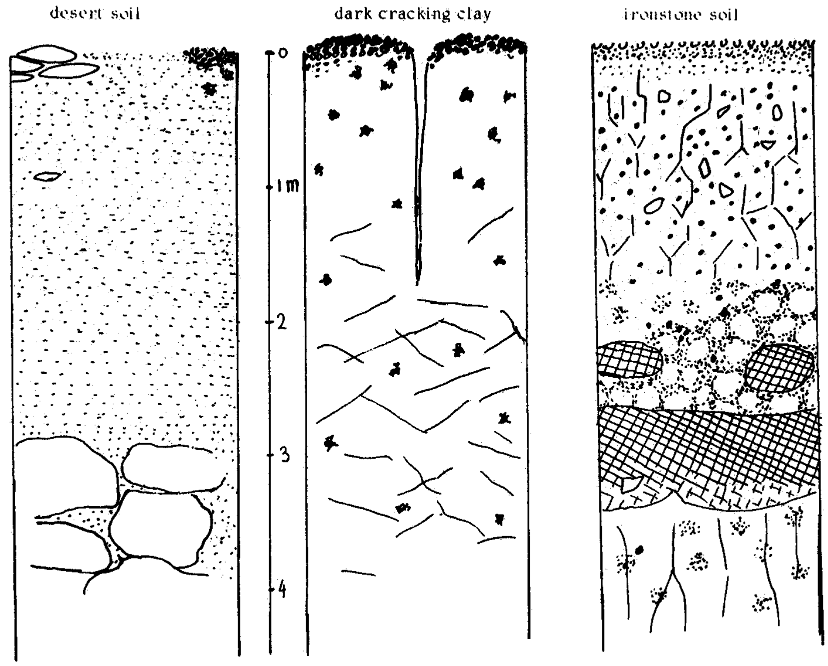


Figure 1.13 Three common soil profiles of the Sudan:

a. *desert soil, consisting, of sand layers without much differentiation, overlying sandstone; on the surface salt crusts can be found, as well as stones rounded and smoothed by wind;*
b. *dark cracking clay, consisting of heavy clay deposits; during dry season wide and deep cracks develop; after start of the rains the soil swells and soil material fallen into the cracks is pushed out again; a relief of mounds and depressions on the surface is the result of these alternations; in the subsoil many smooth surfaces occur along which soil glides when swelling; the soil profile contains calcium concretions throughout.*
c. *ironstone soil, consisting of dark humous loam, crumbly and loose in upper 10cm, overlying less humous and less structured loam; a light clay follows with a weak block* I *structure, with frequent iron concretions and some stones; in the subsoil ironstone mottles become more continuous and an ironstone pan can be seen, overlying a mottled heavy clay; downward movements of water is impeded by the ironstone pan and above the pan, grey zones occur, indica ting lack of oxygen; the profile was formed by clay and iron particles being washed down from the topsoil, during thousands of years. (modified after Ahn).*

Inside the riverbed only gravel or coarse sand is left. When the river overflows its banks it will leave its sand near the bank and its clay further away. In such a landscape a river is continuously changing its course: on the outer side of its bends it 'eats away' the bank, on the inner side soil material can be deposited; when this continues for many years new river channels will be formed and old ones left. If these processes continue for a long time (thousands of years) a complicated pattern of clay and sand deposits is left. Clay soils shrink considerably while they settle and dry out; sandy soils hardly shrink at all. After some time sandy ridges remain (deposited along former river banks), well above the low lying clay plains.

When soil material is taken up by winds the material is sorted out as well. Sand stones often displace material over limited distances but dust storms can carry the fine particles well out of the area. In the desert where the action of the wind is not limited by vegetation and where the soil is dry, almost pure sand is left, the other parts being blown away.

When soil material has been deposited or when it has been formed locally, many changes can still occur provided the soil is left undisturbed by erosion. Excess rain water which seeps into the ground can carry along soluble constituents of the soil and fine soil particles to the underground. In a dry period after rainfall water evaporates on the soil surface and an upward transport of water may also bring solutes to the surface, which can form salt crusts. In areas with a high rainfall the topsoil usually is washed out (and the subsoil enriched), in dry areas salt crusts on the surface are common. Organisms living in the soil can change the pore structure of the soil and can mix the various soil layers. The clearest example of this is formed by the termites which can raise high mounds of clay well above the surroundings. These termite mounds usually have a structure which is favourable for plant growth.

The soils of the Sudan can be categorized into five main groups. Each group is related to a certain landform and climate. The geological history is reflected as well. Figure 1.13 shows some of the soil profiles. Figure 1.17 shows the distribution of land forms and soil types in the Sudan.

1. Various desert soils, formed by the action of wind and a dry climate. Salt crusts and rounded stones and pebbles may occur on the surface.

    Geologically this area is formed of Nubian sandstone (gravel and sandstone formed in the Secondary period (Cretaceous)). Nubian sandstone is found in deeper layers in large parts of the Sudan. It contains important ground water streams (Aquifers, compare figure 1.4).

2. stabilized dunes (**Goz**) formed during periods of a drier climate in the geological recent history. After return of moister conditions vegetation has stabilized the dunes and when the vegetation is removed the dunes can easily become unstable again.

   Coarse and fine sand fractions amount to over 90% and the pH varies from 5.0 to 9.0. These sandy soils are poor in nutrients and their humus content is low, but they are very permeable for water and because of the fine sand may have a relatively high water availability during the dry season.

   These soils partly overly the Umm Ruwaba formation, formed in the Tertiary and Quaternary period: unconsolidated river and lake deposits, which contain some less important groundwater streams. Thc Umm Ruwaba formation comes to the surface in the next area:

3. dark cracking clays, mainly found in the flood plain and deposited by the Nile and its branches, but some may have been formed on the spot from basalt rock formations.

   The clay content is over 60% and the pH around 9.0. These soils crack deep and wide on drying out, but they seal off when wetted, making the surface impermeable, so that flooding occurs during the rainy season. These soils have been called **'black cotton soils'**. They are rich in plant nutrients but their waterbalance is a major obstacle for the growth of many plants. In the rainy season they are ponded an in the dry season they have very little water available to plants.

4. non-cracking clays, occur scattered as smooth clay flats. Their total area is insignificant. A hard smooth surface makes them very impermeable to water.

5. red loam and ironstone soils, occur mainly in the area where the annual rainfall exceeds 800 mm and where drainage of excess water is possible.

   Usually a rather shallow red sandy loam (0-15 cm) overlies a horizon of pea-iron nodules or more consolidated ironstone. The pH is 5.0-7.0. Thc supply of plant nutrients is not very good. Water can infiltrate into these soils without much problem and water availability to the vegetation is good as long as the loamy top soil is intact. When the subsoil becomes exposed to the sun after erosion hard 'iron pan' can be formed into which rainwater cannot infiltrate.

   Geologically the ironstone plateau is part of the Basement Complex of very old sediments and volcanic formation, dating back to the Precambrium (before the Primary period). The Imatong and related mountains also consist of Basement Complex material, but their soils are different, due to a different climate.

1.4 Ecological zones

From the large variation in climate we can understand that ecological conditions for living organisms vary widely in the Sudan. As we have, seen the soil can cause additional differences. This results in a vegetation which ranges from desert to rain forest. Major differences in vegetation can be described on the basis of its structure, without considering which plant species actually form this structure. Figure 1.14 shows various vegetation structures: the rain forests have the most complex structure, consisting of several layers of trees, a layer of shrubs, a layer of herbs and sometimes mosses covering the ground. The savanna consists of patches of trees, seperated by grassland. The semi desert consists of low shrubs with short grasses, while the desert hardly contains any visible plants (except for brief periods after rainfall). The term **habitat** is used to indicate the environment in which an organism (plant or animal) lives. Ecological zones in which the habitat is approximately the same can be distinguished on the basis of vegetation structure. Figure 1.18 shows the major ecological zones of the Sudan in this way. Each zone is characterised by a combination of climate, soils, vegetation structure, flora and fauna. In the next chapter the various zones will be discussed in some detail.

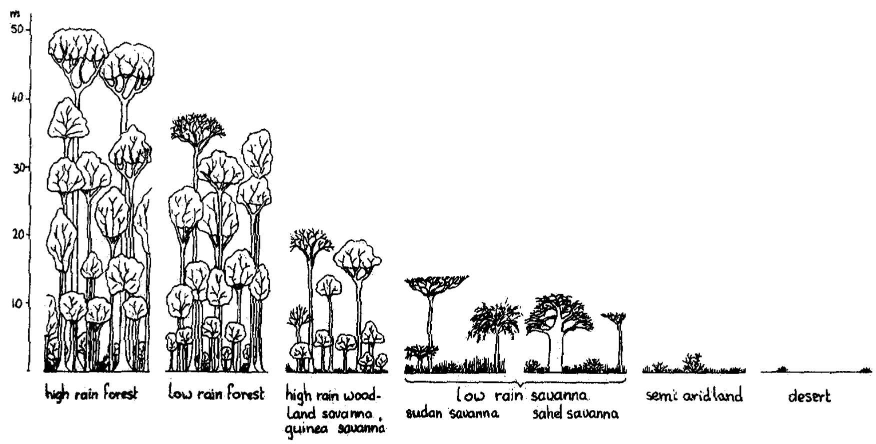


Figure 1.14 *Vegetation structure in the various ecological zones. (after various sources)*

1.6 Suggested practicals

1. Probably you can find grasses, trees, snails and lizards in your environment. Observe them carefully and try to imagine that you take their role in the ecosystem. Can you find examples for the various influences between parts of the ecosystem, indicated *by* the arrows in figure 1.3?
2. Apart from the general trends in the climate discussed in section 1.2, we can study the **micro-climate.** If you can get hold of a thermometer, try to measure the temperature under trees, between shrubs, in grassland and on bare soil. Measure these temperatures three times a day (early morning, noon and late afternoon). Can you explain the results?
3. Take four equal cups, place them in the four localities and fill them witl1 water. After one day you can measure how much water has disappeared by evaporation (provided other factors are excluded). Are there any differences?
4. Describe a soil profile in your own environment. With some luck you can find a place where a hole has been dug recently; otherwise you'll have to dig a new one. Describe the different layers of the soil as you see them: colour, structure (crumbs, blocks, cracks), sand, loam or clay (see method described in 1.3) and whether or not roots penetrate into these layers. Do you find any organisms? What happens if you pour water on the soil: does it infiltrate or not?
5. Try to classify the vegetation in your surroundings according to its structure (use fig. 1.14).
6. By comparing the maps of figure 1.15, 1.16, 1.17 and 1.18, try to fill in the following table:

ecological zone	climate	amount of rainfall	soil type	vegetation
Desert semidesert, etc				

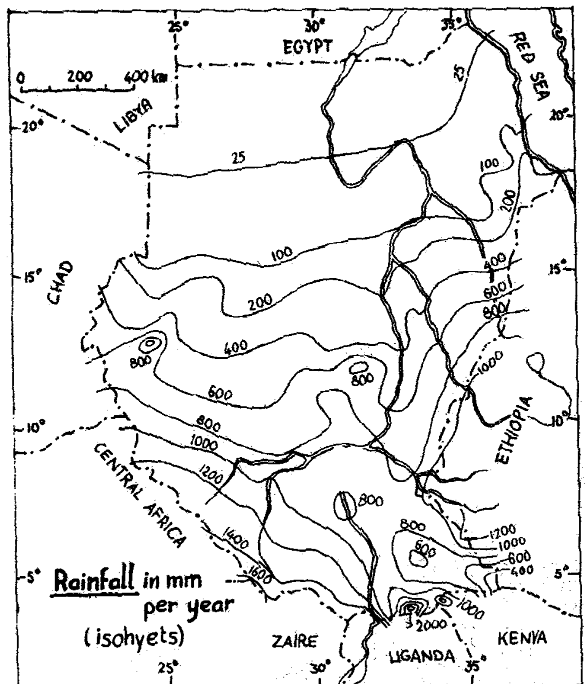


Figure 1.15 Rainfall distribution in the Sudan in an average year. (data Sudan Meteorological Service).

Figure 1.17 Landforms and soil types of the Sudan. (Based on Lebon, 1965).

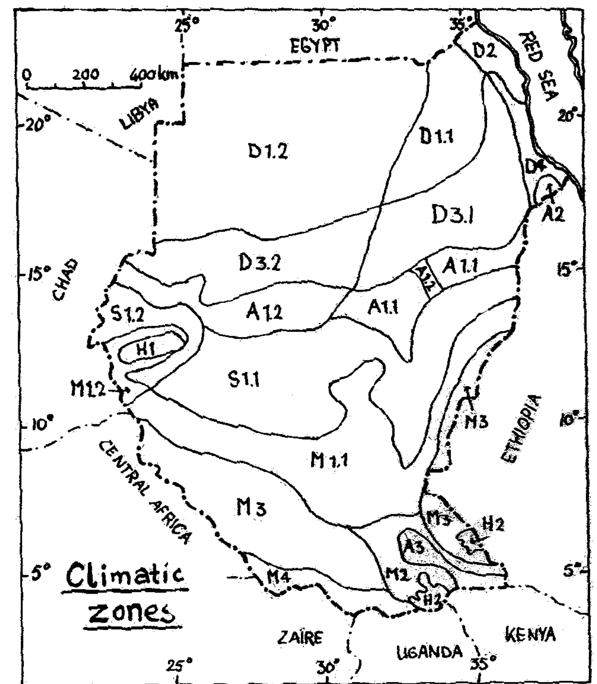
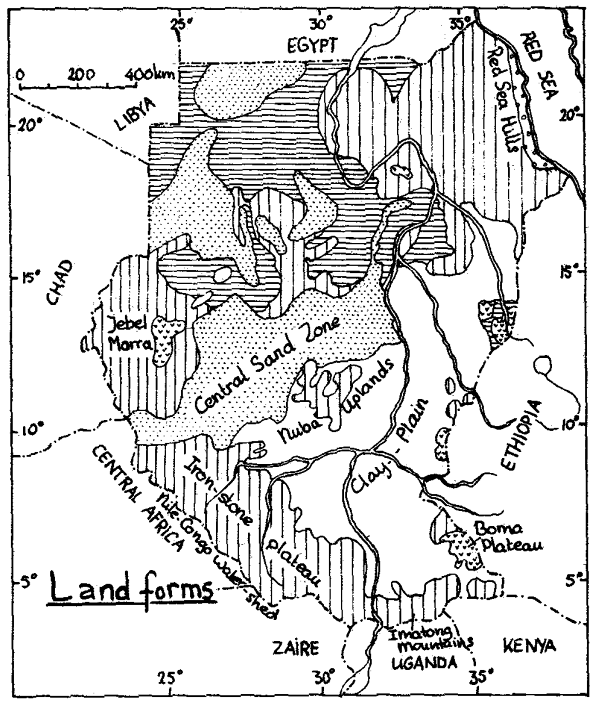
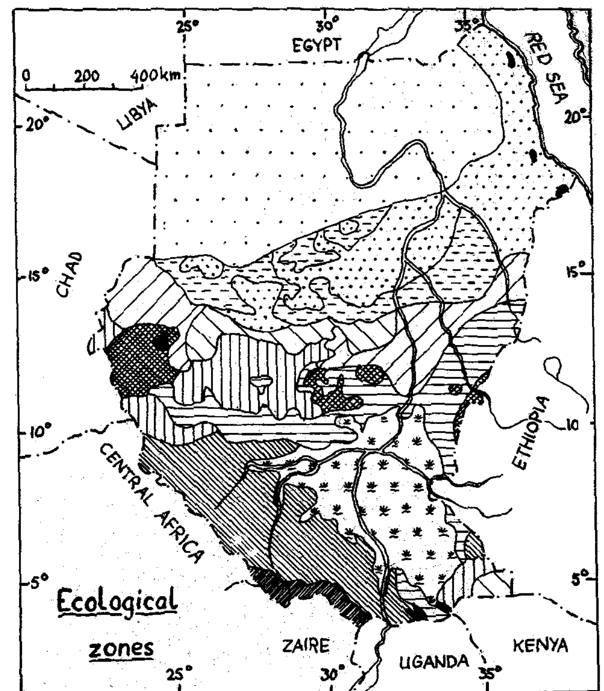


Figure 1.16 Climatic zones of the Sudan; D = desert, A = arid, S = semi arid, M = monsoon, H = highland; further details are given in table 1.1. (after FAO report).

Figure 1.18 Ecological zones of the Sudan. (Based on Jackson and Harrison, 1956).



- superficial clay
- wind-blown sand
- volcanic rocks
- nubian sandstone
- basement complex
- sediments of Red Sea coastal plain.



- desert
- semi-desert (shrub)
- semi-desert (grassland)
- sahel savanna on clay
- sahel savanna on sand
- sudan savanna on clay
- sudan savanna on sand
- hill areas
- flood region
- high rain woodland (guinea savanna)
- woodland recently derived from rainforest (greenbelt)
- montane vegetation

2. The habitats

We will now consider the ecological zones seperately, to see their distribution, abiotic factors and key habitats and to characterize the major factors determining life in that zone. The artistic landscape drawings of the various zones give an overall impression of the habitat and show some typical plants and animals. More detailed illustrations of some of the plants and animals can be found in the appendix.

2.1 Desert and semidesert

More than 40% of Sudan is **desert** or **semi-desert**. The **semi-desert**, or **semi-arid** land receives 90-300 mm rainfall/year and has 11 dry months; the true desert receives less than 90 mm of rain / year and has 12 dry months. In these areas the rainfall is very unreliable and completely dry years can occur. The scarcity of vegetation means that the temperature fluctuates over a wide range with hot days and cool nights. Sand and dust storms (haboob) are a serious problem for all life forms.

The soil is generally poorly developed, due to little rainfall and lack of vegetation.

> The desert soils vary from pure sand with stones eroded by the wind, to brown soils with a distinct crumb structure, usually with much lime accumulation as salt crusts. Often the surface layer of the soils prevents infiltration of rainwater and most of it runs off to low lying places, such as **wadi's**.
>
> Some shrubs of *Acacia tortilis* can be found even in the true desert, but most plants here are only visible in the rainy season and survive the dry season as seeds (annual plants). After the occasional rains a short-lived grass growth is available. In Northern Darfur in the winter the air may cool down at night sufficiently to form dew, allowing certain grasses to grow for some time after rainfall (**'gizu'**).

Figure 2.1 *Artists view of the semi-desert;*
trees are confined to the edges of wadi's or places with ground water at the foot of jebels; many small animals seek shelter under stones and In crevices: scorpion, lizard, jerboa, ground squirrel and fennec fox; some gazelle species find enough food by migrating over large distances: Dama gazelle (front), Scimitar-homed Oryx (left) and Addax (right); man similarly lives in *a semi-nomadic way, keeping camels, long-eared goats and fat-tailed sheep. (or.).*

In the semidesert the growth season is very short as well, but especially in wet years an abundant growth of shortlived plants is possible. Some woody plants can survive the dry season: *Acacia tortilis*, which also occurs in the desert, forms 2-3 m high shrubs on thin desert soils, together with *Maerua crassifolia* (although the latter species seems to have almost disappeared since the 1950's) at deeper soils or wetter sites *Acacia mellifera* (Kitr, (A.)) and *Commiphora africana* are found (although the *A. mellifera* stands have been reduced by human activities as well).
Large parts of the semidesert are tree-less grasslands. Probably this is due to human activities in the past.

For animals the desert is a harsh environment with extreme temperatures, little water and little food. Only a few antelope species can survive, by migrating over large distances to get food all year round (Dama gazelle, Oryx and Addax, see figure 2.1). In the semi-desert more chances are available for small animals which hide in the soil or under shrubs during the hottest and driest part of the day, and. which often survive the long dry season in some form of resting stage.

2.2 The savanna

The largest area of the Sudan is some form of **savanna**: a mixture of grasses and trees. Within the savanna-zone there are still wide variations in climate. According to the amount of rainfall and the length of the dry season, three main types of savanna can be distinguished:

a. Low rainfall woodland = **Sahel savanna** = thorn scrub.
   (300-600 mm of rain/year, 8-11 dry months). Short annual grasses under 1 m and scattered trees up to 10 m.
b. Intermediate rainfall woodland = **Sudan Savanna**
   (600-1000 mm of rain/year, 5-8 dry months). Short annual grasses up to 2 m, trees up to 15 m.
c. High rainfall woodland = **Guinea savanna** = Miombo (1000-1500 mm of rain / year, 3-5 dry months).
   Denser woodland, taller trees and less grass. Climbing plants appear in the crowns of the trees.

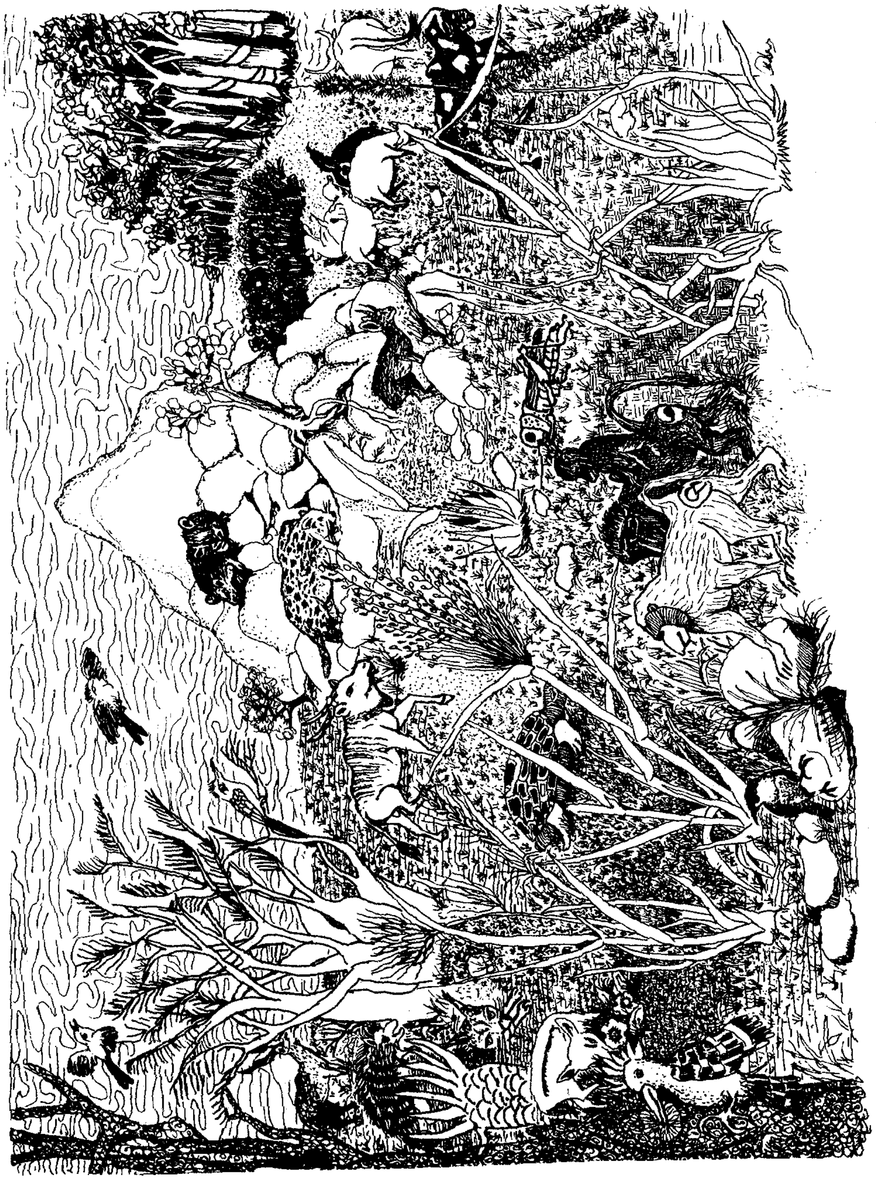
On the map in fig. 1.18 the first two Savanna types have been divided according to soil types: Clay soils along all Nile branches and sandy soils away from the rivers (**goz**). The Guinea savanna occurs mainly on the Ironstone Plateau. Apart from the rainfall, the main factor determining the vegetation is fire. Towards the end of the rainy season the grass dries off and forms fuel for the fires which people set to hunt or to use the regrowth of grass for grazing. Fire generally promotes grass and destroys trees. It also destroys the humus or organic matter in the soil. Fires early in the dry season are not as destructive as later, hotter fires. Early burning may even be beneficial as it reduces the chances of late fires (manmade or spontaneous). In several savanna types, termite-mounds are an important element. They often provide good conditions for the establishment of shrubs and trees and they protect them from fire and flooding.

The Jebels and rock outcrops found throughout the savanna give special ecological conditions. Only few specialised plants and animals can live on the bare rocks which usually form the top. On the slopes some special plants are found as well. Each of the savanna types has its own characteristic plant animal species (fig. 2.2 and 2.3).

> The Sahel savanna is characterized by Baobab trees *(Adansonia,* Tebeldi (A.)) and *Acacia* trees.
>
> On clay soils *A. mellifera* (Kitr, (A)) dominates, on sandy soils *A. senegal* (Hashab (A)), from which gum arabic is collected. In flooded areas of this zone the Dom-palm *(Hyphaene thebaica)* prevails. Various thorny shrubs and low, annual grasses are typical. The Desert rose

Figure 2.2 *Artist's view of a poor, (Sahel or Sudan) savanna community.*
The vegetation consists of a sparse grass-cover with from left to right Aristida, Eragrostis *and* Cenchrus biflorus *(Haskanit, A.) as typical species;* Acacia's, *Baobab-tree (Tebeldi, A.) and the Desert Rose* (Adenium) f*orm the trees and shrubs; Herbivores include: grasshopper, tortoise, dik-dikgazelle, lesser kuduu giant eland; the baboon is an omnivore; carnivores include striped hyaena, caracal and leopard; insect-eating birds are common: Hoopoe, Wheatear, Roller and Bee-eater; on rock-outcrops (jebels) a special community is found with the rock Jig tree* (Ficus populifolia), *hyrax, klipspringer and leopard as typical species; human use of this environment consists of raising goats and cows, tapping gum-arabic and growing millet. (or.).*

Figure 2.3 *Artists view of a rich (Guinea) savanna community.*
The vegetation consists of tall grasses and a variety of trees; typical grasses (from left to right): Panicum, Brachiaria, Setaria, Andropogon *and* Hyparrhenia; *trees like the Sausage tree and the Borassus-palm are confined to streams; old termite-mounds (right in the picture) contain many shrubs and climbing plants and give hiding places Jor mongooses and other animals; the savanna vegetation is eaten by many large herbivores: giraffe, elephant, buffalo, rhinoceros, zebra, Mongalla gazelle, ostrich; carnivores include: lion, cheetah, snake, secretary bird and chameleon. (or.).*



(*Adenium obesum*, Sim Ahmar (A.)), the stem of which resembles the Baobab tree, forms a conspicuous part of the dry savanna.

In the Sudan savanna the grasses are much taller and are mostly parennials instead of annuals. When they are lit they form huge, sweeping fires which are only stopped by water courses or by occasional grass-free areas. Several *Acacia-trees* are typical of this zone *(A. seyal*, Talh (A.)), and *Balanites aegyptica,* Heglig (A.). Sausage trees *(Kigelia aethiopum)* and Fan-palm *(Borassus aethiopum,* Doleb (A.)) occur along the streams and rivers.

In the Guinea savanna many larger trees occur and grasses become limited. Mahogany *(Khaya senegalensis), Isoberlinia doka* (Vuba (A.)) and the Sheabutternut *(Butyrospermum niloticum,* Lulu (A.)), and several climbing Acacia species are typical trees of the Guinea savanna.

The tall -grass -savanna is the main habitat for the larger mammals. During the rainy season food is abundant for them, but in the dry season they have to migrate. Long legs help them in viewing over the grass as well as in fast movements. Various antelopes, zebra and the white rhinoceros are typical of grass-areas, elephant, giraffe and monkeys are usually found among the trees. The large mammals are the most conspicuous but also the soils are full of life. Fig. 2.4 shows some of the animals which can be found in savanna soils.

2.3 River and floodregion

The river Nile and its tributaries take a central place in the ecology of a considerable part of the Sudan. In the North the narrow Nile valley contains more life than all of the desert zone. In Central and Southern Sudan the zone of influence is very wide.

Two types of river can be found. Fast flowing rivers containing large amounts of silt and nutrients with a pronounced seasonal flow regime and comparitively slow rivers which have lost most of their load, often by passing through a lake or a swamp and which often flow throughout the year.

When the Nile enters Sudan at Nimule it has just left the swamps of the Albert Nile and it flows slowly. Between Nimule and Mongalla its name Bahr el Jebel indicates its character: a fast flowing river between mountains. Several seasonal torrents join and add silt to dle river. Between Mongalla and Malakal during its passage of the Sudd the river gradually becomes the White Nile with transparant water. The Bahr el Ghazal which joins the White Nile has passed through a swamp as well (and has been rather poor in nutrients from its, beginning).

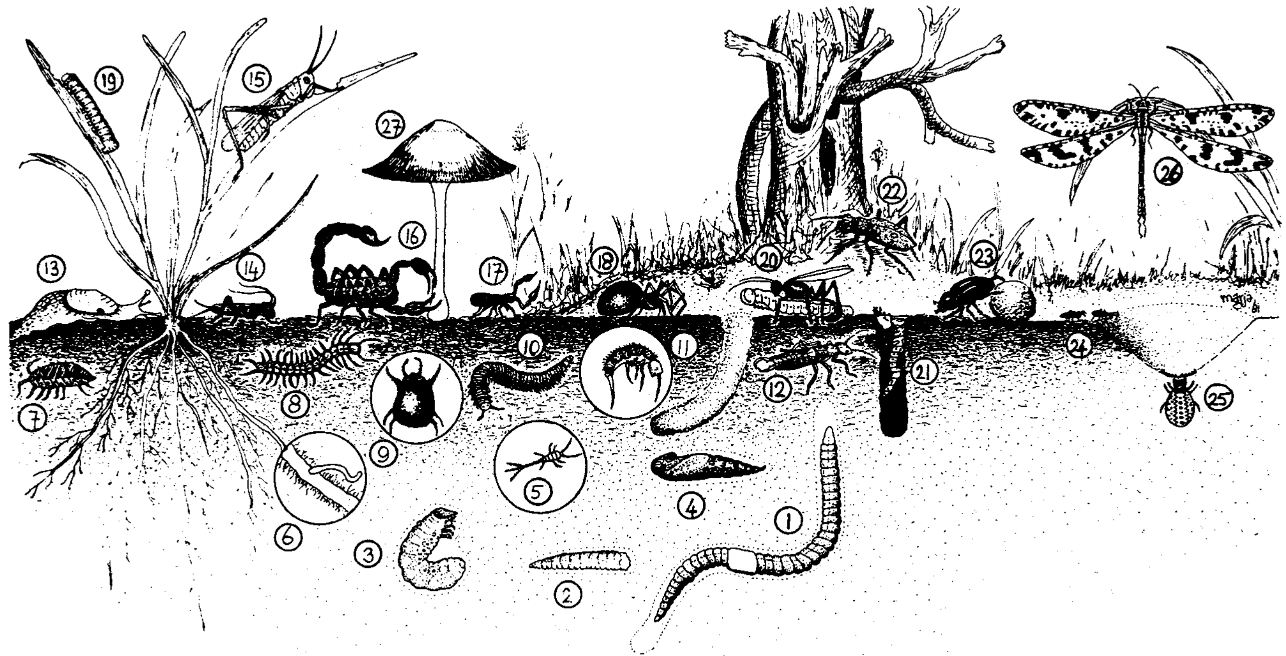


Figure 2. 4. Some organism living in the soil:
1. earthworm, 2. Larva of housefly, 3. Larva of beetle, 4. Pupa of moth, 5. Bristle-tail (enlarged), 6. Eelworm penetrating grass-root (enlarged), 7. Woodlouse, 8. Centipede, 9. Mite (enlarged), 10. Millipede, 11. Collembola (enlarged), 12. Earwig, 13. Slug, 14. Cricket, 15. Grassopher, 16. Scorpion, 17. False scorpion (pseudo-scorpion), 18. Spider, 19. Caterpillar, 20. Caterpillar-killer with its prey, 21. Larva of tiger beetle, trapping small prey, 22. Adult of tiger beetle, 23. Dung beetle, 24. Ant, 25. Larva of ant lion, trapping ants etc., 26. Adult ant lion, 27. Mushroom. (or.)

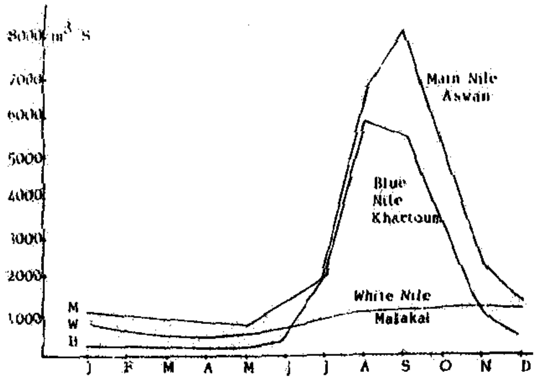


Figure 2.5 Flood regime the Nile branches (average for 1912-1962)

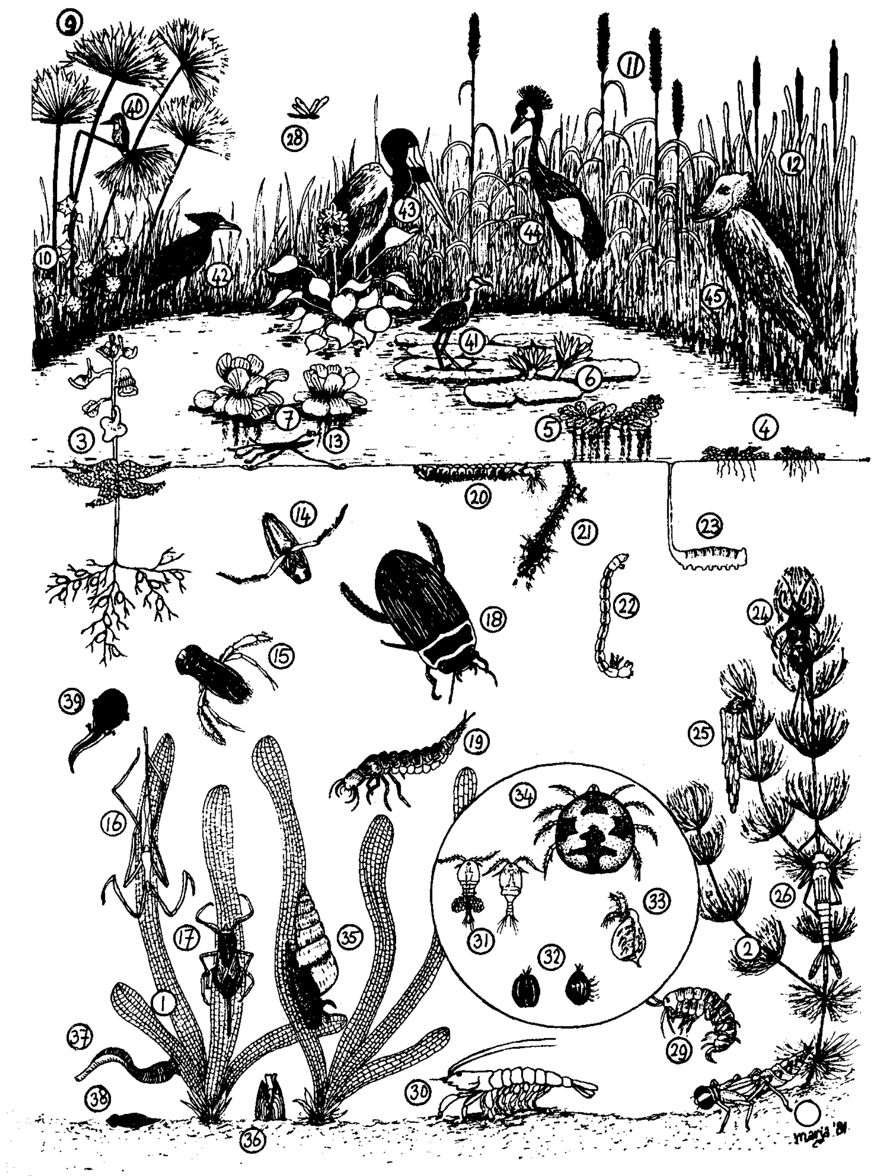
The river Sobat which joins in at Malakal is strongly I seasonal and comes from the Ethiopian mountains. Its character is similar to that of the blue Nile which joins the White Nile at Khartoum and the river Atbara which joins later.

The recent man-made reservoirs in the Blue Nile trap a large part of its silt load. The main Nile which flows from Khartoum to Lake Aswan is of mixed character. Figure 2.5 shows the seasonal pattern of flow.

Water as a habitat occurs in three main types: a) flowing permanent water (river, main irrigation canals), b) stagnant or almost stagnant permanent water (swamp, small irrigation canals) and c) stagnant, temporary water (seasonal swamps, **toic** (D.), **hafir** (A), **maya's** (A.))

Figure 2.6 *Some life-forms of fresh-water.*

Plants: 1. Vallisneria, 2. *Hornwort* (CeratophyIlum), 3. *Bladdenvort* (Utricularia), 4. *Floating blue fern* (AzoIla), 5. *Water-fern* (Salvinia), 6. *Waterlily* (Nymphaea), 7. *Water-lettuce* (Pistia), 8. *Water hyacinth* (Eichhornia), 9. Papyrus, *10.* Ipomoea aquatica, 11. *Elephant grass* (Pennisetum purpureum), 12. *Bulrush* (Typha); *Water-insects:* 13. *Water-skater* (Gerris), 14. *Back-swimmer* (Notonecta), 15. *Boatsman* (Corixa), 16. *Water stick insect* (Ranatra), 17. *Water scorpion* (Laccotrophes); 13-17 *are water-bugs* (Hemiptera); 18. *Diving beetle,* 19 *it's larva; Larvae of flying insects: 20. Malaria-mosquitoe* (Anopheles), 21. *Mosquitoe* (Culex), 22. *Midge* (Chironomus), 23. *Hooverfly* (Eristalis), 24. *May-fly* (Ephemeroptera), 25. *Caddis-fly* (Trichoptera), 26. *Damselfly* (Odonata: zygoptera), 27. *Dragonfly* (Odonata: anisoptera) , 28. *Dragonfly adult; Crustaceans:* 29. *Shrimp, 30. Prawn,* 31. *Copepod,* 32. *Ostracod,* 33. *Water-flea* (Cladocera); 29-34 *are enlarged; Other water animals:* 34. *Water-mite,* 35. *Water-snail,* 36. *Fresh water mussel,* 37. *Leech,* 38. *Planaria,* 39. *Toad-fish; Birds: 40. Kingfisher,* 41. *Lilly trotter* Oacana), 42. *Hammer-kop,* 43. *Saddle-bill stork,* 44. *Crested Crane,* 45. *Shoe-bill stork (Abu Markub, A.). (or.).*



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The main ecological conditions with which organisms have to cope are:

- seasonal swamps they have to survive the dry season;
- in flowing water they have to resist the current;
- n deeper water oxygen does hardly occur, especially in warm, stagnant water;
- in deeper water light hardly penetrates, especially when the water is muddy;
- the nutrient content of water is often low.

Figure 2.6 shows some of the typical organisms living in the water or on its surface. Most of these mainly occur in the permanent swamp.

On the map of ecological zones (fig. 1.18) about one third of Southern Sudan is indicated as flood region. Throughout this area there is higher ground on which people live, but most of the area is indeed flooded for at least a few months every year. A gradual transition exists from deep open water to permanent swamps, to seasonally flooded toic, to occasionally flooded 'intermediate land' and to higher grounds which carry a savanna vegetation.

The growth seasons here are determined by flooding rather than by rainfall. Part of the floods is due to the rivers overflowing their banks. But a considerable area is also flooded because on the flat surface excess water from rainfall cannot be collected in rivers and because the heavy, cracking clays hardly allow water to infiltrate. This ponding occurs mainly in me area receiving more man 800 mm/year of rainfall.

The higher grounds which usually are sand ridges and old termite mounds have a better drainage.

> *Cyperus papyrus* forms the most conspicuous part of the permanent swamps of the Sudd. Its stems (rhizomes) are full of air chambers and can float on water. In permanent water without strong currents it forms a dense vegetation in which only some climbing plants find a place. On the river side of this vegetation two grasses are found which extend long creeping stems into the current. *Phragmites mauritanus* and *Vossia cuspidata.* Between their stems water-hyacinth plants *(Eichhornia crassipes)* may get protection from the current and start growing. Twining and climbing plants such as *Ipomoea aquatica* and *Luffa cylindra* give further strength to these plant masses which may break off the shore as floating islands.
>
> Behind the main *Cyperus papyrns* zone the tall elephant grass, *(Pennisetum purpeureum)* and the bulrush *(Typha australis)* grow to about the same height as the papyrus. These plants are more resistant to

occasional dry conditions or fires. In a mosaic with this high vegetation are creeks and pools with floating and submerged water-plants. Noticeable among these are the waterlily, waterlettuce, bladderwort and floating blue fern shown in figure 2.6. The swamps along the Bahr el Ghazal show a much less luxuriant growth of the tall grasses.

Among the seasonal swamps or toic's that fringe the permanent swamp three types can be distinguished, on basis of the dominant grasses:

1. *Echinochloa* on heavy clay soils with at maximum a water depth of one meter in the flood season. Low lying parts consist of *E. stagnina* and *Vossia cuspidata;* parts with lower floods consist of E. *pyramidalis a*nd the wild rice, *Oryza barthii.*
2. *Phragmites* on sandy soils with a long period of flooding.
3. *Hyparrenia* on sandy clay soils flooded for less than 3 months.

This last type also occurs on the intermediate land. In the permanent swamp there is only one woody plant, ambatch *(Aeschynomene elaphroxylon},* with very light wood. In the toic and the intermediate land trees are confined to old termite mounds and occasional higher grounds. *Tamarindus indica* and the African ebony *(Diospyros mespiliformis)* are typical trees for termite mounds, along with *Euphorbia candelabrum* and several climbing plants. The higher grounds show a savanna-vegetation.

Further along the river Nile several typical tree occurs: sunt *(Acacia nilotica)* which can form dense stands, partly flooded. On new-formed sandbanks *Tamarix nilotica* is often the first tree to grow. The dom-palm *(Hyphaene)* and *Acacia albida* (Haraz (A.)) typically occur on the river banks with ground water within reach.

For land animals moving in a marsh is difficult. The hippo spends its days inside the water and comes to the shore at night to feed on grass. Two types of antelope have special feet which enable them to walk on the soft mud: the sitarunga *(Tragelaphus spekel)* and the Nile Lechwe *(Kobus megaceros).* During the dry season the toic, which is gradually drying up, is used by many other mammals for grazing. Otherwise the marshes and toic's are mainly the domain of birds, with either long legs that reach the bottom (such as the various type of stork have), long toes that enable them to walk on waterplants (such as the lilly- trotter *Uacana)* has) or webbed feet that can stand on soft mud (such as the abundant Egyptian goose has). Crocodiles are common outside the main water currents. Monitor lizards can be seen sun-bathing on the riverbanks; they are good swimmers if necessary.

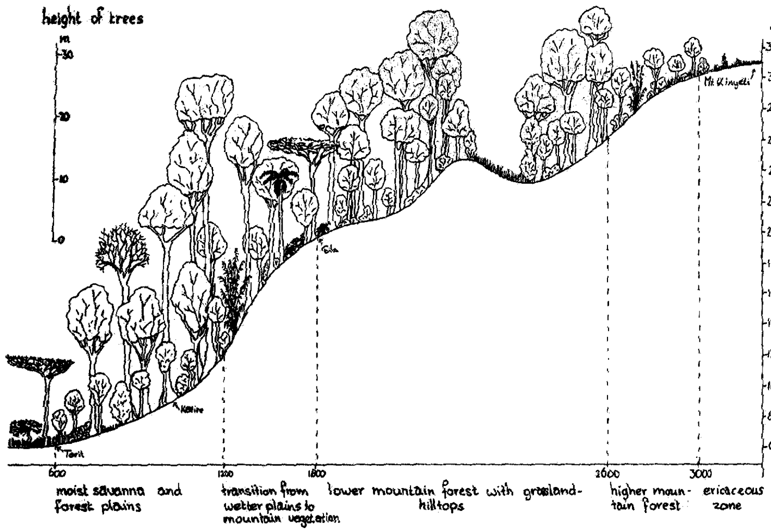


Figure 2.7 *Zonation of the vegetation in the Imatong Mountains (or.)*

2.4 Rain forest and montane zone

The lower limit for **rain forest** is 1500 mm of rain/year and less than 3 dry months. So in the Sudan only on the borders of the country some rain forest occurs. This is 'low rain forest'. The 'high rain forest' of fig. 1.14 with its even more complicated structure can be found inside Zaire. On the map of figure 1.18 the border with Zaire is indicated as 'rich savanna woodland recently derived from rain forest'. Over the last century most of this rain, forest has been transformed into savanna by human activity. This zone is known as the

Figure 2.8 *Some organisms living in It rainforest;*
plants: 1. *emergent tree,* 2. *tree of the main canopy, with plank roots,* 3. *Jig tree,* 4. *dragontree* (Dracaena), 5. *tree fern,* 6. *wild banana* (Ensete), 7. *wild coffee,* 8. *prickly shrubs* (Acanthus), 9. *epiphytic ferns; insects: 10. swallow tail butterfly,* 11. *bee's nest in hollow tree; amphibians:* 12. *tree frog; reptiles:* 13. *python; fruit-eating birds:* 14. *grey throated barbet,* 15. *casqued hornbill; insect-eating birds:* 16. *sunbird,* 17. *tinker bird,* 18. *honey guide; bird of prey:* 19. *Verreaux's eagle; mammals: ground living herbivores: 20. bush buck,* 21. *duiker, 22. bushpig, 23. buffalo (short-horned forest variety),* 24. *bongo,* 25. *elephant; ground living carnivores:* 26. *elephant shrew {eating insects),* 27. *civet,* 28. *leopard; tree living herbivores: 29.jrnit bat, 30. gala go or bushbaby (active at night),* 31. *blue monkey,* 32. c*olobus monkey. (or.).*

greenbelt and still provides opportunities for an abundant plant growth of the relative constancy of the rainfall. Temperature also fluctuates far less than in the drier savanna. Other areas of rain forests are found in Acholi, Imatong and Didinga, mountains.

> The rainfall here goes up to over 2000 mm/year and the climate is much cooler. Along the mountain-slopes we see a gradual change from the savanna types of the plains to a rain forest with more complicated structure. The tops of several mountains are covered by grasslands because of man-made fire. Towards the highest summits (Mount Kinyeti being the highest in the Sudan, 3180 m) the forest disappears for climatic reasons, the rainfall decreases and an open low shrub community remains (Fig. 2.7).

The structure of the rain forest is complicated: a tangled mass of tree trunks, branches covered by mosses and ferns, climbing plants etc. Movement for animals is difficult.

Several small mammals can creep through the ground layers (such as bush-pig and duiker); large ones have to be strong (buffalo and elephant). The majority of the animals live in the trees and are good climbers, jumpers or flyers. (See figure 2.8).

The hill regions of Jebel Marra and Nuba Mountains do not receive sufficient rain for rain forests to develop. They are covered by a savanna vegetation or woodland which is much richer than that of the surrounding plains. Along rivers richer forest types generally come into the neighbouring zones, because of the extra water supply. These are called gallery **forests**.

2.5 Red Sea Coast

The area along the Red Sea coast differs in several ways from the rest of the Sudan. The sea of course contains life forms quite different from any found on land or in fresh water, but the land along the coast is influenced by the sea as well. Rainfall is increased, occurs in winter time rather, than in the summer and the air is more humid. In the Red Sea hills near the Ethiopian border rainfall is highest and the 'mist oasis' of Erkowit carries a rich vegetation, although the vegetation has declined in recent times by human activities.

> A typical tree of the Red Sea hills is *Juniperus procera* which occurs in almost pure stands. *Dracaena amber*, the dragon tree, which used to be quite common has almost disappeared in the last forty years. Because of the frequent mists epiphytic lichens are common.

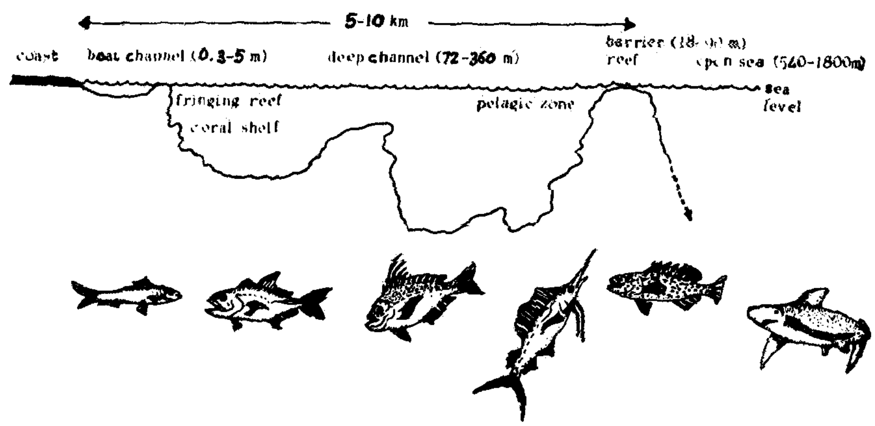
Due to the presence of small water courses, the vegetation in the northern part is of a semi-desert type, instead of the desert which is found inland.

On the actual coast mangroves are quite common: a vegetation formed by the mangle tree (mostly *Avicennia marina)* which lives in the tidal zone and has horizontal roots with vertical structures rising out of the mud for breathing (see fig. 1.1.B).

The Red Sea itself is connected to the Indian Ocean, but the water is more saline (salty) because of the absence of rivers adding fresh water and because of the high evaporation rate. Because of the absence of rivers the water is very clear and lacks mud. In contrast to other coastal seas which are often muddy and contain many algae which support a rich fish life, the Red Sea is comparatively poor in terms of fish production. But the number of fish species is very high, especially on the coral reefs (see figure 2.9 and 2.10).

Along the coast a number of zones can be distinguished, each with characteristic fish species: shallow inlets (known locally as mersa's), a 'boat channel', a fringing coral reef rich in lifeforms, a deep channel and a 'barrier reef before the open sea starts. Especially the edges of the reef are rich in fish species. The coral reef (figure 2.10) is a very special type of ecosystem, which is only found in shallow tropical seas, parallel to the coast. The reefs are formed by colonies of small sea Anemones and polypes which secrete a calcareous exo-skeleton. In geological periods the water level of the sea 'is rising gradually, coral reefs are buildup.

Figure 2.9 *Habitat zonation along the Red Sea Coast, channels and coral reefs; typical fish species for the various zones are (from left to right):* Sardinella, Caranx, Argyrops, Istiophorus, Plectropomus *and the shark. (modified from Reed).*



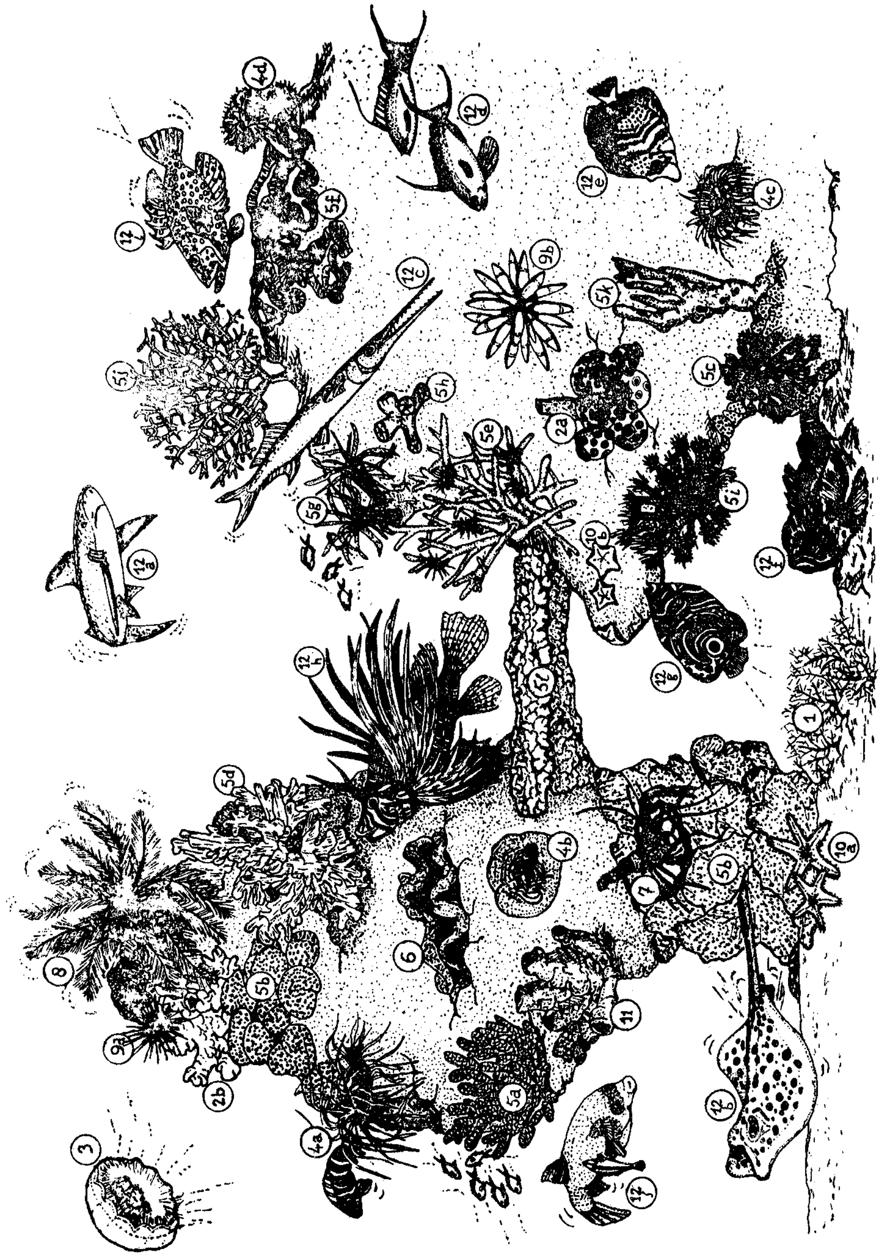


Figure 2 *.10 Lifeforms of a coral reef:* 1. *algae* (Liagora viscida); 2. *sponges: a) bottleforms, b) soft sponges;* 3. *Pink jellyfish;* 4. *sea anemone: a) with 'anemone fish' hiding between tentacles, b) with 'coral fish'* (Amphipron), c*) dahlia anemone, d) plumose anemone;* 5. *corals: a)* Acropora *colony, b) porites, c) soft coral, d)* Millepora, *e) Acropora, with starfish* (Acanthaster) *attacking the coral, f) brain-coral* (Lobophyllici), 9) Dendrophyllia *living polyp, h) coralformed by previous species;* 6. *giant mussel* (Tridacua); 7. *prawn* (periclemenes); 8. *sea-lilly* (Nemaster); 9. *sea-urchin's; 10. starfish: a) common starfish, b) cushion starfish;* 11. *fishes: a) shark (normally behind barrier reef), b) round tailed rock cod* (Cephalophis), *c) needlefish* (Tylosurus), *d)* Anthias, *e)* Chaetodon, *f) stonefish* (Synancela), 9) Pomacanthus, *h) scorpion fish* (pterois), *i) ray* (Dasyatis), *j)* Arothron *with cleaning , fish* (Cabroides). (or.).

The reefs consist of many different species of corals, large sea weeds, many invertebrate animals and fish. The corals are mainly filter feeders, living from small algae and other food particles in the water. As sunlight does not penetrate far into the water, there often is a clear zonation of species from the shallow to the deeper parts.

2.6 Suggested practicals

In this chapter the major ecological zones have been described. Within each of the zones there still exists a large range of different communities on a smaller scale, living in the 'micro-habitats'. Try to identify ten such micro-habitats around where you live or around the school. Describe the, combination of factors responsible for creating this micro-habitat (soil, water availability, sun or shade, treading, slashing, digging and other human activities). Give the (local) names for plants and animals living in each of these micro-habitats. You can use the illustrations of the appendix for naming them.

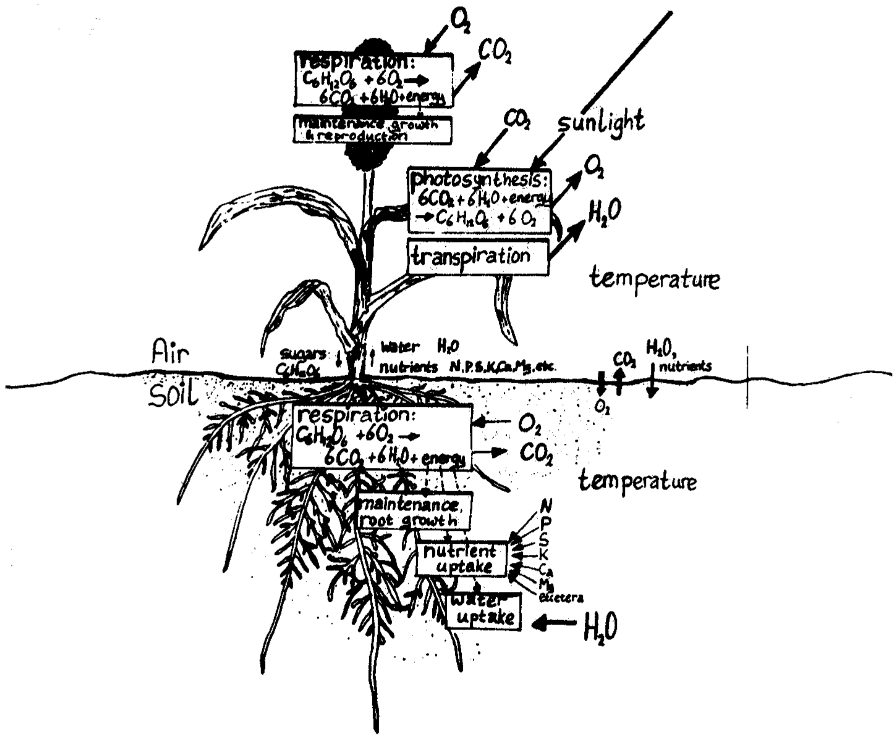
3. Adaptations

3.1 The need for adaptations

Basically all green plants need the same things from their environment to live (figure 3.1). These basic needs include sunlight, water, mineral nutrients, carbondioxide in the air, oxygen in the soil (for respiration by the roots) and a suitable temperature. All animals basically have the same needs (figure 3.2). These are food (containing: energy, protein, vitamins, minerals), water, oxygen and a suitable temperature.

If one of the basic needs is not fulfilled an organism cannot live. In every habitat some of the basic needs may be easily fulfilled, while others are hard to get. So each habitat poses its special problems for life. In the desert sunlight and oxygen in the dry soil will be plentiful, but obviously shortage

Figure 3.1 *Main relationships of a plant with its abiotic environment (or.).*



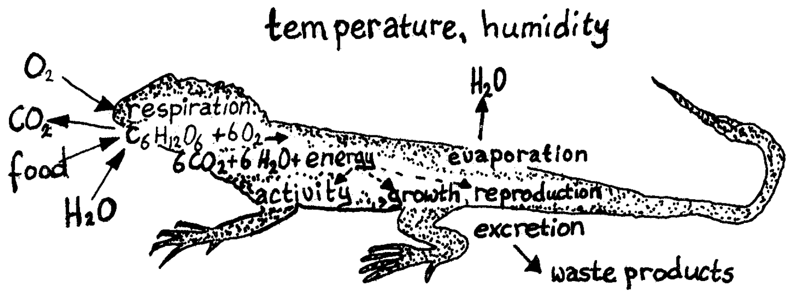


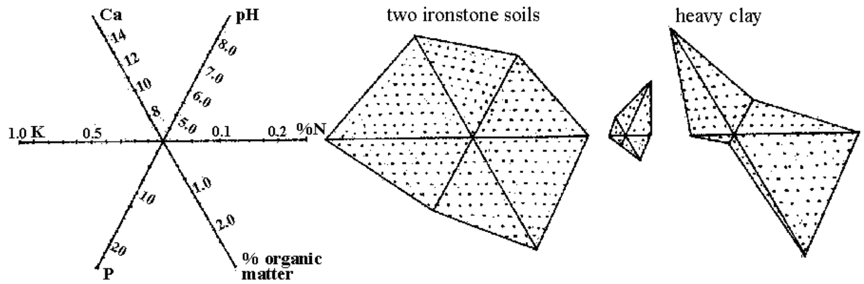
Figure 3.2 Main relationships of an animal with its environment (or.).

of water and the fluctuating temperature create problems. Inside a papyrus-swamp the temperature and the water supply are favourable, but there is little sunlight and in the mud the oxygen supply is poor. So each environment has its limiting factors.

> The concept of limiting factors can be further explained by an example concerning soil fertility. To grow the plant needs certain amounts of plant nutrients such as N, P, K, Ca etc. If one of these is lacking the plant cannot grow at all. In some soils all of these nutrients are available in large amounts, in other soils all nutrients are scarce, but often some are abundant while others are in short supply. The elements which are in shortest supply are the limiting factors. Figure 3.3 shows the nutrient contents of three soils. Which factors will limit plant growth in each case?

Because in each habitat other limiting factors predominate the 'general' type of. plant or animal of figure 3.1 and 3.2 cannot exist. Plants and animals need special modifications of their structure, physiology, behaviour or life-cycle so as to solve these specific problems of each environment. Solutions to the

Figure 3.3 Various aspects of soil fertility for three soils, illustrating different limiting factors: the first soil is fertile in all respect, the second poor in all respects except pH, the third especially poor in phosphorous. (data David Billing, P. F. U.)



specific problems or limiting factors, are called **adaptations**. In this chapter we will discuss as examples adaptations for surviving droughts, surviving high temperatures, or a poor oxygen supply, and adaptations to special abiotic factors such as grazing and predation.

Sometimes the word **strategy** is used to describe the complex of structural, behaviour and life-cycle adaptations of a certain organism as a solution to the specific problems of its environment.

In this chapter we shall give some examples, but you will probably know a lot of it already, as most of Biology is concerned With how organisms live, that means the relation between structure and function.

Before giving examples it is useful to formulate the problem more clearly. Every adaptation not only has benefits, but reciprocal costs too. Sometimes these costs are simply costs in terms of energy needed to build extra tissues of structures (e.g., deeper roots for plants or a special type of bill for a pelican) of energy needed for additional types of behaviour (e.g. running away from danger or migration to other habitats in adverse seasons). In these cases the problem for the plant or animal is how to budget, how to distribute the available energy supplies; for example a plant can use its energy to make either green leaves or roots or flowers and seeds. A basic choice is whether to spend energy on survival of the organism itself or on reproduction ('survival in the offspring').

In other cases the costs a can be more serious. An adaption as a solution to one problem quite often creates new problems, by interfering with other basic needs and functions of the plant or animal. Many adaptations for drought in: both plants and animals for example consist of closing off the surface to reduce the evapotranspiration. But by doing so, problems are created for gas exchange with the air which is needed for photosynthesis or respiration (see fig. 3.1).

3.2 Temperature, waterbalance and growth rate

Much of the outer structure and behaviour of organisms can be interpreted as adaptations to maintain a suitable body temperature in the specific environment of the organism. All life processes in the cells of organisms can take place within a limited range of temperature. This includes a **minimum-**temperature at which the organisms activity is very limited or where it freezes to death and a **maximum**-temperature at which essential parts are destroyed. Somewhere in that range there is an **optimum-**temperature at which the organisms will function best. So all organisms try to keep their temperature as close to the optimum as possible. Birds and mammals are better at this than most other organisms and are able to maintain a fairly constant temperature in the main parts of their body.

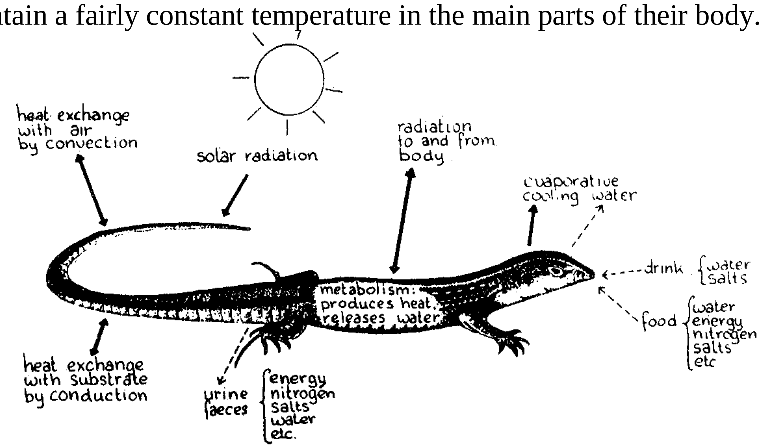


Figure 3.4 *Temperature balance of a lizard; the solid lines indicate exchange of heat with the environment, the broken lines exchange of related substances (modified from Cloudsley Thompson,* 1977).

They are called **homoiothermic** organisms. The other organisms (e.g. reptiles, fishes, insects and plants), whose temperatures varies over a wider range, are called **poikilothermic** organisms.

All organisms produce heat as a side-effect of all life processes for which energy is used. The amount of heat produced depends on the activity level of the organism; it is much higher for insects or birds during flight or running mammals, than for slow, creeping worms and snakes. All organisms gain or loose heat by exchange with the environment via various physical processes, indicated in figure 3.4.

a. **radiation**: the sun heats the earth through radiation, which contains the energy on which all life depends. All organisms and dead objects also lose heat through radiation, the intensity of which depends on their temperature. Colour is important, as white surfaces reflect and black ones absorb radiation energy.

b. **conduction**: if two surfaces are in contact they exchange heat. You experience this when standing on a cold floor or on a rock. Drinking cold water or taking it up through roots cools off animals and plants, respectively, by conduction.)
c. **convection**: air-streams or flowing fluids can bring or take heat, e.g. wind (cold or hot) or fan.
d. **latent heat** exchange: when water evaporates it needs energy from the ' surroundings for the change from liquid to a vapour. Evaporation of water on the surface of a plant or animal results in the cooling down of the surface by this process of latent heat exchange.

Animals can regulate their temperature by manipulating any of these; processes. Behaviour is important: animals can choose for activity in daytime or at night; they can select a suitable micro-habitat (e.g. a position in the sun or shade, or a burrow in the soil); they can orientate their body-axis to the sun or wind, to expose a larger or smaller surface area; some can create cool air streams (e.g. flapping ears of elephants). All these actions influence heat exchange with the environment. Evaporation of water cools down its direct surroundings. Animals can make use of this fact to cool their body temperature by producing sweat.

The related process of transpiration is the main method for cooling down, available to plants, which are restricted in the possibilities to move their leaves and therefore in manipulating the other forms of heat exchange.

The skin and its structure is very important for the temperature balance of an animal. Hairs (mammals), feathers (birds) or scales (as reptiles have for instance) affect all the processes mentioned: they influence absorption or reflection of radiation; they can form an insulating layer limiting heat exchange by conduction; they can reduce the air flow over the skin and in such a way reduce convection; such air flow is also important because it stimulates evaporation by removing water vapour. The same principles apply to the hairs and scales, which some plants have. Many animals are able to influence these factors by putting hairs or feathers down or upright.

An interesting adaptation can be seen in several desert mammals. Instead of storing fat under the skin as most mammals from other habitats do, they put their stores in special organs: the humps of a camel or a zebu-cow or the fat tails of desert sheep are good examples. In this way they can more easily get rid of excess heat.

The size of an animal has important consequences, for the temperature balance. The surface area, which determines heat exchange with the environment increases with the second power of the length, while the volume, which determines metabolism, generation of heat and internal storage of water, increases with the third power of the length. Only comparatively large desert animals have a surface-to-volume relationship so small that they can afford to cool themselves by the evaporation of sweat. These include the camel, donkey, addax, oryx and dama gazelle. Because they have a greater reserve of water per unit area of surface, such large animals can suffer a given rate of water loss for longer than small ones, before their water contents are reduced too far. If a flea would have to preserve a constant temperature by evaporation when exposed to desert conditions, it would dry out completely after five minutes. For a tse-tse-fly it would be approximately twenty minutes; for a locust one hour; for a rabit twenty hours and for a man sixty hours. Small animals can only live in desert-like circumstances by restricting their activity to the night and to the most humid parts of the environment.

Evaporation and transpiration can be regarded as an easy way of regulating temperature for those organisms which can afford it. So temperature balance is related to water balance. We find the most extreme adaptations in desert organisms which live in an environment which is hot during the day, cold at night and with no water available for transpiration. Tolerating higher temperatures during the day and cooling-off at night is typical of desert organisms. Some desert animals (e.g. jerboa, sand-rat) can live without drinking water, living on the water stored in their food (plants), on dew which forms during cold nights and on the 'metabolic water' formed by the respiration of sugars. Many desert animals reduce water loss to a minimum by making very concentrated urine. Plants, extract water from the soil with their roots according to their needs. The main driving force for water uptake is suction by the drying of the leaves which lose their water during the daytime. Waterloss is functional in temperature regulation, but it is mainly a side effect of the gas exchange needed for **photosynthesis**.

Plants need a continuous inflow of carbondioxide into their leaves and therefore they need contact with the air outside, through openings in the leaves. But as they have these openings they cannot stop the loss of watervapour. Similarly, animals loose a lot of watervapour to the air by respiration. **Stomata** are mechanisms plants have to open or close contact between the air outside and the air in cavities in the leaves. Most plants will close their stomata at night, when there is no light for photosynthesis; open them in the morning and close them around midday when water loss through transpiration becomes too high. In this way plants try to make maximum use of photosynthesis for the amount of water spent. Stomata are generally found on the under side of the leaf. This reduces the loss of water. The green cells of the leaf receive light from above and carbon l dioxide from below.

Possibilities for regulation by stomata are limited however, and there are clear differences between plants adapted to dry areas (**xerophytes**), plants, of intermediate land environments, plants of moist, damp places and waterplants. Examples of xerophytic adaptations are shown in fig. 3.5.

They consist of a) thick wax layer covering all surfaces; b) hairs or scales to reduce airflow around the leaves; c) a reduction in size of the green parts of the leaves; d) a very extensive root system (which can be much larger than the I shoot system; e) facilities to store water in the roots, stems or leaves (such plants are called **succulent**) f) possibilities for closing the leaves (for example compound leaves with. 'joints' at the base of the leaflets as in *Acacia's)* or leaves that can roll in (as in grasses) and g) by having few stomata, arranged on the underside of the leaf in deep troughs.

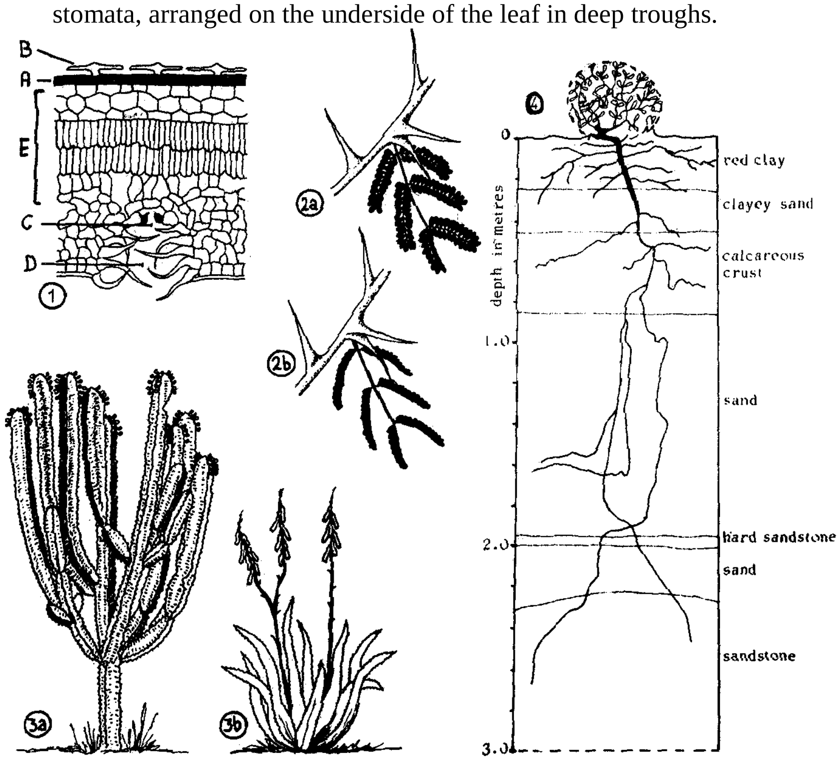


Figure 3.5 *Xerophytic adaptations of plants: 1. modified leaf anatomy, with thick cutickle (A), surface covered by scales (B), few stomata (C), confined to the lower side of the leaf, in deep throughs, covered by hairs (D); cell layer* E *is mainly responsible for photosynthesis;* 2. *composite leaves with moveable leaflets, as in* Acacia: *they open when sufficient water and light are available (a) and close when either is lacking (b);* 3. *succulent plants with reduced leaf area and internal* *storage of water in* Euphorbia candelabrum *(a) and* Aloe *(b);* 5. *modified shoot/root ration with deep and extensive root system as in this desert shrub* Pithuranthos (1-4 or., 5 after Walter).

Most of these structures lead to a reduction of photosynthesis and hence of the growth of the plant. Plants without these adaptations cannot grow in the desert (the habitat of xerophytes) because they dry out. Xerophytes can potentionally grow 10 moist habitats, but they grow so slowly that they will be overgrown by faster growing plants without drought adaptations. There is a gradual transmission from true xerophytes of the desert to 'plants with still some xerophytic adaptations in the savanna.

> Two groups of plants have found a solution to the problem of loss of watervapour as a side-effect of CO_2-influx into the leaf for photosynthesis. The first group has a much more efficient means of biochemically 'trapping' carbondioxide, characterized as the C^4 pathway instead of the C^3-pathway of other plants. Many tropical grasses, such as Sugarcane, Dura *(Sorghum)* and Maize, and Papyrus belong to this group. They can continue to photo- synthesize in dry conditions, with their stomata nearly completely closed. They mainly occur in warm and dry conditions.
>
> The second group consists mainly of succulents which are able to store CO_2 at night in their cells and use it during the day for photosynthesis with closed stomata.
>
> By opening their stomata at night for taking in CO_2 they can use water more efficiently, as the transpiration at night is lower. For more details the reader is referred to modem plant physiology textbooks.

In the rain forest plants we see quite a different adaptation: most leaves have 'driptips' (figure 3.6), which make the surface dry soon after rainfall. In this way they can quickly resume photosynthesis. Rain forest trees show much less variation in leaf shape than plants from other environments. Plants which can only live in moist, damp places usually occur in the shade at very low light intensities. So they need adaptations to use what light there is as well as possible. Their leaf surface area is as large as possible and usually the leaves are very thin. Shade plants usually have physiological adaptations as well to make fuller use of the scarce light.

Waterplants have both water and sunlight available, so they are able to grow very fast (e.g. waterhyacinths and papyrus). Some are submerged in the water, others float on the water surface with their roots floating freely or attached to the bottom. A third group is rooted to the bottom and has emergent leaves above the water. Water currents may disturb the plants, so plantlife in standing (stagnant) water is more abundant than in flowing streams, and plants from streams have finely devided leaves to reduce damage by the flow. Usually the upper surface of floating waterplant leaves has a thick cuticle; not to prevent transpiration, but to prevent water from

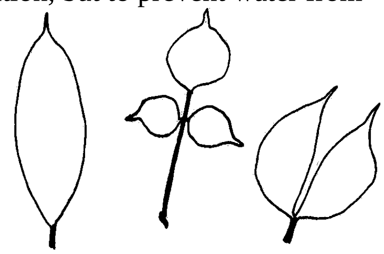


Figure 3.6 *Drip-tips of rain forest plants (after Longman &Jenik).*

flowing over the laves. Often the leaves contain air chambers to keep them floating:

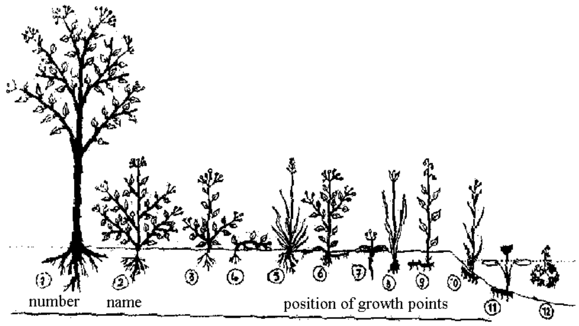
There is almost as much variation between the root systems of plants as between the above groundparts, although much of this variation remains unnoticed. Digging up root systems is a time consuming activity, but still it can be quite rewarding. Most annual plants form a comparatively small and shallow root system, even in the semidesert. The root systems of perennial grasses usually are confined to the first half meter of the soil as well, although they may penetrate deeper. Between trees a large variation occurs. Rain forest trees usually have rather shallow root systems. Many savanna trees have root systems which are deep going but which also are expanded in breadth. The roots of *Acacia seyal, A. senegal* and *Balanites aegyptiaca* can reach as far as 8 m from the trunk in the soil layer 20-60 cm below the surface. Their taproot usually reaches a depth between 1 and 2 meter. Desert trees and; shrubs generally have roots which go deeper, but with less lateral expansion. The lateral expansion is mainly functional in those situations where the trees have to compete for water with a dense grass vegetation. Perennial herbs in the semidesert area, such as *Cassia senna* may have roots to over 2 meter depth. *Acacia nilotica* and *A. albida* often penetrate below the ground water level. Oxygen supply to such roots is a problem but internal air channels inside the roots can overcome these problems. Internal air channels are also a common feature of marsh plants such as the wild rice *(Oryza barthil).*

In section 1.3 the difference in water holding capacity between clay and sand soils was explained. This difference is reflected in the vegetation. Many trees can occur on sandy soils in places with much less rainfall than they require on clay soils. For example, *Acacia seyal* has its optimum on sandy soils at 250-400 mm rain/year, while on clay soils the optimum is 600-700 mm/year. The same applies to the xerophytic shrub *Calotropis procera* (Usher, (A.)) The flood plain offers very extreme seasons to trees: either flooded or extremely dry cracking clay soils. The few trees which occur on the edge of the flood plain and on the lower edge of termite mounds, *Acacia drepanolobium* (whistling thorn, fig. 4.15) and *Euphorbia candelabrum* (fig. 3.5), shows xerophytic adaptations as well as adaptations for tolerating the floods.

3.3 Surviving the adverse season

In discussing the temperature balance of animals we saw that one of the main strategies is to avoid adverse conditions, if possible, by choosing the best microhabitat. This strategy is applied on a much wider scale. Both plants and animals can solve problems of adverse environmental conditions either by tolerating **stress** or by avoiding stress factors. They can avoid it by either moving away from it (**migration**) or by entering into a resting stage and waiting for more favourable conditions. Many plants in the semi-desert are annual plants with a very short life-cycle. Seeds germinate after the rainfall and within a few weeks the plants have flowered and produced new seeds which can survive in the dry soil for a longtime. In this way these plants avoid the drought and they do not need xerophytic adaptations (so they can grow quickly whenever there is water). Similarly, many insects have resting stages in their life-cycle by which they can survive adverse seasons as pupae or in thick-walled eggs. This strategy, avoiding **stress** is applied to many sorts of stress factors or adverse seasons. In temperate climates the cold season is the main adverse season, in tropical climates it is usually the dry season. For land organisms in the flood-region, the flood-season is the adverse period. Fire is a seasonal stress factor associated with the dry season, which only well-protected animals (such as a tortoise) can tolerate and which most mobile animals will try to avoid.
In perennial plants, there are a number of ways of surviving the adverse season, which mainly depend on the position of the growing point, as shown in figure 3.7. Protection of the growing point and resting buds from adverse outside influences (fire, grazing or treading) can be achieved by structures such as scales, leaves or thick bark (for example *Balanites* has thick layers of cork and *Acacia seyal* has fleshy bark), or by a position of the growing points in the soil or high above it.

Figure 3.7 *Life forms of plants (after Raunkiaer); the solid black parts survive during the adverse season*



number	name	position of growth points	
1	large tree	8 m	above ground level
2	small tree	2-8 m	above ground level
3	shrub	0.25-2 m	above ground level
4	low shrub or creeper	0-0.25 m	above ground level
5	tussock grass		
6	plant with stolones or rhizomes	at surface	
7	plant with rosette and taproot		
8	plant with bulbs,	below surface	
9	earms or tubers		
10, 11	marsh plant	in mud	
12	water plant	in water or mud	

(Fires usually have the highest temperatures at about 4 m height).
Young trees and herbs (2, 3 and 4) are easily killed by fire, but bulb plants (8), taproot plants (7), tussock grasses (5) or established trees (1) may survive. Of course full-grown trees can be destroyed by a crown-fire, but they can withstand grass-fires if their bark is thick enough. So growth forms 5-8 and to a lesser extent trees (1) are the successful life-forms of the savanna; growth form 8 and 9 and annuals, surviving as seeds predominate in the (semi) desert and 1-4 in the forest. This last group has an obvious advantage there over plants with lower growing points, in competing for light.

Technical terms exist for the various growth forms:

1, 2, 3	**Phanerophyte**	8, 9	**Geophyte**
4	**Chamaephyte**	10, 11	**Helophyte**
5, 6, 7	**Hemicryptophyte**	12	**Hydrophyte**

Annual plants (surviving as seeds) are called **Therophytes**.

Many plants have seeds which can survive in the soil for many years. We can speak of a **seedbank** in we soil, a collection of viable seeds waiting for suitable conditions to start to germinate. The physiological condition of these seeds is called dormancy.

A distinction should be made between quiescence ('resting') and dormancy ('sleeping'). Quiescent seeds are simply waiting for enough moisture and the right temperature to start the process of germination.

Dormant seeds need some environmental factor to 'break the dormancy' before they will respond to suitable conditions for germination. A clear example is given by seeds which need to be exposed to light, however briefly, before they germinate. Various weeds from arable land, lettuce and *Acacia senegal* (hasbab (A.)) are examples. This reaction helps the seeds to germinate only when we soil has been disturbed to create suitable conditions.

Seeds of various *Acacia's* need passage through animal guts to break their dormancy. Seeds which are produced during the rainy season are usually protected from germination until the next rainy season because they need to dry out completely before they can germinate. Many desert plants contain chemicals in their seed-coat which inhibit germination. A heavy rainfall is necessary to wash these inhibitors away and to trigger germination. Daily fluctuations of temperature often promote seed-germination. The seeds of *Acacia seyal* (Talh (A.)) only germinate after a fire has broken the seed coat.

A difference exists between the general 'germination strategy' of plants in the dry savanna and in the (semi) desert. In the Sahel zone immediately after the first rains large numbers of seedlings can be seen. If the rainfall is interrupted, most of these seedlings will die rapidly. But if the rains continue growth of the seedlings can be so fast and mutual shading can develop so quickly, that apparently seeds which would germinate later would have little chance to find a place. The risk of this rapid germination is that many times the whole flush of seedlings will die, but the seedbank is large enough. Not all seeds of the seedbank will germinate at the same time. Usually there is variation between the seeds of one species in the hardiness of the seed coat, which leads to variation in their germination. The hard seed coat of many leguminose seeds is slowly broken down, even in dry soil, causing always a fraction of the seeds to be ready for germination.

In the (semi) desert zone the seedbank is much smaller, as most plants can only produce a limited number of seeds here. Also the competition between plants is much less than in the savanna zone. From these facts we can see that a more carefull strategy of waiting with germination until enough water has fallen to secure growth, is adaptive in the semidesert.

Many insects and other invertebrates or lower vertebrates (fishes, amphibians (toads, frogs) and reptiles (snakes» survive the adverse season. in a resting stage. This is called **aestivation.**

A good example is the lungfish *Protopterus* of the Sudd and toic (fig. 3.7), It which survives the dry season by burrowing itself in. the mud, making a cocoon. When in water it breathes both from water by its gills, and from air by its lungs. When in the mud it breathes from air by lungs only.

Burrowed in the mud, the lungfish enters into a resting stage with a. minimum level of cell activity. If the stored reserves are depleted it can even it start to break down less essential parts of its body such as the tail. It also changes its metabolism to adjust to the water-shortage, and because excretion is impossible due to water-shortage, it stores excess nitrogenous wastes as urea in stead of the ammonia it usually excretes (since ammonia is poisonous to the cells and cannot therefore accumulate m the body).

Many snails from temporary waters have the ability to use either gills or lungs for respiration and to burrow themselves in. the clay in the dry season. Many *Protozoa* and unicellular *Algae* have thick-walled resting stages

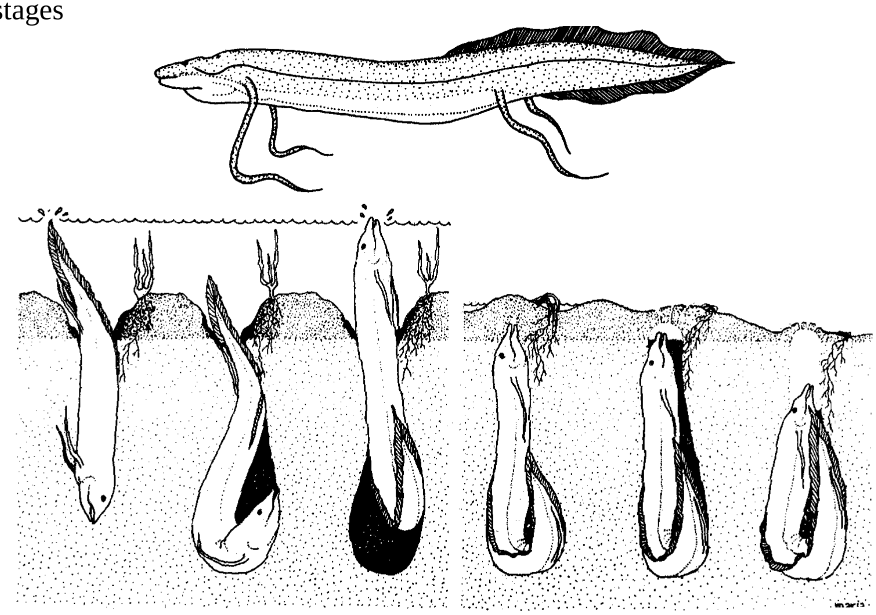


Figure 3.8 *Aestivation of a lungfish* (protoptems). *At the end of the flood season the fish buries itself in the mud, coming to the surface to breathe as long as there is water left; it forms a cocoon in the mud, in which it survives the dry season. (or.).*

(**cysts**) to survive periods of drying out. In insects the resting stages are called **diapause** and are determined internally by hormones. Like seed-dormancy, it requires outside stimuli of various kinds to break it. Diapause can occur in all stages of the life-cycle, but is most common in the eggs and pupal stages. It requires the whole life-cycle to be adjusted to the seasons.

Many animals avoid adverse conditions through **migration** to more suitable habitats. Migration can be distinguished from the usual daily movements of the animal within its environment by being seasonal and on a larger scale. The word migration is used to describe regular, seasonal movements to and from breeding areas. It is found in many birds, mammals and fishes and in some insects as well. For the large mammals of the savanna-grass-plains migration is the only way to secure food and water all year round. Many birds that breed in Europe migrate to Africa to escape the cold winters. But they go back for breeding because of the abundant food supply of good quality there in spring and summer. The Nile is an important migration route for them. When they arrive in autumn they slowly follow the south-ward shift of green vegetation following the south-ward movement of the rains. Most migratory birds spend the winter, when Sudan is dry, further to the South. On their return migration in spring they fly faster across Sudan and are less easily noticed.

Many African birds migrate North- and Southwards according to the seasons as well. Conspicuous examples are the Carmine Bee-eater and the Kite. The Kite breeds on rocks or cliffs and is confined to their surroundings in the breeding season. Afterwards kites spread over a larger area, including the floodplain.

Many fish migrate to special areas for spawning and reproduction. The fringes of the water are favoured habitats for this, because of the usual abundance of food here.

As stated before, the rain forest has much less pronounced seasons than the savanna and drier habitats, so there is far less need for migration.

> The word migration is sometimes used in cases of 'eruptions' of species like Desert locusts which can increase to such numbers that they spoil their environment completely and have to migrate to avoid the adverse conditions created by themselves in this case. But in these emergency migrations the chances for survival or reproduction of the migrants are usually low. Often only the few locusts which remain in the outbreak area can reproduce successfully.

Several organisms avoid adverse conditions by having different stages in the life cycle indifferent habitats.

Several insects such as mosquitoes, hooverflies and dragonflies live during their larval-stage in the water and fly in the air in the adult-stage. The larvae (see figure 2.6) benefit from the abundance of food in the temporary waters, while the adult can move freely to find new suitable habitats, and quite often they can survive the dry season. In such cases larvae and adults require completely different adaptions for respiration, feeding, etc.

> A problem with all the adaptions for avoiding the adverse season is that of timing, of how to adjust the daily rhythm or life cycle to avoid the unfavourable conditions. Different indicators can be used, such as changes in daylength, temperature or watersupply. Many organisms also have an internal 'biological clock' which governs the rhythm and only needs external indicators for adjustment of the clock from time to time. For many plants daylight is very critical in determining the onset of flowering. Dura *(Sorghum)* varieties from Egypt may not flower at all in the Southern Sudan because they wait for long days which never occur.
>
> Sometimes organisms are misled. A small amount of unexpected rain in the dry season may trigger germination of seeds or growth of **geophytes** from their underground reserves, while there is not enough water to complete the lifecycle. This can be very detrimental, not only for the plants, as they exhaust resources without replenishing them, but also for the animals and human beings that depend on these plants. Dormancy and diapause can be seen as adaptions to avoid this sort of situation, to enable the organisms to wait until the favourable conditions really start. But this is difficult for a small seed or resting insect somewhere in the soil to know, and mistakes are unavoidable.

As mentioned before the seeds of one species usually show variation in their time of germination. Depletion of the seedbank is often prevented by the fact that germinating seeds produce substances which stop other seeds from starting to germinate. Usually the seeds of one species are spread over various soil layers. This also contributes to a spreaded germination.

The rainy season is for most plants the best time for growing, but it is not a very favourable time for flowering and for pollination. Many savanna trees flower in the dry season, often about one month before the start of the rains. In this way both the flowering and the seed forming stage which requires much photosynthesis, occur in a suitable season (before and after the start of the rains, respectively). Several trees delay ripening off of their fruits till the start of the next dry season.

Acacia albida (Haraz, (a.)) is an exceptional tree of the Sahel and Sudan savanna, as it sheds its leaves at the start of the rains and waits for the dry season to form new leaves, to flower and to produce its orange seed pots. The deep root system, reaching groundwater supplies, can explain this behaviour.

3.4 Defence against attack

The first two sections dealing with examples of adaptions were for abiotic factors; we shall now consider some examples of adaptions for a biotic factor. Animals depend on plants or other animals for their food so all plants and most animals are always liable to be eaten. Therefore all organisms need adaptions for defence. Animals eating plants are called **herbivores**, and animals attacking other animals **predator**. If they mainly eat other animals they are called **carnivores**, if they eat plants as well **omnivores**.

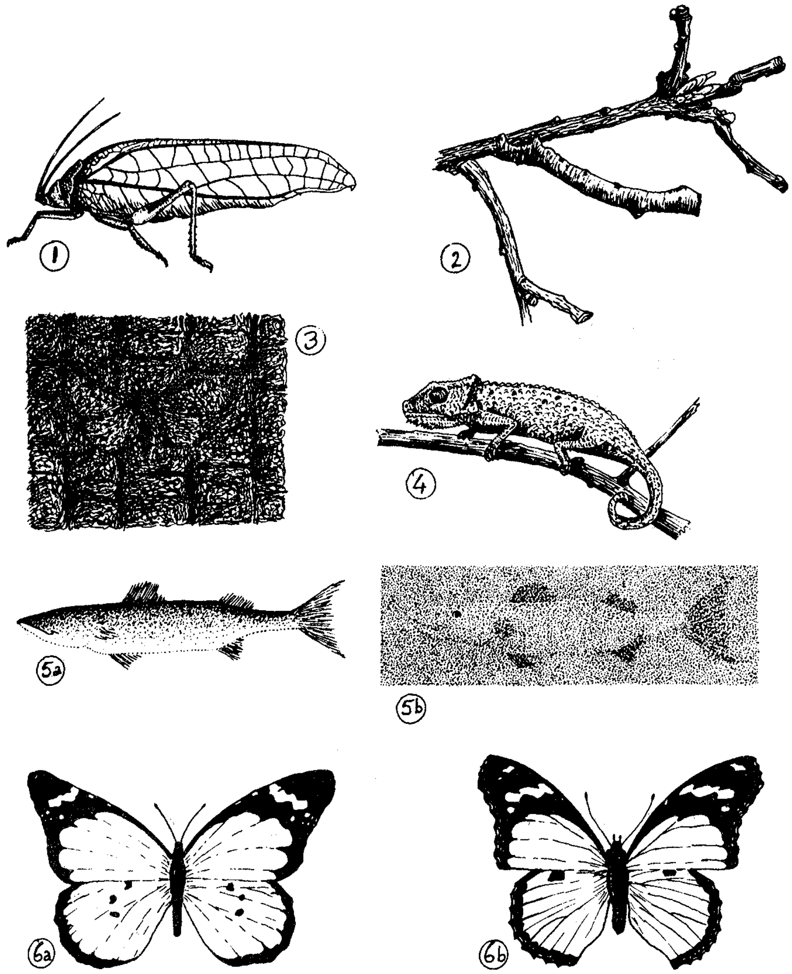
These adaptations can be of various kind according to the different steps in attack: before a predator attacks, it has to notice the potential prey, it has to recognise it as edible, then it will start to approach, before it finally attacks. For each of these steps adaptations for defence exist.

First of all, the prey will try to remain unnoticed, by having a colouration similar to the environment. This is known as camouflage (see fig. 3.9). Camouflage is a strategy used by many animals, the Chameleon being the classical example; but stick-insects, stick-like catter-pillars, leaflike grass-hoppers and praying mantids and brown-spotted moths are equally good at it. Many fish are dark above and light underneath, which makes them invisible in the water in light coming from the top. Even a seemingly conspicuously coloured animal like the zebra may prove to have some camouflage, as it is difficult to see from a distance in the tall grass savanna full of vertical lines. In later stages of an attack the colouration of the zebra is helpful too because it is very difficult to single out one individual between all these moving lines (each individual can be said to have camouflage between the others).

Not all predators move about actively in search of prey. Some have a good camouflage themselves and just wait to trap the prey. Examples are the larva of the antlion that catches ants and termites in its sand-traps (figure 2.4), spiders with webs and praying mantids. In these cases, the prey will have to try to notice these predators as early as possible to avoid them.

The second step in the attack is that the predator has to recognize the prey as edible, and this is related to its learning from previous experiences with similar preys. Animals that are protected by a nasry taste or smell or by a poison or sting will be avoided by predators after an unpleasant experience with them. These animals usually have a conspicuous colouration to make it easy for the predator to recognize them and learn to avoid them. But once the predators have learned to avoid animals with such colours, they can be mislead by other organisms without proper defence, using the same colouration to protect themselves. This is called mimicry. Examples can be found in many insects such as butterflies resembling other poisonous butterflies or wasps (fig. 3.9).

Figure 3.9 *Examples of camouflages:*
1. *leaf like grasshopper,* 2. *branch-like caterpillar,* 3. *moth with the colour of the bark on which it rests,* 4. *chameleon, changing colour according to the environments,* 5. *counter shading of fish: a. shows the fish when seen in uniform light, b. when seen in light from above, as is normal in water,* 6. *mimicry of butterflies: a. the unpalatable African Monarch butterfly; b. palatable butterfly, belonging to a different family, a mimic of the Monarch.* (5 *and* 6 *redrawn from Ewer and Hall* 1978, 1-4 *or.).*



Once the predator starts approaching its prey, the prey can try to escape by flight or by hiding itself. Before it comes to an attack many organisms will try to threaten the enemy by frightening it: a 'warning colouration', suddenly showing bright colours as butterflies do, puffing up to increase size as seen in the fish *Tetradon* or pretending to be a larger size, as cats do by walking sideways, are examples of this.

When an attack is made, there are still many types of defence possible both mechanical and chemical (fig. 3.10):

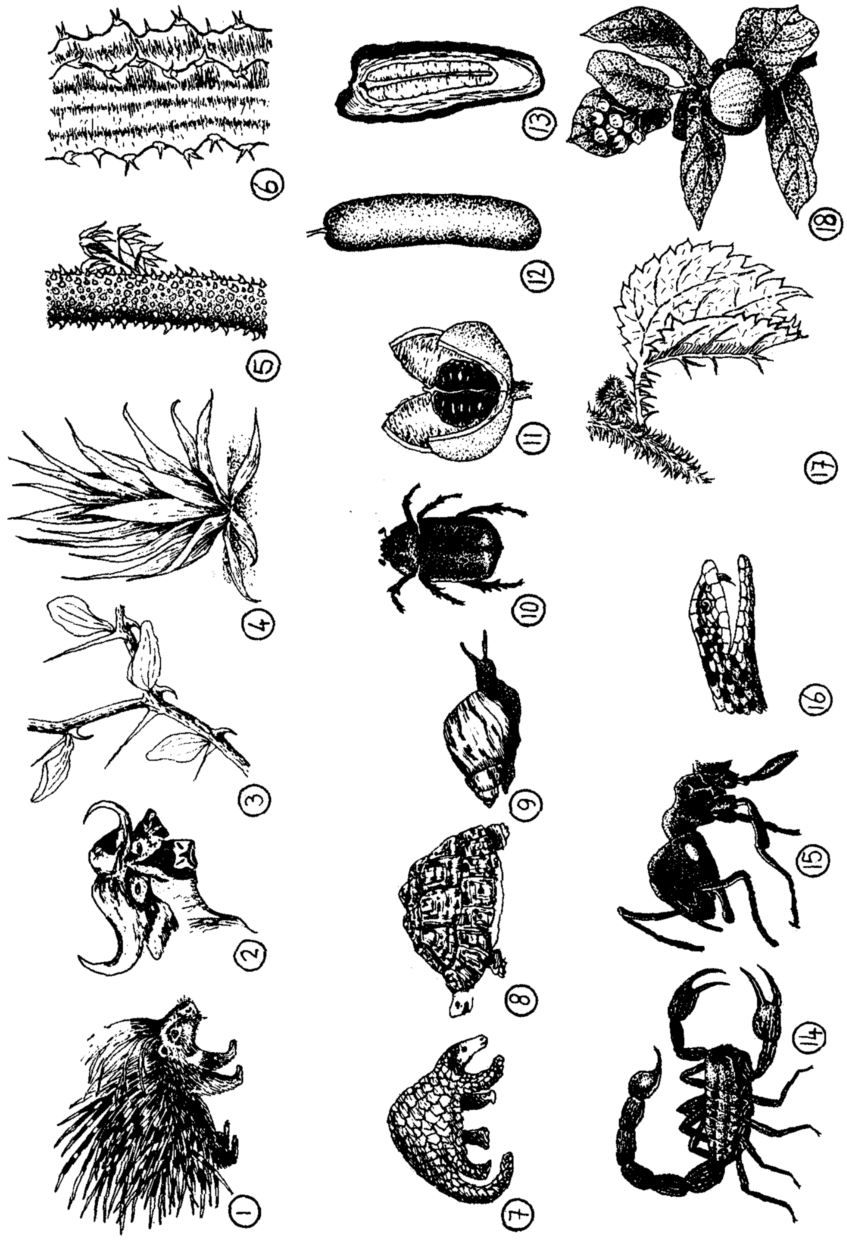
a. horns and thorns; sharp stiff Structures making it difficult to touch the organism are common in both plants and animals: the quills (modified hairs) of hedgehogs and porcupines, the spines of the fish *Synodontis*, and the horns of the buffalo are animal examples.

   In plants there is a large range of similar structures derived from different plant parts:

   1. thorns, modified branches in the axis of leaves, as in *Acacia's* and Lemons,
   2. spines, modified leaves or parts of leaves as in the Pineapple, Sisal and Datepalm,
   3. prickles, derived from surface cells as in the Silk cotton tree,
   4. bristles, modified hairs which are stiff and sharp as in *Euphorbia,*
   5. needles of silica or calcium, deposited on the surface as certain fruits have and *Imperata* (speargrass).

b. armour or hard covers which predators or herbivores cannot bite through: the armour-plates of the pangolin, the hard shell of the tortoise, the scales covering crocodiles and millipedes the exoskeleton of snails and insects and the hard cover of many fruits and seeds, all function in the same way. In many edible fruits the seeds have a hard cover to protect them when passing through an animals intestines (e.g. dates, mangoes (when eaten by elephants))

Figure 3.10 Defence structures.
A. Horns and thorns: 1. *porcupine quills,* 2. *buffalo horns,* 3. *thorns of Ziziphus (Sidr, Nbak, A.),* 4. *spines of sisal,* 5. *prickles of Silk Cotton tree,* 6. *bristles of* Euphorbia candelabrum;B. *Annour:* 7. *pangolin,* 8. *tortoise,* 9. *snail, 10. beetle,* 11. *hard fruit wall of Mahogany* (Khaya), 12. *Hard fruit of Sausage tree* (Kigelia), 13. *hard seed coat* in *soft fruit of Date;* C. *Poisons:* 14. *scorpion with sting,* 15. *ant with biting mouthparts,* 16. *snake with poison teeth (fangs),* 17. Fleurya ovalifolia *(common in forest clearings), with stinging, hairs,* 18. Calotropis procera *(Usher, A.) with poisonous milky juice. (or.).*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c. arms. Stinging and biting as more active defence is found in. many animals and some plants. Plants can have sticky hairs which often contain irritating fluids or just stick to the teeth or tongue of the herbivore. Some plants have stinging hairs which inject poisons into the animal. In animals there is wide range of stings from bees, wasps, scorpions and centipedes to certain fish, biting ants, snakes and biting fish *(Tetradon).*

d. The previous case was a transition from mechanical to chemical defence. Chemical defence can consist of poisons or just a nasty taste or smell which animals learn to avoid. Many plants contain latex, a milky juice which flows out when the stem or leaves are cut and which often irritates or even poisons (e.g. various *Euphorbia* species and *Calotropis procera* (Usher, A.).

Resin is produced by other plants and has a similar effect. Other plants contain alkaloids which may be very poisonous. Many herbal medicines contain alkaloids which have a strong physiological effect. Morphine in Opium, Nicotine in Tobacco, Coffeine in Coffee, Quinine in the bark of the tree *Cinchona,* various types of arrow poisons derived from plants, all belong to this group. Pyrethrin is another type of plants poison which can be extracted from the plant *Pyrethrnm,* for use as insecticide. Many animals contain poisons as well, such as the butterflies of the mimicry- example.
An interesting defence problem is confronting plants. Often dispersal of seeds depends on animals attracted to the fruits as a food source. But before the seeds are ripe and protected from digestion, they are an attractive, nutrient rich food for many herbivores already. Immature fruits often have some form of chemical defence, such as resins or the same alkaloids found in leaves. Ripening of the fruits is accompanied by a change from toxic to edible.
Another aspect of defence is that the individuals of the same plant species in a tropical rain forest usually are far apart. This makes them difficult to find to those herbivores which have special adaptations to overcome their specific defence mechanism.

3.5 The origin of adaptations

So far, we have just described adaptations as such, without asking questions about how these, adaptations come about. We saw that the structure, behaviour and life-cycle of every organism is not a haphazard, random thing, but that it can nearly always be interpreted as function under given environmental conditions. In fact the origin of these **adaptation** can be of various kind. Some adaptations are '**physiological'**, that means they can change directly according to the situation. Eyes have to adapt to light after coming from darkness and vice-versa. Similarly, the colour-change of the Chameleon is a physiological process governed by contracting or expanding coloured pigment cells in its skin, which can be reversed. The opening and closing of stomata in plants is another example of physiological adaptation to current conditions. There are two other types of adaptations, which are of a more permanent character: one occurs during the lifespan of the individual, the other occurs from generation to generation. The environmental conditions during the life of an organism, especially when it is young, can have a lasting influence on the shape of the organism and its behaviour. Examples are manifold: leaves of a tree formed in the sun usually are thicker and more xerophytic than leaves of the same tree formed in the shade. Such a difference is clearly functional. The same applies to the growth form of the tree: when growing in an open habitat with much wind the tree will have a compact and low form; the same tree would have developed a loose, elongated shape when growing in the shade between other trees. We can say that the form shows **plasticity**, that means that it can be modified. A clear example can also be found in the waterhyacinth (figure 3.11): plants growing in open water develop rather small leaves, with swollen petioles containing air chambers; the same plant would have developed large leaves on long, straight petioles when growing in dense vegetation near the shore. Examples of plasticity can also be found for animals, although their form is generally more fixed. Larvae of dragonflies live in water where they rely on camouflage to catch prey; when the larvae grow up in muddy water their skin will be dark when growing up in clear water on sandy bottom they will be light colored.

In all these cases the change comes about during the life of the organism and does not affect its offspring. When we cut either of the two mentioned forms of the waterhyacinth into two parts and allow them to grow in both environments we will always get the 'water form' developing in open water and the 'shore form' developing in shore vegetation.

In other cases the difference between organisms is, at least partly, transmitted to its offspring. We can say mat there are certain **genetic** factors influencing form, physiology and behaviour which are passed on from one generation to the next. You will probably be familiar with this idea if you consider human examples of the similarity between parents and children.

The genetic factors themselves are supposed not to be influenced by the environment directly. But the environment does play an important role: it determines which growth forms will be able to reproduce and hence pass its genetic factors on to the next generations and which ones will not. Because of this selection, a gradual and continual change in the genetic factors that influence the life form and behaviour of an organism is possible in the course of many generations. This process is called **evolution** or genetic adaptation.

Three steps are essential for the process of genetic adaptation to occur:

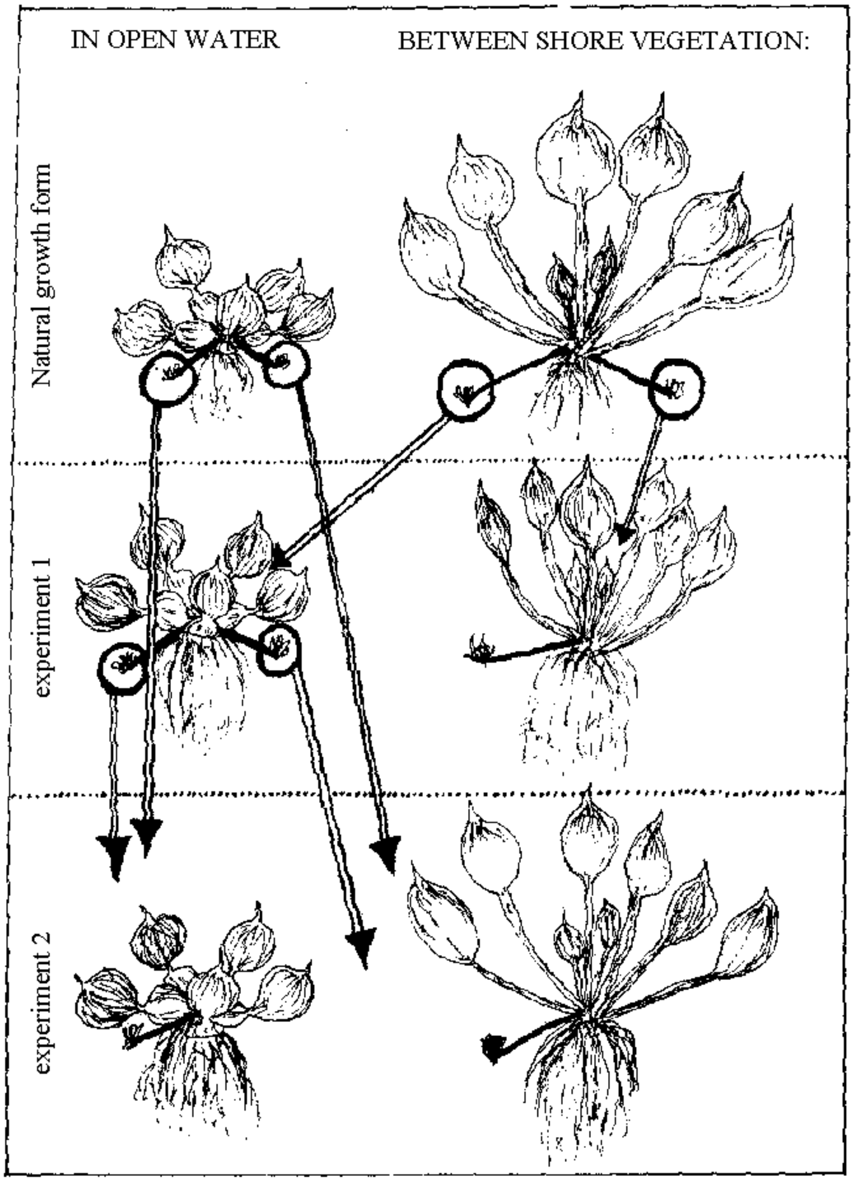
1. All organisms produce more offspring than will survive (for example, consider the number of seeds of a plant). On the average from each pair of parents only two of all the young or seeds produced will survive to maturity. So, there is a 'struggle for live' in every new generation.
2. All these young or seeds are not the same; they vary genetically, having different genetic factors.
   The genetic variation will increase by the process of mutation, responsible for random Changes in the genetic factors. See biology text-books for more details.
3. Some genetic factors will lead to organisms which are better adapted to the current conditions than others, so these tend to survive, while others die ('survival of the fittest'). We can speak of selection by the environment to describe this, as the question which genetic factor leads to the fittest organisms, very much depends on the environment.

It is important to realise that evolution is not just something of the distant past, but something that it is still going on, all around you. Examples of this can be seen if new factors are brought into the environment, like the, insecticide DDT which is poisonous to all life forms. DDT is used to kill insects such as mosquitoes and when it was discovered during World War II it proved to be very effective and killed almost all mosquitoes. Almost all, for just by chance some mosquitos proved to be less susceptible to the poison.

They had some form of resistance, and this suddenly proved a very valuable adaptation for them. They survived the spraying campaign, while all others were killed, so suddenly they got much more chance for reproduction. At least a proportion of their off-spring inherited the resistance against DDT. So after DDT had been used for several years, many of the mosquitoes proved to be resistant and after an initial success, the programmes to eradicate the Malaria-mosquitoes proved to be a failure.

Not only had their been no success, the situation had become even worse than before spraying started, because many of the natural enemies such as birds, bats and lizards had also been killed by the DDT. It takes a longer time for sum organisms to develop resistance than it did for the mosquitoes. Evolution tends to be faster for smaller organisms than for large ones,

Figure 3.11 Experiment to show the plasticity of a water hyacinth plant. For explanation see text (or.).



because of a shorter life-cycle, a generally higher number of offspring per generation and a larger number of organisms in one area; so there is more chance of a suitable adaptation being present, just by chance.

In micro-organisms evolution can be even faster than in insects and the rate at whim they can develop resistance against new 'antibiotics' is a serious concern for medical people.

The three types of adaptations (physiological, plastic and genetic) are answers to three types of changes in the environment, from temporary to permanent.

Of course no environment is constant and as long as the changes are reversible, the adaptations should be reversible as well. The physiological adaptations are reversible; the plastic response is to a certain extent. Genetic adaptations are answers to permanent changes in the environment, which exceed the flexibility of the organism and its plasticity.

The process of genetic adaptation is the main function of sexual reproduction as compared to asexual or vegetative reproduction. Vegetative reproduction just reproduces new individuals with the same genetic constitution. It is very common in plants and lower animals and it is efficient in that it reproduces plants or animals which have proven themselves already in the particular environment. But if the environment changes, new genetic factors have to be present, and for mat purpose genetic variation has to be maintained in the species as mum as possible and new combinations of characteristics have to be tried out continuously. This is done by sexual reproduction, in which the offspring is never completely equal to the parents, but always a new mixture of genetic factors of both parents.

Similar to the **'natural selection'** as described here, we can speak of **'artificial selection'** as a means of improving the genetic factors of crops or domesticated animals. It follows the same steps as natural selection, but human decisions become important in determining the 'fitness' of the off-spring. All crops and domesticated animals originate from nature and often their natural relatives can still provide valuable genetical material for the improvement by breeding of the cultivated varieties.

It is ultimately this process of evolution which distinguishes the living from the non-living world and which makes biology a different type of science from chemistry or physics: we are not only interested in cause and effect but also in function and 'aim'. A certain looseness of language when talking about aims, purposes or strategies in organisms is acceptable as long as it can be translated in terms of fitness and selection.

3.6 Suggested practicals

1. Collect five plants from different micro-habitats (see exercise, chapter 2) and compare their structure. Can you identify adaptations to the limiting factors of each micro-habitat?
2. Classify the plants of a certain habitat according to the-way they survive the adverse season (dry or flood season) (see figure 3.5). Can you understand why certain lifeforms predominate and others are absent?
3. Search for animals like insects, spiders or birds in different (micro-)-habitats. Can you identify structural adaptations to their mode of life? Can you see both costs and benefits for each adaptation?
4. Describe examples of camouflage in your surroundings.
5. Keep record of the presence of birds, insects and/or mammals through-out the year. Can you understand their seasonality as adaptations to the environment?
6. Make a study of defense mechanisms of plants and animals in your surroundings
7. We can simulate the process of adaptation, by studying the way in which selection for camouflage works. On a coloured piece of cloth, we can spread out items of different colours (small pieces of coloured paper or coloured beads or beans). One hundred of these are spread out randomly on the cloth and a 'predator' has to collect them as quickly as possible. The remaining ones all multiply by a factor ten and the process is repeated. Which colour survives?

4. Relations

4.1 Relations through changing the environment

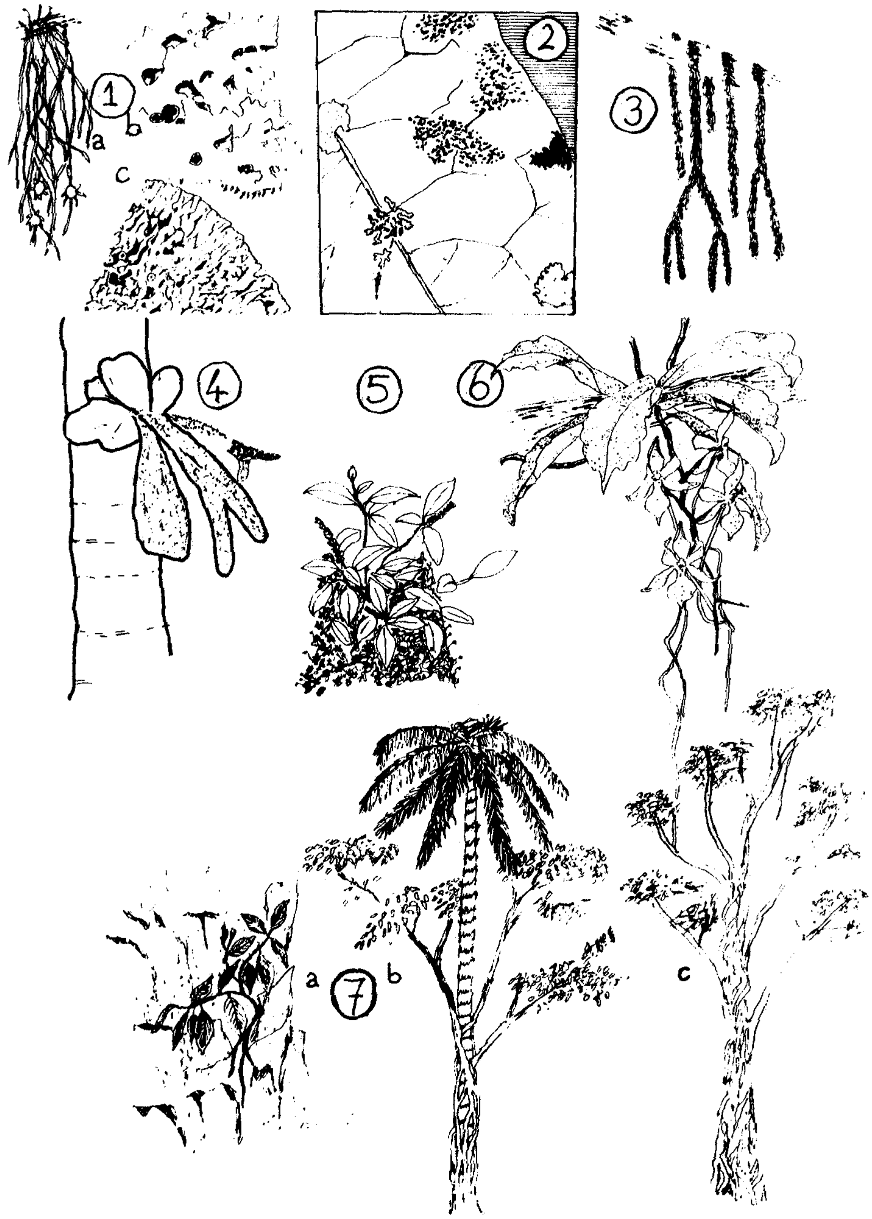
In this chapter we shall consider the different types of relations possible between two organisms.

The simplest type of relation is one of the most important: every organism depends on its environment, but at the same time it changes the environment. If a plant starts to grow in bare soil, it will provide shade and moist air, it will reduce both the heat in the daytime and the cooling down at night, its litter will decay to form humus in the soil and this will change the surface structure of the soil and hence the infiltration of water into the soil; the plant will also use water and minerals from the soil reducing the amounts available to other plants. So the first plant growing on bare soil changes the environment and this will make the environment either more or less suitable for other plants as well as for itself. More specific examples where one plant provides a suitable microhabitat for other plants can be found in the **epiphytes**, plants growing on the stem, branches or leaves of oti1er plants. Epiphytes (fig. 4.1) are common in the moister forest types, as they depend on a continuous rainfall or on the presence of mist. In the savanna prickly shrubs often protect grasses and herbs growing in their shelter from grazing animals.

Another example of plant-induced changes of the environment in the savanna is the fact that grasses form the fuel for natural or manmade fire, thus making it very difficult for less fire-resistant plants to invade the area. In areas with tall grass with sharp edges and strong wind, establishment may be very difficult for other plants by physical damage to their leaves.

Some plants produce toxic chemicals in the soil which prevent other plants from germinating or growing. This is known as **allelopathy**. An example of this is the Speargrass *(Imperata)* which is an obnoxious weed in the Greenbelt. Another example was mentioned in section 3.3: germinating seeds often slow down or stop the germination of other seeds.

Figure 4.1 *Examples of epiphytes: 1. Lichens: a) thread-like hanging from small branches, b) leaf-like growing on a tree trunk, c) crustose forms pioneering on tree trunks*, 2. *Algae and crustose lichens growing on a leaf of a rainforest tree,* 3. *Primitive type of fern* (Lycopodium), *hanging from tree branch in rain forest,* 4. *Fern* (platycerium), 5. *Herb* (Peperomia), 6. *Orchid* (Acrangis), 7. *Strangling fig., establishing it self on a trunk of a palm tree (a), sending roots to the soil and surrounding the tree trunk (b) and finally overgrowing the palm. (or.).*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Animals change the abiotic factors as well, for example when they trample the soil down in tracks or compact it. Elephants and buffaloes often create mud-wallows, which then can be used by other animals such as hippo's. Termites and earthworms (figure 2.5 and 4.6) change the soil structure considerably and termites are also important by erecting mounds in which plants can germinate and grow, which cannot grow on the surrounding soil because of flooding or fire. Of course many animals have a marked effect on the vegetation as well, either creating a suitable environment for other animals or plants or spoiling it (figure 4.4). In the case of man, these effects are even more pronounced: Man changes the structure of the vegetation in large areas, changes the waterbalance of complete riversystems, destroys many natural habitats and creates new ones, from which some organisms benefit but most others do not.

4.2 Consumption

4.2.A. Strategies

All animals depend on other organisms for their food, so consumption is an important type of relation. **Herbivores** eat plants; **carnivores or predators** eat other animals, **omnivores** eat both types of food. So consumption is a relationship between herbivores and vegetation or between predators and their prey.

First of all, we can describe these relations in terms of attack and defence-strategies, as we did in section 3.4. The predators need searching strategies, to find their prey and attack it before the prey can escape or defend itself. The prey has to try to notice the predator as early as possible. The structural defence-mechanisms discussed before, are all related to the behaviour of the predator. The sense-organs of predator and prey have to fulfil different requirements: the predator has to search, so it needs two eyes close together to estimate distances while the prey needs to see predators approaching from all sides so it has eyes on the side of the head (compare a lion with a cow or antelope (figure 4.2)). Camouflage is an important defence against visually-oriented predators, but it only functions if the animals live dispersed and move as little as possible. Prey organisms often keep quiet if they see a predator approaching, relying on camouflage until the predator comes too near, within the 'escape distance', when they run or fly away. More active defences are found in animals living in a group such as buffaloes, closing their ranks facing the predators. Living in a group has the advantage of providing more chances of noticing the predator by a system of warning signals in the group.

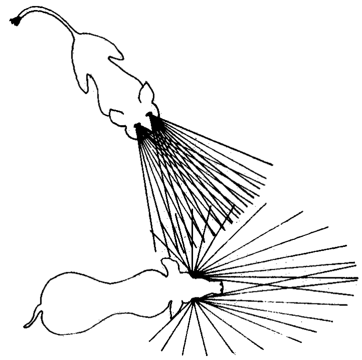


Figure 4.2 *Eye position and viewing angle of a typical herbivore (prey) and carnivore (predator), as seen from above. (or.).*

Interesting mixtures of the predator and prey strategies are found in animals like lizards which have to catch prey (insects) and at the same time avoid being eaten by kites and other predator-birds. The eyes of the lizard are on the side of its head, so it has to shake its head to estimate distances. Lizards sit still most of the time to get maximum benefit from their camouflage, both to a void predation and to wait for insects to land close by. If that happens they will slowly approach and then suddenly run forward and catch the insect with their long tongue.

Passive predators usually will catch less preys than more active ones, but they also spend less energy to get them, so they can afford to get less food (compare a cheetah with a snake or praying mantid).

The defence strategies of the prey always have to be related to the attack strategy of the predator. This has been called an 'evolutionary game of chess' between the predator and the prey, each trying to overcome each others new tricks. Bats produce sounds which are too high for us to hear and listen to the reflections of the sound to find their way when they fly at night, and also to find prey insects. Moths and other insects flying at night usually are covered by wooly hairs which distort these reflections (they absorb them in stead of reflecting, you might call this 'sound-camouflage'. Another unusual sense organ is used by fishes from muddy water which orientate themselves through electric signals. Several types of fish can produce weak electric fields which are sufficient for recognizing any object in the water including prey. Some fish such as *Malapterus* in the Nile use stronger electrical currents both for attack and defence. Other fishes are able to detect electrical fields without producing any themselves. Thus they are able to avoid such predatory fishes. Many insect larvae, such as caterpillars are attacked by certain (parasitoid) wasps which lay their eggs inside the larvae (figure 4.3). These wasps find the prey by smelling with their long antennae and confirm that it is suitable by touching the potential prey with their antennae before laying their eggs inside. After laying their eggs they mark the larva with a special scent so that other parasitoids will avoid this

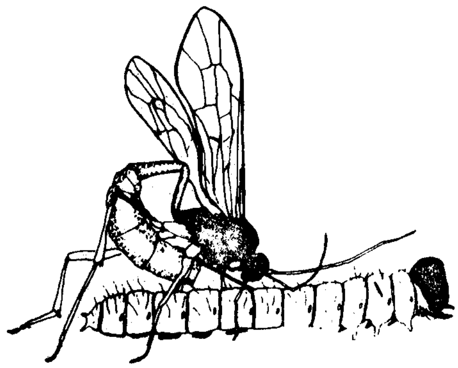


Figure 4.3 *Parasitoid wasp laying an egg inside a caterpillar. (or.).*

larva. If more then one egg would develop in the hosts' body, none of them would have enough food to survive. The defence of the larva consists of wriggling its body when it is touched and by the ability (sometimes) to encapsulate the egg in their body. Despite of this the parasitoids often are effective, and they are important in the biological control of insect pests.

A rather unusual type of consumption is formed by insect-eating plants, such as the bladderwort *(Utricularia*, figure 2.6) from the Sudd which traps and digests waterfleas and similar animals in its bladders. The prey is mainly useful to the plants as an extra source of nitrogen, enabling the plants to live in environments where nitrogen is in short supply.

4.2.B. The number of predaton and prey

If a predator eats prey, it will survive and it will have the chance to produce offspring. Meanwhile the number of prey is reduced. Usually some form of balance is reached, in which the number of predators is such that it will not kill all the prey. If it did so, it would very soon die from hunger itself. But this balance is continuously changing.

If the prey increases in numbers, the predator can respond in two ways: by a **'functional response'** and by a **'numerical response'**. The functional response means that the predators will start eating more of the prey, after they had a good experience with them and consequently learns to search them. This can be a quick reaction, but it is limited because the predators can get saturated. The numerical response means that the predator will increase its numbers in case of an abundance of food, but of course this takes time. Both responses are quite relevant when we consider predators which are helpful to man as natural enemies of crop pests.

Rapid reproduction may be the best defence strategy for microscopic prey such as *Protozoa*. Other prey makes use of the saturation of predators by appearing in large numbers all at the same time; for example animals migrating in herds or termites flying all at the same night. All predators will eat till saturation, but after that all the other prey organisms are safe.

Generally, the amount of food is very important in determining the numbers in which organisms can occur. In this regard we can speak of the **'carrying capacity'** as the maximum number which can be sustained by the environment. The numbers of the prey determine the carrying capacity for predators and as such determine their numbers. Only in certain situations does the number of predators really limit the abundance of the prey.

4.2.C. Grazing

Grazing is similar to predation, but usually plants are not completely killed as preys are. Rather, only parts are removed and the part removed determines whether grazing really damages the plant or not. It makes much difference whether in grazing the growth points of the plant are removed or not. Grazing can even be beneficial to the plant if old parts hindering growth are removed. As we saw in figure 3.7 the position of the growth point is different for different groups of plants. In grasses the growth point is particularly well protected, so grasses survive grazing much better than other herbs or tree-saplings. When the grazing pressure is not too high, the grass may even benefit from the fact that these other plants are removed. If there are too many herbivores the vegetation can be changed considerably: only a few spiny, thorny shrubs and some hard grasses are left. When this occurs the soil loses its protective cover, and erosion can take place.

Usually herbivores are divided into **grazers** (eating grasses and other herbs) and **browsers** (eating shrubs and trees). Often browsers are selective by choosing the best parts of the plant, while many grazers eat a mixture of plants. Cows and sheep are mainly grazers, while goats and camels are mainly browsers, but of course this division is not sharp.

A nice illustration of the fact that some organisms pave the way for others can be seen in the 'grazing sequence' of natural herbivores of the savanna. (fig. 4.4). A tall, mature stand of grass is not suitable for most herbivores: the grass may be old and tough, difficult to move about in and dangerous too, because predators can hide anywhere. Only heavy feeders like elephants and buffaloes tramp into the chest-high grass to take what they need. In the trampled grass some regrowth of young, fine grass will occur and the area will become suitable for zebras. Zebras refine the structure of the pasture even further and make it suitable for the hartebeest arid gazelles. These selectively nip off the leafy parts of the grasses or pluck the herbs left by the other grazers. Grazing birds such as Egyptian geese may come into

Figure 4.4 *Grazing sequence in a savanna: Elephant, buffalo, zebra, hartebeest, Mongallagaze, Egyptiangoose. For explanation see text.* (or.).

the shortest swards, while termites and other soil organisms clean up the animals waste's and take care of all the fallen bits of leaves and 'left overs'. Some unusual ways in which animals use plants as their food will conclude this section. Aphids are very common small insects which can really harm plants by boring their sharp mouthparts through the stem of the plant, into the phloem-tissue, to suck out the very sweet sap. Because of all the sugars in this sap, energy is no problem for them, but they have to consume large amounts of sap to obtain enough protein. They produce wastes full of sugar, and other animals such as ants come to use this. Certain aphids such as the 'white fly' are very dangerous pests of agricultural crops, because they can transmit virus-diseases from one plant to another (see section 4.3.A). Another harmful type of consumption takes place underground, where the plant roots are attacked by many soil organisms. Eelworms *(Nematodes)* are very common and they eat the soft outer tissues of the roots.

4.2.D. Scavengers and saprobes

Not all animals eat live plants or animals. One group lives on the remains of prey killed by predators or on animals died of disease, drought or other causes: the **scavengers**. Another, important group, the **saprobes,** live on all kinds of dead organic matter: dead leaves, stems and roots of plants or animal wastes.

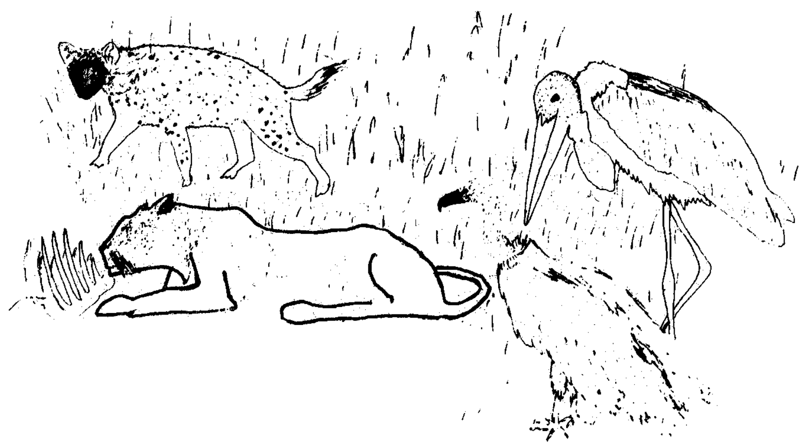
Well-known scavengers are the vulture and the marabou stork (figure 4.5) which both spend much of their time circling and soaring high in the air, looking for dead or dying animals. When they notice a carcass they will come down to feed on it -if they get a chance. Several of the large mammal predators will try their luck on such food as well, and, they will chase away the birds. Hyaena's, lions, jackals and hunting dogs will all take the opportunity to feed on dead bodies if they can; this saves them the energy required for hunting actively. Their feeding strategy is sometimes called opportunistic.

It has long been thought that hyaena's are purely scavengers, while lions are purely predators. In fact the situation is more like the reverse of this: hyaena's hunt actively, mainly at night and they are often chased away by lions after killing. The hyaena's will then wait around untill the lions have filled their stomachs. It is only after the hyaenas have taken their share, that the vultures get a chance. Few predators get a chance to feed more than once on an animal they have killed. The leopard often hides dead antelopes in a tree, where vultures and other scavengers cannot reach it. Hyaena's sometimes store a carcass in shallow water, where other scavengers cannot smell it.

The term saprobes is mostly used for comparatively small organisms in the soil, living just as the scavengers from almost any type of dead organic material they can find. Many of the soil organisms shown in figure 2.4 are saprobes: earthworms, millipedes, woodlice, slugs, dung beetles, bristle-tails and spring tails *(Collembola).* A very important group of saprobes is formed by the termites (figure 4.5).

Termites are social insects which live in large colonies, inhabiting nests which have a typical shape for each species of termites. The majoriry of termites, 'soldiers' and the 'workers' are not sexually active; only the 'queen' and the 'king' are responsible for reproduction; after the first rains winged adult termites fly at night, mate and then try to establish new nests. Inside the nests termites can maintain a microclimate of their own, with a high humidity and a relatively constant temperature. Termites live on dead woods, dead leaves etc. which they carry to their nests from considerable distances, mostly at night.

Figure 4.5 *Scavengers: Lion, hyaena, vulture and marabou stork (or.).*



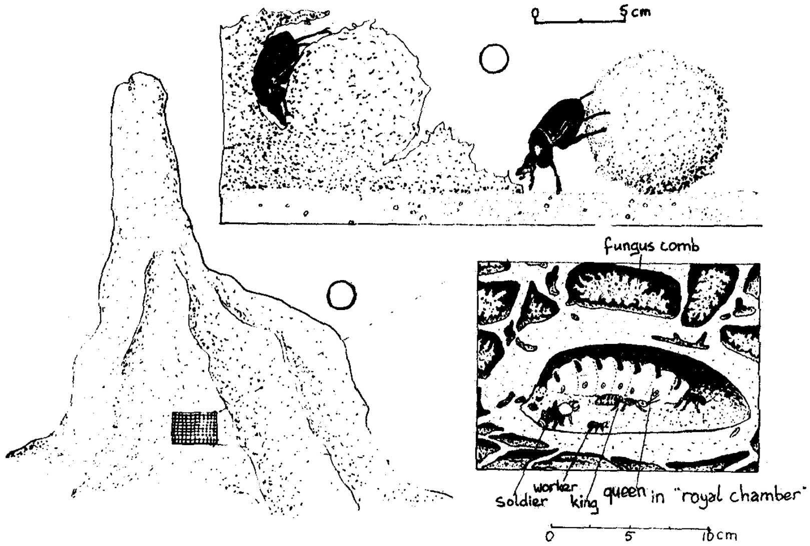


Figure 4.6 *Decomposers, A. Dungbeetle* (Kheper) *making a hall. of dung to transport it to a hole in the ground as food for its eggs when they hatch. B, Termite mound* (Macrotermes) *with a detail of the queens chamber (from various sources).*

Most of these animals, and the same holds for most herbivores, can make use of the cell contents of the plant material, but cannot breakdown cell wall material (especially of woody parts). Breakdown of this material is almost a monopoly of fungi and bacteria.

Fungi and bacteria are a group somewhere in between plants and the animals. Some fungi are known by the mushrooms they form for their reproduction, Bacteria can only be seen through a microscope.

Most fungi and bacteria can only live in humid environments. Several groups of bacteria specifically occur inside the gut system of herbivores (as well as omnivores, including man). Both parties benefit from this association.

> In the soil many fungi and bacteria are active. The large saprobes living in the soil chew up dead plant material and in this way they give more chance to fungi and bacteria to digest the cell wall material. Similar to the grazing sequence, there often is a sort of saprobe sequence: the larger saprobic animals make the material more accessible to the smaller ones (including springtails and mites) and to fungi and bacteria (see figure 5.2).
>
> Fungi and bacteria are often eaten by animals. This happens to many gut bacteria (although always some will survive); fungi are consumed by many

soil organisms. Two special relations can be mentioned in termite mounds of several species 'fungus gardens' are maintained, in which fungi grow on dead wood collected by thc termites, until the time they arc 'harvested' and eaten by thc termites; certain wood boring beetles live on fungi which grow in channels formed in wood by the beetle. In both cases the fungus depends on the insect, as this species does not occur on its own; the insect clearly benefits from the fungi.

In many cases fungi live from dead wood, as well as attacking living parts of the tree. In this case they form a gradual transition to a parasitic mode of life.

In water several insect larvae are active as saprobes, e.g. larvae of the midge and hooverfly, shown in figure 2.6. Several water snails feed on dead fish etc.

4.3. Parasitism

Parasitism is a relationship between two organisms in which one, the parasite, exploits the other, the host, to obtain food, without directly killing the host. Sometimes the distinction between consumption and parasitism is not very sharp. Usually predators kill their prey completely, while parasites only use part of their host's tissues. But the same can be said about grazing animals. Usually predators are larger than their prey, while parasites are usually smaller than their host.

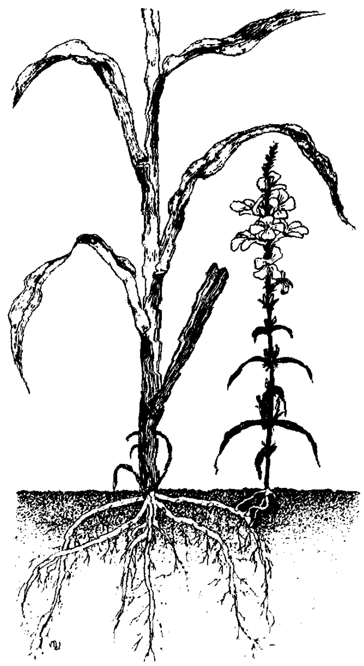


Figure 4.7 *Witch weed* (Striga hermonthica), *Buda (A.), Loreng (B.)) parasitic on/he roots of* Sorghum *(Dura, A.). (or.).*

4.3.A. Plant parasites

Although parasitism is more common among animals, we can start with some plant examples. Most plants are independent organisms, which can get all the resources they need direct from the abiotic environment.

> Sometimes plants are called **autotrophic** because of this ability to 'feed themselves', as opposed to **heterotrophic** organisms that depend on others.

Some plants have learned to use the resources of other plants becoming parasites and losing their independence. Some parasitic plants have lost the ability to use light in photosynthesis *(Orobanche* (broomrape) is an example which is fairly common in N. Sudan on lentils and broad beans); more often parasitic plants rely on the root system of the host plant for getting water and minerals, but still have their chlorophyll to at least partly provide their own energy requirement. Two such plant parasites which are very common in the Sudan are *Striga* (Witchweed (E.) or Buda (A.)) which is a parasite on the roots of Dura *(Sorghum),* and *Loranthus* spec., which parasitizes many trees. See fig. 4.7 and fig. 4.8. The seeds of witchweed can remain dormant in the soil for over ten years, waiting for a dura-root to attach to.

Many 'plant diseases' are caused by parasitic fungi or viruses feeding on plant tissues. Common examples include: the Cassava leaf mosaic virus (figure 4.9), rosette virus in groundnuts, various wilting diseases of tomato and leafblight in Dura *(Sorghum).* If we consider fungi and viruses as plants, it is a plant-plant relation, but quite often animals are involved as well: insects such as white-flies which suck sap from plants, can transfer viruses from one plant to another; insects or eelworms *(Nematodes)* in the soil eating root-tissue can create openings for fungi or viruses to enter the root and from there spread into the whole plant.

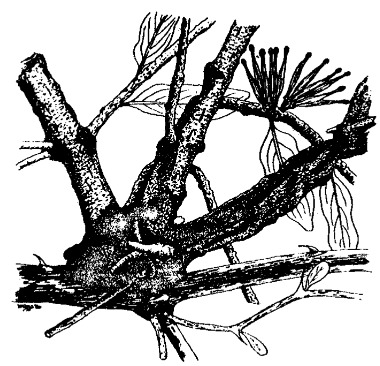


Figure 4.8 Loranthus *(Abu hamada (A.), Anaba, (A.), Nyogadok (D.)) parasitising a* Ziziphus *tree (with thorns). The parasite keeps green leaves during the dry season and can be easily seen then;* its *flowers are orange or pink tubes; the sticky seeds are transferred by birds to other trees.*

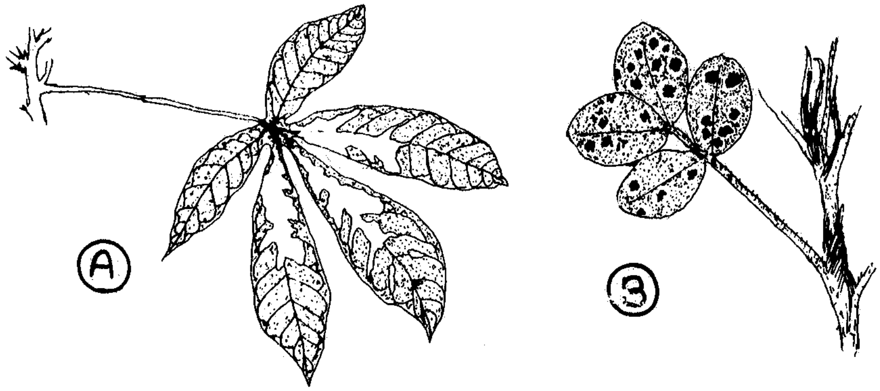


Figure 4.9 *Examples of plant diseases caused by a parasitic virus or fungus: A. Mosaic-virus on cassava, B. leaf-spot-fungus on groundnut (various sources).*

4.3.B. Animal parasites

Among animals, parasitic relations are common. The host partner in the, relationship provides the parasite in many respects with a very favourable environment. The parasite needs special adaptations to make use of these advantages and to withstand the hazards associated with this particular mode of life. A rather special type of parasitism ('brood parasitism') is found among birds: coucals and cuckoos do not build their nests themselves, but the female lays her eggs in the nests of smaller songbirds. The songbird will brood the eggs, which usually hatch more quickly than the host's eggs. The songbird will feed the young coucal while it grows up to a much larger size than the host bird (fig. 4.10). In most other cases parasites are smaller than their host.

Parasites often show a simplified body form compared with their free-living relatives, since the host performs some of the vital functions for them. Tapeworms, for example, lack a gut, since they inhabit the host's gut, which is rich in ready-digested food, which the tapeworm can directly, absorb through its body surface. Similarly, since parasites rely on their hosts for moving around, they generally lack locomotory organs (e.g. fluke or tapeworm). Insect parasites such as lice and fleas which are attached to the outside of their host may have greatly reduced wings and antennae, but may retain powerful legs for jumping. Parasites living on the skin of their host still have to deal with the abiotic factors of the host's environment. For the larger group of parasites which live inside the host's body, the environment merely consists of the 'milieu interieur' of the host.

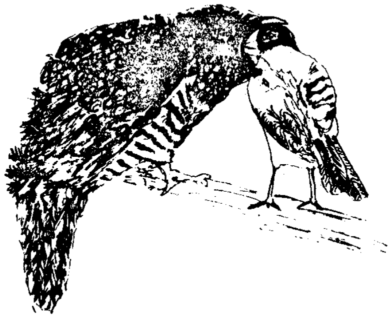


Figure 4. *10 Robinchat feeding a young redbreasted cuckoo which has reached several times the size of its 'parent'. (or.).*

Favourable aspects for the parasite in having the host as its environment include:

1. A constant and unlimited food supply, which is pre-digested in the case parasites living in the gut or body tissue;
2. A favourable temperature and humidity, inside the host's body, particularly if they parasitise **homoiotherms.** The relatively constant environment inside a homoiotherm allows continuous egg production of the parasite independent of fluctuations of external conditions. This is important for the survival of the species, as it helps to compensate for the high mortality rate in the risky sky stage when the parasite passes from one host to the next
3. The chance to use the host as a means of dispersal of its eggs or other infective stages and so increase the likelihood of new hosts becoming infected. The host carries the parasite everywhere and, in the case of parasites of migratory birds and mammals, this can even lead to distribution of the parasite from one continent to another. Outbreaks of malaria in malaria-free areas are quite common, due to malarial parasites being carried passively by air travellers to such areas. Another example is the Cholera parasite which often is carried by people over considerable distances.

Problems for the parasite arising from the parasitic mode of life include:

1. The difficulty of finding a suitable host in which to become adult and sexually mature (the definitive host), and of escaping from this host and locating and entering another definitive host of the same species, a process known as 'transmission'. Escape from the definitive host, the first hurdle of transmission, is important to permit dispersal of the infective stages and so ensure continued infection of new hosts. It also helps to prevent overcrowding of parasites in the host, liable to occur if the enormous numbers of eggs laid by the adults were all to develop inside the same individual host. Without this safety device on the part of the parasites, the host would die quickly and the parasites would not survive for a long time either.

2. Finding a mate for sexual reproduction, necessary for effective genetic adaptation to adverse changes in the external environment.
3. Finding ways of overcoming the host's defence mechanisms and the physical hazards encountered within the host.

   We shall now discuss these problems and their associated adaptations in some detail.

Parasites living outside their host have few problems in finding and escaping from hosts. For example a tick, a bloodsucking parasite of mammals, has the following life cyle. The female sucks a lot of blood from the host, falls from the host's body to the ground and seeks a sheltered place (such as crevices or walls or under stones) and lay all her eggs (up to 18.000 in some species) in one batch, and then dies. Under favourable conditions the eggs will hatch into larvae. The larvae climb on to grass and shrubs, waiting for a suitable host to pass to which they can attach themselves with their claws. The vast majority of these larvae will not encounter a host in time and will consequently die, but the vast number of eggs laid compensates for this. After sucking blood from the host, the larva either moults and becomes a nymph while still attached to the same host or, in other species, it drops to the ground, moults and then lies in wait for another host to which it could become attached. Mating usually occurs on the host.

The simplest method of escaping from and re-entering another host is that used by gut parasites. They enter the host passively through the natural entrance (the mouth) of the gut with food or water. The infective stage (a free-living stage that has to exist in the external environment) usually has a thick wall to protect it from the hazards of the environment. Common examples are two human diseases: the thick-walled **'cysts'** of *Entamoeba histolytica* (the causative organism of amoebic dysentry) and *Giardia* (a common intestinal parasite). It is in this encysted form that the parasite escapes from the host through the natural exit of the gut (the anus), with the faeces.

Gut parasites usually have a single host in their life cycle; sometimes, however, as in the case of the pork and beef tapeworms of man (*Taenia solium* and *T. sapinate*, respectively), a second host (or 'intermediate' host) is included in the life cycle. The free-living stage, an encapsulated egg (see fig. 4. 11) enters the intermediate host (a pig, in the case of *T. solium* and cattle, in the case of *T. sapinate)* together with the food. This egg then develops, within this host into another infective stage, the larva, which becomes embedded in the host's muscles. Escape from these muscles is possible only because man (the definitive host) feeds on the intermediate host.

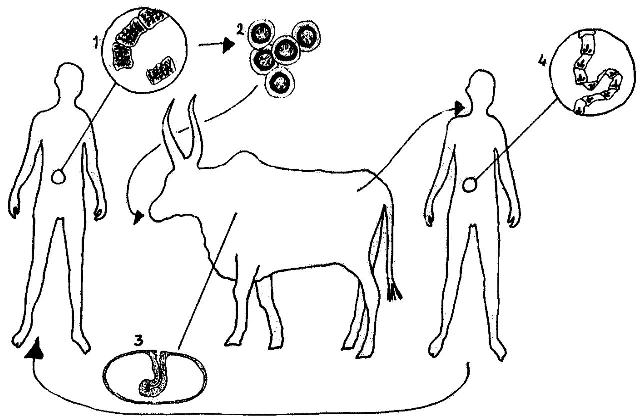


Figure 4.11 *Life-cycle of beef tapeworm* (Taenia saginate). *The adult tapeworm lives* in *the intestine and sheds egg-containing segments which are passed out with the faeces; the eggs enter the cattle with their food; the larvae hatch and bore through the wall of the gut to form cysts* in *the animals muscles; these can be eaten by human beings. (modified after Ewer and Hall).*

Exploitation of the host's sexual behaviour is another simple way by which some parasites gain entrance into their hosts. The parasites which cause syphilis and other veneral diseases of man, and similar parasites which can cause still-birth in cattle are all transmitted during coition or the sex act.

Blood has no natural exit, and so blood parasites usually rely on an intermediate host, a blood-feeding parasite, to both escape from their host and re-enter a new host. This intermediate host is usually called a vector, its main role being to transmit the parasite to another host. In the simplest case the vector only has the role of a mechanical transmitter, like a syringe needle and the parasite does not show any development inside the vector.

> An example of such a relationship can be found in the horseflies *(Tabanid's)* which transmit *Tryponosoma evansi,* the causative organism of the 'Surra' diseasc of domesticated animals, particularly camels, horses and cattle.

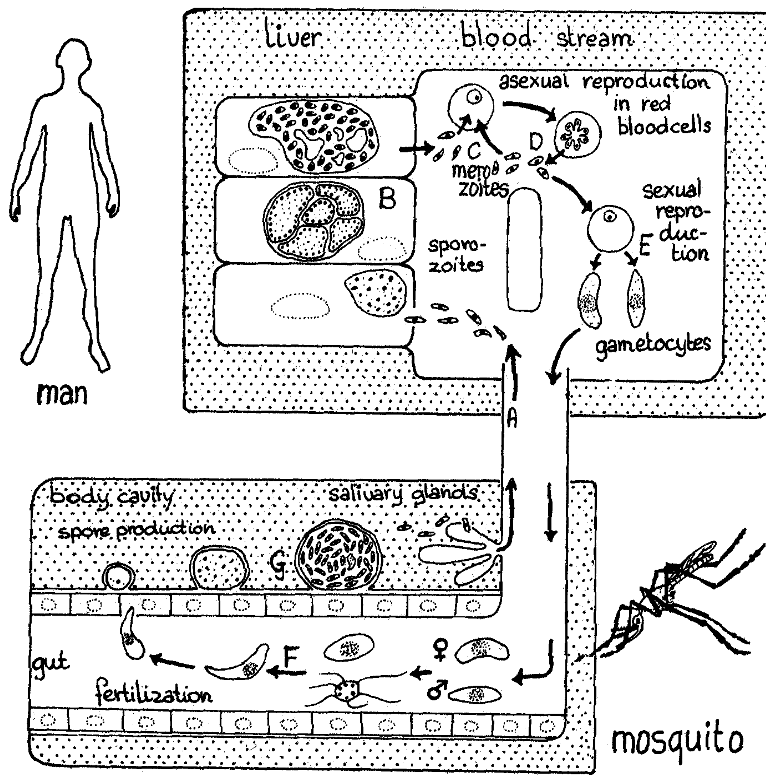
Such a relationship can be regarded as the first step in the evolution towards more complex life-cycles in which the parasite shows some form of development or reproduction inside the vector or intermediate host.

Several important human diseases are caused by parasites and transferred by vectors:

a. **Malaria**: the protozoan parasites, *Plasmodium* species, are transferred by female malaria mosquitoes *(Anopheles).* Figure 4.12 shows the life-cycle.

b. **Trypanosomiasis**: the protozoan parasites, *Trypanosoma* species, are transferred by tse-tse flies and cause human sleeping sickness and the similar disease called nagana in cattle. Figure 4.13 shows the life cycle.
c. **Leishmanniasis**: the protozoan parasites, *Leishmannia,* are transferred

Figure 4.12 *Life-cycle of* Malaria
After injection of a *human being (A), the parasites settle* in liver *cells multiplying rapidly (B); they can* remain in *the liver or a long* time, *but cannot re-infect it once they* have *passed to the next stage of the life* cycle, *the merozoites (C); these attack red blood cells and multiply inside these cells (D);* when *they are released into the bloodstream, fever is the result and* new *red blood cells can be entered; besides this asexual reproduction, cells for sexual reproduction (E) are formed which* have *to be sucked into a mosquitoes gut to fuse; after fertilisation, the parasite multiplies again and enters the salivary glands (G).from which they can enter* new *hosts. (modified after Wilson).*



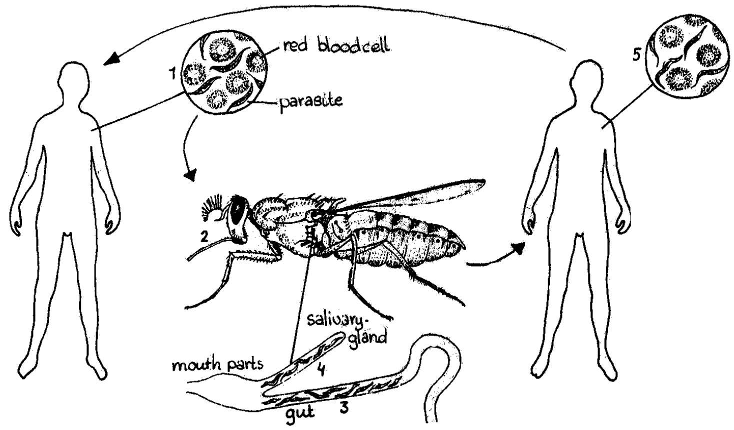


Figure 4.13 *Life-cycle of* Trypanosoma, *causing sleeping sickness. The parasites live in the blood plasma* (1); *if the blood of an infected person is ingested by a tse-tse fly* (2), *the parasites are carried into the gut* (3); *there they multiply and migrate to the salivary glands where reproduction continues* (4); *if then a fly bites another human being, parasites are injected into the blood* (5). (*after Ewer and Hall).*

by sandflies and cause 'kala azar' and skin diseases.

d. **Onchocerciasis:** the nematode worms *Onchocerca* are transferred by biting black flies, *Simulium,* and cause 'river blindness'.
e. Various cattle diseases are transferred by blood-sucking ticks.

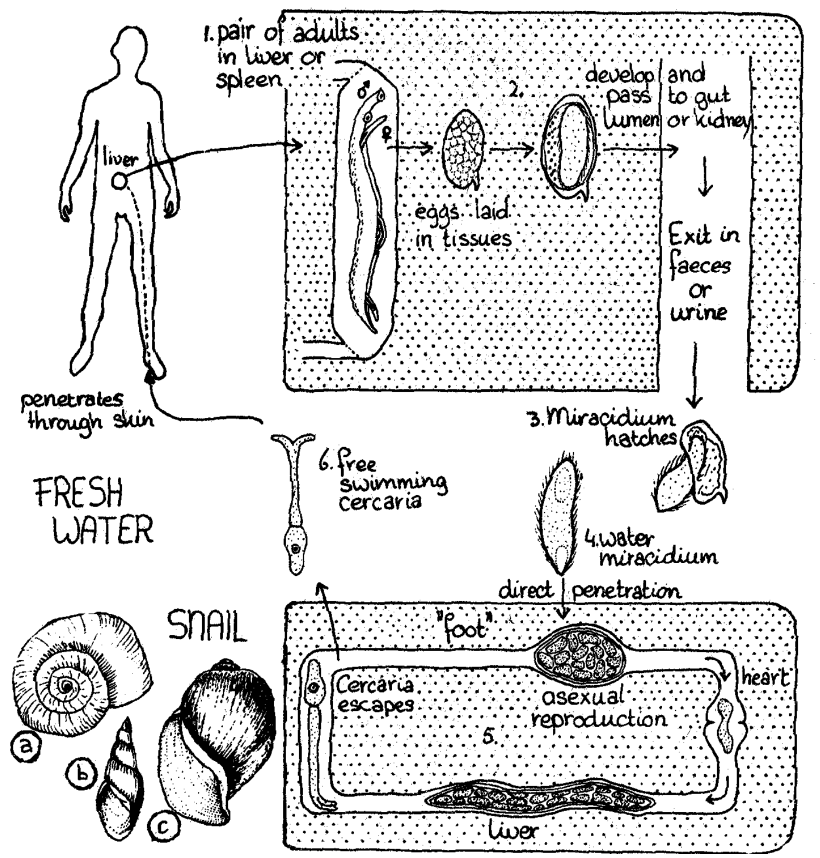
All these vectors suck up the parasite with the host's blood and so enable the parasites to escape from their host. To ensure that the parasites are taken up with the blood, the-infective stages of the parasite multiply rapidly (often asexually) so that every drop of the host's blood is infected. The parasites often concentrate in the blood vessels near the skin at the time of day the vector is active (at night for mosquitoes, during the day for biting flies).

Once inside the vector, the parasite often multiplies again and often moves into the salivary glands of the vector. When the vector feeds on a new host, it injects some saliva into the wound it makes, containing a substance to prevent the blood from clotting while the vector is feeding.

Sometimes the vector, for example a biting, fly can transmit the parasite to other organisms on which it feeds. It is possible that the parasites survive in these other organisms, without affecting them. They thus form a reservoir, from which the primary host can be continuously infected. This is the case for several cattle diseases in which wild herbivores act as a reservoir. Eradicating such diseases is no simple matter. A similar situation occurs in the simple gut parasites e.g. *Entamoeba,* while a large part of the human population carries and spreads the disease without being ill themselves.

As a last example of parasite's strategies we will now discuss the life-cycle of *Schistosoma,* causing **Bilharzia** in man. Figure 4.14 shows the life-cycle. The parasite is a small trematode worm (fluke) which lives in the liver or spleen of its host" Infective stages leave the host with urine or faeces and

Figure 4.14 *Life-cycle of* Schistosoma, *causing Bilharzia; the various types of snail which can act as intermediate host were shown in figure 1.1.C, (modified after Wilson).*



have to find water snails as an intermediate host. After multiplication inside the snail the cercaria stage of the parasite escapes into the water and penetrates through the skin of bathing human beings if they get a chance. Again, the daily rhythm of activity of the parasite is adjusted to that of the host: most free swimming cercaria can be found in the water in the afternoon when most people take bath.

4.4 Competition and niche-differentiation

Another important type of relationship is found between organisms dependent on the same type of food or resources: **Competition**. Plants may compete for light, water or nutrients; animals may compete for food or shelter. In fact, we should speak about competition only in cases of a limiting factor, where the total requirements of all the organisms exceed the available recoures.

The more similar two organisms are in their requirements the more severe competition will be. So the strongest competition is found between members of the same species. Usually several types of behaviour have evolved to divide the available resources among them in the best way. Equal sharing may not be the best way, if it means that all organisms do not get enough to survive. Many animals show some form of 'territorial' behaviour, which enables succesful organisms to secure a certain area (**territory**) for themselves for feeding or breeding. Birds mark these territories by singing; mammals often mark them by scent. An easy to study example of territorial behaviour is the rainbow-lizard *(Agama)* common on many buildings. Threats and display usually make real fighting unnecessary (section 4.7).

Competition between members of different species is important too. The closer the two species resemble each other in their requirements, the more chance there is that one species will eliminate the other. 'Complete competitors cannot coexist', is a phrase commonly used to describe this idea. Coexistence (i.e. species occuring together in one habitat) is only possible if the organisms avoid competition somehow. They can avoid competition in different ways:

1. By developing a different hunting technique, catching different types of food; e. g. the open-bill stork hunts for snails, while other storks hunt for fish).
2. By choosing a different micro-habitat to live in and developing the appropriate adaptations; (e.g. the Nile Lechwe feeds on grass inside the swamps, while most other antelopes live outside the swamp).

3. By choosing a different time of day for activity; (e.g. swallows catch flying insects during the day and bats hunt for them at night in the same way)
4. By choosing a different season (time of year) for the main activity requiring food (i.e. reproduction) and adjusting the life-cycle; accordingly; (e.g. several dragonflies survive the dry seasons as adult and breed just after the first rains; other species survive the dry season the mud as larvae and breed later).

All these points are examples of **'niche differentiation'**. By the **niche** an organism we mean both the place where it lives and the functional role it plays in the ecosystem; that includes the type of food it takes.

> Two organisms can avoid competition by having at least partly different niches. Niche-differentiation is the main explanation for the existence of many different species as there are. The possibilities for niche-differentiation in a certain habitat determine the variety of organisms that can live there Niche-differentiation usually means **specialisation** by concentrating on particular type of food or micro habitat and developing adaptation accordingly. By specialising on a certain type of food the organism, may get this food more efficiently. But specialisation in contrast to the general, all round strategy, contains the risks of dependency. If the type of food 0 which one specialises disappears, then the way back to other types of food usually cut off. So, specialisation is possible only for a type of food which is constantly available. The rain forest is generally a much more constant environment than a desert or savanna, so there are many more chances for niche-specialisation in the rainforest. It is generally a fruitful exercise to try to understand the niche-differentiation of the organisms coexisting in a certain habitat.

Good examples of niche specialisation can often be found between organisms of the same ancestry which diverged to using different types of food in different habitats. Figure 4.15 shows some examples. The bills of birds, which are all adapted to catch certain type of prey or to eat a certain type of plant food. Through this specialisation they avoid competition.

> On a smaller scale more subtle specialisations exist. Some insect-eating birds feed in the tops of the trees while others feed on insects on the lower branches or on the ground. There is a large number of sunbirds, all with slightly different size and form of bill. These slight differences may well be enough to enable them to feed on separate flowers.

The grazing sequence of herbivores explained in section 4.2 can be regarded as an example of niche-differentiation as well. Grazers and browsers have different types of stomach, depending on whether they eat 'roughage' or selectively feed on plants with a higher nutritive value. Most

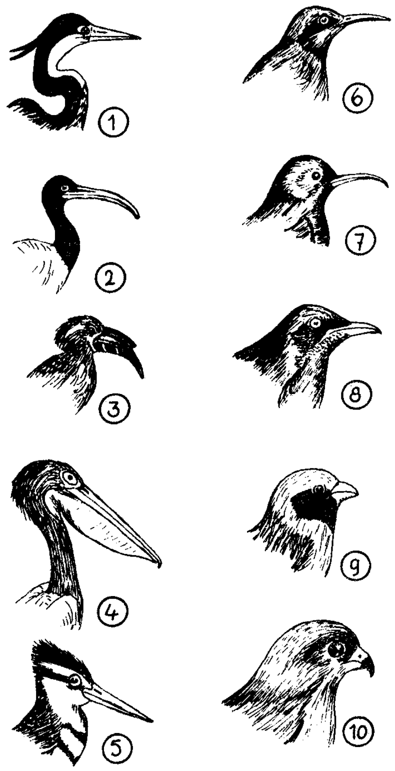


Figure 4.15 *Adaptive radiation in bills of birds, related to their type of food:* 1. *black-headed heron (fish, frogs, mice),* 2. *sacred ibis (worms),* 3. *grey hornbill (fruits),* 4. *pelican (fish),* 5. *pied kingfisher (fish),* 6. *carmine bee-eater (large insects),* 7. *sunbird (nectar, small insects),* 8. *glossy starling (seeds, insects: not specialised),* 9. *red-cheeked cordonbleu (seeds), 10. chanting goshawk (birds, small mammals). (or).*

browsers are very selective in their feeding; the narrow lips of giraffes and the very mobile tip of the elephant trunk enable them to avoid thorns and select young fresh leaves. Many grazing antelopes are also selective and are able to separate different parts of a grass plant, some feeding on leaves, others on inflorescences. Most of the larger grazers, such as the broad-mouthed hippopotamus, are non-selective.

> The hippo's come out of the water at night to graze on the land. Of course this day-night difference does not lead to avoiding competition with day-time grazers, as the grass grazed at night will not have regrown the next morning. (Contrast this with the day-night difference between insect-eating swifts and bats.)

Competition between plants is similar in its effects to competition between animals, but generally the possibilities for niche-differentiation are more limited. All plants depend on the same abiotic resources light, water and mineral nutrients. There can be some differentiation in rooting depth, by which some plants efficiently exploit the surface layers of the soil, while others search in deeper layers for leached nutrients (e.g. grasses and trees in the savanna). Because of the conflicting requirements of adaptations for drought-resistence and for rapid growth, we see a quite narrow niche-specialisation from drier to wetter microhabitats.

In the savanna we find a mixture of evergreen plants with xerophytic adaptations and fast growing plants which shed their leaves in the dry season. In the dry season the xerophytes are able to grow (although slowly) and this makes up for the other plants winning the competition in the wet season.

Weeds are generally more efficient then crops in the competition for light or soil resources, and the farmer has to help the crops by weeding.

In plants a considerable part of niche-differentiation arises through the gradual change of the composition of the vegetation, a process called **succession** (see 5.6). During succession the first, or 'pioneer' plants are gradually out-competed by other, slower growing but eventually taller plants. But the pioneer plants survive by having very efficient means of dispersal, finding new open spots as soon as they are created (by falling trees, fires etc.). This is called the **'regeneration-niche'**. It can be occupied by dormant seeds, requiring light for germination. In the forest it is used by seedlings which hardly grow in the shade, but develop as far as their seed-reserves allow and then merely survive, waiting for gaps in the forest canopy to arise. Some plants are able to fight their way in without waiting for gaps. The 'strangler fig' starts as an epiphyte on trees, sends its roots down, gradually surrounds the stem of the tree and finally kills it. By doing so it acquires its own free access to the light between the tall trees (figure 4.1).

4.5 Mutualism and symbiosis

In consumption and parasitism the benefits of the relationship only accrue to one organism while the other is harmed. Competition has negative effects on both partners, but there are also relations which are positive to both sides: **mutualism** which is an association between two organisms from which both partners benefit: It can be a loose association or one in which the two partners have become completely dependent on each other. The word **symbiosis** is used to describe the latter situation.

The closest associations of symbiosis are found in some plant examples (figure 4.16). Lichens are permanent associations of *algae and fungi*, which together are able to grow in places where no other plants can withstand the extreme conditions: on bare rocks, as epiphytes on the smallest tree branches and in other very exposed places.

Lichens grow slowly and are easily over-shadowed by other plants in more

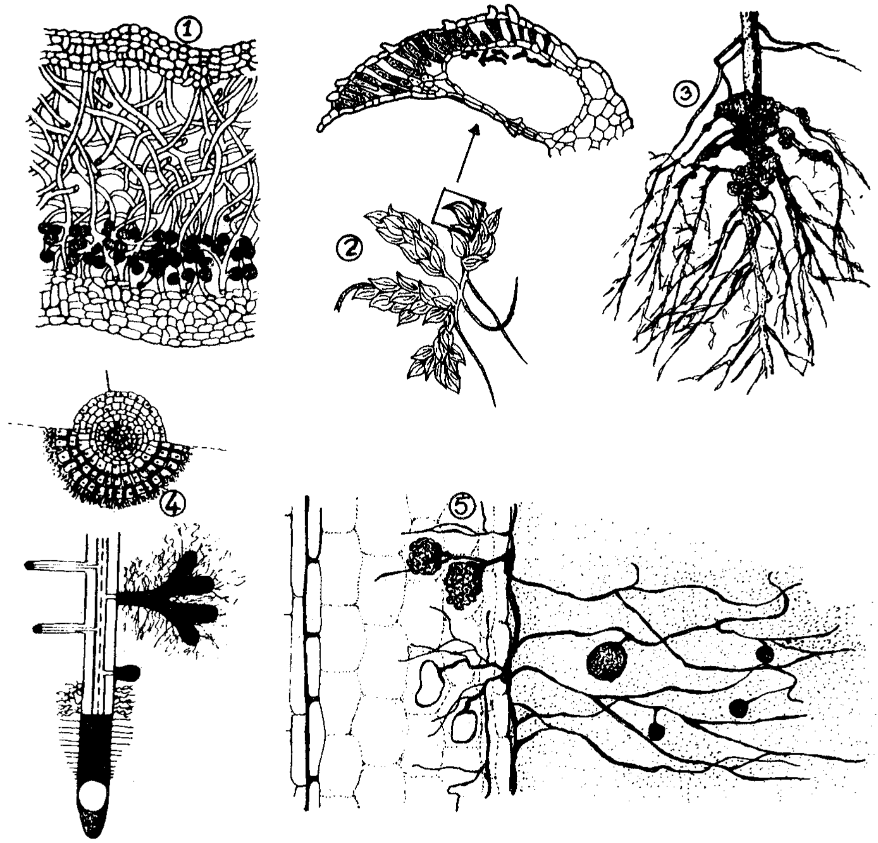


Figure 4. 16 *Examples of plant symbiosis.* 1. *Microscopic section through a lichen, showing fungus threads forming a leaf-like structure and unicellular green* Algae *active in photosynthesis.* 2. *Aquatic fern* (Azolla, *compare figure* 2.6) *with a microscopic section of its leaf showing blue* Algae (Anabaena) *living in an air chamber; the algae can fix nitrogen gass from the air, using photosynthetic products of the fern.* 3. *Root nodules containing nitrogen fixing bacteria* (Rhizobium), *on a bean root system.* 4. *Mycorrhiza on a tree root (e.g.* Podocarpus), *a sheath of white fungus threads surrounds the root and acts as an extensive system of root hairs.* 5. *Microscopic section through a plant root showing 'vesicular-arbuscular mycorrhiza': fungus threads outside the root, producing thick walled spores and various structures inside the root ('vesicles' and 'arbuscles') in which exchange of sugars and nutrients may take place. (after various sources).*

favourable conditions. The algal part provides for photosynthesis and the fungus part provides for surface structure and mineral and water uptake.

Associations between bacteria or fungi and higher plants can be just as close: leguminous plants (e.g. beans, groundnuts, *Acacias,* several fodder plants) often have root nodules with nitrogen-fixing bacteria.

Many other plants have looser associations with nitrogen-fixing bacteria in their root environment. Sugars are exchanged for nitrogen (as ammonium or nitrate).

A small aquatic fern, *Azolla,* lives in symbiosis with nitrogen-fixing blue-green algae. *Azolla* occurs in the Sudd (along with Bladderwort which obtains its nitrogen from catching insects) in an environment where nitrogen availability may be the limiting factor.

There are various types of plant-fungus associations called **mycorrhiza**: the fungus lives either in the root tissues or closely surrounds it and sends fungal threads out into the soil (fig. 4.16).

The main advantage for the plant lies in the better phosphorus uptake of the fungus. This mycorrhiza is especially important for the plant in tropical soils poor in phosphorus. Several trees used in forestry, such as *Pinus* and *Podocarpus* cannot be succesfully planted unless their mycorrhizal fungus partner is present in the soil.

An almost complete interdependence between two organisms can be found in **pollination** relations between animals and plants. The plants provide nectar (energy) for the insects, birds or bats which visit the flowers and in the meantime transfer pollen from flower to flower. The association is usually very close, in that both flower and pollinator develop special structures to select particular partners. There are various types of 'insect-flowers' (e.g. flowers wide open for bees, or flowers with narrow tubes for butterflies and moths), 'birdflowers' (often rather wide tubes and often red, a color seen by birds but not by insects) and 'bat-flowers' (flowering at night, very exposed flowers, usually with a 'bad smell'). See fig. 4.17 for examples.

Savanna-plants are often wind-pollinated, especially the grasses. Wind pollination can function only for very exposed flowers in a windy environment, with few species which are all very abundant. In woodland or forest the number of plant species is much larger and individuals of the same species are wider apart, so there is a need for more specific pollination mechanisms. There are also more insects, birds and bats available. We can say that there are many flowers because there are so many different pollinators available, but also, that there are so many insects, birds or bats because there are so many plants providing seperate niches. So in symbiosis we get a **co-evolution** of die two species, just as in the 'evolutionary game of chess' of predation.

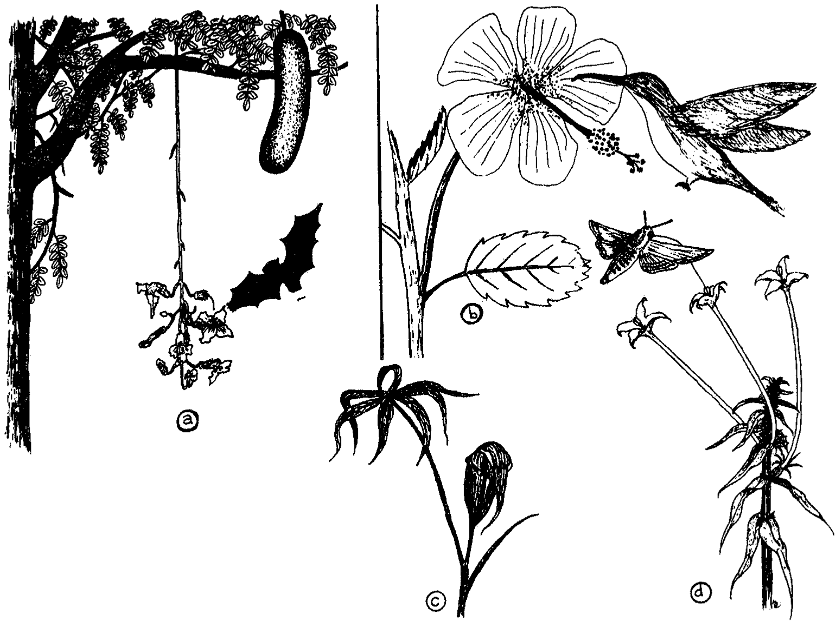


Figure 4. 17 *Symbiosis between plants and animals in pollination. a. bat-pollinated Sausage tree* (Kigelia, *Abu Shutor, A.; Ruwal, D.; Kubuli, B.); b. sunbird-pollinated* Hibiscus, *with anthers protecting the stamen; c.* Arisaema *(occuring in forests) temporarily trapping flies for pollination* in *special type of inflorescence; d.* Oldenlandia grandiflora *with white flowers flowering at night, with long and narrow coronatube for pollination by long-tongued hawk-moths. (or.).*

For dispersal of their seeds many plants are again dependent on animals, which they provide with food to attract them. Often the seeds in fleshy fruits have a hard cover to protect them from the enzymes in the digestive system of the animals. For some seeds passage through animal guts is necessary to break the dormancy.

Animal-animal mutualistic associations are usually a bit looser than the examples we considered so far. An example is the cattle egret associated with cattle or Wild herbivores. The egrets benefit from the cattle by eating the insects disturbed by the cows or wild herbivores. The letter will benefit from the warning the egrets give when a predator approaches. (figure 4.18). Other birds eat ticks and other parasites from the skin of the herbivores, the mutual benefit of which is clear (Oxpeckers, fig. 4.18). An interesting

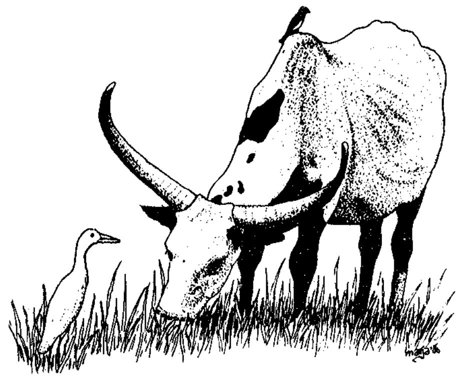
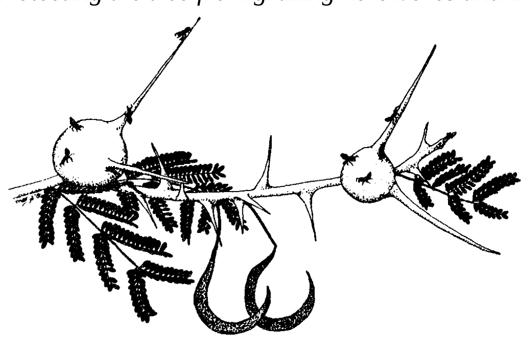


Figure 4.18 *Symbiosis of birds and large herbivores:*
Cattle egret consuming insects disturbed by the herbivore and oxpecker consuming ticks from the herbivore's skin,' the herbivore benefits from warning against predators and removal of parasites respectively (or.).

association can be found in woodland and forest with the 'honey-guides', birds, which attract the attention of man bringing him to a wild bees nest. If man takes out the honey, the bird can feed on the left-overs of wax and honey without being attacked by bees.
To finish this section one more plant-animal association wiI1 be cited: *Acacia-trees* and ants. Several types of *Acacia-trees (A. fistula* (Talh beid, A.) and *A. drepanolobium* have 'whistling thorns', thorns with a very swollen base with openings which produce sound in the wind. In these gall-like structures ants can live (fig. 4.19). The plant benefits from the ants mainly as a defence against grazers, both small insects and large herbivores. That the defence is effective can be concluded from the observation that whistling thorns are especially abundant in over-grazed areas.

Figure 4.19 *Symbiosis of 'whistling thorn'* Acacia drepanolobium *and ants living in inflated spines protecting the tree from grazing herbivores and insects, (or.).*



4.6 Distribution and abundance

To end this chapter, we shall try to see how all these relations influence the **distribution and abundance** of organisms. By distribution of a species we mean the area or range of conditions in which this species occurs; under abundance we discuss the number in which the species occurs within that range, that is, the population size.

To explain distribution, we can start with all existing species in the world and ask ourselves why in any area we find only a small selection of them. As figure 4.20 shows, there are a number off actors responsible for this. First of all not all species in the world have access to our area. Geographical barriers prevent many species from reaching areas where they might be able to live. This of course is related to the dispersal method of the organism in question. For birds; or plants with wind-born seeds this problem is on a different scale than say for eelworms in the soil. The geographical factor is best appreciated when we look at the effect of introducing species into other parts of the world. Quite a few of them will survive (e.g. many successful tropical crops such as maize and cassave are not native to Africa), and sometimes they will do so well that they cause great problems, such as the waterhyacinth brought here from South America. Geographical isolation is best seen on islands, but mountains or large rivers can act as barriers as well and isolated patches of a certain habitat in between other habitats (oases in a desert, isolated crop fields), can be regarded as islands too. In case of pests and diseases precautions such as quarantine are necessary to prevent them from spreading into new areas.

The second and third step in fig. 4.20 have been discussed before. Only those species which are adapted to the climatic conditions and for which all basic needs are fulfilled can survive. But a large number of them will not be present because, of competition. This is shown by the fact that, in a garden, many plants, which would not survive otherwise, can be grown when weeding removes the competitors.

> The competition factor can also be seen by the effect of invading new species on the species already present. Quite often these are excluded or at least reduced to a smaller range of microhabitats. Water-lettuce *(Pistia)* used to be very common in all open water, but after the water-hyacinth (a plant with similar growth form) established itself in the White Nile and Sudd, water- lettuce became restricted to small ponds and streams, and the Nile upstream of the Fulla Rapids, where the waterhyacinth has not (yet) reached. In the Bahr el Ghazal waterhyacinths do not grow well, probably because of the poorer nutrient supply (or excess of Cu?); and water-lettuce is still present.

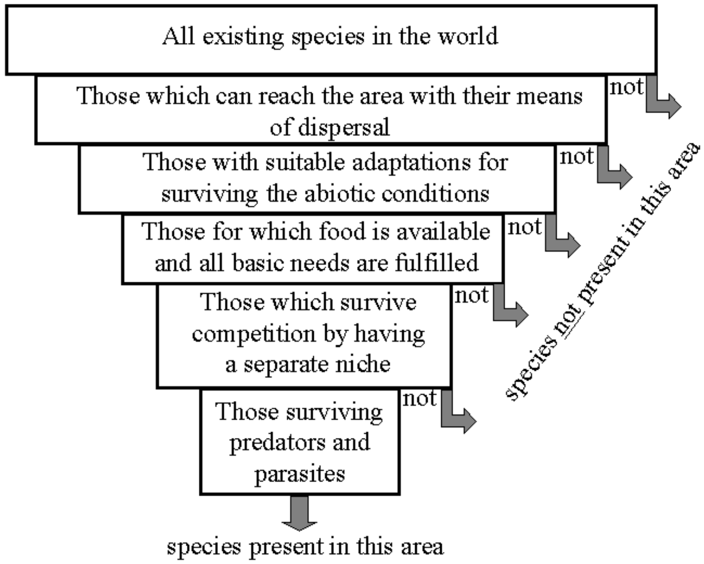
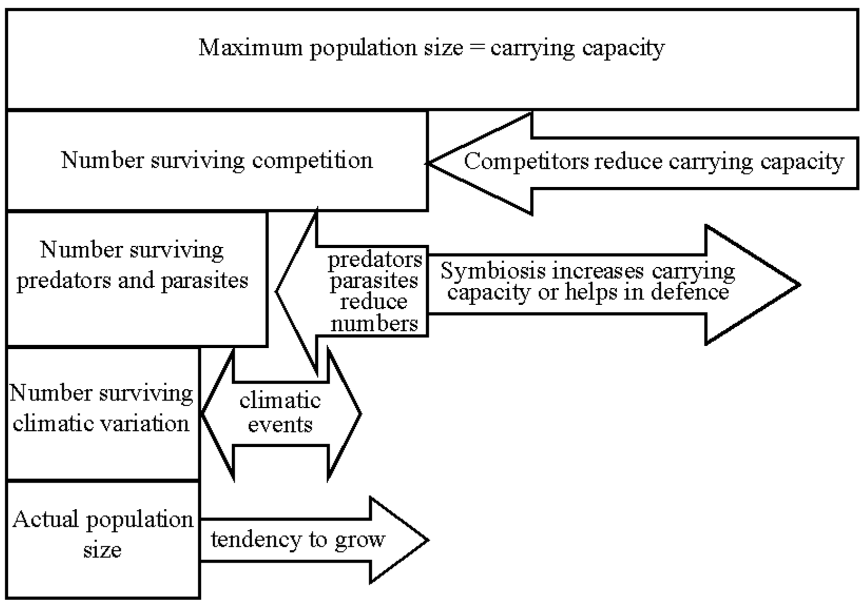


Figure 4.20 Factors explaining distribution of organisms (or.).

Figure 4.21 Factor explaining abundance of organism (or.).



Even among those species which can find a niche without serious competitors, some will not survive in the area because of predators and parasites. For example, tse-tse-fly areas cannot be used by cattle and the presence of eelworms *(Nematodes)* can make land unsuitable for tomatoes. So, in five steps we have 'sieved' the local flora and fauna from that of the whole world.

The last two factors also influence the abundance of the species present. Roughly speaking the amount of food available determines the carrying capacity, the maximum number in which an organism can occur. As fig. 4.21 shows, the actual population size will often be smaller than this **carrying capacity**.

The numbers will never be constant because the carrying capacity itself depends on other organisms which fluctuate themselves. The climate is also never constant and this may affect both the carrying capacity and the organism itself, especially in case of climatic 'disasters' like droughts or floods. All these factors tend to reduce the numbers so reproduction is necessary to maintain the balance.

If the conditions are faourable every population can grow rapidly at an **exponential growth** rate. If we start with one pair of parents producing 10 young, in the next generation we already have 5 pairs of parents producing 50 young, then 25 pairs of parents producing 250 young etc.

generation	number
1	2
2	10
3	50
4	250
5	1250
6	6250

In many species one pair of parents produces much more than 10 young, so their populations can grow even faster. Of course, usually most of these young (or seeds for plants) will not survive. A population can only be constant if each pair of parents produces just two new individuals which reach maturity (on average); (Compare seetion 3.5).

Territorial behaviour tends to regulate the numbers, keeping them at an equilibrium value. If the population size is large, not all individuals will reproduce, but there will be a 'reservoir' of individuals ready to take their chance if an animal with a territory is killed. In such a way the number of breeding individuals can be kept nearly constant. An interesting example can be seen in birds: most birds with territorial behaviour occur in fairly constant numbers, not easily becoming a pest. The 'red bishop' weaver birds for example, only occur in fairly small numbers. The related 'Sudan dioch' weaver-bird *(Quelea)* is not territorial and breeds in large colonies.

The numbers of Quelea can 'explode' under favourable conditions, with the large flocks being a real pest in the Dura.

> In section 3.3 we mentioned the sudden migrations by desert locusts when their populations 'erupted'. Most of these locusts come from areas with alternating wet and dry periods and the eruptions generally occur in dry years when the abundant food supply gradually dimishes. Research has shown that part of the increase in locust numbers may be attributed to the absence in dry years of certain predators such as adult dragonflies, the larvae of which live in water. This example may show how complex relations can be: every organism is not only dependent on its environment and on a limited number of other organisms, but through these other organisms on all the factors on which they depend, etcetera. It is now time to consider the ecosystem as a whole.

4.7 Suggested practicals

1. Make a study of plant-animal relation in pollination. Cam you identify adaptations of both the plant and the animal to serve their needs?
2. Compare fig. 4.15 with the birds around where you live. Can you give further examples of niche differentiation in birds? How do birds make use of their bill?
3. Describe the territorial behaviour of rainbow-lizards (*Agama*). Dominant males are brightly coloured, young males and females are brown. How large is a territory? What happens if two lizards meet each other? Do they react to other types of lizards as well?
4. Study niche differentiation between three types of lizard, common in every school or house-surroundings: Rainbow lizard, Skink and Gecko (see fig.22). Try to define their niche: where exactly do they live, on which prey do they feed, at which time of the day are they active, do they show any adaptations to their mode of live?

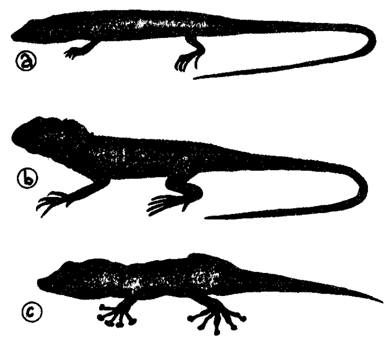


*Figure 4.22 Lizards: a) lizard (*Gerrhosaurus, Zichlia, *A.), b) rainbow lizard (*Agama, *Dab abfenila, A.), c) gecko (*Tarentola, *Dab amien, A.). (or.)*

5. Work out the following example of exponential growth: One water-hyacinth plant occupies a space of 10 x 10 cm^2 and it reproduces vegetatively to form a new plant every 2 weeks. If we start from 1 plant, how many will we have after 2,4,6,8 and 10 weeks? How long would it take them to cover a lake of 1 km2 surface area? (hint: first determine how many plants you need, then how often you have to double numbers to reach this.)
6. Describe all the relations between two types of organisms you can find in your own environment: feeding-relations, symbiosis, competition, parasitism. Make a list of them (necessary for chapter 5) and discuss the adaptations of the organisms appropriate for these relations.
7. In figure 4.20 the means of dispersal where mentioned as a possible factor explaining the distribution of plants and animals. Different plants have different means of dispersal: floating fruits or seeds of the Sausage- tree, Fanpalm and Dom-palm coincide with their distribution along water courses; sticky seeds are effective for dispersal by birds for the tree parasite *Loranthus*. Can you give further examples?

***Table** 5.1 List of observations on feeding relations in a high rainfall savanna habitat*

organism	mouthparts	feeding on
grasshopper	chewing mouth	grass-leaves
hornbill	long broad bill	tree-fruits
butterfly	long 'tongue'	tree-flowers
stick insect	chewing mouth	grass-leaves
beetle	biting mouth	tree-flowers
caterpillar	chewing mouth	tree-leaves
cow	chewing teeth	grass-leaves
weaverbird	strong, short bill	grass-seeds
ants	biting mouth	seeds, caterpillar
mosquito	sticking mouth	Γ plant juices
		E cattle blood
dragonfly	biting mouth	small insects
spider	biting mouth	small insects
bee-eater	narrow, sharp bill	insects
chameleon	long tongue	insects
lizard	long tongue	insects
shrike	strong, curved bill	grasshoppers, lizards
snake	poison teeth	lizards, etc
mongoose	sharp teeth	rats, frogs, snakes
kite	sharp bill	lizards, small birds

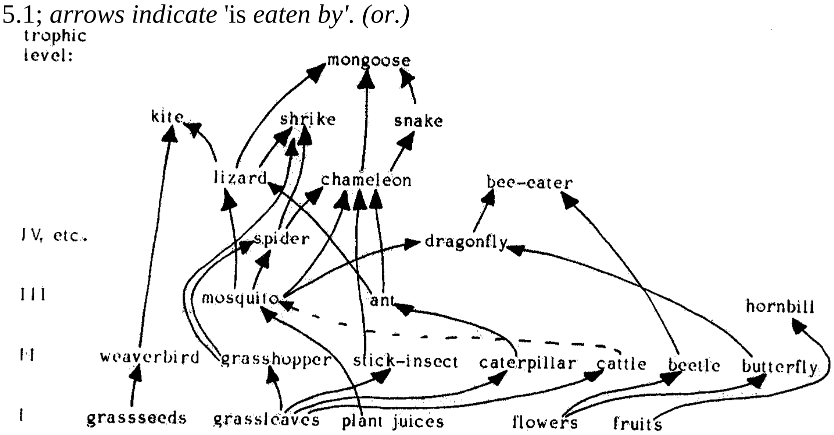
5. The ecosystem

5.1 The foodweb

We can now try to build a picture of the ecosystem as a whole, after looking at all relations seperately. If you have done exercise 4.6 you willpr9bably have ended with a long list of observed relations, many of which concern feeding relations possibly something like table 5.1. From these feeding relations we can now construct **foodchains**: grass is eaten by a grasshopper, grasshoppers are eaten by a shrike, so we get grass ➜ grasshopper ➜ shrike, so we get grass ➜ grasshopper ➜ shrike, which is an example of a foodchain. A longer example would be: flowers ➜ butterfly ➜ dragonfly ➜ chameleon ➜ snake ➜ mongoose. Foodchains always start from plantmaterial, so the second step can be called plant-feedeer (or **herbivore**). The next step can be described as (plant-feeder)-feeder to show that it is ultimately dependent on plants for its food (or: **carnivore** of first order) etc. The various steps of the foodchain are called **trophic**-levels. The first step, the plants, are the producers, while the animals are the consumers. The consumers can be divided in herbivores, carnivores of first order, carnivores of second order, etc.

Of course most organisms feed on more than one type of food, so the foodchains become branched. All food-chains together of the same habitat have all kinds of connections, so they form a **foodweb**, as shown in fig. 5.1 for the data of table 5.1.

Figure 5.1 *Example of a foodweb, constructed from the observations listed in table* 5.1; *arrows indicate* 'is *eaten by'. (or.)*

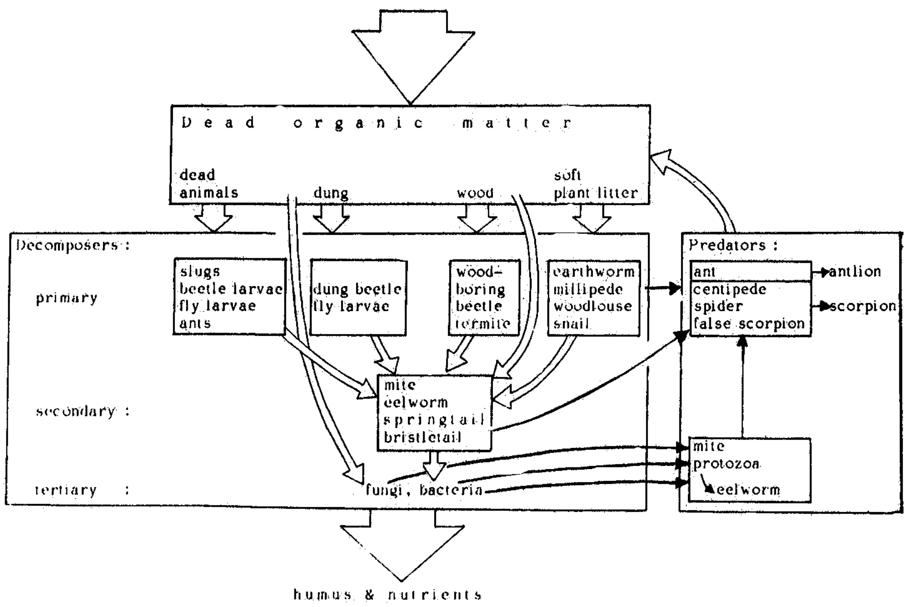


The foodweb shows how every organism depends, in some form or other on all the other organisms in the foodweb. For example, what would happen if the spiders were suddenly removed? The next step in the foodchain would suffer (losing a source of food); but the previous step would benefit (the mosquitoes in our case) by losing a predator; because of this the dragon-fly on the same level as the spider would benefit (losing a competitor: but the cattle would suffer (losing a predator of a predator) as the number of mosquitoes will no longer be controlled by spiders.

5.2 Decomposition

When animal feed on plants or on other animal, they have to digest the food first before they can absorb the required constituents in their blood. Parts which are not completely digested and constituents which are not required, are excreted as waste or faeces. Faeces is part of the 'dead organic matter' produced by the organisms of the foodweb, together with dead plat parts and animal carcases. This dead organic matter forms the food for the scavengers and saprobes (see sectiob 4.2.D.). Breakdown of dead organic matter by this group is called '**decomposition**'; the saprobes are

Figure 5.2 The process of decomposition; open arrows indicate flow of matter closed arrow mean 'is eaten by'. (or.)



also known as 'decomposers'. Along with the terms '**producers**' for plants and **'consumers'** for herbivores and carnivores, the decomposers are called '**reducers**'.

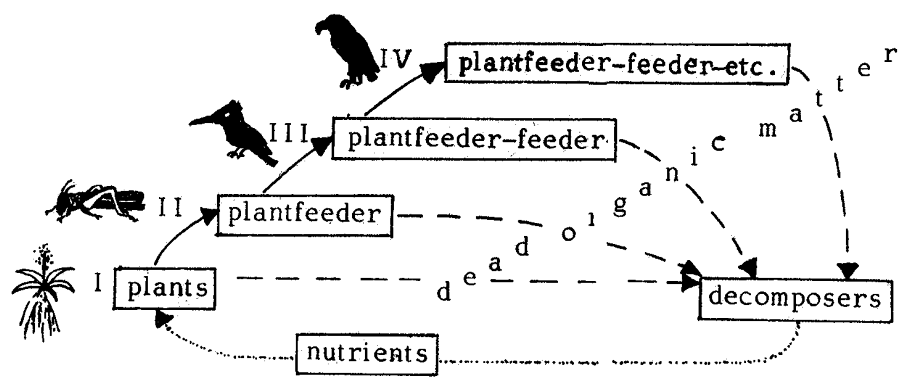
Figure 5.2 shows the 'decomposition foodweb'. Many different organ take part in decomposition; fungi and bacteria are usually responsible the final step, by which humus and nutrients are formed. Many of saprobes are eaten by predators in the soil.

5.3 The nutrient cycle

For all organisms in fig. 5.1 the food is specified, except for the plants.' plants are not directly dependent on other organisms for their food as 11 as sunlight, carbondioxide, mineral nutrients, water and mineral nutrients, are available. However, we have to consider the source of the nutrients needed by the plants. Some nutrients can be stored in the soil, depending soil type, but they will be rapidly depleted if no nutrients are ad, continuously. In natural conditions this happens by the action of t decomposers or reducers.

Every foodchain is a 'nutrient-chain' as well: a plant takes its nutrients from the soil; if a plantfeeder eats the plant it also takes in the nutrients of the plant; if this herbivore is eaten, the nutrients pass on to the carnivore, etc. The process of decomposition brings all nutrients back into the origin state in the soil, available for uptake by plants. Decomposition thus connects the two sides of the foodchain and makes it a **'nutrient-cycle'.** Fig. 5.3 shows a nutrient cycle in schematic form. The most essential parts of the nutrient cycle are the plants and the decomposers. The other grout: are not essential for the cycle to continue.

Figure5.3 Schematic representation of a nutrient cycle. (or.).



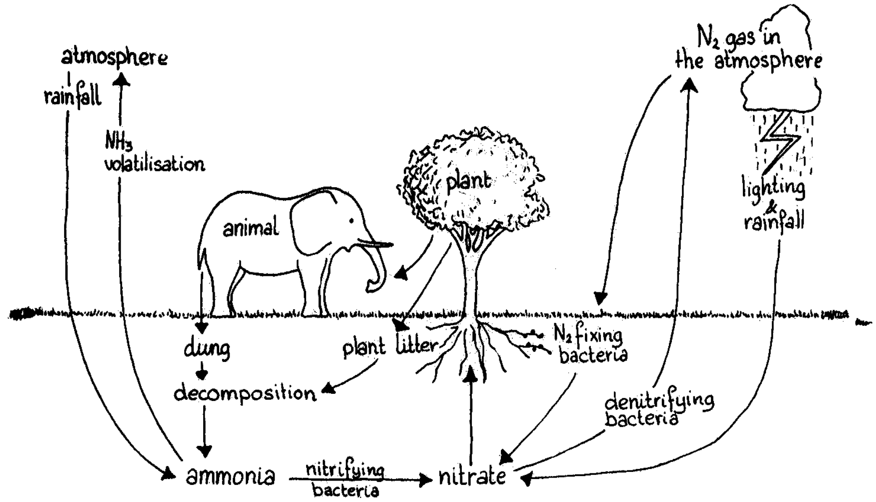
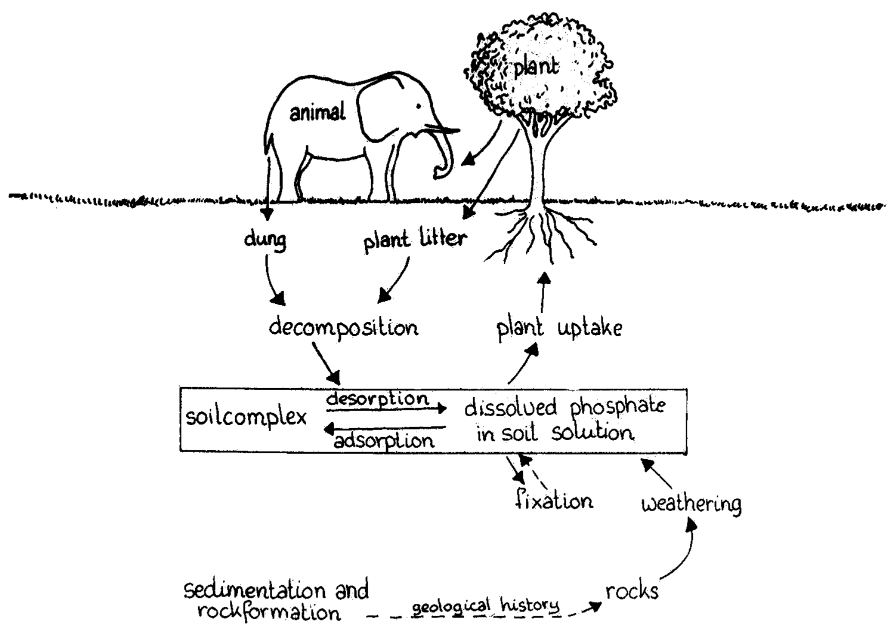


Figure 5.4 The nitrogen cycle (various sources).

Figure 5.6 The phosphorus cycle (various sources).



The nutrient cycle for a particular habitat (compare the water cycle of fig. 1.2), is part of a larger system. Nutrients can be lost from the system to the air or leached to the subsoil and they can be added by weathering of rocks precipitate from the atmosphere with rainfall, be added to the soil by flooding etc. In fig. 5.4 and 5.5 this larger scale nutrient cycle is represented for Nitrogen and for Phosphorus. Nitrogen is a special case, because it can easily be lost to the air by volatilisation and be brought back into the soil by nitrogen-fixing bacteria or by Blue-Green algae or by the effects of lightning Phosphorus is more typical for the other nutrients, and is mainly stored in rock-deposits. The carboncycle resembles the nitrogencycle in so far that exchange occurs between the atmosphere, living organisms and the soil.

The nutrient cycle has a different character in the various ecological zones.
Nutrient uptake by plants is restricted to the growing season.
Decomposition generally requires moist, but not wet, conditions.

In the (semi)desert and savanna zone decomposition is restricted to the rainy season. At the start of the rains decomposition of leaves shed sine the star of the dry season results in a flush of nutrients into the soil. Fire during the dry season can destroy a large part of the dead organic matter: the nitrogen is lost into the air, phosphory and potassium will mainly remain in the ash, but can easily be removed by wind.

In the flood region decomposition in water can be hindered by a shortage of oxygen. After the floods retreat usually much dead organic matter (including dead fish and waterplants) is available for rapid decomposition. The resulting nutrients, together with fresh silt allow a rapid (re)growth of the toic vegetation. Burning the dead grass vegetation will release the nutrients more quickly, however considerable losses can occur, as in the savanna.

In the rain forest decomposition continues all year round and, generally, little litter is present. The vegetation has a dense root mass in the upper layers, trapping almost all nutrients released before they can leach to the under-ground. In the rainforest the largest part of nutrients is present inside the trees, rather than in the soil.

5.4 Energyflow

The nutrients tend to circulate in the ecosystem, but energy does not. The main source of energy is sunlight, which (1) provides plants with the opportunity to photosynthesize their food, (2) evaporates water and thus keeps the water cycle going, and (3) warms up the surface of the earth. By photosynthesis plants 'trap' energy to form organic matter. (Compare figure 3.1). Together with the organic matter, energy enters the foodchain when animals eat plants. During every step of the foodchain only part of the energy will be stored in the tissues of the next organism.

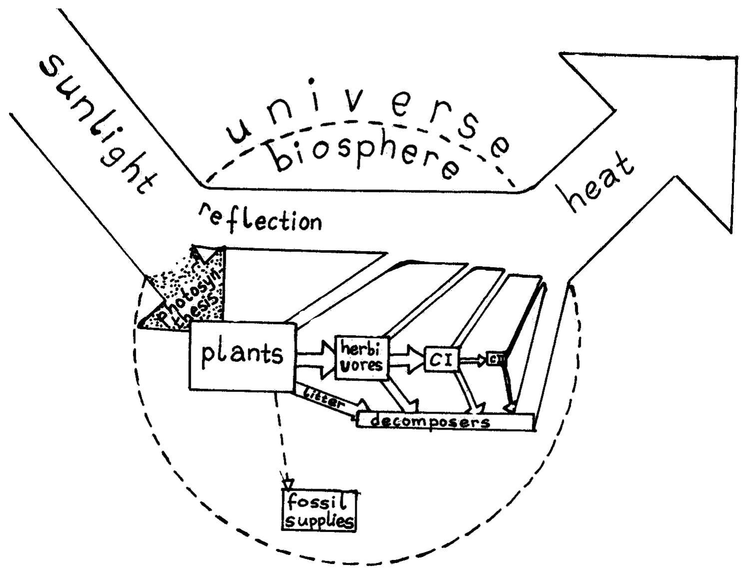


Figure 5.6 *Schematic representation of energy flow (various sources).*

The largest part the energy is excreted as non-digestable material, used for body maintainance, temperature balance or for the many activities necessary to obtain food, water and shelter. All this energy will eventually be lost as heat, the lowest-grade form of energy. No part of the energy consumed by animals will come back to plants; contrary to the nutrient cycle, we should speak of an **energy-flow.** Decomposers use the energy contained in dead organic matter and release nutrients in the original form taken up by plants. Figure 5.6 gives a schematic representation of the energy-flow, starting with incoming sunlight and finally leaving the atmosphere as heat, after various steps of the foodchain.
Figure 5.7 shows in an even more schematic form the relation between energy-flow and nutrient-cycle. We can say that the energy-flow keeps the wheel of the nutrient cycle turning. Plants combine energy and sunlight into their tissues which form the basis of the foodchain. During the sub- sequent steps the nutrients return to the soil while the energy is lost as heat (compare the water cycle). .

The energy-flow can be quantified for every ecosystem and of course the details will be different for every ecological zone. A well-developed plant cover can, of course, use a larger part of the energy of the sunlight than sparse vegetation. But even for a well-developed vegetation rarely more

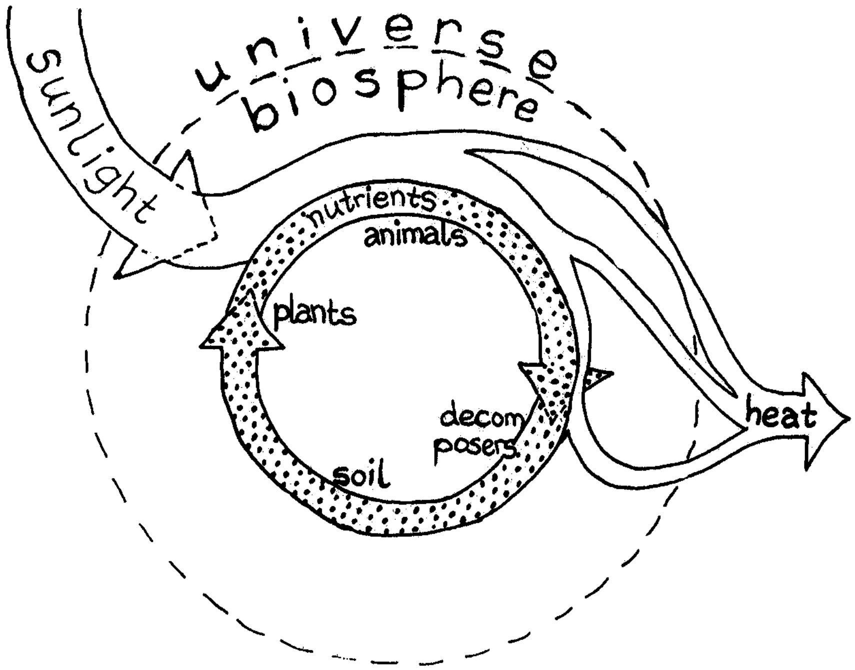


Figure 5. 7 *Relationship between energy flow and nutrient cycle (or.)*

than 2% of the sunlight is stored in plant tissues. If water is in short supply this efficiency becomes lower (the relation between photosynthesis and transpiration was explained in section 3.2). We can speak of the **'primary production'** of an ecosystem as the amount of plant matter produced; this is usually expressed as dry weight produced per surface area per year (or day). Typical values of primary production are:

	$g/(m^2$. year)	kg/(ha. year)
desert	3	30
semi-desert	70	700
savanna	700	7 000
swamp	2 000	20 000
rainforest	2 000	20 000

Of this primary productivity only a small part is used for **'secondary production'** by herbivores. Part of this is used for 'tertiary production' by carnivores. About 90% of the energy in the food is passed out in faeces and urine or is used for respiration to maintain its body and activity, leaving only 10% for growth of the organism itself and reproduction.

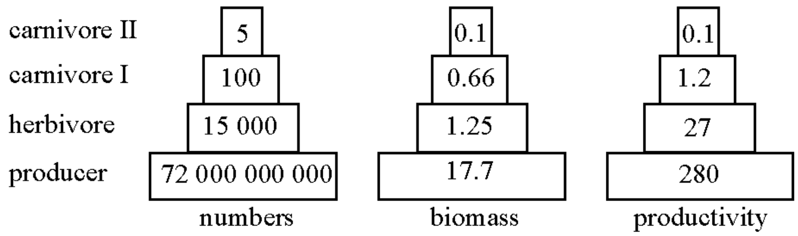


Figure 5.8 *Ecological pyramids for an experimental pond:*
a) 'pyramid of numbers (no. of individuals per m^2), b) pyramid of biomass (g dry weight per m^2), c) *pyramid of productivity (mg* dry *weight per m^2 per day). (After Whittaker*, 1975).

We can say that the efficiency of secondary or tertiary production is roughly 10%. Higher efficiencies than 10% occur in aquatic animals and in carnivores; for herbivores in land-ecosystems the efficiency is usually less than 10%. Summarizing these data, we see that of the energy of the sunlight ca. 2% is available for plant growth, 0.2% is available for plant growth, 0.2% for plant-feeder's growth and 0.02% for (plant-feeder)-feeder's growth.

The energy-flow scheme indicates that in each subsequent step of the foodchain less food is available. A diagram of the amount of plants, herbivores and carnivores present in an ecosystem, will therefore have the shape of a pyramid. Plants form the basis and carnivores the top. Fig. 5.8 shows an example.

The ecological pyramid of a savanna will show much grass, a small biomass of antelopes and an even smaller amount of lion biomass. This can be understood from the amount of energy available to each group.

Pyramids can be constructed in various ways. The 'pyramid of numbers' can be changed into a 'pyramid of biomass' by taking into account the size of the organisms. The amount of **biomass** present at any moment gives some indication of the production rate but we have to realise that there are large differences in accumulation rate. Annual plants hardly store energy in permanent tissues, while trees spend most of their energy on making wood. Although the primary production of a grassland and a forest may be the same, the amount of biomass present will be different. The amount of biomass present divided by the productivity in 1 year is expressed in the 'biomass accumulation rate'. Typical values are:

desert	2 à 10
grassland	1 à 3
shrub	3 à 12
woodland	10 à 30
mature forest	20 à 50

5.5 Microhabitats and home range

In chapter 2 we discussed the broad ecological zones, and we saw that each zone contains several micro-habitats and a specific 'community' of plants and animals. From all the relations discussed in the following chapters we can see that the community of organisms forming the biotic part of an ecosystem cannot be a random collection of species. In a botanical garden or zoo random col1ection of plants and animals can be kept, provided that each organisms well cared for and that. competition and predation is prevented. by weeding and by fences; in nature only certain balanced combinations of species can occur together, each influencing all the other species either positively or negatively. Maybe, if you take a second look at figure 1.1 you can now give examples of all the types of relations indicated. Three points remain to be discussed: the relations between the microhabitats within one ecological zone, the way in which ecosystems can change, and the (pre)historic changes in the Sudanese landscape.

As discussed in section 2.1 in the (semi) desert micro-habitats are mainly determined by run off *of* rain water to lower places such as wadi's, to which vegetation is largely restricted. Almost all animal life is restricted to the vegetated zones as well. Animals which do not aestivate have to migrate over large distances to find places where rain has recently fallen.

In the dry savanna zones, the variation in micro-habitats is determined largely by soil type in relation to the water balance. Figure 5.8 shows some micro-habitats of the Sudan savanna zone. Run off-standing water - rain water infiltration - ground water supplies determine which trees will grow. (Compare figure 1.12) Most animals depend on the availability of a number of these micro-habitats, within a relatively short distance.

> An example can be found in Dinder National Park, near the Ethiopian border in the Sudan savanna zone. The park largely consists of an old floodplain with *Acacia seyal* and *Balanites aegyptiaca* as dominant trees (micro habitat B & C in figure 5.8); Seasonal ponds, called **mayaas**, are present (E) and rich! forest types along the rivers (K, L). When the rivers dry up in the dry season, pools remain in the river bed. Most herbivores spend their time alternating between the *A. seyal* - *Balanites* woodland and the mayaas, for resting in the shade, under cover and for feeding and drinking respectively. This pattern is followed by Reedbuck, Tiang, Waterbuck, Roan and Warthog. In the dry season they cross the riverine forest to the ponds in the river bed. The buffalo spend most of their time in the mayaas; the Oribi needs little water and stays in the dry woodland most of the time. Giraffes stay in the dry woodland, drinking in the river after sunset. The Bushbuck mainly stay inside the

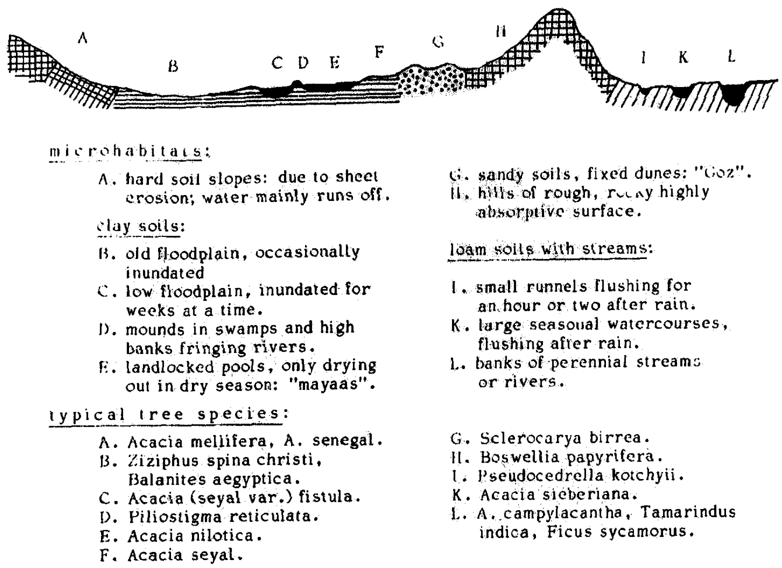


Figure 5.9 *Microhabitats* in *a Sudan savanna according to Smith (1949); for each site typical tree species are mentioned.*

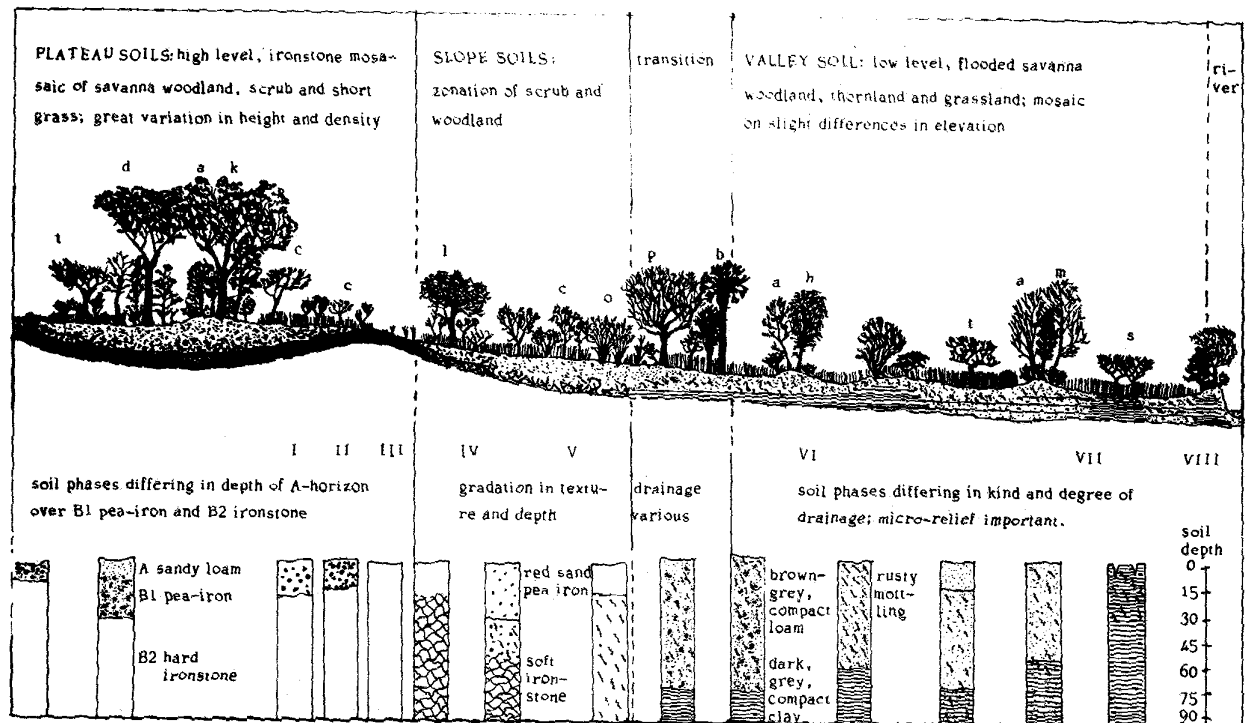
riverine forest, as do the Kudu's which occur in small numbers only. As the mayaas are concentrated in me central, northern part of the park. most of the mammals and the birds as well are found in 15% of the park area only. Only the combination of micro-habitats makes the area suitable for these species.

In the flood region small differences in elevation can result in important differences in duration of die floods and hence in chances for the trees to survive. The importance of termite mounds in this respect has been mentioned, but the heavy clay soils, which crack when dry and swell when wetted, have a tendency to form small ridges by themselves as well.

In the Guinea savanna zone micro-habitats are determined by soil type and resulting water balance, but also by the risks of fire. Spreading of trees from termite mounds, creating mutual protection by shading out the grasses, results in a 'honey-comb' like pattern of the vegetation. Figure 5.9 shows the soil types and vegetation as they occur on the transition between Guinea savanna and flood region.

On the left we see the high grounds with ironstone at the surface (III) or

Figure 5.10 Microhabitats in a transition from Ironstone plateau to floodplain, according to Morison et al., 1948).

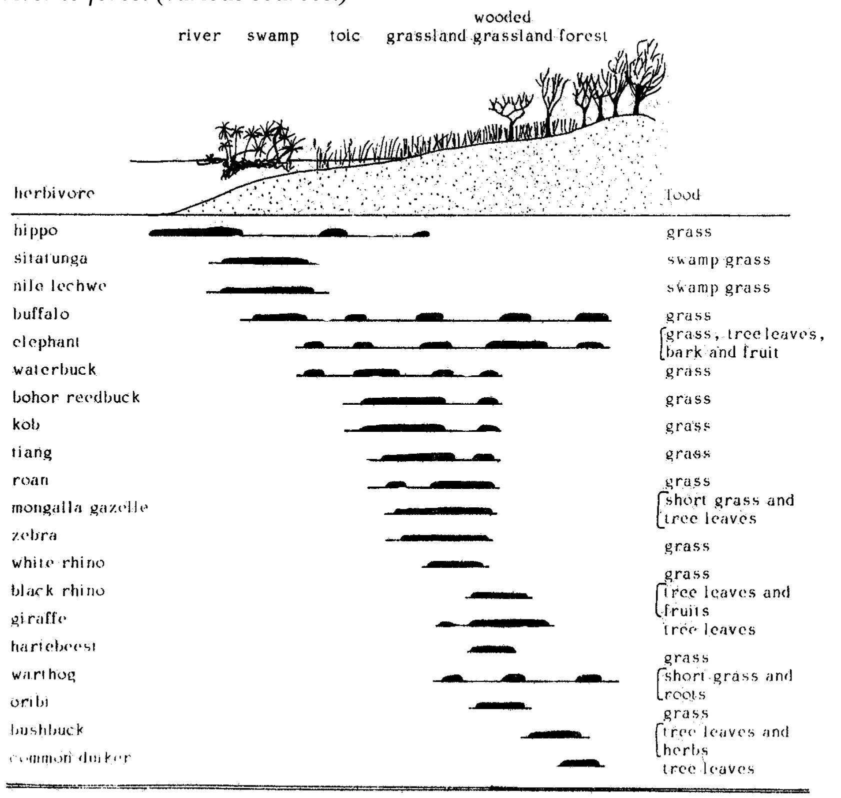


a = Anogeissus (*Seilaj, A.; Ameth, D.*). *b* = Borassus *palm* (*Doleb, A.; Agep, D.*), *c* = Combretum, *various species* (*Subagh*), *d* = Danielia oliveri (*Bu, A.; Beling, D.; Bovotoda, Z.*), *h* = Balanites (*Heglig, A.; Thau, D.*), *k* = Khaya (*Mahogany, E.; Homra, A.; Tit, D.; Kir, B.; Bogu, Z.*). *l* = Butyrospermum (*Shea butternut, E.; Lulu, A.*), *m* = Diospyros mespiliformis (*Abu sebela, A.; Cum, D.*), *o* = Oxythenanthera abyssinica (*bamboo, E.; Gauna, A.*), *p* = Parkia oliveri (*Akon, D.; Abongba, Z.*), *s* = Acacia seyal (*Talh, A.; Ret, Tep, D.*), *t* = Terminalia, *various species* (*Darot, A.; Piok, D.; Lokpa, M.*)

covered by a layer of soil which can be thin (II) or comparatively thick (I). Where the ironstone is exposed it forms a hard pan with hardly any vegetation. The slopes collect soil material from higher grounds and lose it to lower areas. This soil consists of a layer of sand covering a soft type of ironstone (IV). Lower down the slopes, at M, it overlies clay deposited by the river. The valley-bottom receives soil material from the higher grounds as well as from the rivers. Clay loams (VI) alternate with clay soils (VII). Trees here are restricted to termite mounds because of the poor drainage of the clay resulting in ponding and flooding. The river-bank (VIII) usually is a bit higher than the adjacent grounds and allows more abundant tree growth.

Only a few of the mammals in these regions are confined to only one micro habitat. Figure 5.11 shows the habitats preferred by some of the larger

Figure 5.11 *Habitat preference of large herbivores in a transition from permanent river to forest (various sources.)*



herbivores. Many of them shift from wetter to drier habitats, according to the seasons. Some migrate over large distances.

Part of the elephants which can be seen at Nimule National Park in the dry season, migrate to the area North of Torit in the rainy season. Enormous herds of white-eared kob migrate to and from the Boma plateau in South Eastern Sudan. Tiang migrate over large distances on the edge of the flood region (Figure 6.5).

In the rain forest micro-habitats are formed in a different way the complex vertical structure of various tree layers, shrubs and undergrowth provides different micro-habitats to epiphytic plants as well as to animals. When large trees fall down, they make gaps in the forest. A series of micro-habitats is usually present, from recent gaps to closed forest. Grazing by the large herbivores can keep gaps open at least temporarily.

In all these cases the number of animal species which can find a seperate niche is somehow related to the number of plant species and to the number of micro-habitats. But this relation is not simple. An earthworm stays within an area of 1 m^2 for all its life; an elephant travels in an area of several hundreds of km^2's. Obviously the scale on which micro-habitats should be discussed is different for the two examples given. The term home-range has been introduced to describe the area in which an animal can complete its life-cycle.

A study of the ecology of an animal should include the home-range as a whole, to be meaningfull. The term 'community' at anyone place is complicated by the fact that the home-range of the species can be of a very . different scale.

5.6 Community change

All communities are subject to change. There are day/night changes, seasonal changes and yearly fluctuations in climate. But there usua1ly is some more permanent, irreversible process of change as well: **succession**. The basis for succession is the change in conditions brought about by the organisms present, as mentioned in section 4.1. Succession proceeds from a pioneer stage, through intermediate steps to a mature community or **climax**.

Figure 5.12 shows the initial stages of succession as it can be found on rocks in areas with fairly high rainfall. The bare rock is colonised by lichens which can withstand the huge temperature fluctuations of this exposed site. Their presence will increase weathering of rocks. Lichens grow very slowly and may be overgrown by mosses which germinate on the little amount of soil formed and by lichens. The mosses can store more of the rain-water and form a bit more soil. On top of the mosses grasses and herbs can grow, which have no chance to survive on the bare rock. If the conditions remain favourable, the grasses and herbs will overgrow the mosses and eventually

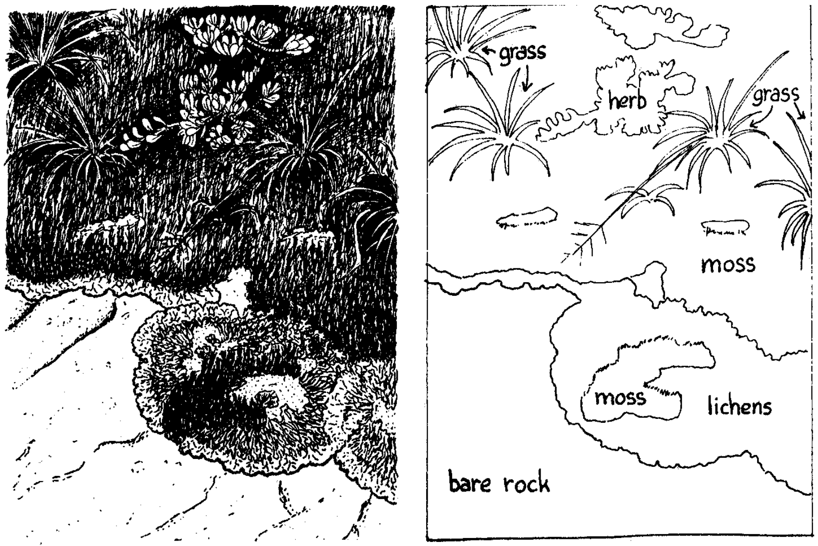


Figure 5 .12 *Example of initial stages of succession on a bare rock, as seen from their zonation (or.).*

shrubs and trees may take 0Va'. Every step in this succession is associated with different animals.

We can study the process of succession starting from an area with bare soil, for example an old farm field. The initial fluctuations of micro climate at the soil level will be high, but some plants with efficient means of dispersal (for example the light, wind blown seeds of *Tridax)* will find the area and start germination. Their survival is initially determined mostly by abiotic factors. They need adaptations to survive drought and high temperatures. As soon as these pioneer-plants grow, they will change the micro-climate. They increase the humidity of the air, provide shade and damp the fluctuation of temperature. Their litter which falls on the soil, will provide chances for decomposers and humus will be formed changing the structure of the soil and possibly increasing the infiltration of rain water. The soil profile will develop under the influence of the vegetation and will in turn influence the survival of plant species. The pioneer-plants usually disappear after a while, because the abiotic conditions may have changed or, more often, because they lose the competition with other plants such as slow but steady growing shrubs and trees. Plants provide food for animals, usually in a rather specific way. So the number of plant species is important for the number of animal species. A high number of animal species in turn, provides plants with possibilities for specialised relations for pollination and seed dispersal.

All in all, the community will become mote complex during succession 'ripening' of the ecosystem, till a certain maximum is reached. This maximum is not necessarily the final stage or climax. Sometimes a few species dominate the climax stage while in intermediate stages a large variation has been present. Table 5.2 summarizes some of the aspects mentioned.

Succession generally leads to a climax stage. The form of the climax however is determined by the main limiting factor. Fire and flooding can both prevent a further development of the vegetation and arrest the succession. If no other factors hinder succession, climate determines the type of climax found. We can see this m the range of climax-vegetations from desert to rain forest in fig. 1.15.

The number of species of plants and animals in an ecosystem can be called **'diversity'**. There is a certain relationship between the diversity of ecosystem and the intensity of fluctuations in the environment. Relative

***Table** 5.2. A comparison of ecological conditions in pioneer and climax stage*

	pioneer	Climax
– main limiting factors for plants	abiotic: water, nutrients, temperature	biotic: grazing, light, nutrients (competition)
– dominant strategy	fast reproduction, short life cycle	survival of competition long life cycle
– plant pollination	wind	insects, birds, bats
– reproduction of plants	many small seeds for good dispersal	few large seeds with many stored reserves
– number of plant and animal species	low	high (sometime decreasing)
– foodweb	simple	complex
– nutrient cycle	most nutrients in the soil	most nutrient in the biomass
– growth rate: standing crop	high	low
– fluctuations of abiotic factors	directly felt	damped by vegetation
– change in species composition	fast	slow

absence of fluctuations or stability is required for diversity to develop. This can be seen on two different time scales: in evolutionary terms and in terms of succession. Evolution of adaptations can only occur for selection pressures which remain present for a long time. In section 4.3 we saw that competition exerts a pressure towards niche-specialisation. But specialisation is only possible in relatively constant conditions. In changing conditions specialists will not survive the extreme conditions and' opportunist' or 'generalist' feeders will be better off. On the time-scale of succession a relative constancy is a prerequisite for the development of a diverse, complex community as well.

In general terms, the diversity of the communities increases as we travel from desert to rainforest, while the environmental fluctuations decrease. The increased stability is partly a result of the existing vegetation, e.g. damping fluctuations of temperature and air-humidity. The internal stability of a community is to a certain extent dependent of the diversity, or complexity of the foodweb etc. If more, potentially regulating factors are available, the populations will vary within a narrower range.

The most extreme examples of fluctuating population sizes occur in environments with large fluctuations. For Sudan the *Quelea-birds* (Sudan dioch) can be mentioned and the desert locust. Eruptions of the desert locust are related to years with exceptionally high rainfall. The desert locust has two forms or phases, a solitary one and a migratory one. If the population density is high, eggs of 'solitary' locusts will hatch 'migratory' locusts which will start swarming. The eruptions of the desert locust start along the Red Sea Coast, an area with winter rains. In years with some extra rain, more plants grow and the grasshoppers produce a second generation. This extra generation will finish off the plants growth in a short time and will start crowding. Their offspring can be of the migratory type and once swarming started every new generation will finish the food available to them faster, causing the swarms to I move to new areas.

The situation with the Red Locust is the reverse; here the population will erupt in dry years, with a low density of predators such as dragonflies dependent on water for reproduction. In both cases instability of the environment, either a high or a low rainfall, can trigger eruptions of the population. In comparing a desert with a rain-forest, and in comparing a pioneer I vegetation with a mature community, we see in both cases simple abiotic; stress factors on one side and complex, biotic limiting factors on the other. The possibilities of niche-specialisation for biotic stress are much higher than for abiotic factors. This is another aspect of why diversity increases in a constant environment.

5.7. Historic changes of the Sudanese landscape

As we have seen, the climate has an overwhelming influence on the vegetation and on the ecosystem. For reasons largely unknown, the climate has changed continuously during geological history. Dry periods alternated with moist or humid periods. In moist periods all boundaries between ecological zones shifted to the north (part of the present desert was covered by a dry savanna etc.); in dry periods they shifted to the south. Sanddunes were formed in dry periods and became stabilised and covered by vegetation in humid times. The large clay plains of Central Sudan were formed in times of high river flow, when presumably a large lake or swamp was present in areas which are now dry savanna. During periods of a low rainfall Lake Victoria did not overflow and the White Nile was a local, seasonal stream. By studying soil profiles (including remains of the vegetation) and the details of landforms much of this history can be reconstructed.

For the present-day ecology of the Sudan such a historical context is useful in many respects, e.g. it helps to explain why isolated mountain areas such as Jebel Marra can contain forests with many of the same species as the forests of Southern Sudan, although now these species cannot disperse over such distances; the history also helps to explain why stabilised sanddunes occur, the sand of which can be blown away if the vegetation is removed by man; in the former riverbed of the White Nile during dry periods salt crusts were formed which can now spoil groundwater for human use or cause problems in irrigation schemes (such as the Western Managil extension of the Gezira Scheme); also the history of the landscape provides us with a background to the history of man in Sudan, to the gradual development of various means of using the environment. On the other hand, in more recent times man has considerably influenced the Sudanese landscape.

The earliest fossil remains which sufficiently resemble present day man to be considered as the same species, *Homo sapiens*, are dated at 40.000 years ago. Presumably early man lived as a hunter, a scavenger and by gathering fruits, seeds, plants, roots, etc. By far the largest part of the human history man lived as such, and probably was not an influential part of the ecosystem. About 7.000 years ago man started to keep animals; cattle, goats, sheep, camels and horses were all derived from wild ancestors. Around the same time agriculture started, by farmers collecting seeds from wild plants and sowing them. Since that time a large variety of agricultural techniques have been developed, adapted to the various ecological zones. The next chapter will discuss these techniques in some detail. Climatic changes have played a role in this history, but much remains unknown.

The end of the Pleistocene period (of the geological time scale), 20.000 to 12.000 years ago, was cool, dry and windy. The boundaries of the vegetation zones were presumably some 450 km to the South of their present position. Lake Victoria had no outflow for most of the time, so the Bahr el Jebel was a local stream. During brief periods of overflow of Lake Victoria, the White Nile became a large and permanent river. In dry periods salt crusts were formed in the former river bed. The earliest remains of human inhabitants in the Sudan have been found at Singa, which was then in a semi-desert zone bordering the Blue Nile. These people probably lived by hunting, scavenging and gathering edible plant products.
The beginning of the present geological era, known as Holocene, 11.000-7.000 years ago, was probably warm and wet in the Sudan. Khartoum probably had the climate which Kosti has nowadays, while Kosti had a climate similar to Malakal today. Vegetation zones probably were 250-400 km to the North of their present position. Grasses colonised and stabilised previously active sand dunes. Small lakes and swamps were common between the dunes. The forests of Jebel Marra were part of a continuous forest in the southern part of the country. Lake Victoria was very high, the White Nile was a continuous stream and the Sudd was formed. The Blue Nile formed a similar swamp in the Gezira-area, in which much of the present surface clay was deposited.
Since then the climate has gradually become drier. The period 6500-4500 years before present were still more humid than at present; vegetation zones probably were 100-250 km North of their present position. The Blue Nile became restricted to its present channel, which it gradually incised into the clay planes. The human population greatly increased in this period. Domestic cattle were introduced into Africa from Asia and people spread into the present deserts of N-Africa with large herds of cattle (see figure 5.13). In Sudan the area of Wadi Howar, north of Jebel Marra, was inhabited in this period. The first remains of agriculture in Africa date from this period as well.
The next period, 4500-2000 years ago was drier again, although still slightly more humid than at present. Desiccation of the Central Sahara caused a great exodus of people to the less arid margins and to the Nile Valley. Archeological investigations at Jebel Tomat near Kosti indicate that people lived here in the beginning of this period by hunting, fishing, cultivating *Sorghum* and owning cattle, sheep and goats. From this time onwards man started to influence the ecosystem, accelerating the natural deterioration of the vegetation due to a gradually drier climate.
For the last 2000 years there is evidence for various fluctuations of the climate on a smaller scale.

The first twelve centuries AD probably were somewhat drier than today. The thirteenth to fifteenth century were wetter than at present and whit-nessed the rise of great muslim states in the Sudan savanna zone throughout Africa. The period 1600-1850 AD was comparatively dry and there was much tribal movement as the vegetation declined. The south ward movement of Nilotic people into Uganda and Kenya occured in this period. 1 period 1850-1920 AD was relatively wet; the Sudd was hardly penetral forests and tse-tse fly zones spread to the North; the Azande Kingdom was spreading across the Zairean-Sudanese border. The period 1920-1950 has been quite warm and dry. The 1950's were relatively humid while the late 1960's and early 1970's were dry. All these climatic fluctuations affect the regeneration and succession of the vegetation and consequently affect the ecosystem as a whole.

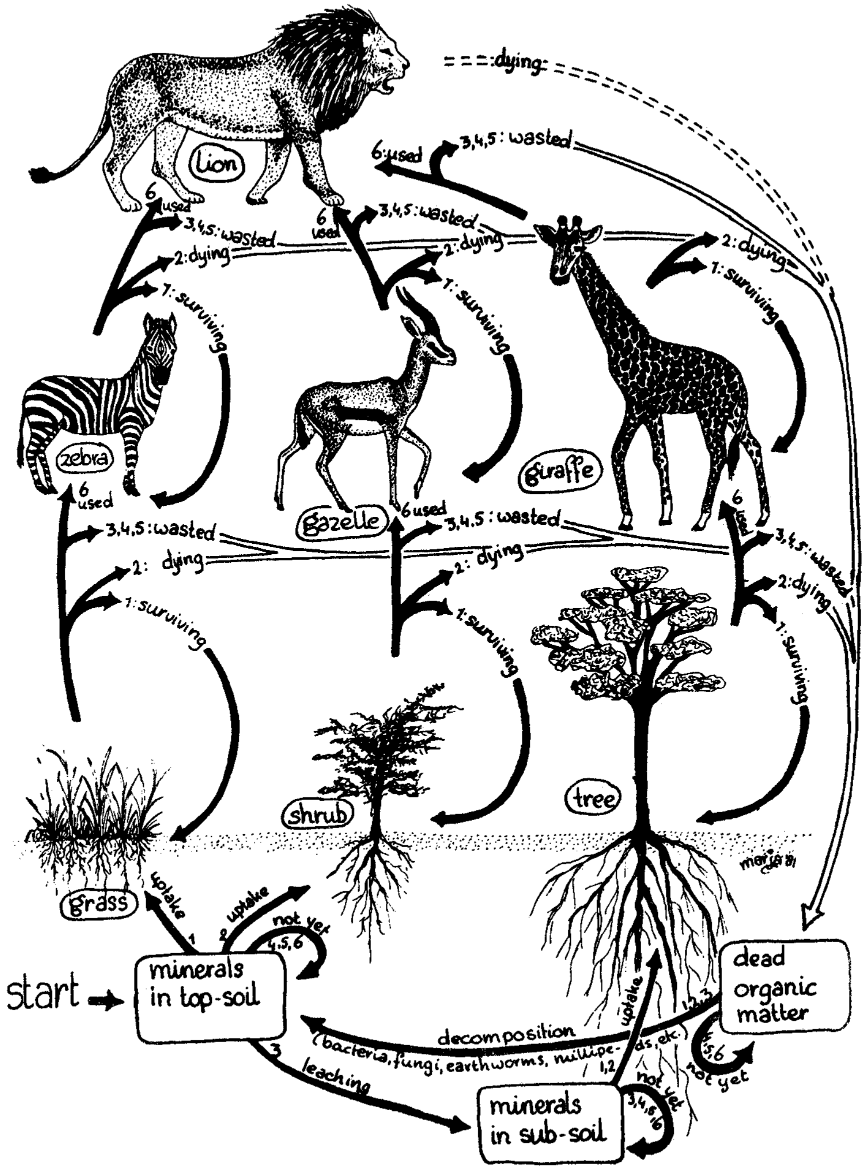
Figure 5.13 *Rock paintings* in *the central Sahara desert (Tassili); left: game animals probably drawn* 7 000) *years ago), centre: people herding cattle (probably* 5 000 *years old), right: camel (probably* 2 000) *years ago) (after J. Cloudsley-Thompson,* 1977).

5.8 Suggested practicals

1. Construct a foodweb for your own environment (compare fig. 5.1 and chapter 4, exercise 6).
2. Figure 5.14 shows a nutrient cycle game, which can be played by 2 -10 players with 1 die. Every player acts as a mineral and starts in the soil. Each turn the number on the die shows your path 'through the cycle: you can be taken up into plants, washed down to the subsoil etcetera. The first player to become a lion has won the game, provided he or she can explain what happens in every step of the game.

   During the game you can count the number of times anybody becomes a plant, a plantfeeder or (plantfeeder)-feeder. If you compare the totals at the end of the game, you can construct an ecological pyramtd. Does this game reflect the nutrient cycle in a natural ecosystem? Can the rules be changed to make it more realistic?
3. The process of decomposition is essential to the nutrient cycle. You can study some of the factors which Influence decomposition: If you collect dead leaves or twigs and put them in small bags in the ground, you can follow the breakdown of this material by frequently digging up some samples. If you use bags of a coarse mesh (say 7 mm) the larger saprobic animals can do their work as well as the small ones; if you use bags of a fine mesh (say 0.5 mm) only bacteria and fungi can reach the dead organic matter. For example: make 20 equal portions (weigh them), bury 8 in the coarse mesh bags, bury 8 similarly in the fine mesh bags; from the remaining 4 portions you determine the weight after drying (in the " intense sun); after two weeks you dig up two samples of each type, dry and weigh them; this you repeat with intervals of 2-4 weeks. What results would you expect?
4. Try to construct a scheme of the Carbon cycle, by comparison with the other cycles given.

Figure 5.14 Nutrient cycle game (or.).



6. Traditional human use of the environment

6.1 Man and natural resources

The ecology of man can be studied just like the ecology of any plant or animal. The 'basic needs' can be compared with the available resources. Adaptations to overcome the limiting abiotic or biotic factors can be distinguished. These adaptations are mainly concerned with man's behaviour, rather than his or her structure or physiology.

The main difference between man and the other organisms is the overwhelming influence man has on the remainder of the ecosystem, far more than any other species has. And the scale of man's activities is still increasing. When 'fishing, hunting or gathering', man still was a consumer like many other species. By domesticating animals he/she exerted a more pronounced effect on the biotic parts of the ecosystem and by domesticating crops his/her influence extended to the soil as well.

In discussing resources for human use we have to distinguish between **renewable** and **non-renewable** resources. Renewable resources are part of the present natural energy flow and nutrient cycle. Game and fish populations continue to provide food, as long as they are not overexploited; trees, foodplants and domesticated animals are a renewable resource as well, as long as their environment is kept in good shape; water used within the cycle of rainfall, evaporation and flow to the sea is renewable; so is energy taken from flowing water, from wind, from the burning of plant or animal wastes or directly from the sun; all of these are renewable resources. Non-renewable resources are for example minerals and energy taken from fossil supplies (oil, gas, coal). Usually these have been part of nutrient cycles and energy flow in former times and are now stored in the ground. There is only a limited supply of each of them. So it is only a matter of time before they are depleted. Nuclear energy also uses a non-renewable resource.

In many cases however, it is difficult to tell whether a resource is renewable or not, although it is very important to know. When deep groundwater supplies are being used, it is not easy to determine whether these are part of the current water cycle and will be replenished after use, or that this water is a fossil supply, without replenishment. Tropical forest can be cut down for timber and replanted with fastgrowing soft-woods, but regeneration of the original forest would take a very long time. Many renewable resources can become nonrenewable if the environmental conditions are changed by human interference. Erosion of the soil and pollution of water, soil or air are clear examples, spoiling the future use of such important natural re- sources as clean water, a living soil and clear air.

> Behaviour forms the largest part of the adaptations of mankind. This is possible because apart from the process of adaptation discussed in section 3.5 cultural transmission of ideas and experience plays an important role. Some animals have a similar way of learning how to use the environment and such knowledge may be transferred from parents to offspring; for mankind this really has become the dominant factor. Trial and error is the basic method of learning, but by cultural transmission new generations can learn from the errors of previous ones, without repeating them. Gradually a body of specific knowledge of the local environment is built up, of the resources available and the ways to use them safely. There has always been an exchange of people and ideas within the same ecological zone or between one ecological zone and another, and many innovations have come through these contacts. But of course, many innovations do not function outside the environment for which they where developed.
>
> Man learned to cope with the environmental conditions almost all over the world by making mistakes. As long as man was active on a rather small scale, many of these mistakes were reversible. With the recent increase of scale of human activities the scale of the mistakes increased as well, from 'trial and error' to 'trial and disaster'.
>
> Many ideas of 'development workers' may be suitable in Europe or other continents, but not under African conditions.
>
> This makes it the more urgent to learn as much as possible from previous mistakes here or elsewhere in the world, to try and avoid them.

In this chapter we shall consider the ways in which man traditionally used the environment of the Sudan; in the next chapter we shall discuss some of the errors and disasters of present day development.

First we shall consider those pests and diseases which limit the use of certain parts of the land.

6.2 Ecology of diseases limiting land-use

6.2.A. General

Along with the wide variation in climate and ecological zones the Sudan harbours many diseases. The human diseases can be roughly classified in four major categories:

a. diseases due to malnutrition,
b. diseases due to infections by bacteria (such as tuberculosis) and viruses (such as influenza),

c. diseases due to parasites (see section 4.3) and
d. diseases due to old age (or to other reasons for parts of the body to stop functioning).

Of course there is some interaction between these categories as mal nutrition weakens the body's resistance to other diseases.

Malnutrition can be caused by lack of food, but' also by an inadequate composition of the food.

> In different ecological zones different types of staple food are used to supply the major part of the human energy requirements. In zones where cassave or maize are predominant, problems of malnutrition due to shortage of protein are common (maize has a low content of some essential amino-acids). But in every ecological zone an adequate diet can be composed from different plant products (cereal grains such as Dura or maize in combination with legumes such as beans and with 'dark green leaves' and fruit), especially when supplemented with some animal products. Lack of vitamins and essential minerals usually is the result of an unbalanced, monotonous diet. This is more common in towns than in rural areas. Lack of iodine in the drinking water leads to goitre in some areas.

Diseases caused by bacteria and viruses often have the character of an **epidemic**: new strains of the disease spread rapidly throughout the human population. Usually the body is able to develop a form of resistance after a while, which is efficient until a new strain of the disease has been formed, Diseases of this type have a rather weak relationship with the environment; the climate can have some effect on them.

For the diseases caused by parasites the ecological relationships are much clearer, often because their intermediate hosts or vectors (see section 4.3) have definite ecological requirements. This can be demonstrated by listing:

- **Malaria**: the vector, the malaria mosquito is restricted to stagnant water.
- **Bilharzia**: the intermediate hosts, snails, are restricted to permanent water, with enough waterplants.
- **Kala-Azar**: the vectors, sandflies, are restricted to the dry, Eastern and South-Eastern parts of the Sudan.
- **River blindness**: the vector, the biting black fly, is restricted to streaming water.
- **Trypanosomiasis**: the vectors, tse-tse flies, are restricted to moist savanna habitats.
- In the case of **amoebic dysentery** the parasite depends on moist conditions for an efficient dispersal.

In this section we shall concentrate on two groups of parasitic diseases which restrict land-use. Many other diseases affect the human labour potential but usually not to the extent that large areas remain uninhabited. Trypanosomiasis and river blindness however, do have such an effect.' Trypanosomiasis prevents cattle-keeping in large areas, while river blindness prevents the use of fertile river valleys.

6.2.B. Trypanosomiasis

The two main forms of tryponosomiasis each have their typical species of tse-tse fly as a vector. *Trypanosoma rhodesiense* (causing nagana in cattle) is transferred by *Glossina morsitans; Trypanosoma gambiense* (causing the main form of human sleeping sickness) is transferred by *Glossina palpalis.* G. *morsitans* is a tse-tse fly of woodland savanna while G. *palpalis* is restricted to denser, wetter forests near the Nile/Congo watershed, protruding into the savanna along rivers. Fig. 6.1 shows the distribution of the two species in the Sudan. In the true floodplain no tse-tse flies occur.

The life-cycle of a tse-tse fly is different from that of most other insects, in that only a single egg is produced at a time. This egg develops inside the body of the female until the mature larval stage, benefitting from maximum protection by the mother. When the larva is mature it is deposited in a moist, shaded place: under the shade of a tree, log or rock. The substrate on which the larva is deposited must be loose enough for the larva to burrow. After burrowing the larva pupates and after about a month an adult fly emerges and starts looking for large herbivores, birds, reptiles or humans to obtain its blood meal. It has to feed about once every four days, may live for two or three months and the female flies produce two to three young during each month of her life. Because of this low reproductive potential hands-catching

of flies has better prospects as a simple way of combatting the fly, than for most other insects.

The tse-tse fly can breed throughout the year except at the height of the rains.

The flies increase in number mainly during the early rains, when climate, availability of food and sites for larviposition are more favourable. In the dry season the fly population is at a minimum, restricted to certain limited areas where the vegetation provides a suitable micro-climate. Such places are called 'permanent breeding places'.

Tse-tse flies feed during the day and find their host primarily by sight and secondarily by smell. They are attracted by movement, rather than by form of the body. Some of their most suitable feeding sites are alongside

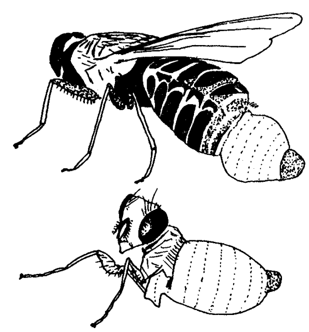


Figure 6.1.A.Tse-tse fly reproduction

roads, paths, banks of rivers and streams and water holes. At such sites concentrations of their food sources are common.

The life-cycle of the Trypanosoma parasite has been shown in fig. 4.13. Human beings can carry the disease without being affected. Such individuals may act as reservoirs of the parasite. For the cattle disease, various wild herbivores can act as reservoirs.

Sleeping sickness has been reduced in intensity by control programs in the first half of this century. To enable easy access for frequent medical inspection, the population over large areas was obliged to leave their villages and to resettle along the roads. Sometimes this meant that they had to abandon the areas with the most favourable soil and were forced to live in places of much lower soil fertility. Later people moved back to their original sites. During the civil war (1956-1972) the sleeping sickness problem has intensified again. Recently the disease has spread in Eastern Equatoria, around Torit.

The control of the cattle trypanosomiasis is an important economic problem, as at present an area of possibly 230.000 square kilo metres is almost devoid of cattle because it is occupied by tse-tse flies. A large area to the North of the main tse-tse area suffers from sporadic outbreaks of cattle trypanosomiasis, with other biting flies as vectors. Fig. 6.1 shows the distribution of 'surra' as well, another cattle disease transferred by biting flies.

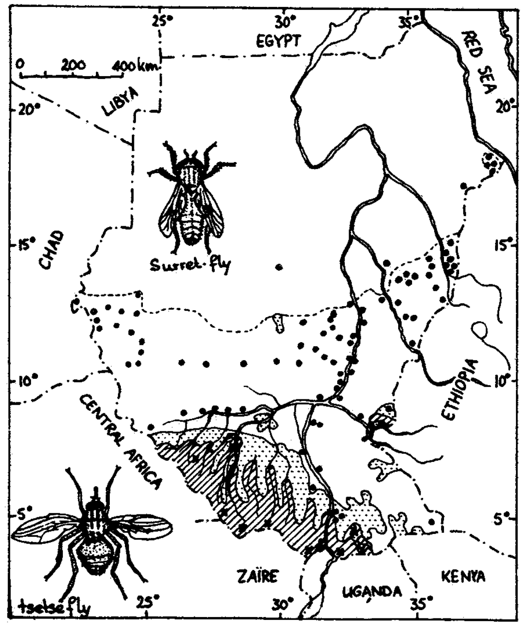
The most successful control of tse-tse flies is obtained by radically changing the environment. As the flies depend on shaded bushes for reproduction, deforestation of large areas can free these areas from cattle diseases. This has been done around Kajo-kaji. But obviously such a measure has effects on many parts of the ecosystem.

A major problem to the use of drugs for curing the cattle diseases is the resistance developed by the parasite. The evolution of resistance has been promoted, especially because large amounts of drugs are used in doses which are too low to kill off the parasite population.

6.2.C. River blindness

River blindness (or Onchocerciasis) is caused by a nematode worm *Onchocerca volvulus* and is transmitted by the biting black fly *Simulium damnosum.* The disease is common in Southern Sudan, as shown in fig. 6.2. The vector occurs along rivers as the larvae depend on fast-flowing water. In the Southern Sudan the flies breed from April or May to December or January at the rimes of heavy river flow. The flies occur in the Northern Sudan along the Nile, breeding from October until April, after the Nile flood and before the hot season. The parasite has a more restricted distribution than its vector.

After infection the larvae of the nematode worms migrate inside the human body and collect on certain sites, under the skin or in joint capsules,



Glossina morsitans (woodland species, transferring nagana to cattle);

G. morsitans and G. palpalis (riverain species, transferring human sleeping sickness);

X crosses indicate places where outbreaks of sleeping sickness have occurred;

● dots indicate areas where tabanid flies ("surret") are troublesome.

Figure 6.1.B. Distribution of tse-tse flies in the Sudan and outbreaks of sleeping sickness (modified after Abushama, 1974)

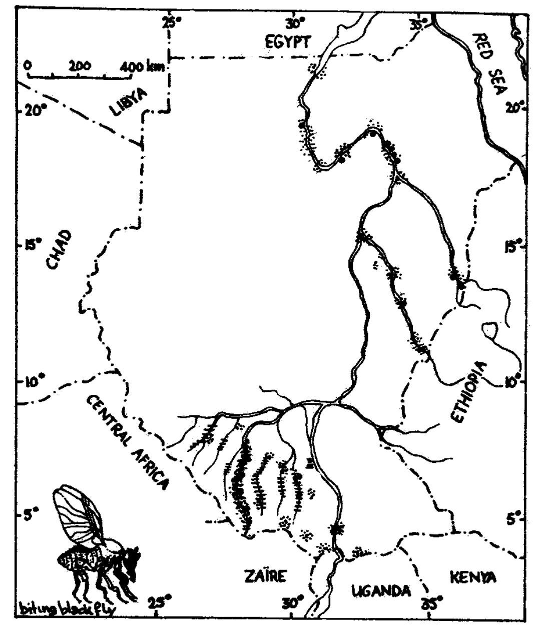


Figure 6.2 Distribution of Simulium damnosum *(small dots indicate occurence, large dots abundance) and the river blindness it transfers (Onchocerciasis) (indicated by stripes). (modified after Abushama, 1974)*

especially around the hip joint or on the head and shoulders. Here they reproduce and the embryo's wait underneath the skin for ingestion by *Simulium* flies. Blindness (due to invasion of the tissues of the eye by the embryo's) develops only after a heavy and prolonged infection. Blindness only occurs when there is excessive biting by many *Simulium* flies. However, it has serious con- sequences, as the vicinity of rivers would be excellent agricultural land, if not for the presence of the disease.

6.2.D. Effects of development on prevalence of diseases

A few remarks may be made anticipating the next chapter, on the effects of development on the occurence of diseases. Two major developments are important: irrigated agricultural schemes and urbanisation.

In irrigation schemes the presence of permanent water in the canals promotes the chances for Malaria-mosquitoes and snails transferring Bilharzia. The effects of urbanisation are more complicated. Malnutrition is common in urban areas because of a monotonous diet. Also, people tend to change their staple-food when living in urban areas. Polished rice and white wheat flour commonly eaten in towns, lack essential vitamins and proteins, as the rich germs have been removed from the grains. -. Poor hygienic conditions in crowded urban areas promote the chances for all kinds of diseases. Spreading from one human being to another is much easier here than in rural areas, due to the higher population density. Amoebic dysentery, Cholera and Gastroentritis can therefore spread easily in towns. A more complicated case is the Plague-virus transmitted by fleas from rats to man.

6.3 Gathering, hunting and fishing

6.3.A. Gathering plant products

In some form or other a large number of all the plants in each of the ecological zones can be used by man. Many trees have edible fruits, seeds or gum (see table 6.1 for some local examples), many grasses have edible seeds (table 6.2), the leaves of many herbs, shrubs and trees are edible and many plants have tubers, storage roots or bulbs which can be eaten in the dry season. Many of these wild plants still play an important role in human nutrition, especially during droughts or shortages of other food. They often help to provide variation and add important vitamins and minerals to an otherwise deficient nutrition.

In drier zones gourds and melons and other fruits of the *Cucurbit* family form an important source of water in the dry season for man and domestic animals.

Table 6.1 Some examples of trees which provide edible fruits or seeds

Code for ecological zones: I = desert, II =low rainfall savanna, III =intermediate rainfall savanna, IV =high rainfall savanna, r = along watercourses

Scientific name	**Local name**	**Ecological zone**
Palmae:		
Phoenix dactylifera	date palm; Nakhla (A.)	Ir
Phoenix reclinata	Kinge (Z.)	IV
Borassus aethiopum	fanpalm; Doleb (A.); Agep, Tuk (D.); Wawuki(B.); Olcwa (Z)	IIIr II, IIIr
Hyphaene thebaica	dom palm; Dom (A.); Taam (D.), Nyieth (D.)	
Anonaceae: Anona senegalensis	Apinrot (D.); Bogora (Z.); Lomudi (B.)	IV
Capparidaceae:		
Crateva adansonii	Dabkar, Urn Bukesha (A.); Kait (D.)	II, III
Boscia octandra	Mokheit (A.); Fog (D.)	III
Courbonia virgata	Kurdan (A.); Daya (B.)	III
Capparis deciduas	Tundub (A.); Naugot (Sh.)	III
Ochnaceae: Lophira alata	Tanga (D.); Zawa (Z.)	IV
Myrtaceae: Syzygium guineense	Sanambiri (Z.); Kula (J.)	IV
Tiliaceae: Grewia tenax	Gaddeim (A.); Apor (D.); Tireye (B.)	II, II, IV
Ulmaceae: Celtis integrifolia	Tutal (A.); Bakka (B.)	III
Bombaceae: Adansonia digitata	baobab-tree; Tebeldi (A.); Dunydud (D.)	III
Caesalpiniaceae:		
Piliostigma reticulata	Abu Khameira (A.); Pac (D.); Dagpa (Z.)	III, IV
Tamarindus indica	Ardeib (A.), Cuei (D.), Abanza (Z.)	III, IV
Mimosaceae: Parkia filicoidea	Umrashad (A.); Akon (D.), Abongba (Z.); Muluti (B.)	IV
Papilionaceae: Cordyla africana	Donyduak (D.)	IV
Moraceae: Ficus sycomorus	wildfig; Gameiz (A.); Ngap (D.); Kuyi (B.)	II, IIIr
Salvadoraceae: Salvadora persica	toothbrush tree; Arrak, Sac (A.); Acuil (D.); Kurreh, Lupari (B.)	II, III, IV
Olacaceae: Ximenia americana	Kalto, Alankuwe (A.); Melat (D.); Lama (B.)	III
Rhamnaceae: Ziziphus mucronata	Sidr, Nabak (A.); Lang (D.); Lujbati (B.)	III
Simarubaceae: Balanites aegyptica	soapberry tree, desert date Heglig (A.); Tnau (D.); Lallik (B.)	II, III
Anacardiaceae: Sclerocarya birrea	Homeid (A.); Akarnil (D.)	III
Ebenaceae: Diospyros mespiliforrnis	african ebony Abu sebela, Jukhau (A.); Cum (D.); Kumi (B.)	III, IV
Sapotaceae: Butyrospermum niloticum	sheabutternut; Lulu (A.); Rak (D.); Kumuru (B.)	IV
Loganiaceae Strychnos spinosa		III, IV
Oleaceae: Olea africana	brown olive; Badda (A.)	III
Boraginaceae: Cordia africana	Sudan teak; Gambil (A.)	III

Verbenaceae: Vitex doniana	Kurain, Abdugulgul (A.); Konink (D.)	II, III

Table 6.2. Some examples of wild grasses with edible grain.

Scientific name	**Local name**	**Ecological zone**
Eragrostis pilosa	Am Hoy, Kwoinkwoin (A.); Nua (D.)	II, III, IV
Dactyloctenium aegypticum	Koreb, Absaba (A.)	II, III, IV
Oryza barthii	Am belele, Ruz (A.); Lop (D.)	IIIr
Panicum laetum	Kreb (A.)	II, III
Echinochloa colonum	Defera (A.); Akuath (D.)	II, III
E. pyramidalis	Urn Suf (A.); Kam (D.)	IIIr
Brachiaria obtusiflora	Urn Khirr (A.); Ajoak (D.)	III
Cenchrus biflorus	Haskanit (A.)	II, III

The Baobab tree (Tebeldi, A.) is used for storing drinking water. A large number of plants is traditionally used for their high mineral content. After burning them, man uses the ash as salt for cooking or preserving food. Some plants contain enough soaplike substances to be used for washing.

> One of these plants, the Soapberry *(Phytolacca dodecandra)* was recently identified in Ethiopia as an important killer of snails in bathing water. After the introduction of synthetic soap, replacing the use of soapberry the incidence of Bilharzia increased enormously. The fruits of *Balanites aegyptica* (Heglig, A. or desert date, fig. 6.3) also contain substances which can kill watersnails (as well as waterfleas which transmit the guineaworm, a human parasite).
> As the fruits of the desert date are bitter it is common practice e.g. in the floodplain to soak the fruits in water before eating them. The fruits ripen during the dry season when water levels are rather low. Soaking desert dates in these comparatively small pools may be sufficient to kill the snails potentially transferring Billiarzia.

Many plants are used in traditional medicine and many others supply building materials, firewood, ropes or materials for weaving baskets and making other utensils (calabashes). The very light wood of Ambatch occuring in the floodplain is used for making rafts. In fact, in many areas there are few plants which man has not learned to use in one way or another. This knowledge is an important part of the culture and it is in danger of disappearing when formal school education replaces traditional education.

When the human population is still small, the use of plant parts does not really damage the vegetation. However when population density increases people have to care for these useful plants. Sparing useful trees when land is being cleared for cultivation is the first step. By actually planting them or promoting their growth, man is 'domesticating' plants (section 6.5). Many of the wild plants mentioned in this paragraph might become of further use by the process of domestication through selection of the best varieties.

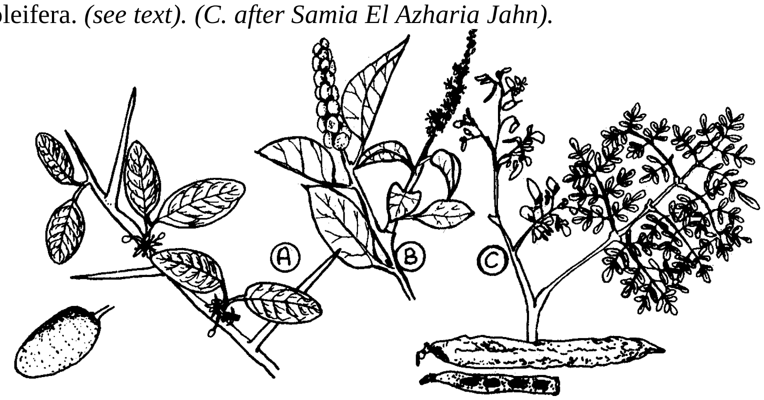
A tree which has been introduced into Sudan early in this century as ornamental now plays an important role in village sanitation. The tree, *Moringa oleifera* (fig. 6.3) is locally called 'Shagra al rauwag' (A.) or 'clarifier tree'. Seeds of the tree are powdered and mixed with turbid water taken from pools or rivers. When left for some hours, the water will become clear, all solid particles (including germs of disease) being collected at the bottom of the pot. This fact was discovered by Sudanese women, probably extending upon the use of broad beans ('ful masri', A.) for the same purpose. In other parts of the world other plants are used for the same end, but none is as potent as *Moringa.*

6.3.B. Collecting anima] products

Man traditionally is an opportunist, taking all opportunities for collecting edible products. A large variety of animal products can be collected: eggs of Ostrich and Guinea-fowl, some species of snails, locusts and the termites which swarm after the start of the rainy season.

Honey is an important product in the richer savanna-zones and the forests. It is collected from wild nests, sometimes with the help of Honey-guide birds (section 4.5) or from bees attracted into beehives.

Figure 6.3 *Trees important for village sanitation: A;* Balanites aegyptiaca, *B.* Phytolacca dodecandra *which occurs in the Imatong Mountaim,* C. Moringa oleifera. *(see text). (C. after Samia El Azharia Jahn).*



In the majority of beehives used the bees are expelled and many are killed by smoke before the honey is collected. The fire used for burning out trees to collect honey sometimes gets out of hand and thus collection of honey is one of the sources of uncontrolled bush-fire. The felling of full grown trees, just to collect some bottles of honey is wasteful anyway. In improved beehives the bees can be kept alive and then may be considered as domestic animals (fig. 6.4).

6.3.C. Hunting

Fire is an important tool in traditional hunting. It is used to drive animals into nets or towards hunters waiting with spears or bow and arrow. It can also be used to create favourable grazing conditions in the dry season for herbivores which can then be easily shot. For trapping or catching animals a good knowledge of their behaviour is essential. Snares, traps, nets and pits are especially used in heavy forest. If spears and bow and arrows are used these tend to be smaller than the ones used in more open savanna country. Certain plants and the cocoons of a beetle can be used as arrow poison.

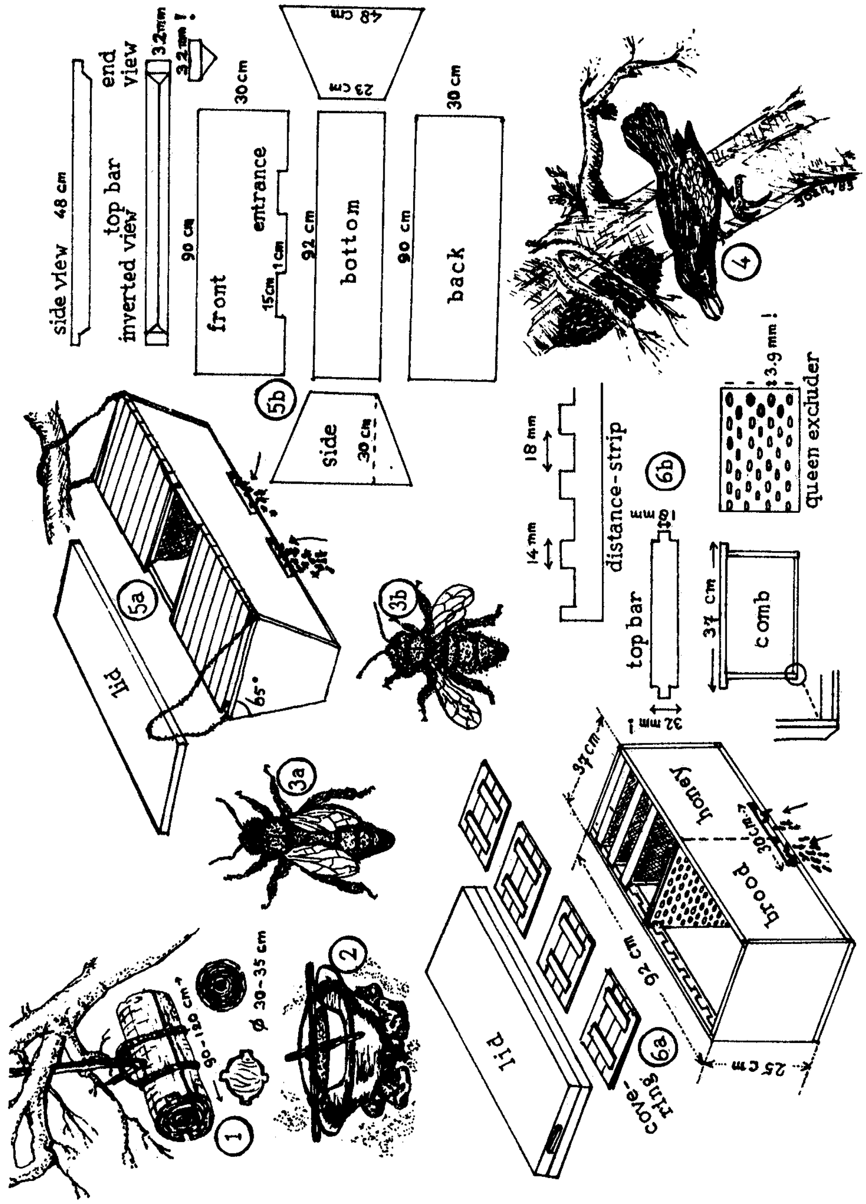
As long as the human population remains fairly small, traditional hunting does not seriously affect most game animals. But the introduction of fire-arms and poaching for special products (ivory, rhino horns) has changed the situation considerably.

6.3.D. Fishing

Fish is an important source of protein in the diet of many people, especially as it can be preserved by simple means such as drying, smoking or salting. Table 6.3 lists some of the most important edible fish species. Different techniques are used for fishing, but most fishing is done in the dry season, when flood waters recede and rivers dry up into isolated pools.

In the flood region fishermen make use of the migratory movements of the fish. Fish enter the toic during the early rains, reproduce in the shallow

Figure 6.4 *Bee keeping in Africa.*
1. *Traditional split, hollowed out log hive, hanging in a tree out of reach of fire;* 2. *warming of wax (indirectly* in *water) to harvest this important by-product;* 3. *the african honey bee,* Apis mellifera adansonii *a) queen, b) worker;* 4. *honey-guide showing a swann of bees;* 5. *Kenya top bar hive, with movable top-bars on which the bees make combs with either brood or honey; the slope of the sides has to be around* 65º *to prevent the bees from luting the combs to the sides; the bars have to be exactly* 32 *mm, otherwise the bees may fill* in *the remaining space with wax;* 6. *modified African long hive* (in *which honey-chamber and brood-chamber are separated by a 'queen excluder' from which combs with pure honey can be-collected, without disturbing the brood. (various sources.)*



side view
48 cm
top bar
inverted view
end view
3.2 mm
3.2 mm !
30 cm
90 cm
front
entrance
15 cm
1 cm
92 cm
bottom
90 cm
back
30 cm
23 cm
48 cm
5b
side
30 cm
5a
lid
65°
3a
3b
4
18 mm
14 mm
distance-strip
6b
top bar
32 mm
37 cm
comb
3.9 mm !
queen excluder
37 cm
honey
brood
30 cm
92 cm
25 cm
6a
lid
cove-ring
1
2
90-120 cm
ø 30-35 cm

Table 6.3. Some important edible fresh water fish species of the Nile and Sudd

Scientific name	Local names			Habitat	Main food
	A.	D.(Bor)	Sh.		
Bagrus	Bayad,	Alau,	Adwar	Sudd	insects, fish
Citharinus	Betkoya,	Apurot,	Othago	Sudd	plants, small prey
Clarias	Gatmut,	Attek,	Cogo	Sudd	plankton, fish
Gymnarchus niloticus	Weer,	Rial	Mok	Sudd	Custaceans, fish
Heterotis niloticus	Nok,	Lek,	Olak	Sudd	seeds, molluscs
Mormyrus sp.	Khashm el banat,	Ashambil,	Adolalok	Sudd	plants, insects
Protopterus aethiopicum	Samak el teen,	Luth,	Luth	Sudd	molluses, fish
Alestes sp.	Kawara,	Nyang,	Kodo	Nile	plants, insects
Clarotis sp.	Bamseka			Nile	insects, fish
Distichodus sp.	Kraish,	Aciar,	Caw	Nile	plants, insects
Labeo sp.	Dabs,	Ukuro,	Acang	Nile	algae, mud
Lates niloticus	Igle,	Cal,	Gur	Nile	Fish
Synodontis sp.	Gargur,	Nogk,	Okok	Nile	plants, molluscs
Tilapia sp.	Bulti,	Aturo,	Odweko	Nile	plants, insects

waters and return to the main channels at the start of the dry season. Elaborate systems of dykes are sometimes built, with narrow openings containing traps. Much fishing is done after the floods have receded and fish are left in small ponds (fig. 6.5). A special skill is required to find the lungfish which have burrowed in the mud; early in the dry season their breathing holes can be recognised visually or by sounds which the fish make in response to scraping a finger over a calabash. More specialised fishermen work along the permanent rivers, using a variety of nets.

Along the Blue Nile fishing activities are strongly influenced by the flood seasons and the migration patterns of the fish. In April and May the Nile perch migrates downstream from the Upper Blue Nile to seasonally flooded spawning areas. Adults and young return to the river and migrate back to the upper reaches before the water level falls. During the downward migration the water is clear and the Nile perch can be caught by hooks, using *Tilapia* and *Labeo* as bait. On the return migration the water is turbid and catfish such as *Clarias* are used as a bait, as they stay alive in muddy water. When the Blue Nile carries much silt, many Nile perch die because their gills get blocked by silt.

Traditionally much fishing was done with the help of poisonous plants. Table 6.4 lists some of the plants used. These are mainly used in shallow streams or pools, and kill or stupefy the fish. Most of the poisons used are dangerous for man, although they kill most types of water-organisms by soap-like substances. Of course fishing by the use of poison is extremely destructive for the fish populations as all the young are killed as well. It is prohibited by law, but it is still practised.

Figure 6.5 *Traditional fishing techniques* in *the floodplain during the dry season: a. trapping fish when the floodwaters are retreating, in a weir (rok, D.); b. fishing spear (bith, D.); c. net, used by two women in shallow pools (alom, d.); open-bottomed basket for catching fish in shallow water (thoi, D.). (or.).*

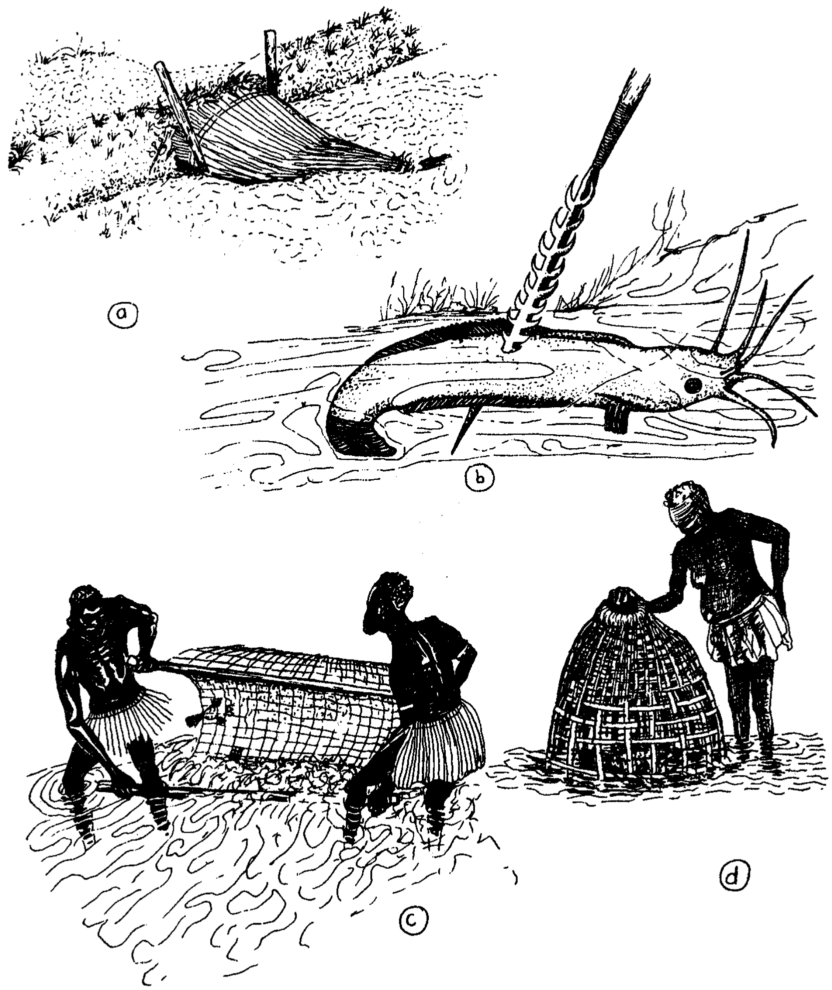


Table 6.4. Some examples of plants used as fish-poison

Family	Species	Local names	growth form	part(s) used	Distri-bution
Thymeleaceae	*Lasiosiphon kraussianus*	Bururu (Golo)	herb	roots	III
Euphorbiaceae	*Huggea virosa*	Dabalab (A.)	Shrub	Bark	II, III
	Calotropis procera	Usher (A.), Apabuong (D.)	shrub	fruits, leaves	II, III
Mimosaceae	*Prosopis africana*	Abu surug (A.); Jier (D.);Zangare (Z.)	tree	pods	III, IV
Papilionaceae	*Tephrosia vogelii*	Dawa na Samaki (A.)	shrub	Leaves branches	IV
	Mundulea sericea		Shrub	Seeds Leaves Branches	III III
	Neorantanenia pseudo-pachyrhizos	Jekoro (Golo)	climber	Roots beans	III
Simarubaceae	*Balanites aegypnca*	heglig (A.); Thau D.); Lallok (B.)	tree	Roots bark fruit	II, III
Meliaceae	*Khaya grandifolia*	Bogu (Z.); Kiyir (B.)	tree	bark	IV
Sapindaceae	*Paullinia pinnata*		climber	Seeds, roots	IV
Apocynaceae	*Adenium obesum*	desert rose; Sim amar (A.) Loreng (B.)	shrub	roots	IV
Rubiaceae	*Lachnosiphonium niIoncurn*	Kharum, Abu marfein (A.); Aghei (D.); Kuluji (B.)			I
		Abbaha, Abu gawi	Shrub	Fruit	III
	Gardenia lutea	(A.); Dong (D.); Du-pin (B.); M'Begge (Z.)	shrub	fruit	III, IV

6.4 Keeping animals

6.4.A. Domesticated stock: limiting factors

Camel, sheep, goat, cow, donkey, horse and chicken constitute the main domesticated stock. Their ecological requirements are quite different. Camel and sheep are best adapted to arid conditions, they stand the heat and sandstorms better, need less water and trek longer distances than goats and cows. Cows need drinking water every other day and therefore cannot graze more than 4-8 km away from watering points. In the cool season camels can go without drinking water for 2-3 weeks and in the hot season still for 3 days.

Camels and goats are browsers, feeding mainly on shrubs, bushes and trees. Cows and sheep are grazers, mainly feeding on grasses and herbs. In accordance with the principle of niche differentiation to avoid competition we find mixed flocks of either camel and sheep in the drier areas or cows and goats in the wetter parts.

Food supply, food quality, water supply and diseases all can act as limiting factors in the distribution of domestic animals. Although the amount of plant growth increases with rainfall, the quality of these plants may deteriorate. The quality of the fodder is usually best in the areas of low rainfall and decreases as we move South. Figure 6.6 shows the seasonal pattern of grazing quality of the natural vegetation in four ecological zones in Mali, West Africa. For the Sudan the conclusions probably are valid as well. The low biomass of the Northern Sahel zone is mostly of good quality and high protein content. The high biomass production in the rich savanna zone is of good quality only at he start of the rains. Later on, hard stem and leaves are present with a low protein content and a poor grazing quality. The importance of flood plains (compare the **toic's**) in supplying good' quality forage is evident in these data as well. Burning the vegetation destroys much biomass, but results in young grass of high grazing quality.

> In the desert with an average rainfall of less than 50 mm only occasional nomadic grazing of camels is possible. The herds have to search for the places where rain fell that particular year, as rainfall is very much localized. The herds travel several hundreds of kilometers per year. In areas with 50-100 mm of rain on average, nomadic camel-keeping with some sheep is still the only possible use of the land. Fifty ha or more is needed for one livestock unit (the equivalent of one cow or seven sheep).
>
> In regions with 200.400 mm of rain the requirement for one livestock unit is still in the order of 10-15 ha and where there is 400-600 mm of rain 6-12 ha is necessary. When the rainfall exceeds 200 mm cattle keeping becomes possible, provided there are water points.
>
> In the region with over 600 mm of rain diseases and forage quality become the main limiting factor, rather than shortage of food or drinking water. Biting flies are the main reason for cattle migrations here. The main disease is 'nagana' or trypanosomiasis, which is transferred by the tse-tse-fly *Glossina morsitans* (section 6.2). Other biting flies, mosquitoes and ticks are additional factors limiting the use of the wetter grazing land. In the floodplain the limiting factor usually is the availability of non-flooded grazing land in the wet season, although dry season grazing land may be in short supply as well.

Corresponding with the different limiting factors, we find two main ecotypes in the domestic stock of the Sudan.

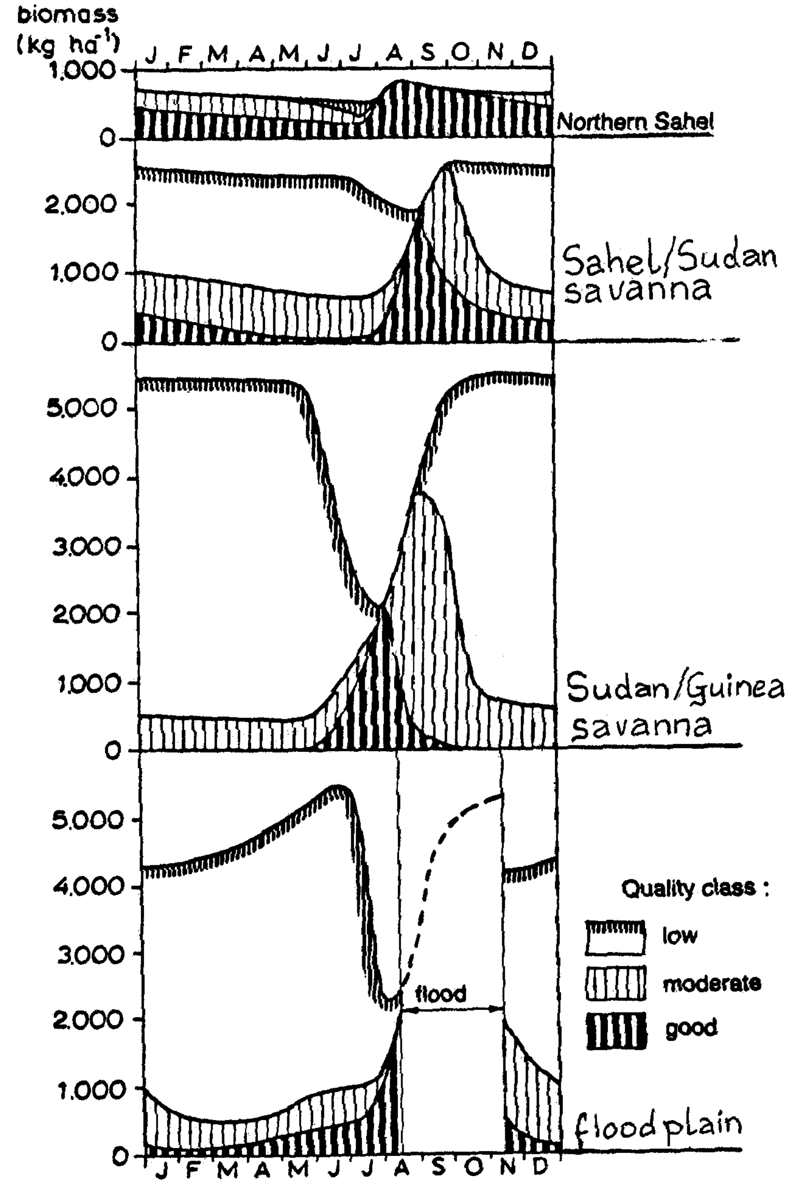


Figure 6.6 Biomass development over the year in four ecological zones, differentiated in forage quality classes (data for Mali) (from de Ridder et al., 1983).

The Baggara cow, desert sheep and Nubian and desert goat on the one hand are mainly adapted to heat, lack of water and dry food; the nilotic cattle, sheep and goats are resistent to diseases and withstand wet and muddy conditions. Neither can live in the environment of the other. Horses and donkeys are generally not resistant against the pests and diseases of the wetter areas and are mainly restricted to the Northern parts. Chicken are kept in all ecological zones and they are important by using all kinds of waste products, helping to keep compounds around the house clean. In some areas chicken are only left to breed their eggs in the season that the kites are absent.

6.4.B. Seasonal movements

As the environmental conditions vary, movements on various scales are necessary. Complete **nomadic** movements throughout the year constitute, the only way of using the scarce resources, of a good quality(!), of the fringe of the desert. The animal owners do not have a permanent place of residence, although the movements are far from random and people generally move in regular cycles, modified by the rainfall pattern of that particular year. **Semi-nomadic** grazing is the sytem in the next zone, with more rainfall. The animal owners have a permanent place of residence where they grow crops. But for long periods of the year they travel with their nerds to distant grazing areas. **Transhumance** is the system in which farmers with a permanent place of residence send their herds, tended by herdsmen, to distant grazing areas for long periods of time.

> The main limiting factors in the Northern and Central Sudan are water and grazing, and this explains the pattern of movements. Fig. 6.7 shows the patterns of movements of the Zaghawa, who live north of Jebel Marra, on the border with Chad. They keep camels, sheep, goats and cows. The camels and sheep make the longest movements. After the start of the rains they disperse into the Goz, where grass starts growing and water is temporarily available. After the rains they go to temporary pools and graze in their vicinity. Some of the camel herds go North in the cool dry season to use the giza-grasses, growing with dew as their watersupply (section 2.1). They travel far and come back when the hot dry season starts. During that season all animals concentrate around the few permanent water points. The goats and cattle are kept closer to the water points all year round.

During the dry season especially trees can be an important source of food. Pods of *Acacia* trees, which are very nutritious, are shaken out of the trees.
Sometimes branches of trees are chopped to the ground to provide grazing as well.

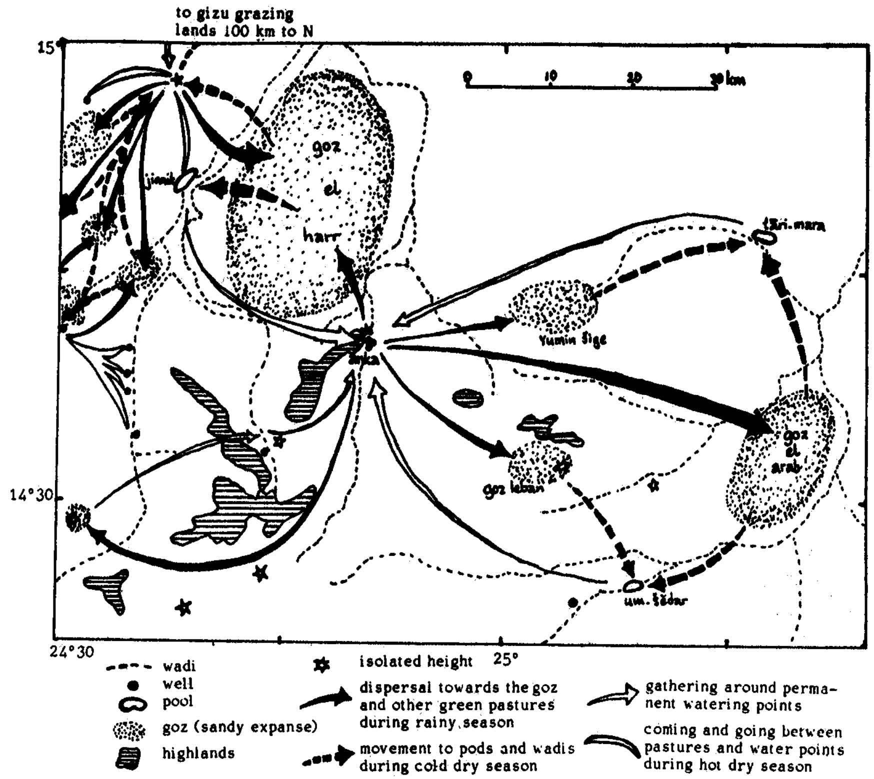


Figure 6.7 *Seasonal movements of the Zaghawa, North of Jebel Marra with their flocks of sheep and herds of cattle (from MJ. And J. Tubiana,* 1977).

> The Rizeiqat cattleherders on the border of Bahr-el-Ghazal Province move Northwards after the rains have started and they return to the South in the dry season. Thus they escape the mud and biting flies of the rainy season, they make use of the good quality grazing areas and they preserve the grazing near the permanent waters for later use.
> Similar movements are made by the Butana herdsman of the Eastern Sudan, who disperse over a wide area during the rainy season and concentrate around the rivers and move South when the pools and shallow wells dry up.

The migration patterns of Nilotic herdsmen (Dinka, Nuer, Shiluk) are shown in fig. 6.8. The map shows that the tse-tse fly limits the use of higher land, In the rainy flooded season cattle are kept on the fringe of the Ironstone plateau and on isolated bits of higher land.

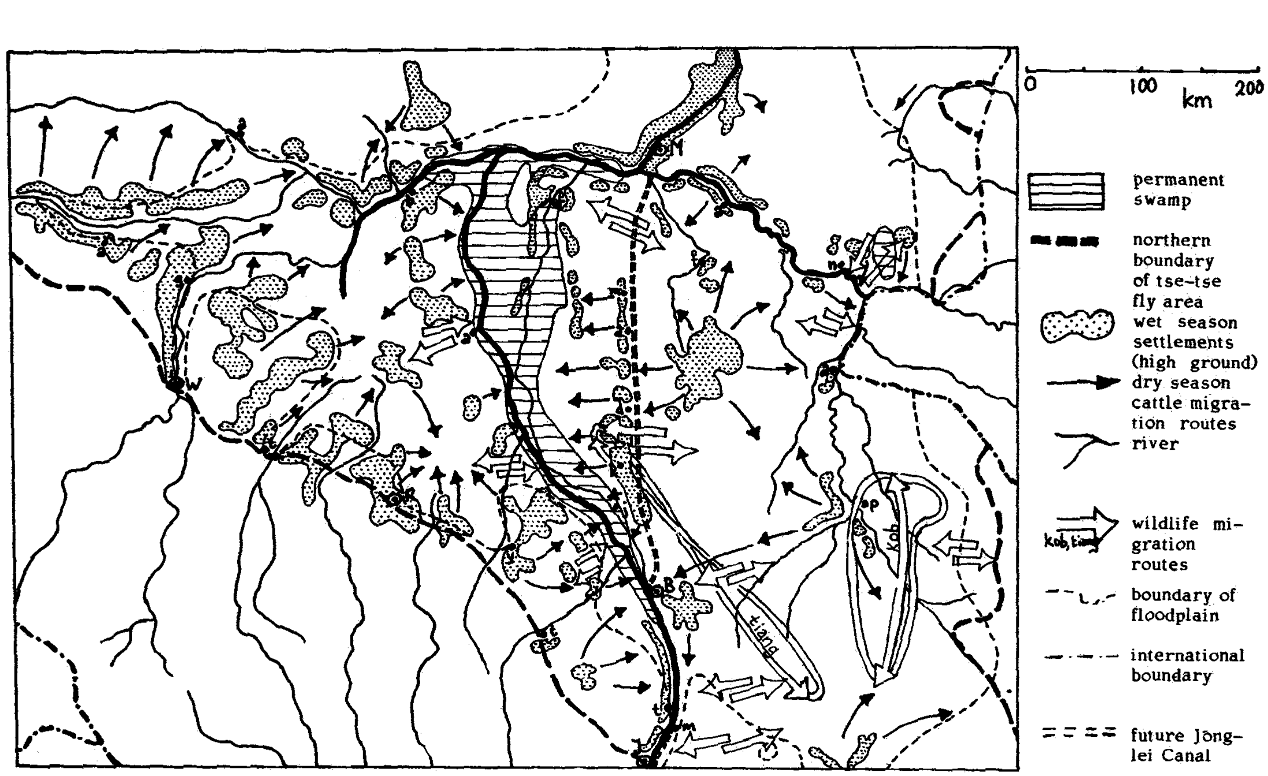


Figure 6.8 Seasonal migrations in the floodplain; during the wet season cattle are kept near the permanent villages on high grounds, outside the tse-tse belt; in the dry-season cattle are brought to the toic's along the river. Wildlife migrations follow a similar pattern, but are restricted to the parts which are less densely inhabited. (after various sources).

The best parts of this land are used for crops and cattle often have to graze on the flooded intermediate land. Keeping the cattle concentrated in small areas has the advantage that the grass is kept short and thus young and palatable. Also predators such as lion and leopard get less chance than in tall grass. In November the old grasses on the intermediate lands can be burned to get fresh regrowth. During the wet season cattle are kept in large cattle byres (or luak's) at night, from which mosquitoes are repelled by the heavily smoking fires of dried manure. In the temporary cattle camps during the dry season fires are burned as well to keep mosquitoes and wild animals away. When the floods gradually recede during the dry season the cattle follow the water towards the main channels.

By trampling the tall *Ethinochloa* toic along the rivers they stimulate re-growth of young grass (compare the grazing sequence of fig. 4.4). The toic's along the river can be used during the dry season. Of the three types of toic mentione4 in section 2.4, the *Echinochloa* toic of the heavy clay soils is by far the most important one for grazing. The *Phragmites* toic is unpalatable and the *Hyparrhenia* toic only provides a small amount of green regrowth after burning. The use of intermediate grazing land in the dry season is often limited by lack of drinking water. Grazing animals here concentrate around **hafir's,** natural or man-made ponds collecting rain or groundwater. The grasses of the high lands, such as *Setaria* provide hardly any regrowth after burning.

In all cases pastoralists need an elaborate knowledge of their environment to find good grazing lands and drinking water in all seasons. What may seem random movements at first, usually follow fixed patterns, with traditional grazing rights for each tribe and clan. Herdsmen often have an extensive knowledge of plants or plant communities, knowing which ones are palatable, which ones poisonous and which plants may cure certain mineral deficiences developed by deficient grazing in part of the cycle. Many plants are used to cure animal diseases.

6.4.C. Regulating herd-size

Animals and especially cattle traditionally play the role of capital reserve, as they can be kept and exchanged more easily than crop surpluses. In years of poor crop harvest they are exchanged with neighbouring agricultural tribes.

But animals can suffer in dry years and a number of contagious cattle diseases such as the rinderpest introduced into Africa at the end of the last Century, or 'foot-and-mouth' disease are particularly dangerous. Often the animals of one owner are distributed over several herds to spread the risk. The herd size is always a balance between manpower available to herd them and the resources available for grazing. The more the animals disperse, the fuller use they can make of all resources, but this requires more people to guard the cows.

Exchange of cattle is an important social event and, as a side effect, a1so helps to prevent inbreeding in the cattle herds.

Maintaining a high genetic divesity in the population is a form of spreading of risk, by keeping traits in the population which may unexpectedly prove valuable on later occasions. To some extend it seems as if the system of paying dowries couples the regulation of the human population size to the animal population size. Human reproduction is thus related to the carrying capacity of the environment.

6.5 Growing crops.

6.5.A. Domestication of crops

From collecting wild food plants such as grass seeds or tubers it is quite a small step to start creating favourable conditions for these plants. Usually this means one has to stay in the same place for at least one growing season, but not necessarily. Some nomadic herdsmen still just sow seeds of quickly maturing grain in wadi's on the fringe of the desert and return only after the growing season has ended to see whether there has been any rain and whether any crop was produced. This may well have been the start of domestication of crops. Domestication generally is accomplished by artificial selection (as opposed to natural selection). By always keeping the best plants as seed for next year man can accomplish a genetic change towards higher production of the edible parts.

Sorghum (Dura, (A.)), *Pennisetum* (Dukhn, (A.), Bulrush millet) and *Eleusine* (Fingermillet) originated from wild grasses in this part of Africa and their wild relatives are still around. Sesame (Sim-sim, A.), Lentil (Addis A.) and Yam are of African origin as well. Groundnuts, maize, sweet potato and cassave were all domesticated in the America's and spread into Africa after the 15th century, finding comparable ecological conditions here.

Of all these crops many local varieties were developed, each adapted to the varying conditions of soil, climate, length of day and diseases present. There still is a large potential for improvement in these varieties. Also there still are many possibilities of domesticating other useful wild plants. But in order to keep this possibility, we have to be careful to preserve these plants for future generations. This can be only be done by preserving representative parts of their environment as nature reserves (see chapter 9).

6.5.B. Growing a crop

Many crop plants are grown outside their natural ecological range, in places where they would not survive competition with other plants, if not for human interference by 'weeding'. The artificial selection is directed towards producing more of the edible parts, rather than towards improving the competitive strength. In most wild grasses the seeds easily disperse when ripe; but in domesticating these grasses, selection favoured the plants which keep their seeds in the plume or ear until after harvest.

Many tuberous plants contain various poisons to protect them from attack by animals. The wild yams found in the rich savanna for example lead to vomiting if you try to eat them. Only prolonged soaking or cooking makes them fit for human consumption (like the bitter Cassave). By cultivating varieties with less poison, the plants lose their defense mechanism and now need human protection from other consumers. So the domesticated crops became completely dependent on human activities for creating a suitable environment for their growth in between other plants (so-called 'weeds'), for their seed dispersal and for their protection from consumer organisms other than man (so-called 'pests and diseases').

Most crops are essentially pioneer plants, with a high growth rate, short lifecycle and poor competitive strength. Land has to be cleared from other plants cover before crops can be sown and afterwards continuous weeding is necessary. But by doing all this, man is greatly changing the local ecosystem and may easily lose important functions of the natural system, such as nutrient cycling and protection and build-up of the soil.

After a few years of cropping the system usually has deteriorated to such an extend that new plots of land have to be cleared. On the first plot of land the natural process of succession can get a chance, which may in the long run lead to a savanna or forest vegetation, depending on rainfall conditions. Real natural rainforest may take hundreds of years to regenerate; the impoverished forest which develops after cultivation is called secondary forest.

6.5.C. Reasons for shifting

The main reason for shifting to a new plot of and is that the yields are declining, or more precisely, that the amount of work necessary to improve the yields on the first plot is larger than the amount needed to clear new land. The decrease in yield, as shown in fig. 6.9 may come from three factors:

1. **Nutrient** shortage. The nutrient cycle of the original ecosystem has been broken up, because the nutrients in the harvested parts are removed from the land without being returned.

    Equally serious is that the root systems of the crops usually develop too late in the rainy season to prevent nutrients from leaching to deeper soil layers, with the first heavy rains. Trees normally act as 'nutrient pumps', bringing

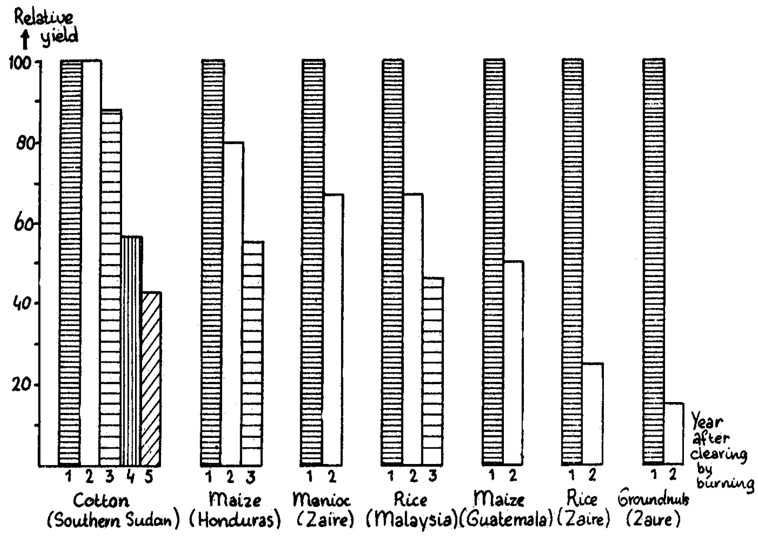


Figure 6.9 *Decline of yields of crops in shifting cultivation agriculture, when the soil is used for several years. (from: Ruthenberg, 1976).*

leached nutrients to the surface with their deep rootsystems. But the trees have been removed from the land.

2. **Loss of soil structure**. In a natural vegetation the soil is protected by some form of plant cover, dead or alive throughout the year. In crop fields man exposes the soil to sun, wind and rain for considerable parts of the year, before the crop has formed a complete cover and after harvest time.

   The direct radiation of the sun on the soil leads to a rapid decay of the soil humus, which is important for a good structure of the soil. Raindrops falling on plants are scattered and can penetrate in the soil as long as the surface structure is loose. But without plant cover the raindrops of heavy tropical rainstorms compact the surface, hence cannot penetrate and will -run off superficially. This run-off leads to sheet erosion of the soil, especially the fertile upper layers of the soil are lost. Loss of soil structure and erosion both lead to a reduced storage of water in the soil, so that the crops suffer from drought.

3. **Weeds, parasites, pests and diseases**. The conditions of the field are not only favourable for the crops, but for other pioneer plants as well (weeds). The crop plants themselves provide a new niche for parasites, insects, nematodes and other 'pests' and for bacteria and viruses causing

diseases. When a new plot of land is cleared, especially if it is far away from previously cropped land, very few of these organisms will be present and it will take some time before they reach the area, depending on their efficiency of dispersal. But after a while these organisms gradually build up their populations, once cropping has started. Usually they become a serious problem after the first cropping season.

In Dura it is the half-parasitic weed *Striga* (Witchweed, Buda (A), Loreng (B)) which causes the most serious problems (see section 3.4). Once a large population of seeds has formed in the soil, these seeds can remain dormant in the soil for at least ten years, waiting for the presence of a suitable host plant root to start germination.

Several plants are very well adapted to the conditions of the cultivated land and become obnoxious weeds. *Cyperus rotundus* (Nutgrass) possesses rhizomes and corms with which they survive the dry season; and these are not easily destroyed by cultivation, and nutgrass becomes abundant, especially on clay soils. *Imperata cylindrica* (Speargrass), mentioned in section 4.1 for its allelopathic capacity, also has rhizomes which can be cut during cultivation, but not destroyed. Both these plants are outrivalled when natural succession is left to occur.

6.5.D. Shifting cultivation or crop rotation

Probably some form of 'shifting cultivation' has been the oldest method of cultivation all over the world. Land is cleared and cropped for a few seasons and then the people move on to new land. As long as the human population is small there is plenty of suitable land and it will take a long time before the cultivators ever come back to the previously cropped land. But as the number of people increases, they will come back to the same plot earlier, perhaps even before the natural succession has led to the climax vegetation. A more or less regular alternation comes into existence of cropping and periods that the land is left to regenerate as a fallow. Fig. 6.10 shows that soil fertility can be fully restored if the land is left fallow for a long time (at least 10-20 years); if not the system collapses progressively.

Systems in which the land is cropped for 1/3 to 2/3 of the time are called 'fallow-systems'. We can speak of bush fallow, savanna fallow or grass fallow according to the type of vegetation. When the pressure on the land is further increased, the duration of the fallow is further reduced to only a small portion of the crop rotation and we speak of permanent cultivation when crops occupy the land for more than 2/3 of the time.

Quite often the situation is complicated further when there are two types of cycles. Around many villages some form of fallow system is employed in which the duration of the fallow is not sufficient to restore the fertility of the soil completely. Because of various social reasons people like to live close

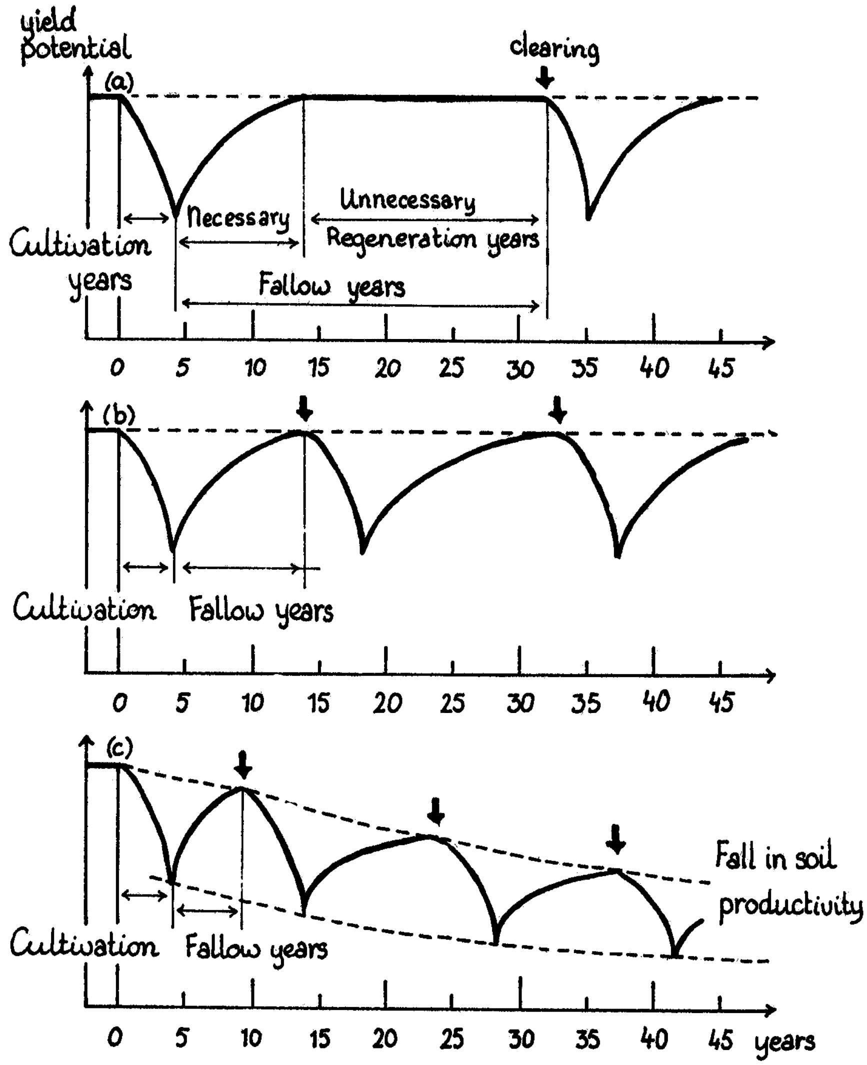


Figure 6.10 The *relation between the length* if *the fallow period* and *soil productivity* in *shifting cultivation;* when *cultivated the soil productivity drops (compare fig.* 6.9) and it *recovers slowly* when *the land* is *left fallow;* a & *b give situations where the fallow period* is *long enough for the soil to recover fully;* in *c the land* is *cultivated with intervals* which *are too* short, so *the soil productivity declines.(from: Ruthenberg,* 1976).

together and therefore they may not have enough land in the vicinity to allow for long fallows. When the soil around the whole village has deteriorated, say after one generation, the whole village will move to a new location. The system used can be described as a mixture of shifting cultivation (the long cycle) and bush fallow (the short cycle).

As explained here, more permanent cultivation i~ usually a response to an increased pressure on the land, but it is only possible if measures are taken to prevent the loss of soil fertility and the increase in weeds during cropping. As regards the problem of nutrient shortage the following practices can facilitate more permanent cultivation:

* **Choice of land**: clay soils contain a larger store of nutrients than sandy soils, so it will take a longer time before nutrient shortages will appear.

  But generally the poor drainage of the clay soils gives problems and cultivation is more difficult than on sandy soils, with the simple tools available.

* **Recycling wastes**. A close approximation of a natural nutrient cycle is possible when the fields lie directly around the homestead and all human wastes go back to the fields. The areas closest to the homestead benefit from sweeping the compound and are generally the best plots, used for vegetables.

* **Applying mulch** or wood from outside. An important source of fertility of newly cultivated land is the burning or destruction of grasses and trees. They may contain as much nutrients as the soil. In several places people learned to make use of this fact. In stead of clearing a new plot, they bring dead wood or cut grass to the crop fields and either burn it there or leave it for termites to clear.

  This is done, for example, in some part of the flood-plain, where high land for cultivation is scarce, but tall grasses and wood can easily be found. Plant-remains covering the soil as mulch are important for protecting the soil from sun and rain.

* **Applying manure**. Some of the cattle-keeping tribes have learned to use manure on the crop land. Thus the nutrients contained in the manure, which were 'harvested' from the large area where the animal grazed, are concentrated on the crop field. Sometimes the manure is collected and brought to the fields, but a simpler method is to keep the cattle on the crop fields at night after the harvest or to tether the cattle there before and after they go out for grazing during the day.

  This practice seems mainly to occur in Aweil and Gogrial Districts of Bahr el Ghazal province. In many other places tse-tse flies prevent the keeping of cattle on cultivatable land.

Manure helps to increase the humus content of the soil, which important for the soil structure. If it is burnt for cooking or keeping insects away with the smoke, the ash still contains many of the nutrients.

* **Flooding.** The river Nile with all its tributaries is the main natural resource of the Sudan, not only for the water it brings, but also for silt, rich in nutrients, which it leaves on the land after flooding

  Annually flooded land can be cultivated almost permanently, without exhaustion. In the Northern part of the Nile-valley this land is called **Gerf** land or **Seluka (A.).**
* **Green manure.** To some extend the cultivation of 'green manure' crops can help to restore soil fertility. These are mainly leguminous crops, which contribute to the nitrogen status of the soil. Several form a good quality fodder for the cattle. When left on the soil or ploughed under they help to increase the humus content of the soil as well.
* **Trees**. If some trees are left on the land, they can keep their function of nutrient pumps. Leguminous trees, such as *Acacia*, can contribute to the nitrogen supply in the soil as well.

  A particularly helpful tree is *Acacia albida* of the Sudan savanna zone, which has the peculiar characteristic of shedding its leaves in the wet season. So it does not shade the crops, it provides valuable shade in the dry season, and its leaves are available for decomposition at the start of the rains.

Many of these practices not only help to maintain the nutrient levels of the soil, but they also help to maintain a good structure of the soil. Keeping the soil covered with living or dead material throughout the year, to prevent the direct contact of sun and rain with the soil, is the main issue. Inter-cropping various crops will contribute to this end.

As regards the weeds, pests and diseases, more intensive cultivation is only possible if these are kept at low levels. By using a strict system of crop rotation, different crops alternating with each other on the same plot, the pests and diseases which are specific for certain crops can be kept at a low level.

In case of *Striga*, growing certain crops such as Cotton or Melon may be even better than a bush-fallow, as the Cotton or Melon roots stimulate the *Striga* seeds to germinate, without a chance of survival.

A fallow period of one or two years can help to reduce the weeds which are not restricted to particular crops. This was experienced in the Gezira for example when in 1960 the crop rotation was reduced from an 8 year cycle with 4 years of fallow to a 4 years cycle without fallow. The weed problem greatly increased.

6.5.E. Suitability of the land for cropping

The choice of the right type of land for clearing is an important aspect of both shifting cultivation and fallow systems. Often farmers have developed an elaborate knowledge of the soil and vegetation to judge the suitability of the land.

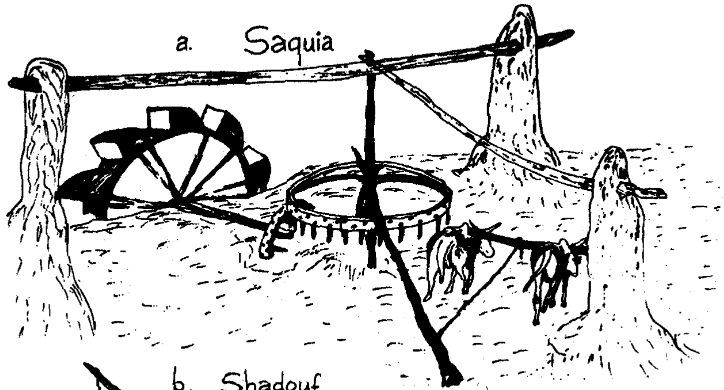
> The Jur, living near Wau in the soil and vegetation series shown in fig. 5.10, are reported mainly to cultivae the middle level slopes and terraces, covered" by *Anogeissus.* This vegetation indicates a good and deep soil. The higher lands of the Ironstone plateau are only used near anthills and-other small pockets of deep soil. For Dura *(Sorghum)* loamy soils are preferred, for groundnuts sandy soils. They avoid shallow soils, indicated by Mahogany *(Khaya)* and by annual grasses.
>
> In the Kajo-Kaji area a variety of soils is available and farmers prefer different soils for different crops. Soils are recognised on the basis of colour, structure in both the dry and the rainy season and on the species and quality of the grass. Maize, pumpkin, rice and sugarcane are grown on loam or clay soils, rich in nutrients; groundnuts and cassave on sandy soils which are easier to dig. Dura *(Sorghum)* Can be grown on both types of soil.
>
> In the floodplain the choice of land is mainly governed by the height and the likelyhood of flooding. Usually the lowest parts are cultivated first, so that the crops can ripen before the floods reach the field.
>
> In Western Sudan cultivators used to live close to the boundaries of the land systems, exploiting the different properties of soils on two sides of the boundary to spread production over the year. Dura and Dukhn can be grown on sandy soils during the rains; in the dry season vegetables can be grown on heavier, alluvial clay soils.
>
> In the Northern Sudan the low-lying lands along the Nile are preferred, I because of the flooding whicb brings fertility. Besides, the traditional means of irrigation, the **Shadouf** and **Saqiya** waterwheels, can only lift the water to a limited height (figure 6.11).

6.5.F. Clearing the land

Various methods are used for clearing the land, depending on the type of vegetation. In forest or dense woodland savanna clearing is a matter of cutting trees, waiting till they dry and then burning them.

> Sometimes trees are killed by girdling: removing a ring of bark, thus pre venting phloem-transport of sugars to the roots. Once they are dead and dry, the trees can more easily be cut and/or burned. Sometimes this is not done till I after the first cropping season.

Tall grasses in the rich woodland savanna are usually cut with the malodiahoe. When this is done during the rainy season dura seeds can be broadcasted in between the grass first and worked under the soil while removing the grass.



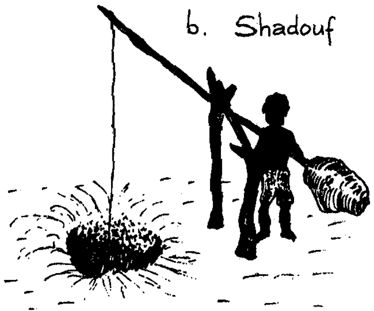
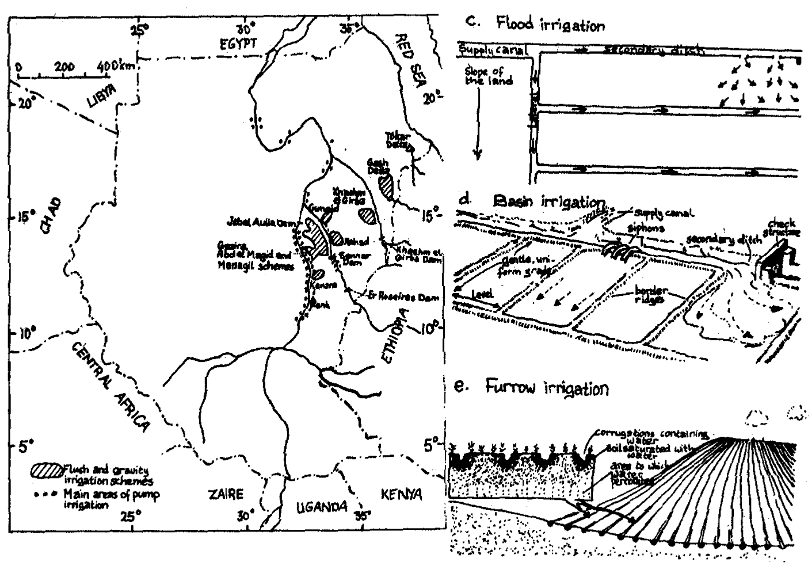


Figure 6.11 Traditional. irrigation techniques:
a. Shadouf, a hand-operated lever,
b. Saquia, with camel or oxen as draught animals
c, d, e. irrigation layouts (various sources).



When these grasses are cut in the flowering stage they do not cause many problems by regrowth.
In the Sudan savanna zone the 'hariq' clearing system is used. Tall grasses are kept free from fire throughout the dry season and are burnt only after the first rains have started. The grass plants have then exhausted their dry-season reserves in the young regrowth and are completely killed by fire. For young trees this type of fire is very destructive as well. Protection of the hariq-grasses during the dry season is a village obligation.
In other cases valuabe trees are spared in clearing the land. *Butyrospennum* (Lulu, A.) in the rich savanna area, *Balanites* (Heglig (A.); That! (D.)) in the drier savanna types and *Acacia albida* (Haraz, (A.)) in the poor savanna zone are often left on the land.

6.5.G. Mixed cropping

In traditional agriculture, **monocultures** of one crop only are rare. Often the fields are used for several crops at the same time, simultaneously, partly overlapping or in some sequence during the cropping season. This **mixed cropping** (fig. 6.12) can have several advantages.
The first advantage is a form of spreading of risk: if one crop fails others may do well and partly compensate for the failure. The fact that traditionally no pure breeds of a crop are used but always mixtures of varieties, works in the same direction.

> In a survey around Gogrial it was found that a farmer used four different varieties of Dura, with different qualities and times for sowing and harvest. Within these four varieties a total of31 different lines were recognised, each with their own name and characteristic. In an environment where rainfall and flooding vary from year to year, this variation in the crops used, helps to stabilize the yields. If one line fails due to shortage or excess of water, others may do well. Variation in the crops used is also of importance in the resistance to pests and diseases. Of a broad spectrum of genetic lines some are likely to do well, while others fail, depending on the disease attack. This spreading of risk is even better when different crops are grown in the same field.

A second advantage of mixed cropping is that sometimes the combination of a crop with others helps to protect it from attack by pests and diseases. Finding the desired crop plant visually or by smell is much more difficult for pest organisms when these plants are not grown in a monoculture but mixed with other plants.
A third advantage for mixed cropping of different crops is that with some combination the total yield will be higher than the yield of one crop only, even in the absence of pests and diseases. When there is some form of

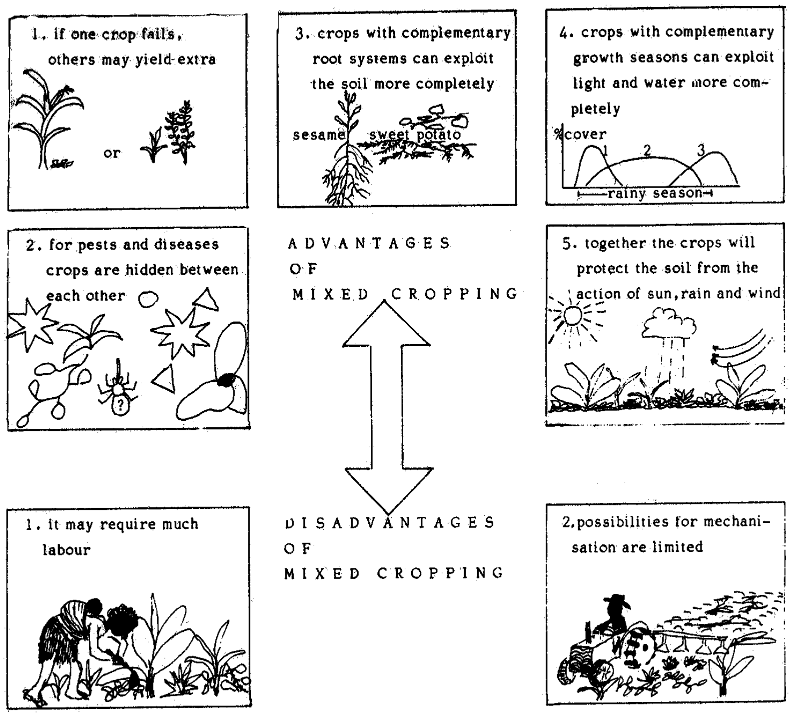
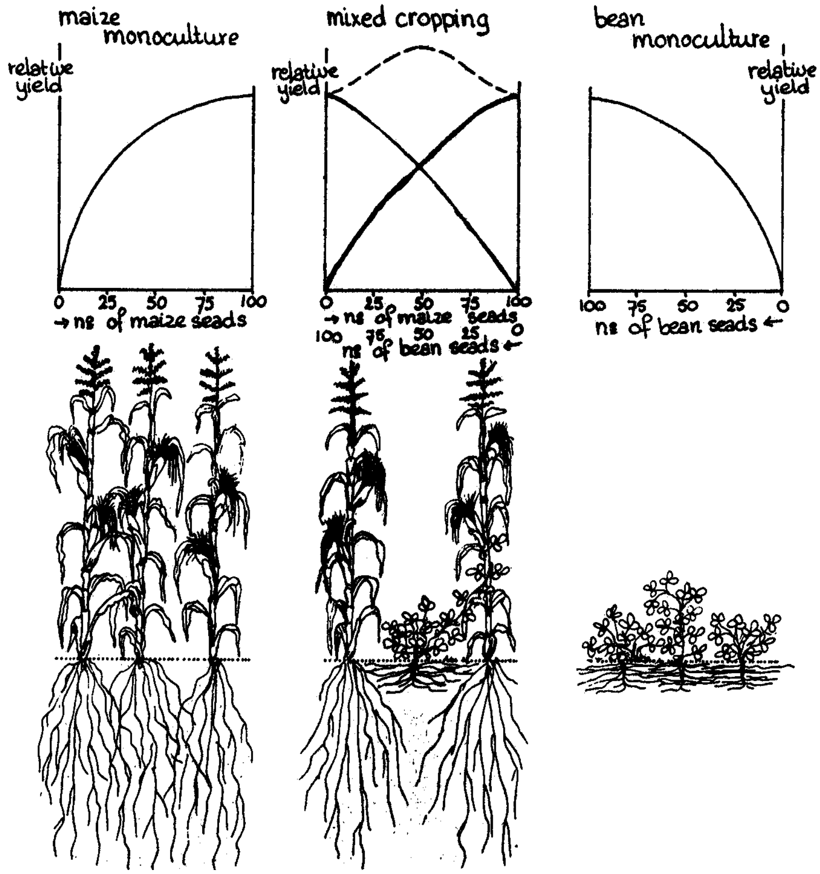


Figure 6.12 *Advantages and disadvantages of mixed cropping. (or.).*

niche-specialisation between the plants such an advantage can be expected. Combinations of a leguminous crop with a cereal grain (e.g. groundnuts with dura, beans with maize) are the best example: the leguminous crop have their own supply of nitrogen, (fig. 6.13) while the cereal grains with their more elaborate root system are the stronger competitors for other nutrients and water. Yam, sweet potato, fingermillet *(Eleusine)* and groundnuts have a shallow rootsystem; sesame, cassave and the large cereal grains have a deep root system.

In selecting combinations of crops, the growth pattern of each crop has to be considered. For combinations of maize with climbing beans, the maize has to be planted earlier to provide support to the beans. A combination of Dura with green gram beans (Mungbean, *'Phaseolus aureus)* can be sown together: the beans will mat\1re in about two months and will not interfere with the growth of the Dura, even when the latter is sown at the same density as in a monoculture.

Figure 6.13 *Experiments comparing yield* in *mixed cropping of maize and beans, with the two monoculture's; mixed cropping is advantageous* in *this combination, as, seen from the 'hump' of the total relative yield curve. (or.).*



When the field is not homogeneous other possibilities for niche specialisation exist. On cropped fields of an Azande farm, a total of 68 crops was once recorded. These are not randomly mixed -each crop has a special place, rich in nutrients (refuse-heaps, old anthills) or poorer (sandy spots or land after a few years of cropping), in the full sunlight or partly shaded, near the homestead with a constant protection against pests (e.g. sweet cassave)-or away from the homestead for crops which are not attacked such as bitter cassave.

This large variation in crops has often been described as 'primitive' by people educated in foreign agriculture. But instead of being primitive, it probably is the best way of using the land, especially if variety in the diet and spreading of risks of pests and diseases are accepted as advantages. The main problem of mixed cropping is that it cannot be mechanised easily.

6.5.H. Pests and diseases

If man causes an abundant growth of crop plants on the fields, it is quite natural that this food supply attracts other organisms as well, who start to compete with man for this food resource. These organisms are called pests or diseases because man wants to have a monopoly. But to keep this monopoly requires much activity and many tricks. Colonisation of the field by the pest organism can be hindered by choosing isolated fields, or growing the crops in mixtures with others so that they become difficult to find. The same crop should not be grown on the same land in consecutive years. As to plant diseases, the best way of preventing them is to maintain a strict hygiene, removing and burning diseased plants.

Once a pest has colonised a field its growth can sometimes be hindered by the presence of other plants with a repellant smell. But in many cases little can be done with traditional means. Chasing away birds and baboons is the main occupation of many children in rural areas in the season that the crops ripen and become attractive.

> Fences are often made from chopped *Acacia* branches but these are never completely effective. An alternative may be to plant a dense row of Sisal plants around the field, the spines of which (see figure 3.10) can stop animals from trespassing.

After the harvest large losses can still occur during storage of the crop (figure 6.14). Rats, mice and insects cause the worst problem. Various tricks are used to prevent them from eating the stored products.

> The use of smoke is the main one: cattlekeeping tribes store their grain in the cattle byres, where a smoking fire is used to keep mosquitoes and other

Flgure 6.14 *Some of the factors affecting ain storage (from: Appropriate technology source-book* 2).

insects away; other tribes use the place under the raised store for cooking or hang the crops for storage near the fire, especially the seeds needed for next years sowing. Keeping the stores clean and tight, regularly drying the stored products in the sun, mixing the crops with sand or ash and putting certain herbs in the store all help to keep the insect attack at an acceptable level. The raised grainstores of the Azande have clay-disks around their poles to prevent rats from entering the store.

The Neem tree *(Azaridachta indica),* introduced into the Sudan in this century for its fast growth contains substances which repel insects. One can use this either by burning neem-wood and using the smoke or by making an extract of leaves or ripe fruits (soaking overnight 0,5 kg of leaves or 1 kg of crushed fruits per 101 of water), for weekly spraying the crops to be protected. Pyrethrum *(Chrysanthemum tinerariaefolium)* grown in the East African high-lands contains 'natural insecticides' as well.

Remaining unaffected by insects during storage is an important quality for a crop variety. Traditional crop selection favoured resistant varieties, such as dura with a hard seed-coat or maize with leaves tightly around the cob, both of which hinder penetration by grain eating insects.

6.6 Farming systems

After considering the separate activities of animal husbandry and agri-culture, we shall now look at the complexity of the 'farming systems'. This term is used to indicate the interrelationship of all the human activities at the farm level in the natural of the man-made environment (fig. 6.15).

Just as the ecosystem consists of all the natural relations in the environment, the farming system is to a certain extent determined by the ecosystem. But human decisions, based on social or economic considerations play their role in moulding the farming system. Farming systems are in balance with the ecosystem if they do not depend on non-renewable resources and if they do not negatively affect essential environmental factors. Not all farming systems fall in this category.

In describing farming systems we shall first pay attention to the relationship between the various agricultural activities. Keeping animals and growing crops can be related activities, for example when the animals feed on the remains of the crops for at least part of the year (although they are often of low grazing quality), when the production of fodder crops is part of the crop cycle, when manure is used to fertilize the crop fields, or when oxen are used as draught animals for ploughing. Similarly, trees can be kept for some special edible product, but at the same time playa role in maintaining soil fertility, and provide a source of shade or fodder for animals.

All these interactions are only appreciated when we try to understand the combination of man's activities in the environment. Usually non of these

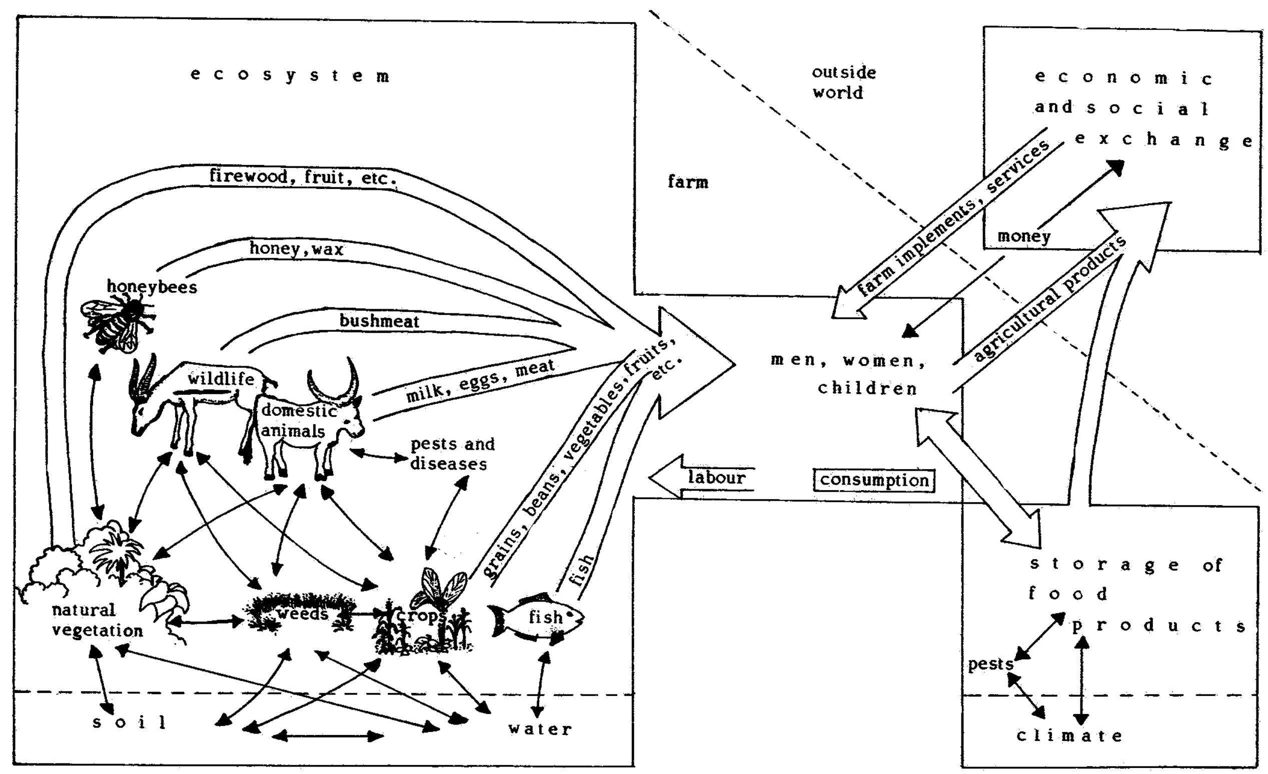


Figure 6.15 ***Farming system.*** *The farmers interact with the ecosystem (exchanging labour for edible products) and with the outside world (exchanging agricultural products for money, implements or commodities) (or.).*

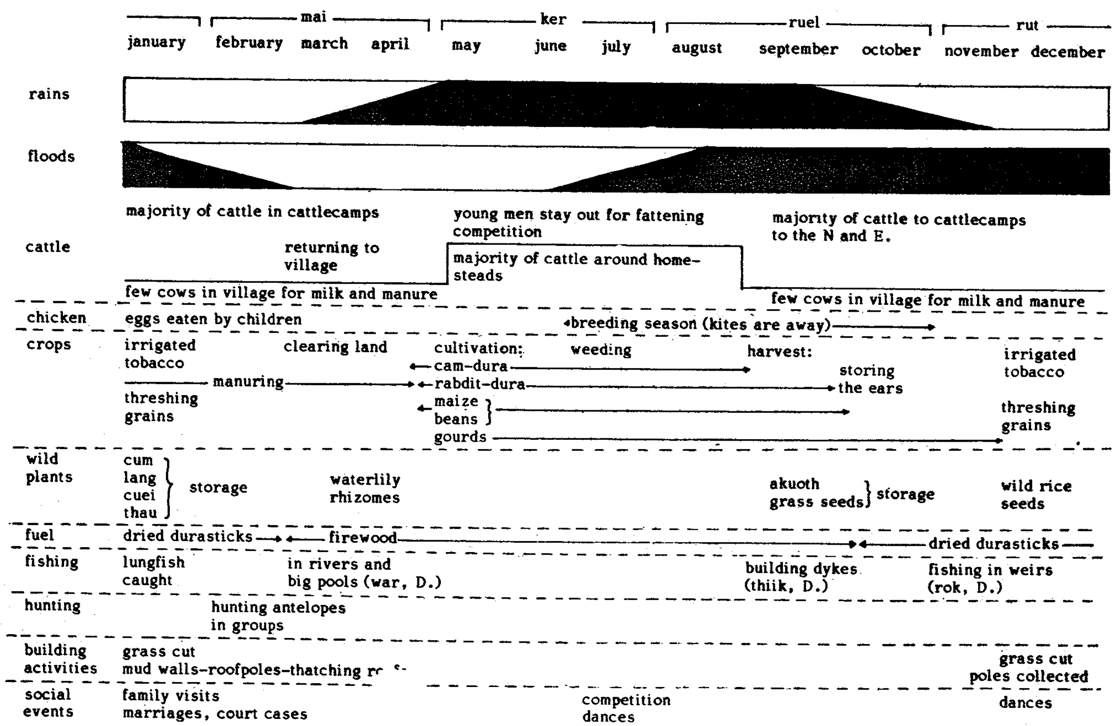
elements functions at an optimal level as such, but still the complex is a meaningful combination which can easily be distorted by trying to improve one part of it, neglecting the other parts.

As a first example we shall now discuss a common farming system of the Sudan savanna zone, characterized by the 'gardens' of gum arabic trees *(Acacia senegal;* Hasbab (A.)) The trees in the garden (Geneina (A.)) can be tapped for the valuable gum for 6-10 years before they deteriorate too much as a result of tapping. Then the trees are removed, except for some stunted *Balanites* trees, the land is cleared and used to grow a mixture, of Dura and Duhkn (Sorghum and Bulrush millet), groundnuts, simsim, watermelon and lubia beans etc. This cropping can last for 4-10 years, till the soil is exhausted or till the *Striga* has become unmanageable. When the fields are no longer cropped they are colonized by grasses such as *Cenchrus biflorus* (Heskanit (A)) and *Acacia* trees, *A. seyal* (Talh (A)) and *A. senegal.* After three years the trees are about 1 m high and become reasonably fire-resistent. With the increase of grasses fires become more frequent and they prevent the establishment of new trees. When the first generation of *Acacia* trees is around 8 years, tapping starts and the whole cycle can be repeated. The trees play an important role in the cycle, restoring soil fertility and yielding the valuable gum as well as firewood. Regeneration of trees depends on protection from fire and from grazing in the first few years.

An example of a traditional farming system with an interesting interaction between animal husbandry and an early stage of crop husbandry has been reported for the Zaghawa, living North of Jebel Marra in the Sahel-savanna zone. This area is too dry for the successful growth of most crops, but several grasses with edible seeds grow there naturally in the short rainy season. Traditionally, the valleys with good grasses were reserved for collecting grass seeds and animals were not allowed to graze there till after the harvest of these wild grasses. This procedure ensured that the grasses produced ripe seeds for next years. After the harvest of the grass seeds a good grazing land remained. Times have changed, and collecting wild grass seeds has been replaced by growing Millets, which fail in many years because of droughts. The grazing land degenerates as a result of this, because the positive inter- action with the collection of grass seeds is now lost.. There is no longer a restriction on grazing early in the rainy season and many parts are (over) grazed before the grasses produce ripe seeds. Thus the grass cover detoriates. The situation is made worse, because the grass *Cenchrus biflorus* (Heskanit) is replacing most others. Animals because of its spiny leaves and inflorescence do not like this grass, but it has edible seeds and used to be kept at a relatively low density because most of its seeds were collected. Now that this is no longer done, it replaces the grasses which provide valuable grazing.

A course of development which would do justice to this farming system might have been not to introduce the growing of Millets but to improve the available edible grasses by careful selection, because these are better adapted

Table 6.5 Agricultural calendar of Twic-Dinka (Gogrial District).



to the climate and fit in the animal production system as well. Such selection and breeding is a time-consuming process however, and the success would be limited by the ecological constraints on the production level.

As a third example of a farming system, we shall now consider the land use of the North-Western side of the floodplain by the Twic-Dinka of Gogrial District. Table 6.5 shows a calendar of activities throughout the year. Growing crops alternates with building and fishing as main activities in the permanent villages, while the young people spend most of their time outside the permanent village, trekking with the majority of the cows. A small part of the cattle are kept in the village all year round to supply milk and manure used to fertilize the Dura fields around the homesteads.

The calendar shows that in every season suitable parts of the environment are exploited. Fishing is a specialised activity for some people, but at the end of the dry season everyone participates. Elaborate systems of dykes (thiik (D)) are built to manipulate the waterflow in the seasons that the floods recede. Weirs are used for fishing and wild rice seeds are collected. One wonders why this aspect of growing rice has not yet been extended.

The calendar shows how the various parts of the farming system are connected through the amount of time people can spend on each of them. It. is of no use to stimulate fishing, for example, if this would have to be done in the time the land is cultivated. Weeding usually provides the main bottleneck timewise and restricts the area cultivated.

In the ecological zones further South the farming systems are almost completely crop-oriented.

An exception is the Kajo-Kaji area, where a large area has been cleared from tree vegetation, so that cattle can be kept without too many problems of nagana. But the Kuku have no tradition of making full use of the manure to fertilize the land and degradation of soil fertility has become a problem. The only trees available overlarge areas are Mango trees. There is hardly a fallow period in the cropping sequence and the absence of natural vegetation, while good for human and animal health, makes for difficulties in the supply of firewood.

The Azande-system of agriculture has been studied extensively and the Azande have become known as excellent practical ecologists. In their choice of where to cultivate, what crops to grow and then to sow their seeds they follow a system closely adapted to their environments.

When one enters an Azande homestead for the first time, the impression is that of complete chaos. The courtyard is shapeless; the huts in it are scattered. Crops, food and household belongings may lie about the courtyard in what seems to be a most disorderly fashion. Worst of all no fields can be seen. The thickets of plants surrounding the homestead seem as patchy and purposeless as any wild vegetation. It is impossible to distinguish a crop from a weed. It seems almost incredible that a human intelligence could be responsible for this tangle.' This is a quotation from an elaborate description of the shifting cultivation system by De Schlippe.

Azande-agriculture should be looked at in the light of two concepts, the field-type and pseudo-rotation. The field-types consist of the following associations of crops which are grown together from time to time:

* öti-moru, the main fingermillet *(Eleusine)* association, in which maize and fingermillet are sown side by side;
* baawande, the groundnut-association, in which groundnuts, maize and cassave occupy the same field, perhaps followed in the same year by fingermillet, maize or other crops;
* bamuno, the fingerrnillet through grass association, with perhaps sesame following; .
* the ridge cultivation around the homesteads with many vegetable crops;
* various beans, sown through grass;
* and finally the cassavefallow.

Variations in the weather, the actual success of the crops as they grow, the appearence of the land, the weeds present and the question of how much time or energy the farmer can spare, all affect the order in which these types are sown on anyone field. For these reasons it is not possible to speak of any fixed rotation of crops, but rather of a pseudo-rotation, which is none the less securely rooted in the soil because it varies from year to year. In view of the large number of crops cultivated it is not surprising to learn that the Azande enjoy a diet balanced in most respects. They are even able to obtain enough protein, though they keep no animal stock, obtaining it partly from vegetable sources, partly from hunting wild animals (bush pigs) and partly from collecting termites.

Of course not all farming systems are equally well adapted to the environment. Especially in cases, where people have moved into their present: environment quite recently, ill-adapted systems can be found.

An example is found in the Dongotona mountains, where anti-erosion measures are quite inadequate. According to local traditions people moved up into the hills relatively recently, perhaps little more than a century ago. If this is true it helps to explain the obvious unsuitability of their system of agriculture, to the steep and rocky places they inhabit; it would also explain the fact that there is any cultivatable land left at all, for if erosion had been continuing at its present rate for a long period the whole of Dongotona hills would have been barren rock by now.

An interesting aspect of any farming system is the question of the scale of the fields. Concentrating the fields offers the advantages of an easier defence against intruders (in historical times) and against wild animals such as baboons. But weeds, insect or bird-pests have far less chances in isolated crop-fields than in concentrated ones.

> Obtaining firewood and protecting the soil is a problem in case of concentrated fields. For tse-tse flies the relationship with the environment has been mentioned already. For the *Quelea* (Sudan dioch) weaverbirds obvious relations with the environment exist, as the birds need roosting sites and drinking water close to their feeding areas, which may include crop fields. The cotton stainer bug *(Dysdercus spec.)*, an important pest of cotton can use the Baobab tree as an alternative host and as a breeding site for continuous infection of cotton fields in the neighbourhood.

It is important to stress the complexity of traditonal subsistence farmind systems. These systems were developed to supply all basic human need within he possibilities of the ecosystem. A 'generalist' or 'opportunist' strategy was used-to overcome the problems of a fluctuating environment. When subsistence farmers enter into the money-economy of the 'modern' world, they will feel strong pressures of competition. And just as in natural ecosystems, competition leads to specialisation. Farmers will start to concentrate on the one crop with best financial prospects, neglecting the other components of their farming system. Often the diet of the rural families deteriorates when the variety of traditional crops disappears because al time is spent on cash crops. Complex systems with much spreading of risk are replaced by simple systems with a maximum financial yield it favourable years. Just as in natural ecosystems, specialisation is only successful in stable environments. In the present world-economy with its fluctuating prices, concentrating on one or two crops is a very vulnerable strategy. Sudan as a nation has experienced this for cotton. More diverse, complex farming systems may not give the best short-term economic returns, but they may well be the best way of preserving the natural resources and fulfilling all basic needs.

6.7 Suggested practicals

1. Key-questions for ecological analysis of farming systems

Before we can develop any system in a meaningful way we have to understand how it works, what the strong and weak points are and which connections there are between the different parts. This also applies to 'farming systems', the way In which man makes use of the natural resources. As a starting point we can assume that systems which have a long tradition have gradually become adapted to the local situation, although this 'wisdom of the people' may consist more of their actions than of their explanations. By trying to analyse the system with the following questions as guidelines, we may gain insight in this and may arrive at appropriate

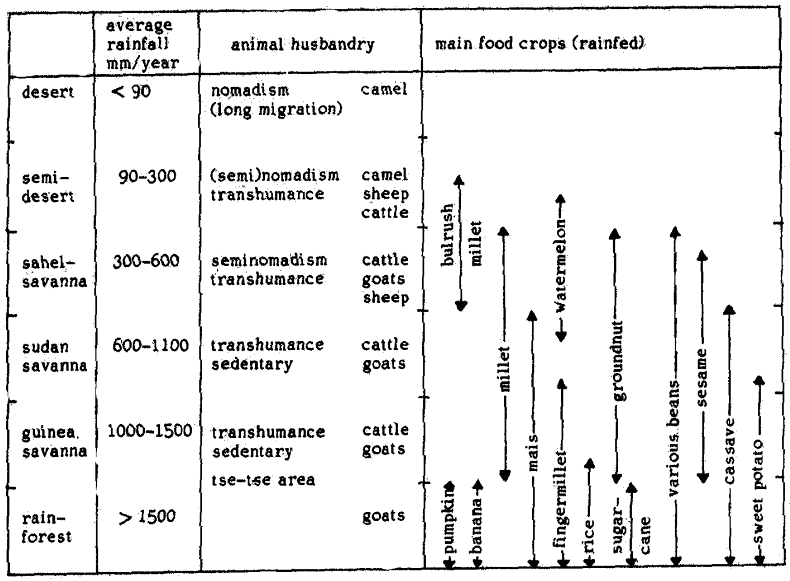


Figure 6.16 *Type of animal husbandry and major foodcrops for the various ecological zones (from various sources).*

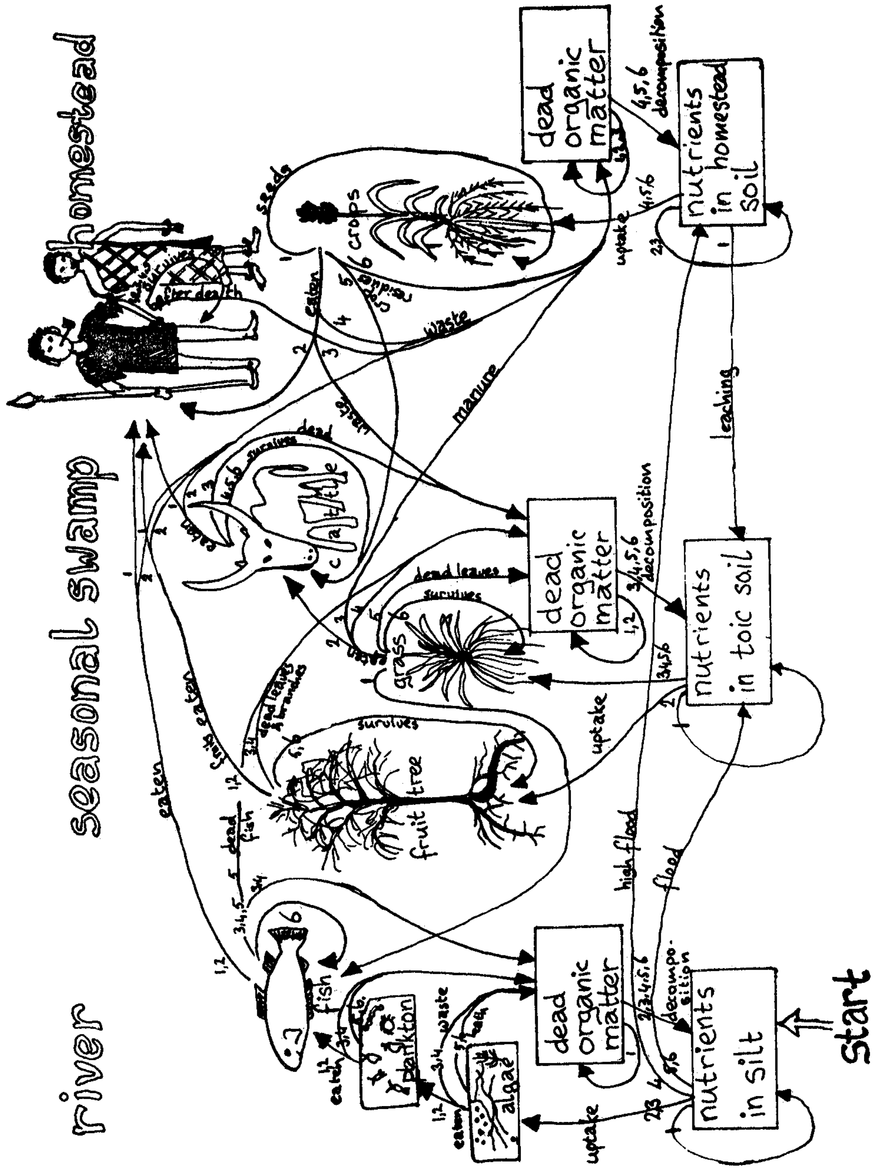
suggestions for improvement:

1. How are the environmental conditions, climate, soil, topography? What kind of local variations are there? Which seasonal fluctuations, reliability of rainfall etc.?
2. Which plants and animals are used, what are their adaptations to the environmental conditions throughout the year and throughout their lifecycle?
3. In which ways is man interfering with these resources: just collecting and harvesting or really managing (with all kinds of intern1ediate steps)?
4. Which micro-patterns in land use can be distinguished, in relation to (small variations in) soils and microclimate?
5. What is the settlement pattern, are there any long-tern1 cycles in land use?
6. Is there anything like transhumance in seasonal habitats? What is the human food in different seasons?
7. What is the human influence on vegetation structure and species composition (grass/tree balance in savanna, fire, habitat destruction, deforestation)?

8. Is the present system stable? (Ask old people, seek historic references).
9. In which way can we speak of multipurpose land-use (integration of animal production, forestry, crop production, wildlife and/or fisheries)?
10. What happens to the wastes and manure? Is there a nutrient cycle? How is soil fertility maintained? (flooding, recycling, fallowing, manuring).
11. Which elements contribute to pest control during production and storage?
12. Which elements contribute to weed control?
13. Which elements contribute to control or spread of animal diseases?
14. What is the scale of migrations of relevant fishes, wildlife or pests during their life-cycle? To which extent is life in this area dependent on other areas?
15. How far has the human population grown in relation to the carrying capacity of the system? Are there signs of competition for land? Land degradation?
16. How is the quality and quantity of food for all age groups throughout the year?
17. How is the hygienic situation, what are the major causes of illness and death?
18. Which sources of energy are used? Are they renewable?
19. Which human resources are used and how is the distribution of labour?
20. What are the main problems according to the people concerned?
21. Which changes are presently going on in all the aspects mentioned? Which outside forces are pulling or pushing?

2. Nutrient. cycle game (fig. 6.17) for mixed farming as practiced in the flood plain (for roles see practical 5.2).
3. In this chapter the traditional usage of many different plants was mentioned; can you give further examples?

Figure 6.17 *Nutrient cycle game for floodplain agriculture; the game can be played in the same way as figure* 5.14. *(or.).*


river
seasonal swamp
homestead
fish
plankton
algae
fruit tree
grass
crops
dead organic matter
dead organic matter
dead organic matter
nutrients in silt
nutrients in toic soil
nutrients in homestead soil
uptake
leaching
flood
high flood
decomposition
manure
waste
eaten
start

7. Environmental problems of development

7.1 Human population size and pressure on land

Part of the environmental problems of development arise merely from the increase in the number of people living in the world. The increase in numbers is mainly a result of improved medical care and hygiene, taking away many natural limiting factors. The numbers can only increase as long as the' carrying capacity' of the environment has not yet been reached, so that enough food can be produced. It is to be hoped that the world population will stabilize before this carrying capacity is reached. Many social, political and religious arguments play their roles in the decision about family planning however. As long as social security is mainly based on the family, restriction of the family size is not to be expected. Increased possibilities for education and finding jobs, for both men and women seem' to be a prerequisite for a smaller family size. An important consideration should be that even if today everyone will decide not to produce more than two children, the population will continue to grow for some time, because """ now there are relatively many young people.

An increase in numbers leads to an increased pressure on the land, which means that the exploitation has to be intensified. For every person food, drinking water, energy and a place to live has to be made available.

Many traditional farming systems are well adapted to the environment as long as the pressure on the land is fairly small, but when the numbers increase, new and unexpected problems will have to be faced.

In the Sudan the human population size increased from around 2 million in 1900 to around 20 million in 1980. These data are not very reliable, but they show an obvious trend.

> In every generation (20 to 30 years) the population size is apparently doubled. The population would be constant if every woman on average would give birth to two children surviving till they marry themselves. Apparently in the Sudan this number is on average 4 rather than 2.

The average population density of Sudan is low of course, but many parts cannot be used for living at all. In several inhabited parts it seems that the human population has approached the carrying capacity of the environment already, at least with the agricultural techniques available.

> In the floodplain conflicts over grazing land are very common, showing that all the suitable land is used. In the dry savanna zones the pressure on the land leads to soil degradation already.

Not only the total number of people is important, but also their distribution. The concentration of people in towns results in extra environmental problems, as the locally high pressure on the land for food and fuelwood will lead to overexploitation and degradation of the land.

Waste problems also increase when people become urbanized. The permanent settlement of previously (semi)nomadic tribes also leads to a locally increased pressure on the intensively used land around the new villages, while previously a large area was used extensively.

Apart from the size and distribution of the human population, the life-style and consumption pattern of the citizens is important as well. Generally, the more one consumes, the more environmental problems occur.

In a world scale this factor is far more important. The life-style of large groups in the Western world is such that it affects the environment all over the world. Here a change in life-style 'is more important than a change in population size.

Large scale pollution of rivers, seas, oceans has become common practice; the soil is in many cases polluted to such an extent that crops grown are no longer safe for human consumption and groundwater is only drinkable after intensive cleaning operations; the air is polluted to the stage that it can be hazardous especially for very young and old people; the high rate of consumption of fossil energy has released such quantities of carbondioxide into the atmosphere that effects on the climate on a worldscale can be expected; the use of nuclear energy (for electricity and weapons) has released radioactivity into the environment potentially affecting the genetic constitution of all life forms. Most of these problems can be counteracted to some extent by technical and legal means, but of course prevention is better than cure! We will here focus on the specific environmental problems in Sudan.

7.2 Desertification

A major environmental problem caused by recent developments in the Sudan is the process of desertification. Large areas the dry savanna zone have become desert:1ike already. This means the loss of usable land and an increased pressure on the remaining land. Yields decrease and dust-storms (habub) become more frequent. Quite often desertification is still described as 'the Sahara is creeping Southwards'. This is a confusing description of what is happening. Moving sanddunes are only the last stage of a process of local deterioration of the land on sandy soils. On clay soils deterioration can be as severe, without moving sanddunes.

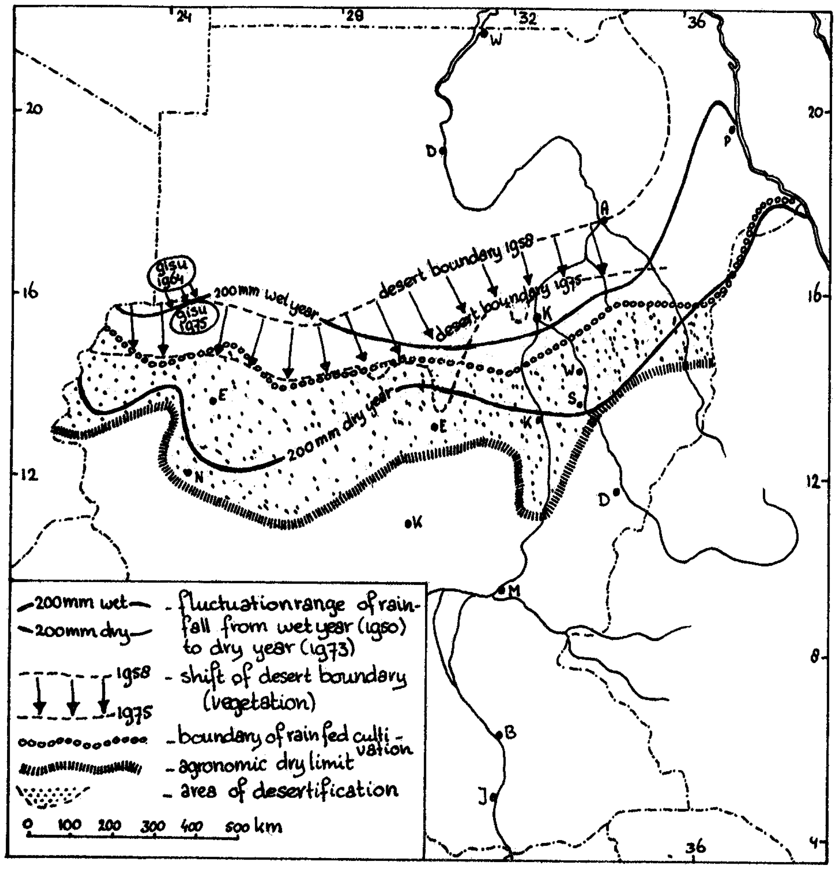


Figure 7.1 Desertification in the Sudan;
yearly fluctuations of rainfall are shown by the 200 mm isohyet for a dry and for a wet year; rainfed agriculture is hazardous when there is a chance of receiving less than 300 mm of rain; a safe limit is indicated, but the actual boundary is far more to the North; the zone between these two lines is in risk of desertification; according to certain sources the desert boundary in 1975 was 200 km to the South of its 1958 position. (based on Rapp, 1976 and Fouad Ibrahim, 1978).

The land is over-used and the vegetation disappears, leaving the soil open to erosion by wind and rainstorms. So desertification comes about by degradation of patches of land, which gradually unit to form a continuation of the desert zone. Fig. 7.1 shows the approximate boundary of the desert for 1955 and for 1972. In this period of 17 years, a zone of about 100 km has become desert as a result of several factors. A further 680.000 km^2 is directly threatened with desertification at the moment. Large areas of the Sahel zone are locally deteriorating. Factors which are held responsible for this desertification include:

a. climatic changes
b. overcropping
c. overgrazing
d. deforestation
e. overexploitation of groundwater.

We shall discuss them seperately, although in fact they interact.

7.2.a. Climatic changes

During geological history the climate has changed considerably. Dry periods alternated with wet periods. During wet periods all vegetation zones shifted Northwards, during dry periods they shifted Southwards. (See section 5.7).

The present process of desertification is however, of a different scale. There is no evidence of permanent rainfall changes over the last century. Periods of some wet years (such as in the 1950's) alternate with periods of dry years (1970's), perhaps in a cycle of about.40 years. In dry years the desert shifts to the South; but in wet years the vegetation does not recover any longer because of human activities. Trees such as the Baobab seem to get established only in relatively wet periods. During dryer periods destruction of the trees is extra serious because replacement is impossible.

7.2.b. Overcropping

The main factor in desertification of the Sahel zone is overcropping. Too much land is cleared of the natural vegetation for growing crops, in areas where a good crop is possible only in exceptionally wet years. In normal or dry years hardly any crop grows and the land is open to the wind. Large scale mechanised farming schemes are far worse than the traditional small scale operations, because often no trees are left to break the wind. .

> Traditionally the crop fields were always relatively small patches amidst bush. For mechanised farming trees are considered to be an obstruction to the machinery and the fields are much larger, out of the influence of bush-vegetation as windbreak.

Overcropping is mainly the result of applying agricultural methods not adapted to the environment. Mechanised farming methods which had proven to be successful in the clay soils of Central Sudan were transferred to I the sandy soils of the West, with devastating results.

A similar mistake was made in North America in the 1930's when soil tillage methods from Europe and the American East coast were transferred to the middle of the continent. Large scale wind erosion, known as the American dustbowl, was the result and large areas of good agricultural soils lost their value.

Good farming methods, including soil tillage, have to be developed for every ecological zone seperately, to avoid such disasters.

Overcropping means, using land which is not really suitable for growing crops, because the rainfall is unreliable. Paradoxically, the wetter-than-normal years in the 1950's were probably more decisive for desertification than the dryer-than-normal years in the 1970's. Wet years lead to too much optimism and to clearing unsuitable land. In fig. 7.1 a line indicates the present boundary of crop production and the area where at least 300 mm of rain can be expected taking into account the normal yearly fluctuations. This can be considered as a safe limit for rainfed crop production.

This description of desertification suggests that in first instance vegetation and soil disappear in areas where on the average sufficient rainfall is still available. It seems as if rainfall may decrease locally as a secondary effect, because normally the transpiration by the vegetation can trigger new rainfall. In many areas affected by desertification however, lack of water is no longer the main limiting factor, but has been replaced by poor nutrient supply because of soil degradation.

7.2.c. Overgrazing

The role of overgrazing in desertification has been overestimated, but it certainly can contribute. Between two censuses in 1916 and 1956 the numbers of sheep and goats increased by a factor 6, while the numbers of cattle and camels increased by a factor 10. But the amount of grazing grounds available did not increase.

In section 6.3 we saw that in the dry savanna zone insect pests and the availability of drinking water limit domestic animals more often than availability of forage. But increased veterinary service and well-drilling for supplying drinking water have partly changed this situation. Projects to settle nomadic cattle keeping tribes permanently often lead to overgrazing.

Especially around towns and around permanent water sources, overgrazing of the vegetation, is common. Only plants like *Cassia senna* (Senna, A.) and *Caloptropis procera* (Usher A., fig. 3.6) are left over, because they conntain poisons. Overgrazing leads to a reduction of the carrying capacity by preventing regrowth and by trampling which reduces the infiltration of rainwater into the soil. A further concentration of animals on the remaining land is the result and thus more land is overgrazed. It is a vicious circle which can only be broken by restricting animal numbers, and by giving the vegetation a chance to recover by fencing off certain parts and establishing rotational grazing.

> Programs to permanently settle nomadic pastoralists have been set up in many places, but these programs neglect the fact that only by roaming through large areas sufficient amounts of the high quality fodder can be found in the Sahel zone. Mobility is essential. High biomass production is often associated with poor quality on the permanent grazing land. Recent research showed that in sedentary herds the death-rate can be double that of migrating herds, while the calving rate is only 60 % of that in migratory herds.

7.2.d. Deforestation

The original vegetation cover is removed to create crop-fields, but also to supply fuelwood and charcoal for cooking. Around all towns the circle from which charcoal and fuelwood are collected widens every year. For the, Khartoum area it is now over 200 km already.

> The consumption of fuelwood is ca 1:5 m3 or 200 .kg per person per rear, while the growth rate m the Sahel savanna can be m the order of 5 m per hectare per year. As long as 0.3 ha of well managed woodland per person is available, no problems should arise (300 persons/km2 of well managed woodland). The population density in the Sahel zone as a whole is ca 8 persons/km2 but around El Fasher or El Obeid it is ca 70.
>
> In such areas one quarter of the area would have to be set aside for production of fuelwood. In general the main problem is that of managing the forests in such a way that the growth rate can remain high enough by establishing new trees, protecting the soil etc.

In practice cutting the wood comes down to using a non-renewable resource, because several factors hinder the establishment of new trees: fire, in the grass vegetation which usually develops, grazing especially by goats and degradation of the soil when this becomes exposed to the sun, wind and rain.

> A major aspect of both overgrazing and deforestation is the social aspect of a communal resource. Everyone can benefit from using it, but no one will take care to protect the resource. Especially since the original tribal restrictions on land use weakened or disappeared the problem is acute. Who will plant or care for young trees if other people will come to cut them before they are full grown? (see chapter 9).

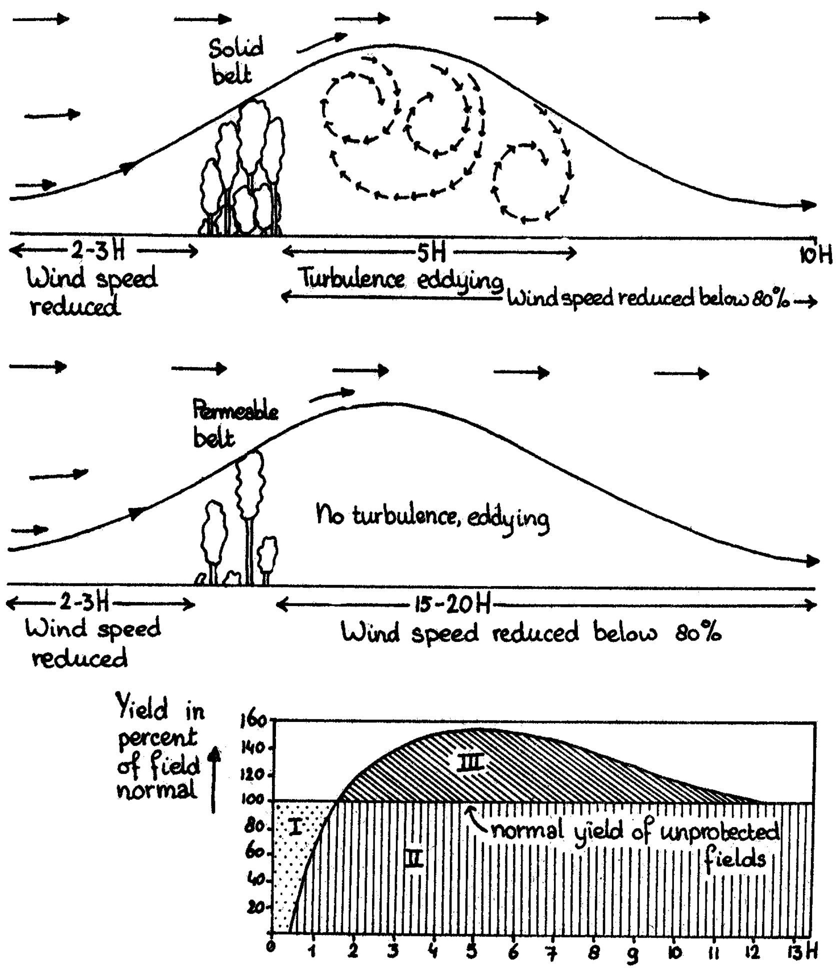


Figure 7.2 Effect of a shelterbelt on micro-climate and on crop yields:
a) A solid belt gives shelter, but behind the belt the air becomes turbulent and this is a disadvantage; b) A half-open, permeable belt does not give turbulence and gives a maximum reduction of the wind-speed the wind-speed may be reduced below 800% for more than 15 times the height of the trees (H); c) The shelter belt usually has a positive effect on crop yield, although this is not easily seen in the field, as the loss near the trees due to competition (1) is more evident than the gain further away (III), which is larger but spread out over a large area based on FAD 1977.

7 .2.e. Overexploitation of groundwater

Amazingly little is known about groundwater resources, especially whether they are renewable resources or fossil supplies which can be depleted only once. Many well drilling programmes therefore contain the risk of a success for a few years and a complete failure afterwards, especially because the vegetation can be affected by deepening the groundwater level as well. Well-drilling programmes can also lead to overgrazing of the surrounding land.

> It is important to know in which way deep groundwater resources are recharged, before desicions about well-drilling are made. Part of the loss of water from riverbeds refills groundwater streams. The main groundwater streams occur in the Nubian sandstone.

7.2.f. Possible solutions

Any solution should be based on a proper understanding of the causes of the problem. Overcropping has been mentioned as the major factor causing desertification, especially when all trees are removed from large areas. Keeping solitary trees on the field and planting rows of trees between the fields as shelterbelts (fig. 7 .2), helps to alleviate the problem of wind-erosion.

> Often the crop-plants directly adjacent to the shelterbelt show a reduced growth due to shading by and competition for water with the trees, but the plants further away benefit from the shelter and the reduction of wind speed, slowing down transpiration; for the field as a whole yield is increased.

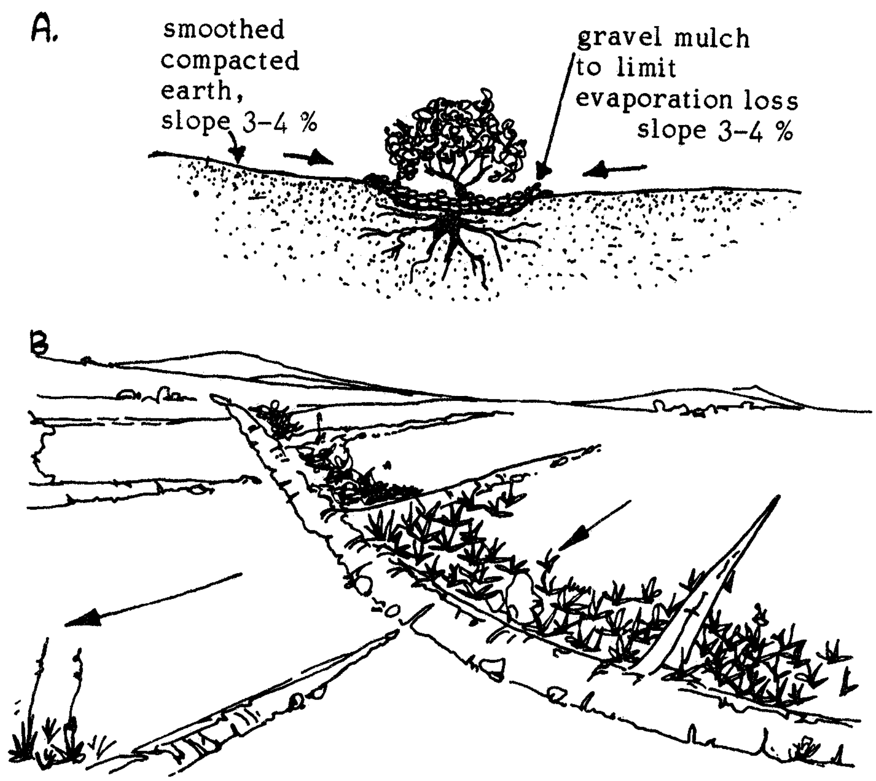
Several introduced exotic species of trees are used for planting in arid

Table 7.1 Some exotic tree species suitable for afforestation programs; ecological zones 1 =semi-desert, 2 = Sahel savanna, 3 = Sudan savanna, 4 =Guinea savanna.

Scientific name	English	Ecological zone				Products
Tamarix aphylla	Tamarix	I,	II			firewood
Prosopis juliflora	Mesquit	I,	II,	III		firewood
Eucalyptus microthera	Eucalyptus		II,	III		building wood
E. camaldulensis	Eucalyptus			III,	IV	building wood
Azaridachta indica	Neem		II,	III,	IV	building wood, insecticide
Leucaena leucocephala	Leucaena			III,	IV	forage, firewood
Cassia siamea	Cassia			III,	IV	construction wood
Mangifera indica	Mango			III,	IV	fruits, firewood
Gmelina arborea	Melina				IV	firewood
Tectona grandis	Teak				IV	poles, timber

regions, because they grow faster than indigenous species (table 7.1). Some of these trees are doing so well that they spread by themselves and may even become a problem in the crop fields as invasive exostic (Mesquit).
Eucalyptus is a fast growing tree with some species adapted to dry conditions. However the soil under Eucalyptus is hardly protected from erosion.
The social aspect of communal land rights on grazing land or fuelwood production has to be considered for any solution to work. Some techniques are available for 'water harvesting' in arid zones, trying to collect rain water around trees (figure 7.3). Further aspects will be discussed in section 8.4.

Figure 7.3 A. Technique for 'water-harvesting' around a tree by promoting run-off in its surrounding and promoting infiltration under the tree; B. Strip farming collecting run-off. (Appropriate technology sourcebook 2; FAO).



7.3 Savannisation and deforestation

Similar to a desertification of the (dry) savanna-zone, there is a 'savannisation' of the forest zone, shifting the border between closed forest and savanna to the South. The boundary between forest and savanna generally is a sharp one, because a continuous grass cover is absent from the former one and present in the latter. Once there is a grass cover it will maintain f itself through annual fires, killing the tree seedlings. Fire is the main factor in savannisation.

> Wild creeping fires usually start from fires used to clear small parts of land for cropping or larger parts for grazing on the green regrowth after a fire. Fire is also used in hunting to drive the animals towards the hunters. Fires used to smoke out bees nests to collect honey can escape controle and are another source of the 'wild creeping fires'.

These fires prevent succession of savanna back into forest, but they can only nibble small bits of the forest itself, because the forest usually contains little inflammable material on the ground. Small bits are lost every year however and these bits plus the forest cleared for cropping are responsible for a slow but steady loss of forest. Fig. 7.4 shows a retreating forest edge.

Evidence for fire as a major factor in the retreat of the forest can be found in the good tree growth on termite mounds or rock outcrops, protected from fire. Deep valleys may still contain remnants of rain forest, while the surroundings have become savanna. Protection from fire is the main effect of a valley and not increased moisture supply to the trees, because on flat river banks with a similar moisture regime as in the valleys, the forest is generally absent. On sloping ground fire can travel uphill, but not easily downhill. Sharp edges on hill-tops can therefore stop fires and can explain why many hills are forested on one side and grassy on the other side.

After the process of savannisation of the forest, there can be a further loss of trees from the savanna vegetation. This loss of trees can be called deforestation. It is especially evident around towns. Fig. 7.5 gives an artists impression of the surroundings of Juba some 20 years ago and now. Fire, browsing goats and collection of charcoal and firewood all contributed to the loss of trees and the absence of natural regeneration.

> Fires late in the dry season are much hotter than early in the dry season, when the grass is still partly green. This had lead to a policy of 'early burning' causing fires at the end of the rainy season in large parts of the rich savanna to remove most of the inflammable material with a fire which does little harm, to prevent uncontrolled fires later in the dry season.

Clearing the land for cropping in the shifting cultivation system means

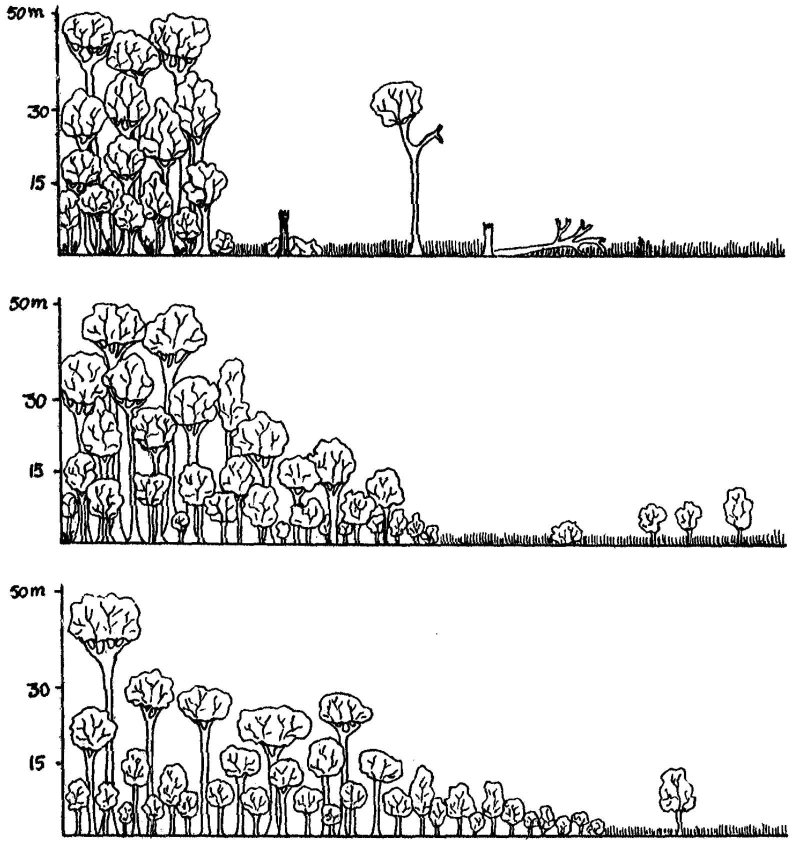


Figure 7.4 Savannisation of the forest zone: A. shows a retreating forest edge, where scattered forest trees remain in the grass-zone; B. shows a stable situation where the edge of the forest is protected from the savanna-fires by Acanthus-shrubs; C. shows a forest advancing into the savanna, by an expanding Acanthus zone. 77Ie trees in the savanna are different species than in the forest. (from: Langdale brown, 1964).

killing most of the trees. By the time the land is left fallow to recover, the soil may have been degraded to such an extent that trees cannot establish themselves.

Sheet erosion by run off of water from the plot can peel off the fertile topsoil

> layer by layer. It gradually exposes the less fertile and almost unstructured subsoil, in which rainfall cannot easily penetrate (except on sandy soils). Drying out of the subsoil may create hard pans, especially on Ironstone soils. Because of this, run off erosion will progress at an even faster speed and continue till all the topsoil is gone. The remaining land cannot easily be colonised by plants because their roots cannot penetrate the hard soil. In such a situation, much of the rainfall will now be lost through surface run off creating much drier conditions for the plants.

In hilly country the run off can easily lead to gully erosion (figure 7.7 which is even worse. This transforms former farmland to rocky, barrent landscapes.

All these processes take place when cropping continues for too many seasons as a result of an increased pressure on the land because of a locally high population density. If the land is left fallow as soon as the yields decline tree growth is still possible and the fertility can be restored.

> A grass cover in a savanna will usually maintain itself through fire. But when overgrazing has removed too much grass, fires will no longer spread and a thornbush vegetation will develop, with poor grazing quality and not much other use either. *Dichrostachys cinerea* (Kadada (A.); Kir (D.)) is a typical shrubs for this situation.

Solutions for the problems of savannisation and deforestation can be found in maintaining a good tree cover in cropping areas and regulating fires. Maintaining or planting trees in between crop fields can help to maintain the soil and provide fruits, animal fodder and wood as well. Recently interest has increased in **'agro-forestry'** systems, with trees planted in between the crops. When the trees are small, crops are grown between them; after some two years the trees are left to grow by themselves while new plots of land are planted. If good tree-species are chosen a ten-year cycle to produce firewood and building poles may be very profitable.

> For combinations of Teak and low crops such as groundnuts or simsim good results have been obtained in the Greenbelt. In the Imatong mountains 'combinations of *Cupressus* trees with maize, dura and potato give good results.

Agro-forestry systems of land use are a modern variant of shifting cultivation systems (figure 7.6). By planting well-chosen trees, the tree-phase of the cropping cycle can become as profitable as the crop-phase, ensuring the soil fertility for a permanent land use at the same time. By planting trees and taking care of them in the young stages at the same time as weeding the crops, their establishment can be ensured, which has become prolematic for the natural tree-growth.

Figure 7.5 Deforestation around Juba; an artists view towards Jebel Kujur twenty years ago (A) and now (B). (or.).

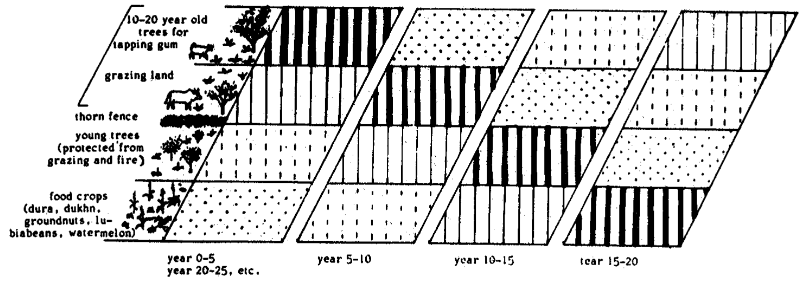


Figure 7.6 Agroforestry based on the Acacia senegal-crops cycle. The young tree need protection in the crops and early fallow stage. (or.).

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7.4 Mountain and hillside erosion

Wind erosion is the main danger of the drier areas, erosion by water is the main danger of the zones with a high rainfall, especially on sloping soils of mountains and hillsides (figure 7.7). In the Jebel Marra, the Nub mountains and the Southern mountain ranges of the Imatongs, Dongotona and Didinga the risk of erosion is very pronounced.

> Erosion by water very much depends on the rate of flow. If the rate of flow is doubled the water has four times the scouring capacity, thirty-two times the carrying capacity and can carry particles sixty-four times as large. Any obstacle (plant, stone or ridge) will decrease the rate of flow and give more time for infiltration. If trees are removed raindrops can splash on the soil directly and cause serious damage to the soil structure.

Table 7.2 gives some data for West African stations. The percentage of rainfall as run-off is clearly related to soil loss for all stations.

Clearing the forest from sloping ground to plant crops will lead to the soil being washed away, unless good terraces are built. On some of tile older

Figure 7.7 Erosion.

A. Rain splashing on bare soil can displace fine soil particles and can compact the soil slowing down infiltration; B. Rain falling on land covered by crops or by a mulch layer is spread out more evenly and can infiltrate more easily; C. Symptoms of sheet erosion: stone are left on the surface while fine soil particles are washed away, high, exposed tussocks of grasses can be seen dying, on the right hand a soil deposition site can be seen; D. Landscape, showing rill erosion; E. Formation of gullies: a small interruption in the vegetation on (slope can be sufficient as starting point, a steep bank is formed and an erosion gully; F Landscape with severe gully erosion; G. Landscape with terraces for crops and forest on the steeper valley sides. (after various sources).

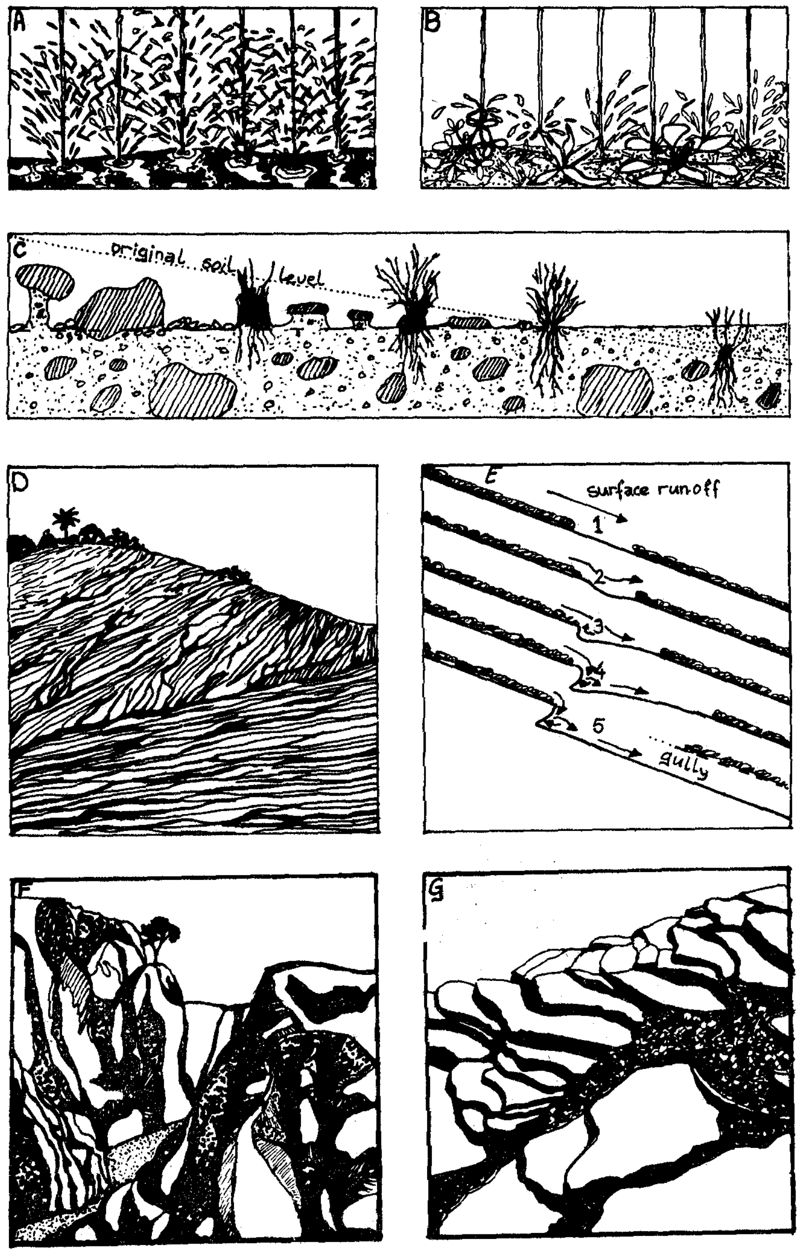

A
B
C
original soil level
D
E
surface run-off
1
2
3
4
5
gully
F
G

Table 7.2 Run-off and erosion as affected by the vegetation; data for three West African sites; run-off is given as percentage of annual rainfall, soil loss is given in ton's of soil per ha per year. (from: Sanchez)

locality	Ouagadougou Upper-Volta		Bouake Senegal		Abidjan Ivory coast	
slope	0.5%		4%		7%	
average rainfall	850 mm		1200 mm		2100 mm	
	run-off	soil loss	run-off	soil loss	run-off	soil loss
natural vegetation	2	0.1	0.3	0.1	0.1	0.03
agricultural fields	2-32	0.6-8	0.1-26	0.1-26	0.5-20	0.1-90
bare soil	40-60	10-20	15-30	18-30	38	108-170

inhabited mountains terraces have been built in the past which are no longer used.

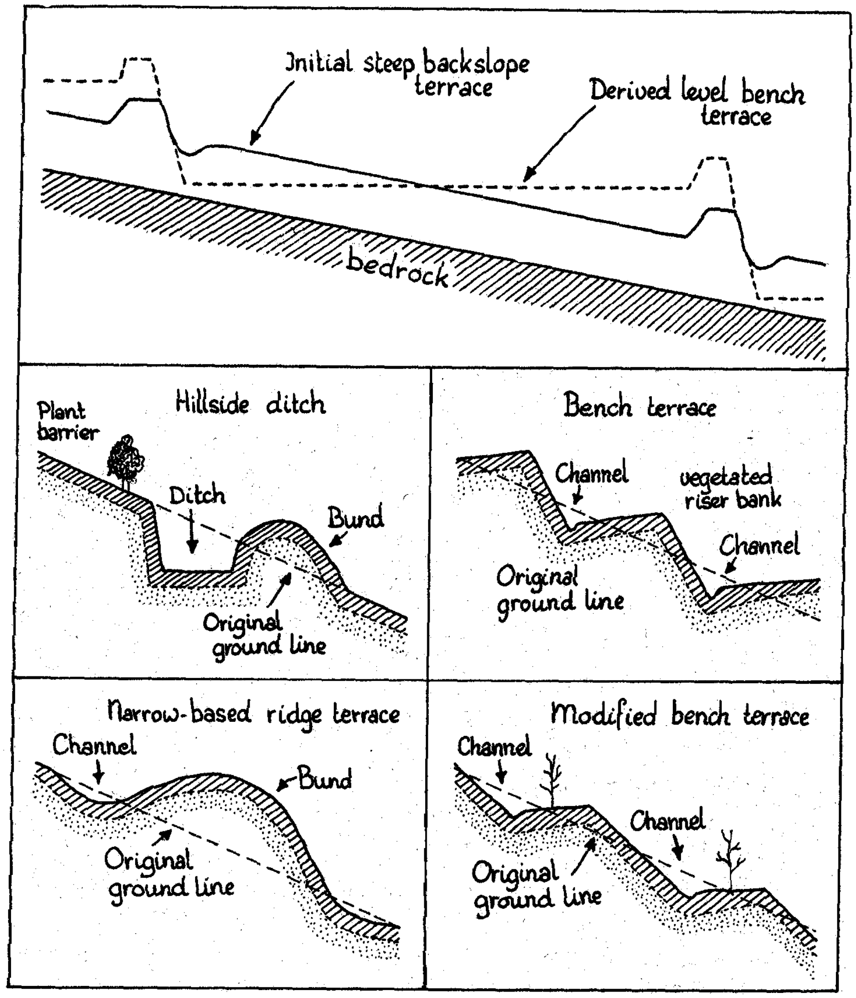
> This can be seen on Jebel Liria halfway Juba-Torit and in the Jebel Marra and Nuba mountains. People lived in the mountains for reasons of safety and protection from sleeping sickness. When these risks were reduced they moved back into the plains.

The increased rainfall of mountains, the cooler climate and the valuable timber still attracts 'development projects' to mountain forests. All over the world forests have been cut for some quick profit on valuable hardwoods and then the soil is used for cultivation without proper protection from soil erosion. Within a few years all soil has been washed away to the rivers. The rivers become brown from all the mud they contain. After a heavy rainstorm all the water flows to the rivers immediately, without the sponge-like effect of a well developed soil under a forest. The river flood after rainfall causes many problems downstream. In the dry season the rivers will dry up, while previously the forest soil provided a constant trickling of water. So, some years after the forests have been cut, bare rocks remain in the mountains and life in the adjacent plains has become far more difficult. This process is very well known from other tropical countries such as India and Indonesia. In some parts of Kenya it has occured as well.

> There are indications that a similar process has started in the Imatong mountains as well. Downstream of the local potato project the river Kinyeti is now muddy in the spring, which was not the case before. The potato project uses steep hillsides, with only very provisional ridges instead of terraces. On the farms of the labourers of the forestry and potato projects who moved into the mountains after the 1940's, erosion is very clear. When most of the soil has been washed away Fingermillet (*Eleusine*) is the last crop giving a meagre harvest on the spare soil left between the bare rocks.

Protection from erosion is possible by not using steep slopes at all at building proper terraces on the medium slopes. Fig. 7.8 gives a design for terrace. Trees have to be planted on the edges of the terrace to fix the soil.

Figure 7.8 Erosion control by making terraces on sloping ground (based on FAO, 1977).



By all means water has to be stopped from flowing downhill with a high. speed. Building terraces requires investing a lot of time, but it is the only way to ensure permanent cropping.

> An 'agro-forestry' system as used by the Imatong forestry project, allows farm labours to plant crops between the young tree plantations for two years. In this way erosion is much lower than on the crop fields and the area can still be more or less self-sufficient in food production, yielding wood products at the same time.

7.5 Irrigation schemes

Irrigation greatly enlarges the potential for crop production in the drier zones and thus is a valuable development. However, it has certain ecological risks as well.

The establishment of irrigation schemes can be compared to the effects of changing river channels after climatic changes in geological history. The Gezira clays have been deposited by branches of the Blue Nile. Later they became dry savanna or semi-desert areas. The irrigation channels have more or less reversed this situation, using water of the Blue Nile again. The resulting ecosystem is completely man-made however.

The demands for a rational land use and mechanisation have completely dominated the design. No place has been reserved for the. variety of vegetation of old landscapes. Small tree plantations may be present for fuelwood production, but often the schemes are not self sufficient in this respect. In the internal environment of the schemes diseases such as Malaria and Bilharzia are important. The permanent more or less stagnant water of the canals gives good chances to the vectors of these diseases. The difficulties of preventing the spread of Bilharzia in irrigated areas is well illustrated by the Gezira scheme. One million hectares of what was formerly part of the semi-desert and Sahel zone is under irrigation from a single water source on the Sennar dam. From the very beginning efforts have been made to prevent the spread of the disease, but control has been ineffective, in spite of the efforts of a very devoted staff and a very considerable expenditure.

> Similarly, hydroelectric schemes increase the risks of Onchocerciasis and riverblindness. This is because fast flowing water, as obtained below a dam, is ideal for the larvae of *Simulium*. The building of several dams on the Nile (Blue, White and Main Nile) has produced additional lakes that are ideal breeding sites for *Chironomids*. An increase in the population of 'Nimitti' has resulted, since these dams increase the production of Phytoplankton, which acts as food for the developing larvae.

In the establishment of new schemes the traditional users of the land are often neglected. If these were farmers, in permanent settlements, they may be offered plots in the new scheme, but if they were cattle-herding people using the area only part of the year, their interests are often not considered at all. They will loose an important link in their annual cycle of migrations. They will have to avoid the area of the scheme and concentrate on the remaining land, causing problems of overgrazing there. The rapid decline of Dinder National Park in recent times is partly due to the establishment of the Rahad scheme, forcing the cattle-keepers to enter the park and compete with the wildlife for grazing resources.

A major risk of irrigation schemes is salinisation, when salty groundwater t comes to the surface because of the changed water balance in the area. As described in section 5.7 part of the Managil extension to the Gezira scheme had to be abandoned because of this.

Generally one can say that the larger the schemes, the larger the unexpected and undesired side-effects can be. The creation of artificial lakes for irrigation purposes can have enormous side-effects. The example of the Aswan High Dam may illustrate this. The Aswan High Dam was built to store water in the season with a high riverflow for use in the season of a low waterlevel, to increase the intensity of irrigation for crop production. . Storage is also meant to accommodate for years of reduced riverflow.

> A first effect of the dam was that the people living in the Nile valley upstream of he dam had to leave their land. But there are many effects downstream as well. The silt which was formerly deposited on the land during the flood season now accumulates in the lake. The natural source of soil fertility is lost and agriculture becomes dependent on inputs of artificial fertiliser. In the mean time silt accumulates in the lake, clogging the electricity pipes; storage capacity of the lake is used for silt in stead of water. Loss of water from the lake by evaporation is high, because of the waterhyacinths and other waterplants, benefitting from the silt. Changing the regime of riverflow has other effects as well. The Nile delta in the Mediterranean Sea has been a fertile, intensively used area since thousands of years. But the delta is a balance between silt deposit by the river and erosion by the sea. Now that the riverflow has been reduced by the use of water for irrigation, the sea ingresses into the land and valuable land is lost. The delta also used to be important for many fish species. The results of marine fisheries in the adjacent sea however, showed a marked decline after the establishment of the dam. The reduced siltload of the river is considered to be the main reason for this fact. Because of the reduced siltload, algal growth is reduced and all subsequent steps in the food chain are affected as well. Another problem caused by the lake is that the riverwater has become more saline. This is partly because considerable amounts of water from the lake leak into groundwater-flows, changing their

pattern, and partly because of the reclamation of new land. When salty groundwater around the former riverbed became part of the circulation system, this salt got mixed through the whole system. Any change in the pattern of movement of groundwater is risky. Irrigation with saline water contains the risk of spoiling the soil by formation of salt crusts on the surface. The rise and decline of many Middle East cultures in historic times was associated with the initial success of irrigation and the subsequent salt problems.

Of course all these negative aspects have to be considered with respect to the positive ones of an increased food production. But usually the people who suffer from the negative aspects are not the ones who mainly benefit from the positive aspects.

7.6 Pest and disease control

Pests and diseases are important limiting factors for crops, animals and man. Measures to control these pests and diseases can therefore directly lea to an improvement of the production or well-being. But many of the control measures have negative aspects, which usually appear after a few years, when the first excitement about their success is tempered.

DDT is a not-naturally occuring chemical of high toxicity to insects as well as other organisms. It is very persistent, which means that it is not broke down at all or very slowly by decomposers. Once it has entered the ecosystem it will remain in circulation in food chains for a long time. DDT was developed during the Second World War and proved to be very effective against mosquitoes, lice, fleas and other insects causing human diseases. Later on it was used on a large scale for spraying against crop and animal pests. Now it is present in nearly all organisms of the world, even in human breast milk and in penguin living on the South Pole, although DDT was never directly sprayed there. If you try to work out the food-chain via which penguins and human beings take in DDT, you will see that it involves many steps. In the Western world the use of DDT has been banned, because it is considered to be too dangerous (although they) continue to produce it for export to other countries. ...). In the Sudan the use of DDT was stopped in 1981 for the Gezira; in other parts it is still used against mosquitoes.

After DDT has been sprayed most of the insects will die. The DDT will not remain on the spot where it was used, but will spread over a larger part of the environment causing pollution. DDT will remain in the ecosystem and all natural enemies and decomposers of the insects will consume DDT. Many of the predators of insects will be killed, because of an accumulation process, illustrated in fig. 7.9. A large part of the food any organism

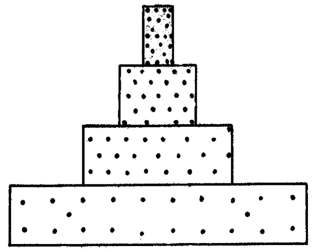


Figure 7.9 Accumulation in the ecological pyramid for substances which are excreted; the same amount leads to increasingly high concentrations in the high levels of the pyramid, due to the smaller biomass; such accumulation has been found for DDT, mercury, PCB's etc. (or.).

consumes is excreted or used for their energy-supply; only a small part will remain in the body. DDT however is not used or excreted, but mainly stored in fat tissue, If an organism continues to consume food with low, concentrations of DDT, gradually a high concentration can be built up in its fat reserves. The figure illustrates this by showing the same amount DDT - particles in all layers of the ecological pyramid, with a concentration rising the further we go in the food-chain. Predators on the top of pyramid are easily killed, especially during seasons when they use their supplies, during breeding or migration, Spraying with DDT sometimes results in the immediate death of predators, as is sometimes seen in Gezira for Crested Cranes and White Storks, or after spraying around houses with lizards and bats, but more often it results in a slow but steady decline of these organisms by the process of accumulation.

When the natural enemies of the pest are killed, natural checks on population growth of the pests are removed and a next outbreak can more intense. It is sometimes said that **the surest way to create pest outbreaks, is to start spraying pesticides**, advertised to control the predators are killed and an outbreak can be the result.

> This can be well illustrated by the experiences with cotton pest control in Gezira, (figure 7.10). Cotton is attacked by many insects. Growing large areas of cotton therefore contains the risk of pest outbreaks. Before 1945 pest control was achieved by non-chemical means; careful field sanitation, proper soil tillage, balanced crop rotations and a strict administration enforcing control measures, reducing the carry-over of pests and diseases from one season to another as far as possible. This allowed for little freedom to farmer (tenant). Still, insects did occur and the first experiments on the use of DDT showed an increase in cotton production of 20-40%. A gradual

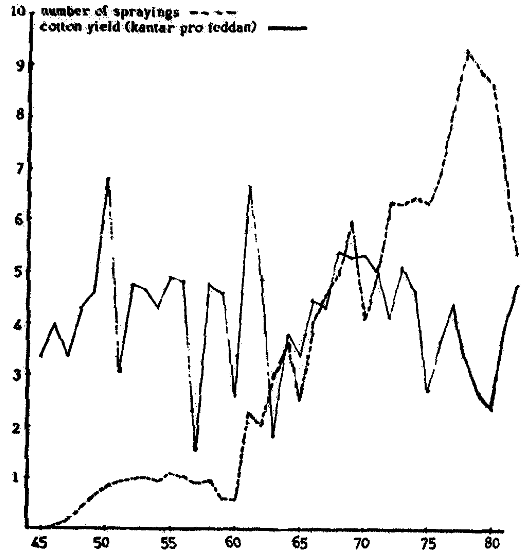


Figure 7.10 Cotton yields in the Gezira and the use of pesticides. Between 1945 and 1950 spraying resulted in yield increase; in 1951 the first negative effects were seen and yields returned to the original level; in 1960 land use was intensified and spraying doubled, with good results in the first year, but again, setbacks in the next; in the period 1960-1978 the intensity of spraying increased steadily but yields still fluctuated around the 1945 level; since 1980 the use of DDT was stopped with more personal interest of the tenant-farmers; the first results of this policy are promising (data from Sudan Gezira Board).

introduction or insecticides (mainly DDT) was a logical step. At the same time the farming system was changed in a direction of higher risks of insect pests: a more intensive use of the land, with a larger area used for cotton; new high yielding cotton varieties without increased resistance; earlier sowing; denser crop stands; the use of other crops in the rotation which harbour cotton pests (groundnuts replaced the lablab bean (*Dolichos lablab*) and harbours the Amerian bollworm). Birds had been important predators of bollwonn pupae in the dry season. The use of DDT decreased bird numbers, along with those of other predators. The use of DDT resulted in a decrease of three common pests (Stemborer (*Sphenoptera*), thrips (*Helcothrips*) and seedbug (*Oxycarenus*)) but in an increase of three other pests American bollworm (*Heliothis*), Sudan bollworm (*Diparopsis*) and whitefly (*Bemisia*).

The number of sprayings increased to about 7/year in 1977, but still the increased whitefly incidence could not be checked. Whitefly produces sweet excreta which make the cotton lint sticky and useless. In fact the increase whitefly as a result of the use of DDT was not unexpected. As early as 1961 it had been investigated without any change in policy. This neglect of warnings was at least partly due to the fast that spraying was done by pesticide marketing firms in Europe, through package deals: the firms got payed spraying large parts of the Gezira in a certain year, guaranteeing high yields in that particular year but not feeling responsible for an increase of problems in the next year (in fact they benefitted from the increased demand for spraying. ..). In the late 1970's this lead to a sharp decrease in cotton quality, with large economic effects. It is difficult to return to the pest control (situation of before 1945 (especially as the low amount of freedom of the tenant is no longer acceptable). Some form of compromise has to be found 'integrated pest control', with a minimum use of selective insecticides maximum use of cultural control procedures.

As explained in section 3.5, most mosquitoes die after the DDT-spray, but the very few which happen to be resistant will get more chances for reproduction. After several years of spraying a considerable part mosquitopopulation will be resistant and will no longer be affected by the DDT. In 1977 it was shown by investigation that mosquitoes from and Khartoum were highly resistant against DDT which has been in use since the fifties, while mosquitoes from Port Sudan where less DDT ha sprayed as yet, are still sensitive to spraying. This process of development resistance should be a warning against indiscriminate use of the sprays for 'prevention', as it will make the chemical ineffective when it is really needed. The natural enemies of the pests can develop resistance as well, but it will them much longer (section 3.5).

So, after ten years of use of insecticide the insects are no longer killed, while the natural regulation has disappeared. New insecticides are made by industry, but after some years they will become ineffective as well. After the discovery of the negative side effects of DDT research has been directed to find chemicals which are less persistent and which are more slpecific, killing the target organism only, without affecting the rest of the ecosystem. But such chemicals are hard to find and that makes them far more expensive. A good alternative for DDT is formed by Pyrethrum-plants which are grown in the uplands of Kenya. They contain a substance with favourable qualities as it is not persistent and reasonably specific, killing insects only.

Several other pesticides cause similar ecological effects as DDT. Chemicals used to treat seeds against fungal attack contain mercury which can accumulate just as DDT and is a real threat to human health. Dieldrin, which is used for locust control by spraying from the air is as persistent as DDT and is dangerous for grazing animals as well as human beings.

In the Sudan chemicals ('pesticides') are also used on a large scale to destroy

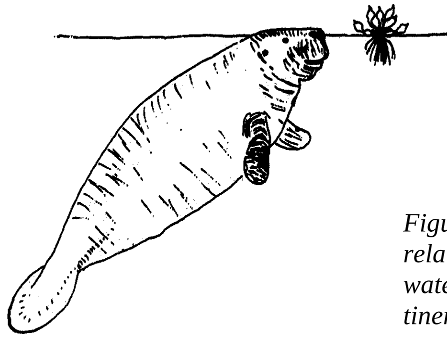


Figure 7.11 Manatee, a West-African relative of the animals which keep the waterhyacinth under control in its continent of origin, South-America. (or.).

Quelea-weaver birds (Sudan dioch) and waterhyacinths. The weaverbirds are usually sprayed in their breeding colonies, using airplanes. Large numbers of other birds are killed as well, especially if the spraying is done under conditions of too much wind. The practice of pqisoning water pools has obvious dangers as well. The waterhyacinths are combatted by spraying large amounts of the herbicide 2,4 D from airplanes or boats. This herbicide kills many plant species, including crops such as cotton, so there is a constant danger that the chemical will spread to areas used for irrigation agriculture. Succes in combatting waterhyacinths has only been very partial. The campaign started in 1960 and is still going on. In the papyrus swamps many parts are inaccessible and 'breeding sites' of waterhyacinths remain, continuously supplying the downstream stretches of the river. Therefore spraying is not very effective, it is expensive and it has negative influences on the environment. Alternative control measures have been sought. In South America where the waterhyacinth is native, various organisms help to keep their numbers down: several insects eat from the leaves and whole plants are eaten by Manatees (fig. 7.10). Manatees are large fresh-water mammals. Manatees also occur in West Africa and as far inland as Lake Tchad. They may once have occured in the Nile as well. They are potentially important for the control of waterhyacinths but they are endangered with extinction because they are overhunted because of their edible flesh. So introduction should be combined with protection. In Sudan trials are currently done to introduce some South American insects eating waterhyacinths as a form of biological control.

In programmes for 'biological control' natural enemies of the pest or disease organisms are stimulated or measures are taken to break the life-cycle of the pests. *Quelea* colonies are dependent on the vicinity of drinking water and suitable bush for nesting. By preventing these requirements near the crop fields most damage can be avoided. But of course such deforestation causes problems as well. By stimulating fishes feeding snails (e.g.

catfishes), Bilharzia problems can be reduced. The Grass-carp, a fish from China which consumes large amounts of waterplants can be introduced to reduce the occurence of algae and water weeds and hence the occurence of snails and Bilharzia. The introduction of fishes (*Gambusia*, *Tilapia*) into wells and ponds to eat mosquitoe larvae is an old technique in Africa, worth keeping. In many other cases biological control may be possible as well, but it requires a much better understanding of the ecosystem.

> The main successes of biological control have been achieved in the control pest species introduced from other continents such as the Waterhyacinth and several other weeds in the Sudan. The introduction of natural enemies of these immigrants from their home countries has been successful in several cases in Australia and America.
>
> Much research is required to make sure that the species introduced for biological control will not become pests themselves, by eating other types of food than the original pest organism. It is important to note that the biological control will not completely eradicate the pest, as the introduced natural enemies would not survive in such a case. Biological control will only reduce the population size of the pest organism; whether or not these reduced population sizes are acceptable, depends on the situation.

Quite often the complexity of relations between pest organisms and their environment is such that factors contributing to control are only recognised as such when they no longer function. The soapberry example of fig. 6.3 is a good example of this. It is to be hoped that the role of *Balanites* in Bilharzia control will be investigated before it is too late. The increased migration of people from the floodplain to and from irrigation schemes already increases the risk of Bilharzia spread.

7.7 Green revolution

In the 1960's all over the world people started speaking about a 'green revolution'. Modem agricultural techniques and high-yielding varieties had been developed for wheat and rice which could increase food production all over the world dramatically, solving the hunger problems of the urban poor. In practice, the green revolution was only a partial success, only in part of the tropics and only for a minority of the farmers.

Ideal plants do not exist and the outcome of a selection procedure is dependent on the conditions used. Generalising one can say that the 'green revolution varieties' give a high yield on very fertile soils, with a good water supply and the use of many pesticides to control pests and disease. In the conditions of most of the fields of small farmers the yield of the new varieties will be the same or less than that of the traditional varieties,

selected by many years of growing under local conditions. The new varieties are only successful if additional sources of soil fertility are available and if other techniques for pest control are available.
Adjustment to the local climatic conditions is necessary and careful testing of the new varieties in the complete farming system is essential. This means that a relatively slow evolutionary process of selection for each set of conditions is the only possible way, in stead of a 'revolution'.

> Mistakes can easily be made, as was shown in Southern Sudan in the Greenbelt, where a new maize variety was introduced which gives a higher yield, even under average farmers conditions. But the maize cannot be stored with traditional methods, as the cobs are much more sensitive to attack by storage insects. Thus the gain of a higher yield is quickly lost for the farmer, who cannot but sell the maize just after harvest, when the prices are low. This example shows that even, if higher yields are obtained, the small farmers may not benefit; the benefit may go to merchants and to the towns.

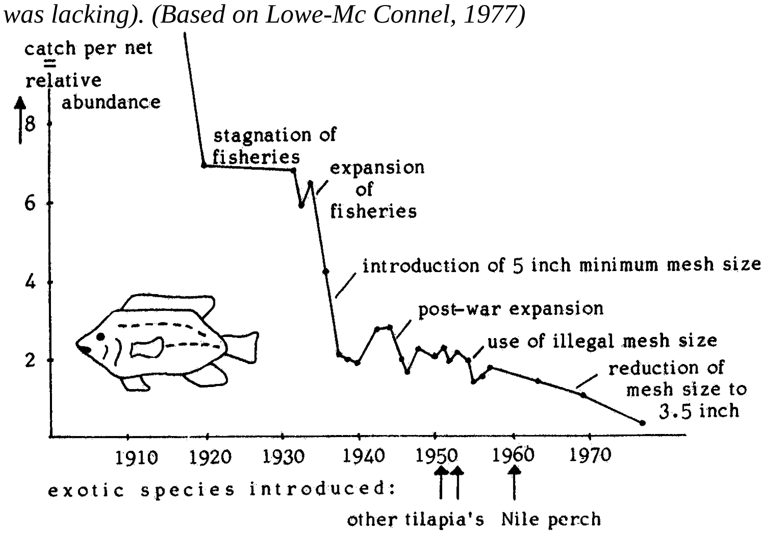
The main problem with the 'Green Revolution' propaganda is, that it creates false expectations of quick success. The idea that the same answer can be used for all questions, leads to the uniformity of mono cultures with a high dependency on artificial fertilisers and pesticides, with resulting problems of pollution. The alternative is to improve the farming systems from inside making a more intelligent use of their complexity. It is not surprising that in research programmes testing new introduced varieties against local varieties the difference between the two decreased, not because the new varieties changed but because better local varieties were found. From a careful selection of the genetic resources in the locally adapted crop varieties more real progress can be expected than from 'Green Revolution' varieties introduced from elsewhere.
A major problem is the increased dependency on seed-production firms. Many of the green revolution varieties are hybrids which means that they cannot be multiplied by the farmer but only by the seed, production firm. Instead of keeping part of the harvest as seeds for next year (and possibly improving the adaptive value of the 'crop by selection), the farmer has to buy new seeds every year. When the traditional varieties have disappeared completely, the farmer has become completely dependent on the market, with the risk of interrupted supply at certain times. Improvement of the varieties has now become dependent on the seed production firms, as the farmer's selection activities have stopped.

7.8 Overhunting and overfishing

Populations of wildlife and fishes are important natural resources. But when they are not managed correctly they can easily be destroyed, by overhunting and overfishing. The effects of overhunting are clear to anyone who hears or reads descriptions of the abundance of wildlife in the Sudan a century ago. The large migrating herds of Dorcas and Oryx gazelles in the Central Sudan have been decimated or worse. Even in the more scarcely populated Southern Sudan the reduction of wildlife is evident. On the map in fig. 6.8 wildlife migration around the floodplain is sketched and it is clear that wildlife only thrives on the empty parts, not used by man and cattle. The Southern National Park, south of the road Wau-Tonj-Rumbek occupies an area not used by man because of tsetseflies.

Habitat destruction by desertification, savannisation and deforestation and the obstruction of migration routes by irrigation schemes, roads, canals and other development projects are responsible for the permanent disappearance of wildlife, after overhunting has reduced their numbers

Figure 7.12 Decline of Tilapia (Sarotherodon esculeritus) fisheries in the Kavironde Gulf in Lake Victoria.
The catch per standard net was around 25 at the establishment of the fisheries during the 19-th Century; the subsequent decline is the result of overfishing and the introduction of exotic species competing (other Tilapia-species, around 1950) or predatory (Nile Perch, in 1960). Small-scale recovery of the fish populations occured during World War II and when legal restrictions were introduced on the nets used, to protect young fish (but adequate control to implement these measures was lacking). (Based on Lowe-Mc Connel, 1977)



already. Southern Sudan was at one time famous for the large herds of elephants. Since the middle of the 19th Century the trade in ivory (as well as slaves) increased and elephant numbers have gone down rapidly. Poaching for the valuable ivory will soon limit their numbers to a few herds in incompletely protected National Parks.

> Ivory was one of the first natural resources to be robbed from Southern Sudan during the colonial exploitation and this is still continuing. The increased availability of fire arms has further aggrevated the problems along with the involvement of some politicians.

Policies to legalise a limited degree of hunting suffer from lack of adequate data on population sizes and insufficient knowledge of the species concerned. Large parts of grazing land in the savanna can probably be used more efficiently by wild herbivores than they can be by cattle. A careful management of wildlife with controlled hunting is a valuable alternative to agricultural development.

The fishery resources in the many tributaries in the Nile are many and are not yet fully used. Locally, fishery resources have declined by overfishing, especially where techniques are used which kill the young fish as well, such as fish-poisons or nets with a small mesh size. In other countries projects to improve fisheries, sometimes called the 'blue revolution', have often lead to overfishing, destroying future resources after an initial period of success.

> Examples of overfishing after the introduction of modem gear can be found in two parts of Lake Victoria. Fig. 7.12 shows the decreasing amounts of Tilapia-fish caught per unit effort in Lake Victoria, in the period 1950-1975. This decrease can be related to the increasing fishing efforts, using nets with small mesh sizes, in spite of regulations. The introduction of the Nile Perch, a predator of Tilapia further contributed to the decline of the Tilapia population.
>
> Another example comes from the Mwanza Gulf on the Tanzanian side of Lake Victoria. Around 1975 large sized trawler fishing boats were introduced, because initial estimates predicted a catch of 60 tons per day of the *Cichlid* fish *Haplochromis*. The trawlers can only fish in deep, muddy parts and the expectation was that after catching fish from these parts, fishes from the rest of the Gulf would restock the deep parts continuously. But after three years of fishing the yields declined, without ever having approached the estimated 60 tons per day. Ecological research then showed the initial estimates to have been wrong. In stead of one species, there appear to be as many as 200 different species of *Haplochromis*, each with their own microhabitat and with adaptations to a special niche. This extreme example of niche-differentiation explains why the exhausted parts used for trawling are not replenished. Species from the neighbouring waters lack the necessary adaptations to live there. More detailed research has now given advice on

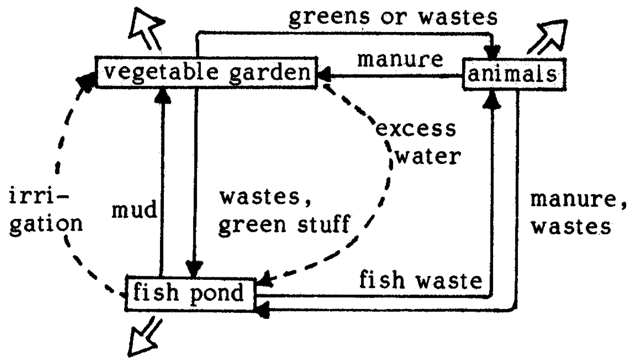


Figure 7.13 Integration of a fish pond into the nutrient cycle of a farm. (Appropriate technology source book 2).

minimum mesh sizes to be used and on protection of the fish in the breeding, season. Increasing fishing efforts without careful research is obviously dangerous development.

An alternative to fishing can be found in using fish ponds to grow Figure 7.13 shows how a fishpond can be integrated into the farming system. *Tilapia* has often been used in such ponds, as it can grow rapidly; combination of species might improve the efficiency, provided that can be managed in a similar way.

7.9 Waste-disposal, hygiene and pollution

In section 5.3 the nutrient cycle of a natural ecosystem was explained. All nutrients remain in the system and there is no such thing as 'waste'. In rural areas with a subsistence type of economy this nutrient cycle is still functional, though usually on a somewhat larger scale (figure 6.17). All nutrients taken from the soil return to the soil somewhere in the area used for the shifting cultivation cycle. Human wastes do not cause hygienic problems when there is sufficient space. In towns or any other large concentration of human people human wastes become a problem. Food is imported into the towns, but the resu1ting wastes are not spread out over the large areas of the crop fields, but remain concentrated near the house, giving ample opportunities for human parasites and diseases to complete their life-cycle. Epidemic diseases are much more common in towns than in rural areas. In most towns some sort of sewage system is started to collect the waste materials. This solves the direct hygienic situation around the houses, but if the sewage water flows into a river, as is often the case, the

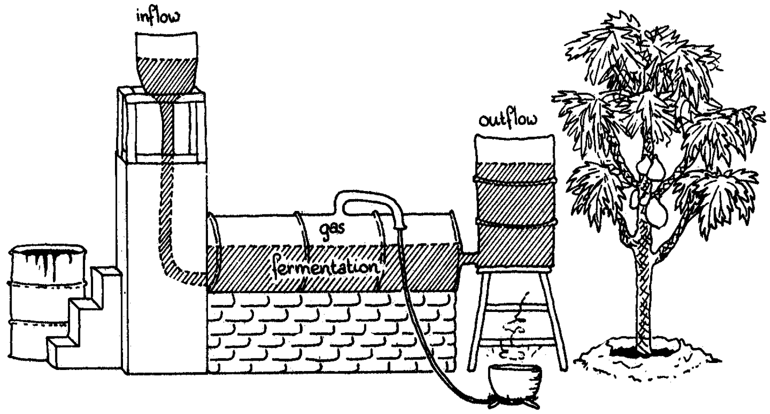


Figure 7.14 Biogas installation as used at the village technology centre in Torit; manure and other organic waste matter slowly passes through a tank where bacterial decomposition produces methane-gas (biogas); the gas can be used for cooking and is kept under pressure by the level of decomposed fluid in the outflow; this waste product is a good fertiliser, as shown by the luxurious growth of the paw-paw tree (or.).

washing and drinking water for people living downstreams is spoilt by pollution.

As soon as people live in towns there is no longer a nutrient cycle, but a nutrient flow (figure 7.14). Nutrients removed from the fields with the crops do not return to the land after consumption, but are transferred to the rivers and eventually to the sea. Depletion of the soil is the problem on one side of this nutrient-flow, pollution of the water on the other one.

> Initially, a considerable amount of the wastes in towns is used by goats and chicken and returned into human food. As long as organic materials form the largest share of household wastes, free-roaming goats and chicken help to remove them, reduce hygienic risks and at the same time form an important source of protein for the urban poor. Conflicts with gardeners and the desire to improve the status of the town will bring a town council to propose a system of garbage collection and deposition in one place. This becomes more urgent, when the nature of the waste material changes, following the consumption pattern, from decomposable organic material into non- decomposable plastics, tins, glass, etc.

In the modern Western lifestyle, the amount of waste produced per person has increased dramatically. Plastics, glass, tins and other metal objects are not produced for a long period of use, but are intended to be replaced quickly to keep the industries going. These industries cause pollution of the air and water, and produce many by-products for which no other solution exists than to dump them on the ground, into the water and into the sea. If the garbage collected in towns and the industrial wastes are burned, they cause air pollution; if they are dumped on the land, the soil is polluted and after some time the groundwater as well, making wells for drinking water useless; if they are dumped into the water, the water is polluted and all human use of surface water for fishing, bathing or drinking is endangered. Pollution of soil, water and air has become a major problem in the Western world, damaging the natural resources for future generations.

Problems of pollution in the Sudan are mainly restricted to the industrialised centres in Khartoum North and Port Sudan.

> Oil spills are one of the most important threats to the coral reefs (along with overfishing and trophy-collection by tourists). The temporary closure of the Suez-canal improved the situation on the coast, but after re-opening pollution has started to increase again.

It is annoying to see, that many of the measures and safety-regulations developed in the Western world recently to reduce the dangers of pollution, are considered to be too expensive for developing countries such as Sudan. It seems as if every nation has to learn the hard way. One can only hope that the recent oil exploitation will not cause pollution problems in the flood plain and river area.

> The re-use of non -decomposable wastes, as is done on a considerable scale in the Sudan with oildrums, tyres and tins is an important solution in the initial stage. But the production of wastes should be limited to the amount which can be re-used and the Western countries form a very poor example to go by in this respect. Hygienically safe methods exist to use decomposable human wastes to make compost, which can then be returned to the crop fields to give back the fertility to the land. Few countries are using these composting methods on a significant scale, but it is the only way to manage the natural resources of soil, water and air such that they are not damaged irreparably.

7.10 Energy

The energy flow of a natural ecosystem was explained in section 5.4. Energy from the sun is stored during photosynthesis by plants in organic materials and is released stepwise during transfer in foodchains, to finally leave the earth as heat after complete decomposition of the organic matter. Traditional human systems of land use follow this pattern of energy flow, by deriving the energy necessary for food production, heating and all other activities directly from the sun, via plant products used for fuel or via draught animals. Technological development has only become possibly by a large increase of the energy consumption per person. Energy from fossil supplies (oil and coal) is used to replace human physical power or energy of draught animals. These fossil supplies, however, are non-renewable resources and their availability is limited. This has been reflected in the recent increase of their economic price. Renewable energy sources exist in the form of sunlight, wind and flowing water but the techniques for using these resources have yet to be fully developed. .

> The use of water flow for generating electricity requires careful planning when artificial lakes and dams have to be constructed, as illustrated by the adverse effects of the Aswan High Dam (see section 7.5). Part of the potential of the Blue Nile for electricity has been used; for the White Nile, the stretch between Nimule and Juba deserves most interest. The use of wind energy, via windmills, has sofar been very limited in the Sudan, although wind speeds are sufficient in many areas. The energy of sunlight is used directly for drying various food products to conserve them, but other applications are limited. Sunlight can be used for generating electricity, but this requires advanced technology, which is not yet sufficiently available. Indirect use of solar-energy via plants can be improved if measures are taken to counteract the deforestation especially around towns.

When the price for oil increased in the mid-seventies, the term 'oil-crisis' or 'energy crisis' was used. But a more serious energy crisis is affecting the large group of people dependent on charcoal and fuel wood as their source of energy. Deforestation has to be stopped by a planned use of the forest resources and by reforestation of denuded areas with suitable tree species, protected from fire, grazing and illegal cutting in the initial stages.

An alternative source of fuel at a village or household level can be formed by gasses produced by decomposition of organic waste material by Bacteria (biogas). Human or animal wastes, together with plant remains, can be made productive by a relatively simple construction made from oildrums and other wastes to store gas. (fig. 7.14).

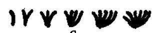
The possibility of harvesting waterhyacinth plants for biogas production on a larger scale, or for compaction into briquettes as alternative for charcoal is now under study. It is to be hoped that the recent finds of oil in the Sudan will not take away the interest in these more permanent solutions to the energy requirements of the people.

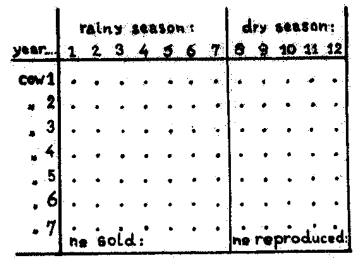
7.11 Suggested practical

1. Overgrazing-game

The game can be played by one person or more and is meant to show some of the processes leading to overgrazing and desertification.

Requirements:

- chessboard
- markers for the amount of grass 
- a die
- two herd indicators 
- registration form:



Rules

A. Rainfall and vegetation

Characteristic for semi-arid areas is that rainfall is not only low, but also ferratic. In our game a die will determine the amount of rainfall once a year for each field of the board. So the amount of grass growing varies from 1 to 6 markers.

B.Grazing

Each month each cow in the herd needs one unit of grass. The herd can move through 2 neighbouring fields per month (as indicated in the lower left corner). In the 7 months of the rainy season all fields may be grazed, but in the dry season the herd must return to the well in the middle of the board each turn, so they can only graze in the central 16 fields. If the full requirements of the cattle are not met, they can be fed at half a ration but this will affect both the reproduction and sales value. If a cow is not fed at all, it dies.

The game starts with a herd of 5 cows in one of the centre fields

C. Reproduction and sale

At the end of each dry season the cows that have been fed on a full ration for the past 6 months will give birth to a calf. At the end of each rainy season cows can be sold at the decision of the player; if they have not been fully fed in the previous 6 months, they count as ½. If the herd consists of 6 cattle or more, it may be split into 2 subherds, grazing separately. Th subherds must be joined again if any one is reduced to less than 3 cows.

D. Regrowth of vegetation

After the first year there are some additional rules for determining the vegetation on the basis of rainfall:

- If there is no vegetation left, nothing will grow (desert)
- If the vegetation is reduced to 1 unit there will be slow recovery: only half the rainfall will be used (1➜ 0, 2 & 3 ➜ 1,4 & 5 ➜ 2,6➜3).
- If the vegetation is left at 6 and another 6 is thrown, the vegetatio1 changes into bush and is no longer palatable.

E. Aims of the game
The player should try to manage the herd in such a way that there is maximum production of cows and yet no desertification. After each year you should count: the primary production of grass, the amount of grass used and the secondary production of calves, the number of desert patches and the number of bush patches.
F. Change the rules in any way you like to make it more realistic.

2. The 'nutrient-flow' game (fig. 7.15) can be played just as the previous games in fig. 5.14 and fig. 6.17. Discuss the results in comparison with the other games.

3. Make a list of environmental problems of development in your home area: can you see solutions for them?

4. In many cases ecological problems of development interact with social political problems. Two examples are given here which can be worked out as 'role-plays':

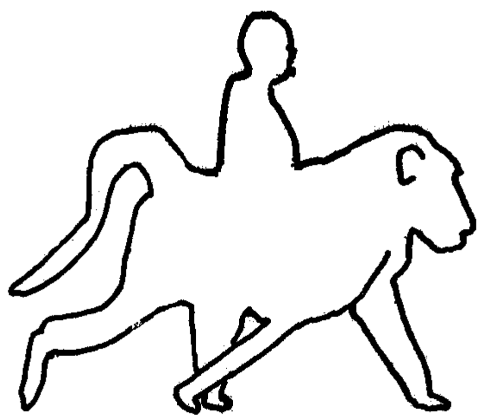
Role Play Situation one
In an area an agricultural programme has been initiated to introduce cash-crops. Extension workers have been working with the farmers well; the extensionist has been able to introduce better methods and the farmers are able to make some profit. So, the programme is considered as being successful, and will expand; More agricultural extensionists are being called for.
However, coupled with the success of the farmer is the deterioration in living standards of their women and children. Much of the land they used to grow their food on is now used to grow cash crops. So now they spend a great deal of time helping their men folk with weeding the cash crop and they have less time for growing food {or the consumption of the familly. Instead of being self-sufficient in their food supply, the family has now become, partly, dependent on the market and shops.
Even though they have some money, the local food available is rather uniform and often there isn't much to buy at all. Some vegetables are available, but not very nutritious ones, few fruits and, only on rare occasions, meat.
A sharp increase in malnutrition is noticed among the children and this is leading to diseases and deaths.
Because of this, a nutrition extension worker is called to give information about 'good porridge' to help alleviate this situation.
Work out the roles of villagers (both men and women), the agricultural and the nutrition extensionist. Concentrate on how the latter can try to analyse the situation and look for more fundamental solutions:

Role Play Situation two

An agricultural extensionist is called in to help in solving the problems of a certain village. The yields of dura here are much lower than they used to be, according to what people say. The women are complaining about the difficulties of getting firewood, for which they now have to walk very far it takes them several hours per day.

In the past people never lived in the same place for more than one generation and moved on to new land in such a situation. But now their village is near the road, with a school and a primary health care unit, so they do not want to leave these. The Sub-chief who used to be the person guiding decisions about moving is hardly ever seen in the village. He prefers to live in the nearby town. So the villagers are not able to solve the problem themselves.

Possible roles: agricultural extensionist, sub-chief, villagers, both men and women. Show how the extensionist can analyse the situation and try to help the villagers in finding a solution.



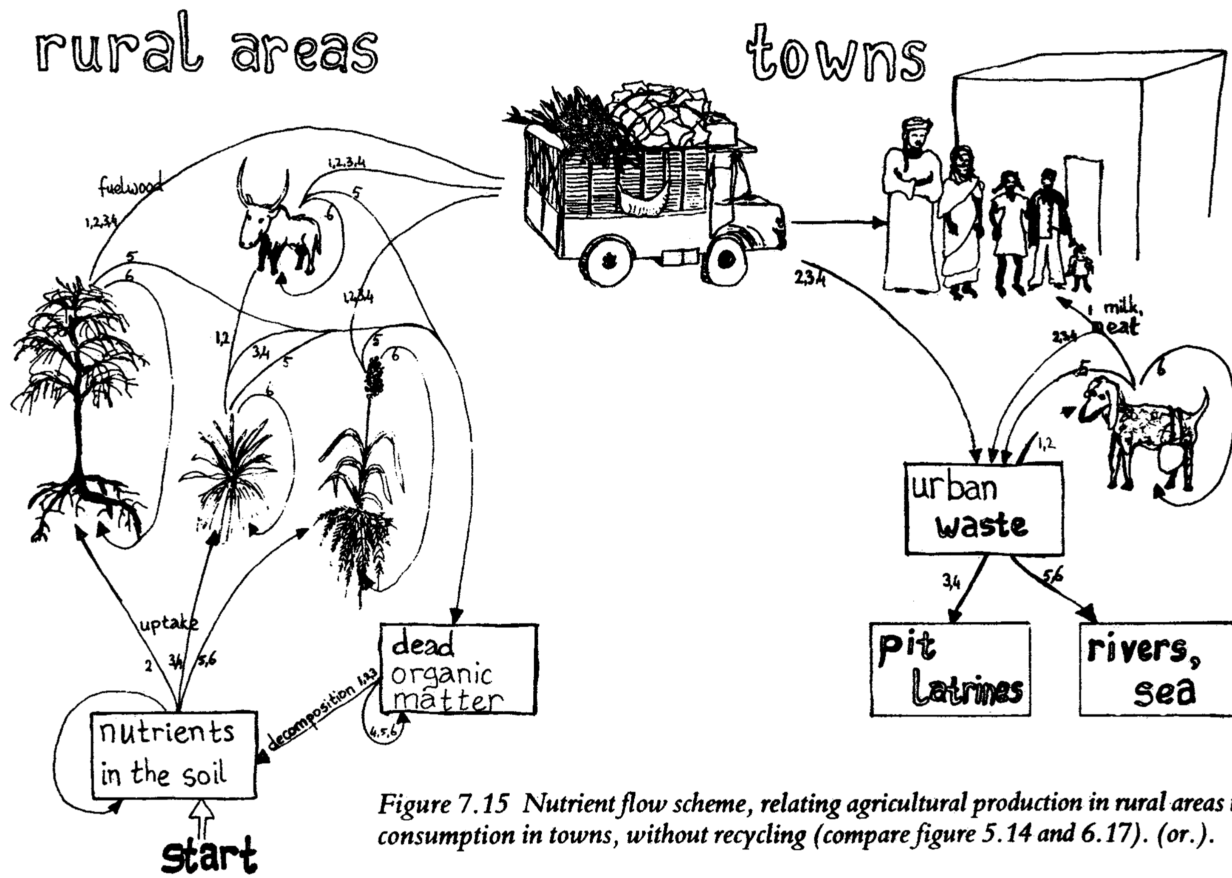


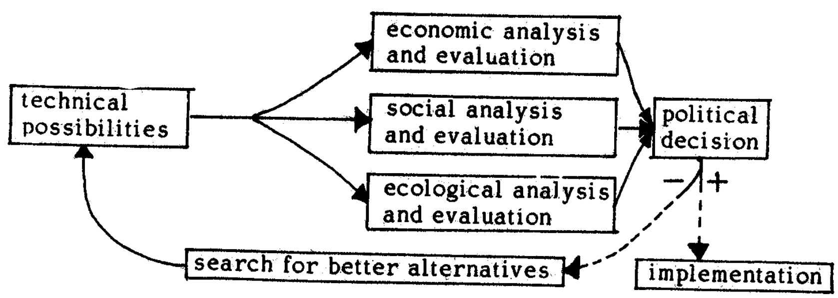
Figure 7.15 **Nutrient flow scheme, relating agricultural production in rural areas to consumption in towns, without recycling (compare figure 5.14 and 6.17). (or.).**

8. Ecological analysis and planning

8.1 The need for ecological analysis

In Chapter 7 we saw that many of the recent developments have lead to the creation of new, environmental problems. Some of these examples consisted of large-scale activities, planned by the local or national government. Especially for these cases it may be obvious that a carefull consideration beforehand of the possibly negative side-effects might have helped to prevent or lessen these side-effects. Every technical proposal for new developments in land-use, agriculture, water management etcetera should be thoroughly analysed on the ecological effects, as well as on the social and economic effects, before a political decision can be made to accept the proposal, to change it or to reject it. (Figure 8.1).

Figure 8.1 Schematic representation ~f the way decisions should be made about development plans; technical plans have to be evaluated on economic, social and ecological merits before any political decision about their implementation can be made. (or.).



It is always much easier to tell what went wrong afterwards, than to predict these negative aspects beforehand. Any prediction will keep a degree of uncertainty and the worst possibilities have to be considered. But the final decision remains a political one, weighing the various pros and cons. As an example of the, role to be played by ecological analysis, we will now consider three cases: the Jonglei canal, the Imatong mountains and the dry savanna zone.

8.2 Jonglei canal

8.2.A. The Equatorial Nile Project

The first plans for digging a canal to bypass the Sudd originated in the beginning of the century. The water losses in, the Sudd by evaporation and seepage were calculated to amount to 50% of the water of the Bahr el Jebel and more than 10% of the total water flow in all Nile branches. In 1938 a serious proposal was made to reduce these losses: the Equatorial Nile Project.

> This proposal consisted of manipulating the outflow of the Equatorial lakes in Uganda to store extra water during the wet season and to release it during the dry season when the Nile's natural flow in Egypt was inadequate for irrigation. A canal system with a capacity for 55 Million cubic metres a day should bring this water past the Sudd.

The Sudan Government of that time was wise enough not to accept this proposal as such, but to appoint the Jonglei Investigation Team to thoroughly analyse the effects on environment and social and economic life of the local people. The result or this investigation was a four-volume report in 1954, predicting so many negative consequences that the original proposal could not but be rejected by the Government.

> The Equatorial Nile Project would have resulted in a complete reversal of the flooding regime of the Nile in the floodplain. The toic's would have become dry in the wrong season to be usefull in the grazing cycle of cattle and wildlife and their role as breeding ground for fishes would have been eliminated. Clearly, this Equatoriaf Nile Project would have been in the interest of Egypt only, destroying the means of livelihood of the local population of the floodplain. This thorough evaluation of the project beforehand was a major achievement and still stands as an example for other projects.

The Jonglei Investigation Team suggested that the only form in which a canal could be acceptable would have to leave the flooding cycle as it is and the canal should have a smaller capacity.

The various changes in the political situation since that time decreased the influence of Egyptian interests (through the Anglo-Egyptian colonial administration the whole Nile valley used to be in one hand) and a project like Equatorial Nile Project became no longer feasible. By building the Aswan High Dam around 1960 Egypt made its own provisions for manipulating the seasonal flow in the Nile and this aspect of the Equatorial Nile Project became unnecessary. But the need for more irrigation water in Nile for Egypt and Northern and Central Sudan remained and became more urgent as both countries approached their quota according to the Nile Waters Agreement of 1959.

8.2.B. The Jonglei canal, phase 1

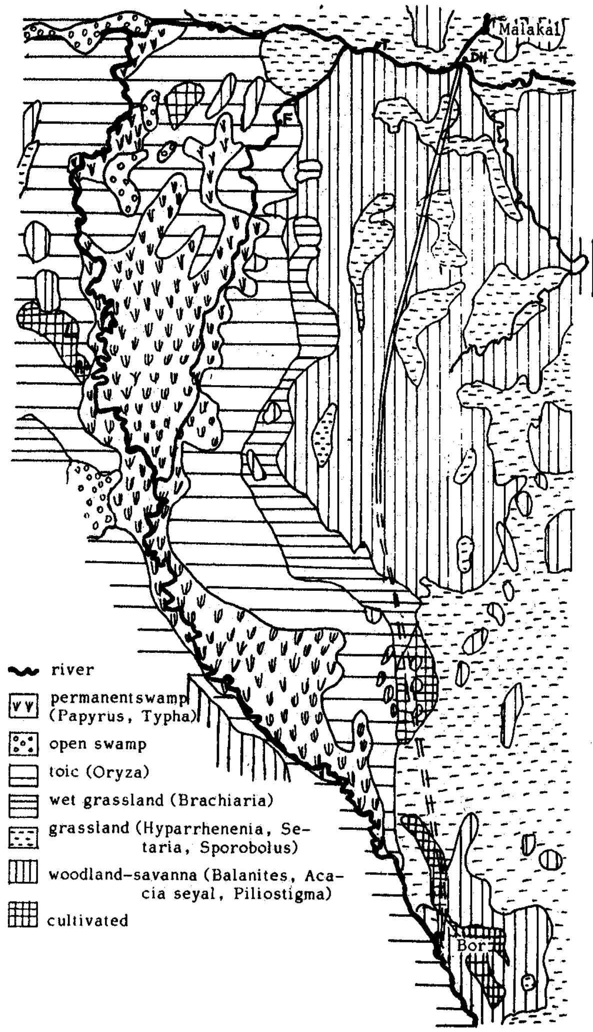
A new plan had to wait till after the Addis Abeba agreement of 1972 and had to be formulated in such away that it would be in the interest of the local population as well.

> Rumours that Egyptian farmers would be settled in the area while the Sudd would be drained, caused protests of the inhabitants of the area and bloody riots in Juba in 1974. But these rumours were not based on facts.

The new proposal 'Jonglei Canal, Phase l' is quite different from the previous ones. It consists of a smaller canal (capacity 20 instead of 55 Million cubic metres a day) and no change in the flood cycle. The canal will accompanied by programmes to improve the grazing potential of the area, to create new possibilities for crop growth by the local inhabitants, as well as improve medical, educational and economic possibilities. The significance of the future canal for transport is emphasized and the project clearly no 1onger is a purely Egyptian interest.

Still, the publication of the project in 1974 aroused concern of ecologists and 'environmentalists' in Sudan as well as internationally. Part of this concern was based on confusion with the previous plans or on wild speculations without grounds. But another part was genuine. The plans have been modified again as regards the alignment of the canal and there will be a continuous study of the effects, both environmental and socio-economic, to watch against and possibly counteract adverse side-effects. In many ways the project still is an experiment, the effects of which cannot be fully predicted. We will now consider some of the remaining uncertainties.

Figure 8.2 Vegetation of the Sudd and the future Jonglei canal (from Bor to Malakal);
A general zonation of the vegetation along the river can be seen; open swamp occurs in the areas relatively poor in nutrients and silt, away from the river and upstream of the main papyrus swamp; the grassland East of the Jonglei canal is seasonally wet because of 'creeping flow'; the canal will interrupt the drainage of these parts in the future. (source: Mefit-Babtic interim report 1980, vol. 2).



8.2.C. Possible ecological effects

* Effects on waterlevels and vegetation

The present vegetation zones are shown in fig. 8.2. Despite all the energy and time spent on surveys and measurements, a clearcut prediction of the waterlevels and hence vegetation zones after the completion of the canal is still not possible.

> The flooding of the toic's and intermediate lands comes from three sources: spill-over of riverwater over the banks of the river-channel, local rainfall in the wet season in excess of the transpiration and infiltration into the clay soil, and 'creeping flow'. This 'creeping flow' is the superficial drainage of excess rainfall in the large almost impermeable clay plain adjacent to the Sudd with a very small slope to the North-West. The plain is too flat for rivers to form, especially on the Eastern bank of the Nile up to the Ethiopian highlands.

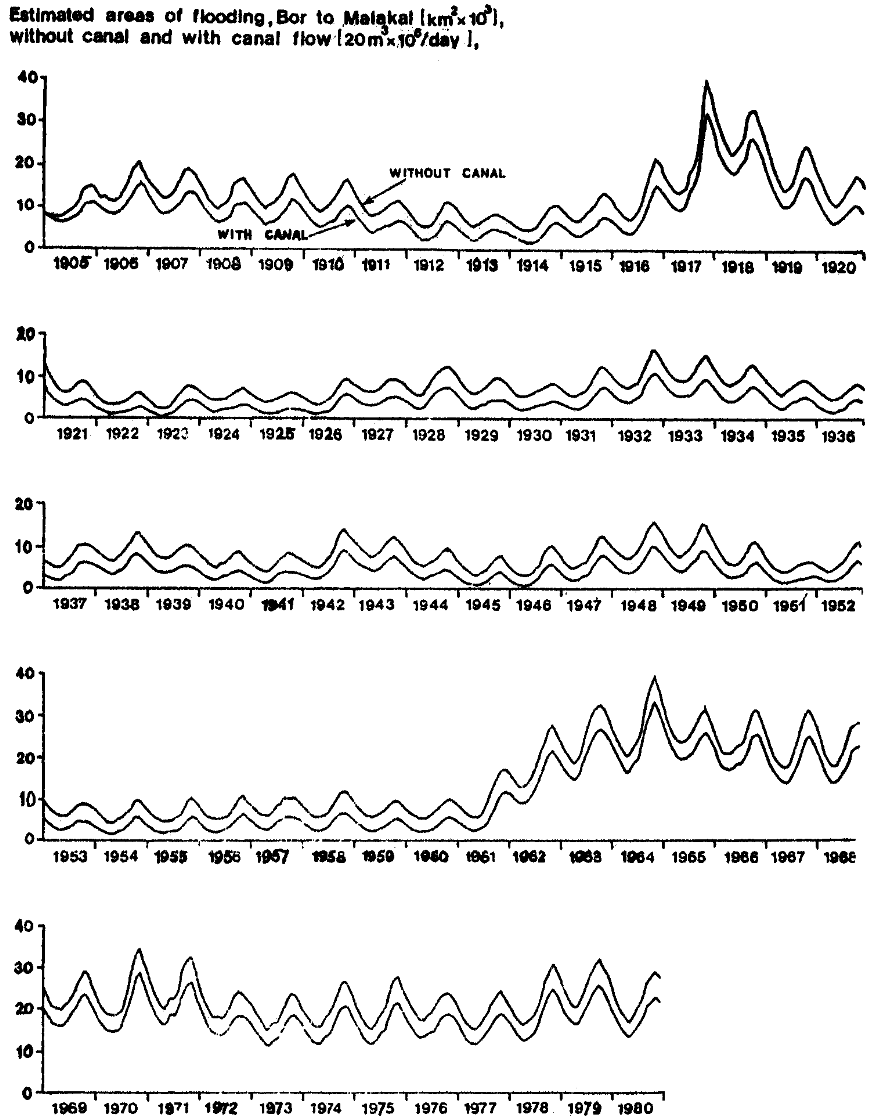
The canal will reduce the spill-over of the river and will intercept the creeping flow on the East bank. Part of the present permanent swamp will only become seasonally flooded toic and most of the present toic will be dry for a longer part of the year. The ponding of the flood plain in the rainy season because of local rainfall will still occur, but the land will dry up faster in the dry season. The complete zonation Sudd-toic-intermediate land-high land will be shifted towards the river. The degree to which this will occur remains uncertain, because the future riverflow of the Nile is uncertain.

In 1961-1963 the riverflow of the Bahr-el-Jebel almost doubled and this caused the swamps to expand. The Zeraf-island was partly flooded, causing problems for the Nuer living there. In the other parts, the floods disrupted the grazing pattern to a smaller extent, but still, since then the major concern of the people has been too much water, rather than a shortage.

> The reason for this increase of the Nile flow was a rise in the level of Lake Victoria by 1 à 2 m, for reasons which have remained obscure. Since that time the levels seem to gradually go back to the 1960 situation, but it may take another 15 years before that situation is reached. Sufficient data are lacking but there is evidence for a rise of the river level before, in the middle of the 19th Century and around the turn of the century.

If the Jonglei-canal Phase 1 would be opened now, the river flow would more or less return to the 1960 situation. In that respect the canal fits within the 'natural' fluctuations of the water level and the vegetation and fauna may be expected to adjust itself to the new situation. But if the river levels will then continue to drop their 1960 level, the floodplain will become drier than ever before. Permanent swamp will then probably be limited to the

Figure 8.3 Evaluation of the effect of the Jonglei canal on the permanent and seasonally flooded area in the Sudd; calculations were made to show the effect of the canal if it would have operated since the start of this century. (from: Sutclilfe & Parks)



Southernmost part of the present Sudd and to areas around the outlet of the canal. Figure 8.3 shows the estimated areas of flooding if a canal would have operated from the start of the century. In certain years, e.g. 1913, 1923, 1925 and 1945 the permanent swamp would have dried up completely during the dry season if a Jongleicanal would have been present.

> Because of the increased water-flow on the outlet of the canal in the Sobat river, the water level here will rise due to what is called a 'back-water' effect. Just upstream of the canal-outlet some of the present toic's will become permanently flooded and new grazing land will have to be found.

All the present vegetation types and ecological conditions will remain in the area, but their distribution will change. The toic's are in many ways the most important part of the zonation (for grazing cattle, wildlife and migrating birds in the dry season and for breeding fish in the flood season). Toic's will remain on the fringe of the contracted permanent swamp.

> Much depends on the manipulation of the creeping flow of the Eastern plain. Increased possibilities for year-round grazing may be created through small dykes and dams keeping water out of some parts and concentrating water in other parts and hafirs to supply drinking water. An interesting new situation may arise, but the natural conditions of the toic will be lost.

* **Effects of the water balance on a regional scale**

Wild speculations have been made about possible effects of the Jonglei-canal on the rainfall in the rest of the Sudan. The large evaporation of water in the Sudd and floodplain may play some role in the rainfall for the area downwind, to the North-East, but certainly not for the whole of the Sudan.

> The main share of the water-vapour for any rainfall comes from the Oceans, but local evaporation might have some triggering effect, stimulating rainfall. If this is true, after the rise in floodlevels in 1961 a stimulating effect on rainfall can be expected for the area to the North-East of the floodplain. There is some evidence that the drought in the Sahelian zone in the seventies

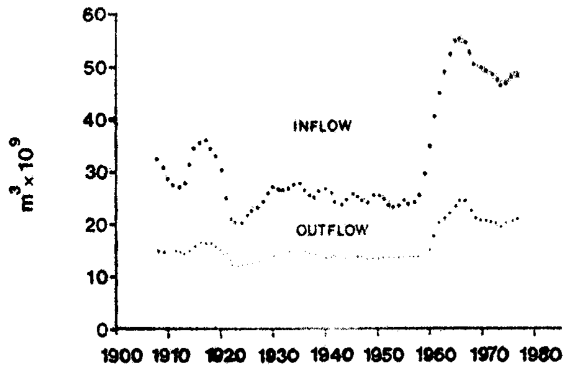


Figure 8.4 Records of river flow, at Mongalla (inflow) and Malakal (outflow) showing the regulating effect of the swamps: the outflow is relatively constant compared to the variations of the inflow (seven years moving mean), (from: Sutcliffe & Park).

was not as strongly felt in Eastern Sudan. Rainfall records to fully substantiate or contradict this view are lacking, however. The natural variation in rainfall from place to place and from year to year makes it difficult to prove any such influence, given the scarcity of rainfall records. A future decrease in the evaporation of water in the swamps might accordingly be expected to have an effect on rainfall, but this influence, if present at all, will be gradual. Part of the water gained will be used for irrigation agriculture in areas not too far from the Sudd, and will thus evaporate in roughly the same area, offsetting part of any negative effect. Summarizing, the possible effects on rainfall will not be of a dramatic nature.

As figure 8.4 shows, the Sudd as a whole is regulating, the waterflow: despite large fluctuations in inflow, the outflow is relatively constant.

Part of the water losses in the Sudd is probably due to leekage to roundwaterstreams. If this seepage would be reduced after concentration of the swamps, groundwater supplies of the dry savanna zone might be affected. The major part of the area has a clay soil of low permeability and will not contribute much to seepage. Sandier parts in the area might recharge groundwater in Nubian Sandstone, but very little information is available. Negative effects of contraction of the swamps might be offset by creased leekage from the Nile-valley North of Malakal.

Papyrus swamps show a luxurious growth, suggesting a high transpiration rate. But in fact their water use is less than the evaporation from an open water surface especially if wind can cause waves on the water. Water use of a papyrus swamp is about three-quarter of (to equal to) open water evaporation, while for waterhyacinths water use is about double that of an open water surface. Water losses in the Bahr-el-Ghazal swamps, with a poor vegetation are proportionally much higher than in the Bahr-el-Jebel papyrus swamps, Any increase in occurence of waterhyacinths downstream will result in large water losses. By complete control of waterhyacinths along the whole Nile, more water would be conserved than by the Jonglei canal.

Papyrus swamps are very efficient in their water use. Hardly any plant grows faster, using the same amount of water. If techniques would be developed for using papyrus fibres for making paper, as an energy source (through biogas for example) or as raw material for chemical industry, the reduction or loss of the swamps as a biologically very productive ecosystem might be regretted later

* **Creating new swamps North of Malakal**

It is quite obvious why there is little papyrus swamp between Nimule and Bor. The gradient in the river causes a fast stream, which is not suitable for papyrus. Also, the riverbanks are high enough to prevent spill-over. North of Bor both these factors change. The gradient in the 770 km long stretch to Malakal is only 5 cm/km and the rate of flow decreases from 1.1 m/s at Bor to 0.6 m/s at Lake No at the confluence with the Bahr el Ghazal. But it is not quite clear why the Sudd ends near Malakal. The gradient North of Malakal is even less, 1.5 cm/km up to Jebel Aulia dam, and the rate of flow consequently drops till 0.l m/s. The river flows in a well defined but broad channel. Physical conditions for swamp development seem to be present, without being realised.

An important effect of papyrus swamps is that they act as a filter for silt and nutrients contained in the water. After passage through a swamp the water contains much less silt. Oxygen levels fall rapidly in the swamp and the pH drops. Sulphate-reducing bacteria can live in water without oxygen and the production of H_2S-gas is evidence of their existence in the Sudd. After passing through the swamps almost all of the sulphate in the Nile water has been used. The lowering of the pH leads to an increased availability of iron and phosphate, as long as there is some absorbed to the silt particles. This phosphate can then be used for plant growth. The concentration of other salts can rise because of the concentrating effect of water loss. It seems as if the Sudd extends for as long as there still are silt and nutrients in the water and ends if these fall below critical values. The Bahr el Ghazal has lower concentrations of nutrients such as phosphate than the Bahr el Jebel and has a much less luxuriant papyrus swamp development.

From this point of view one may expect significant changes to be caused by the Jonglei canal bringing water with a high silt and nutrient content from Bor to Malakal. North of Malakal ideal new chances for papyrus swamp will be created: slow-flowing water with much silt. Papyrus swamp can harbour 'breeding sites' of waterhyacinths out of human control and the simulated water-hyacinth growth in the Jebel Aulia reservoir will lose a considerable part of the water gained by the canal. Already there are concentrations of water-hyacinths around partly drowned trees in the Jebel Aulia reservoir which can be the starting points for new swamps. The chances for mosquitoes and snails will improve, so Malaria and Bilharzia can increase. The silt-load of the White Nile in the new situation will fill in Jebel Aulia reservoir in the same way as happens in the Blue Nile reservoirs at the moment.

In this view the canal might result in many changes North of Malakal. The Sudd has been described as merely weed growth, blocking navigation and evaporating water. But the papyrus swamps play an important role as filter and buffer, regulating water and nutrient flow. Loss of this function may the problems downstream.

* **Effects on fish population**

Many people have expressed concern about possibly negative effects of the cannal on the fish population in the Nile. Again it is difficult to predict accurately what the effects will be, because the breeding habits of many of the Nile fishes are still unknown. The toic and fringe of the permanent swamp is used, by some fish species at least, for spawning and growth of fish fry, and fingerlings. The rivers and cannals are rich in fish, but inside the permanent swamp lack of oxygen restricts the occurence of fish as well as fish-predators. In the rainy season the oxygen levels in the water drop and a heavy mortality of fish has been noticed.

> The toic is important for young fish because much food is available and the plants give protection from predators. Towards the end of the dry season nutrients accumulate on the surface as animal dung, plant remains or ash from the fires. After flooding these nutrients dissolve and give rise to a high production of plankton and the following steps in the foodchain. The production of young fish is high, but only a small part of them will survive the dry season in permanent water. The majority will be trapped in ponds which dry out completely. Only the lung-fish has found a way to overcome this problem. For all the other fishes survival of the dry season probably is the factor limiting population size.

Effects of the canal on the toic are probably less important for the fish population than effects on Ute distribution of permanent water. The fisheries potential of the area has not yet been fully realised and possibly negative effects of the canal can be offset by creating better contact between toic and permanent water. Certainly the techniques and the locations for fishing will have to change.

*   **Effects on migration routes of cattle and wildlife**

As can be seen in fig. 6.7 the canal will intersect several routes presently by used by migrating herds of wildlife and cattle, towards the river in the dry season and away from the river in the wet season. As the cattle migrations routes are based on traditional, tribal land rights, fear has been expressed that changing the routes will lead to tribal conflicts. This concern has lead to a change in the alignment of the canal, which will now pass to the East of Kongor in stead of on the Western side. Along the whole length of the canal crosing points for cattle will be constructed. Whether or not wild animals will learn to cross the canal is uncertain. Wildlife will be affected by the new settlements and agricultural development along the canal anyway. The part of the canal which has been dug already but is still not water filled, certainly is an obstruction to wildlife migration. Poaching along the canal will become very easy.

For cattle new possibilities or year-round grazing may be created along the canal, as mentioned under point A. This will cause significant change in the social and cultural pattern of the people in the area, for whom the life in the cattlecamp of the young generation away from the permanent village is a characteristic feature.

8.2.D. Final remarks

Jonglei canal offers an interesting case study for the way in which man interacts with the environment. Positive change of the environmental conditions is only possible, if this is based on a proper analysis of the ecogical situation and the traditional way this situation has been used by man. For a project on the scale of 'Jonglei canal Phase' a full prediction of effects beforehand is impossible, as shown by the many 'might be's' and possibly's' in this chapter. As far as the change remains within the range of natural fluctuations, the ecosystem can be expected to adjust itself to the new situation. Opening the Jonglei canal can be compared with the natural changes in the river system in the geological history, when from time to time new river branches were formed bypassing swamps etcetera. Such changes have always resulted in local extinction for many species, providing new chances on other places. The canal may give such new chances as well, but much will depend on the way the canal will be managed in the future, especially in years of low riverflow as in the 1920's. Political control in such a situation will be important, but the decisions to be taken will be difficult: it will affect either the people dependent on irrigation culture or the people dependent on the natural sudd and toic system.

The title 'Phase l' indicates future plans, on an even larger scale: drainage of the Machar marshes on the Sobat river, a larger Jonglei canal and various

diversion canals in the Bahr al Ghazal system which together might triplicate the water gain of phase 1. Any decision on such plans should wait for a carefull analysis of the effects of phase 1.
So far the Jonglei-canal project has been quite exceptional in the thoroughness of considering environmental effects beforehand. It is to be hoped that all this work can be used positively for improving the long-term conditions for the local population as well as for the natural elements of the ecosystem and for the Sudan as a nation.

8.3 Imatong mountains: conservation or development/ destruction

The Imatong Mountains are a unique area for the Sudan, containing the highest mountains, and receiving the highest rainfall (figure 1.9). The lower slopes are covered by the best areas of rain forest left in the Sudan. The area has attracted several 'development projects', which may easily conflict with the vulnerable quality of the natural resources. Only carefully planned projects are acceptable in such areas. Unless a balanced plan will be worked out soon for conservation of the mountain vegetation along with a limited human use of the resources, much destruction will take place in the near future.

8.3.A. The ecosystem

The Imatong Mountains rise rather abruptly from the surrounding savanna covered plain of about 600 m above sea level (figure 8.5). The highest part is formed by Mount Kinyeti. Two river systems have carved horse shoe shaped valleys into the mountains: river Kinyeti flowing North to swamps beyond Torit and the Ateppi river flowing West towards the Nile. Rainfall data for Katire and Gilo were given in figure 1.9. The middle ranges of the mountains have the most humid climate. The western part (the Ateppi basin) receives the highest rainfall. The zonation of the natural vegetation has been shown in figure 2.7.

- a lowland and transition zone (1000-1800 m) differing markedly from the surrounding savanna due to the higher rainfall. *Khaya* and *Chlorophora* are typical species of this rain forest. The best remaining areas of this forest type are at Laboni, Lotti and Lower Talanga.
- a lower montane zone (1800-2400 m), with Olea-*Podocarpus* closed forest and grassland on hill tops,
- a higher montane Zone (2400-2900 m) with *Podocarpus-Dombeya* open forest, with many lichens as epiphytes,
- an Ericaceous zone (over 2900 m) with heather shrubs and an open vegetation.

Tabe 8.1 Number of higher plant species collected on a recent collecting trip in Imatong Mountains. Species occuring in more than one zone are counted only once.

	lowland and transition		low montane zone		montane	erica-
	rain forest	rocky outcrops	forest	grassland	forest	ceous zone
trees 30-50 m	21	-	-	-	-	-
trees 15-30 m	32	2	15	-	8	-
trees 3-15 m	58	3	20	7	8	-
shrubs)	148	46	28	2	6	4
groundlayer)			119	99	24	45
lianas and vines	35	7	26	2	2	-
epiphytes	1	-			3	-
Total	295	58	226	110	51	49
	353		336			

The flora of the mountains is very rich and contains hundreds of species which are not known elsewhere in the Sudan. Many species from the the area have not yet been described scientifically. Table 8.1 gives the results of a recent botanical expedition. About 800 plant species were collected, more than 150 of which had not yet been recorded in the Sudan before but were known from elsewhere in Africa. As a result of this expedition 6 species were described, which are not known from any other place in the world. The Imatong Mountains have a unique flora because the area is the meeting point for plants from West African rain forest, the Ethiopian plateau and the East African mountains (Ruwenzon in Uganda, Kenyan mountains); because the mountains are relatively isolated many local varieties and species have been formed. Figure 8.6 shows two new species for the flora of Sudan.

> An interesting point is that not only the forests contain species typical for the Imatongs but the grasslands and open vegetations on rock faces as well. This indicates that such vegetations must have existed in the area fora long time (long enough for new species to develop), before the human exploitation and modification started.

The high number of plant species of the mountains should be sufficient reason to try to protect at least representative areas of each vegetation type from negative human influence. In the forests occur wild coffee varieties which may one day be important for breeding new coffee strains. From the

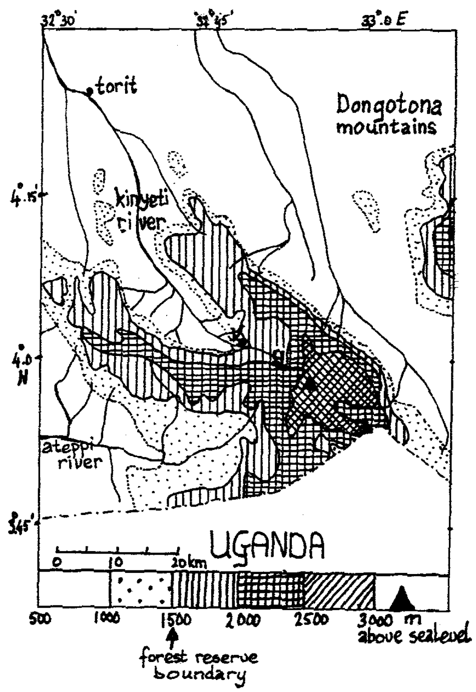


Figure 8.5 Map of the altitudes of the Imatong Mountains and surrounding plains (k = Katire, g = Gilo) (from: Jenkin et al.).

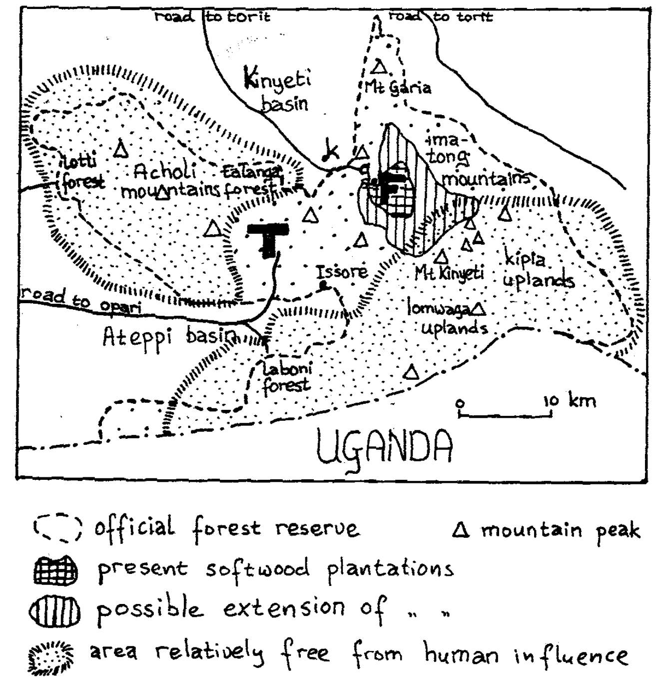


Figure 8.7 Map of the forest reserve showing the forestry project, the tea project and the area which might be set aside as nature reserve (or national park) (or.).

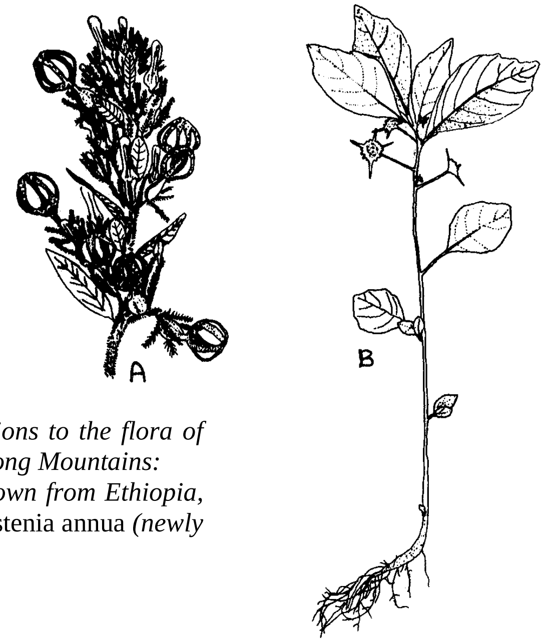


Figure 8.6 Two recent additions to the flora of the Sudan, found in the Imatong Mountains:
A. Ceropegia abyssinica *(known from Ethiopia, determination: Friis), B.* Dorstenia annua *(newly described species by Friss & Vollesen). (A. or.).*

majority of species no human use is known as yet, but they have not been investigated either.

Wildlife is abundant in the area as well. Colobus and Blue monkey are numerous, as is the Bush-pig and the local montane race of the Bushbuck (which can be considered to be aseperate sub-species). Elephant, buffalo, duiker's, hyaena and leopard are most abundant in the South Eastern part (Kipia and Lomwaga Uplands), the area least frequently visited by hunting people from the villages in and around the mountains.

The forests contain many birds not found elsewhere in the Sudan. The area is important for migrating songbirds from Europe on their way to overwintering places in East Africa.

8.3.B. Human use

The Eastern side of the mountains have since long been inhabited by Latuka, who named the Imatong Mountains. The British colonial administration resettled these people at the foot of the hills; later they returned to the mountains. The plains on the Western side are inhabited by Acholi.

During an outbreak of sleeping sickness in 1927 they were moved into the hills. As they were not accustomed to hill farming erosion was the result and they soon returned to the plains; their brief stay in the hills can still be traced in the vegetation.
In the 1950 mountains above 1500 m were officially declared to be a forest reserve, in which any further settlement was not permitted.
The higher parts of the mountains, above 2500 m seem never to have been inhibited and human influence has been restricted to fires caused by hunters and honey-gatherers and occasional felling of trees by the latter. Man-made caused the forest of many hill tops to be replaced by grasslands.

In the 1940's the colonial administration started a forestry project near Katire, in the Kinyeti basin. Natural forest was cut and replaced by plantations of fast growing softwoods, *Cupressus* and *Pinus*. The project attracted many people as labourers, who started hill-side farming, especially during the Civil War. Shifting cultivation has affected the forest in a wide circle around the forestry project. Erosion has been the result. After 1972 a program started for rehabilitation of the plantations which had been neglected. A new road was built from Torit, a hydro-electric scheme for the sawmills etcetera. Katire-Gilo became the focus of much human activity. Hill side farming by them is being made unnecessary by adopting agro-forestry methods, by which they can grow maize and potatoes in the new plantations. Hunting now affects a large part of the whole mountain range. Natural forest in the plantation area is restricted to the steepest. Plans exist for a considerable extension of the project, clear-felling a part of the Kinyeti-basin. (Figure 8.7).
Around 1975 a tea project was started at Upper Talanga, making use of the rainfall on this side of the mountains. The project site may have been well chosen from an agricultural point of view, ecologically it was ill-conceived. The tea project has opened a new entry into the mountains, through the Ateppi valley. The project has attracted many more people to live the mountains, without supplying food in an integrated farming system. Hill side-farming, erosion and an increased hunting pressure is the result. In fact the forest reserve has now been cut into three parts (figure 8.7): the central part is used for tea and softwood plantations, the Acholi mountains on the Western side and the inaccessible area South East of Mount Kinyeti remain relatively unaffected.

8.3.C. A plan for conservation

If further projects such as the tea project would be started in the area, very little would remain of the natural resources. In its present state the mountain are a genetic reservoir, with a great potential for educational and touristic visits. The forestry project can be managed in such a way that even in the long term, stable wood production is possible; the project has to aim at local food production to reduce the pressure on the natural forest. The existing Rest House at Gilo might be turned into an educational centre for sschool, students etcetera. Meanwhile the two areas which have been little sofar, should get a better conservation status, as nature reserve or national park (figure 8.7). The Acholi Mountains, including Lotti and Lower Talanga forest, should become a reserve mainly for botanical reasons; Mount Kinyeti, Kipia and Lomwaga Uplands for wildlife as well. By including the Southern part of the Ateppi basin in this area (including forest) the full range of habitats from savanna to montane vegetation can be protected. A plan for conservation has to be worked out allowing for a zonation of human influence, with buffer zones around the present villages and projects. Such a plan should be worked out by the Regional Ministries for agriculture, forestry and wildlife, as it would clearly be for the benefit of Sudan as a whole, that such aunique area would be protected adequately.

8.4 Sahel zone: Development or/and conservation

As described in 7.2 desertification of the Sahel zone is a real threat. Increased agricultural activities are held to be mainly responsible, with overgrazing and deforestation adding to the problems. In this zone, efforts to raise food on production seem almost inevitably to lead to environmental destruction and hence to a decreace in food production. We will now look into the backgrouds of this problem, to see whether or not solutions exist which lead to an increased food production without destroying the vegetation which has to protect the soil. The data used in this section have been collected in Mali, West Africa, in an area with circa 400 mm of rain/year.

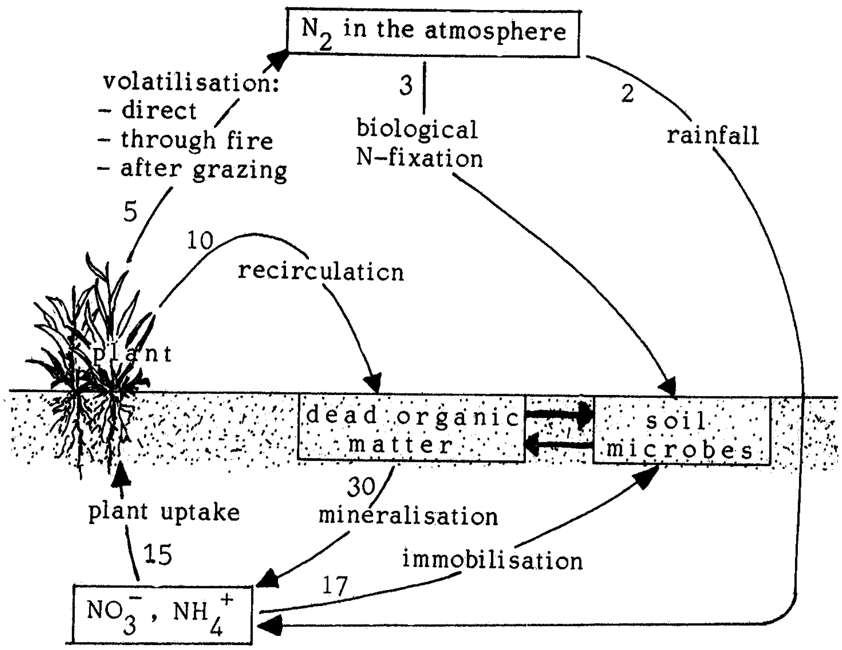
When new land is cleared the yields of dukhn or dura (*Pennisetum* or *Shorgum*) can be around 700 kg/ha. A family of 5 persons therefore needs 1 à 1.5 ha to produce enough food. By cultivating 3 à 4 ha enough surplus can be produced to survive two or three dry years or to sell on the market. In this system land is abandoned after 2 or 3 years of cropping and a fallow period of at least 20 years has to follow. If for some reason or other the farmer cannot shift to new fields the yields will drop to ca. 300 kg/ha. As a farmer cannot cultivate more than 4 ha a marginal existence is the result, with hunger in dry years.

One way out of the problems is to use manure to fertilise the fields, but this requires many animals and hence a large grazing area. To keep a farm of 3 à 4 ha at a production level of 500 kg grain/ha one has to use the manure of 7 cows (or equivalent number of other animals) for which about 100 ha of grazing land is required. This means that only 3% of the land can be used to grow crops (in the rich savanna areas this figure is 5-10%). If the area used for cropping is increased, less manure will be available per ha resulting in lower yields. When the number of animals is increased the vegetation will suffer and too many tree branches will have to be chopped off to provide sufficient food.

Basically, the dilemma of the Sahel zone is the low production level of the natural vegetation and of any derived, man made vegetation. Efforts to use a larger part of the production for human consumption are often counter productive. To solve the prob1em we have to know the limiting factors for promary production.

Water may seem to be the main limiting factor, but in fact poor soil fertility is of greater importance in large areas of the Sahel zone. In some field-experiments irrigation increased production by a factor 1.5, fertilisation by a factor 3 and irrigation plus fertilisation by a factor 15. Nitrogen and

Figure 8.8 Nitrogen cycle of the poor savanna zone (ca 500 mm of rain); Rates as kg/ha/year. (from: de Ridder et al.)



phosphorus appear to be the soil nutrients which mainly limit production. Figure 8.8 shows the nitrogen cycle for natural sites in this zone. When in equilibrium the ecosystem receives 5 kg N/year from the atmosphere by rainfall and biological N-fixation. The yearly losses by volatilisation to the atmosphere will be 5 kg N/year as well, directly from soil or plant, through fire or after consumption by herbivores.

> This input of ca 5 kg N/ha is relatively constant if we compare dryer areas.In these dryer areas nitrogen is no longer a limiting factor, at the lower production level caused by a lower rainfall. The good grazing quality of the small amount of biomass produced here (figure 6.6) can be explained along such lines.

By clearing such a field the nitrogen supply to the crop can be 15 kg N/ha in the first year, allowing for a yield of 750 kg grain/ha. By depleting the amount of soil organic matter the nitrogen supply will be reduced to 5 kg N/ha, allowing for only 250 kg grain/ha.

In section 5.4 the difference between 'standing biomass' and 'primary production rate' was mentioned. We can see now that this production rate depends on the presence of the nutrient cycle. If we remove from the ecosystem the biomass produced in one year, production in the next year will be lower. We can define a 'maximum sustainable extraction rate' equal to the yearly inputs into the nutrient cycles. Using a larger share of the biomass is only possible if increased inputs can be realised.

> In the discussion about the area needed to supply enough fire wood (section 7.2) this point has to be considered as well. 'Well managed forest' implies that depletionofthe soil is prevented.

Improving soil fertility can be achieved by various means:

1. reducing losses by fire and soil erosion as far as possible;
2. stimulating biological N-fixation by growing leguminous plants;
3. applying chemical fertilisers.

The last solution may be technicaly adequate but is economically imposible on any largescale, because of the high energy requirement for industrial N-fixation and hence its high price. The best solution seems to be simulate leguminous plants in the grazing land and to include them as far possible in the crop rotation.

> Efforts to do so have failed in many cases. Most leguminous plants have a rather high phosphorus requirement but due to their relatively small root system they are poor competitors with grass for soil phosphorus. When growing on poor soils, grasses and legumes will attain a natural balance. The grasses can take advantage of the nitrogen produced by the legumes, to outcompete the latter; but if the proportion of the latter decreases, the relative advantage of the grasses decreases as well, till the point that both are in

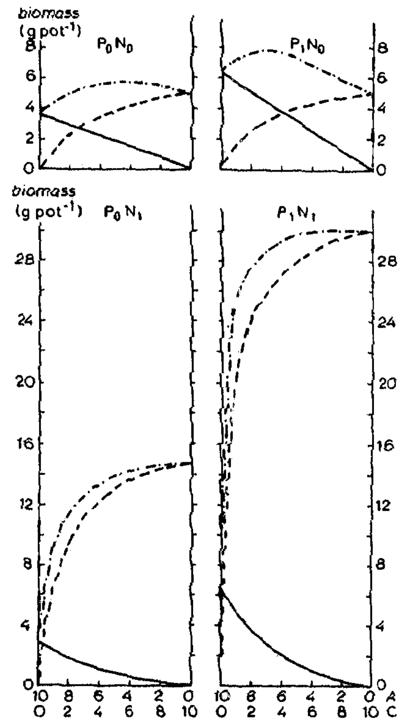


Figure 8.9 Competition between a grass and a legume, as influenced by N 8 and P fertiliser (compare figure 6. 13 for the design).
-------- = Alycarpus ovalifolius *(legume),* -·-·-·-·- = Cenchrus biflorus *(grass). (from: de Ridder et al.).*

equilibrium. Introducing other leguminous plants into the pastures, possibly with a higher N-fixation rate, will lead to a shift in the equilibrium towards the grasses. TotalN-input will therefore increase hardly at all.

The best way to change this equilibrium is to add phosphate to the system. By doing so, growth conditions for the leguminous plants are really improved, while the grass can benefit secondarily from the higher N-fixation which is the result; Figure 8.9 shows the result of a pot experiment using replacement series (compare figure 6.13). Applying nitrogen increases the yield of grass, while depressing the legume in mixed culture; applying phosphate stimulates the legume, from which the grass benefits when in mixed culture; applying both, greatly increases grass growth in mono culture as well as in mixed culture. The experiment shows that to attain the maximum production levels possible under well-watered conditions, high amounts of both Nand P are needed. But comparing the costs, applying P only and in this way stimulating N-fixation is worthwile. In many cases locally available phosphate-rock can probably be used directly by leguminous plants, with the help of mycorrhiza, instead of industrially processing phosphate-rock to make 'superphosphate'.

Table 8.2 Effects on environment and on food production, of technical 'development projects'. Negative, neutral and positive effects are indicated.

		Effect on food -production (short term)	Effect on environment	Effect on food -production (long term)	costs
A	Well drilling	+	_ _	_	_ _
	Veterinary services	++	_ _	_	_ _
	Mechanised farming	+	_ _	_	_ _
B	Introduction of improved stock	0	0	0	_ _
	Introduction of legumes	0	0	0	_
	Introduction of 'High Yields Varieties'	0	0	0	_
C	Fire control	-	+	0	_
	Cotrolled grazing	0	+	+	_
	reforestation	0	+	+	_ _
D	irrigation	++	0	+	_ _ _
	Legume + P-fertilisation	+++	+	+++	_ _
	Irrigation + fertilisation	++++	+	++++	_ _ _ _

Table 8.1 lists the effects of several common components of technical aid programs on the environment as well as on food production. Negative effects on the environment in the long run lead to negative effects on food production (by both crops and animals); here the primary effects are shown as well as estimated long term effects. In all cases it is assumed that social and economic conditions allow the technical changes to be effected. The first group of measures (A) increases the use of the environment: short term food production improves, but long term effects are negative. The second group (B) is non effective because the factors changed are not the limiting factors. 'Improved stock' or 'High yielding crop varieties' will not be effective given the environmental constraints. The third group (C) reduces the human pressure on the environment. Direct effects on food production will be negative or neutral which will hinder acceptance by the population, although long term effects on food production will be more positive. As explained above, the only way to increase food production both in the short and in the long term, is by increasing soil fertility (D).

The best chances for development as well as conservation are stood by a combination of technical changes. Reforestation as well as increased soil fertility in the *Acacia senegal* -crops -animals farming system will be needed to supply enough firewood, to provide windbreaks and to protect as well as to the soil as well as to produce enough food.

To try to achieve environmental conservation without adequate food production is fighting a lost battle.

Figure 8.10 What does the cartoonist tvant to say?

8.5 Suggested practicals

1. Simuation game on the Jonglei canal issue.

   The political issue whether or not to construct the canal, is the result of weighing the various arguments pro and con. But it is also influenced by the pressure exerted by the various interest groups. We can try to gain some insight in this process by playing a simulation game. The game consists of two parts. First of all, all participants are evenly distributed over the nine groups mentioned below. Every group then prepares their point of view, selects the arguments they can use and other ways of exerting political pressure.

   After this preparation the game is played for a limited period of time (say 2 hours). During this time group 1, the political body, has to listen to all other groups and then take a decision.

   Participating groups:

   1. A political body, consisting of people of various backgrounds,
   2. The Central Ministry of agriculture, department of irrigation schemes,
   3. The Egyptian government
   4. External technical advisors, expatriate col'lsultants on canal building, irrigation (and ecology if requested),
   5. Regional Ministry of agriculture, planning irrigation scheme for Jonglei area,
   6. Regional Ministry of wildlife and fisheries,
   7. Anthropologists and livestock researchers concerned with the area,
   8. 'Environmentalists' lobby from other countries: 'friends of the earth',
   9. The local people themselves.

After the game has been played the roles and the effectiveness of each group should be analysed.

2. Discussion on Jonglei Canal. A recent report by expatriate consultants on environmental effects of the Canal comes to the following conclusions: 'We are convinced of the need not to try to dismantle the existing surprisingly efficient traditional system. There is no place in that existing system for the introduction of exotic cattle, for the introduction of commercial ranching enterprises, for elaborate mechanical fodder harvesting projects, for dairy and poultry farms, or the extensive provision of clinical veterinary services.’

   'The objective must be to assist the people of the area to help themselves to improve animal production in the face of increasingly difficult times ahead'. Do you agree?

3. Discussion on Imatong Mountains.
   How do you think the following groups would like the Imatong Mountains to be fifty years from now? What do you expect their opinion to be on the current activities in the area?
   a. forestry director
   b. tea project manager,
   c. potato project manager
   d. minister of wildlife and tournism
   e. villager of Gilo
   f. plant breeder searching coffee strains resistant to local diseases
   g. farmer of village near Torit depending on water of the Kinyeti river all year round.
   h. wildlife conservation club of your school
   i. the generation of your grandchildren (not yet born. ..)
   j. Podocarpus tree and a Colobus monkey

   What is your own opinion?

4. Discussion on dry savanna
   Table 8.2 lists various solutions to the desertification problems of the Sahel zone. Can you make a plan combining several of these activities, which would serve the direct needs of the people as well as ensuring possibilities for future development by protecting the environment. (Basic needs include: drinking water, food, fuel, housing, shelter and a source of cash income). What kind of external inputs would your 'project' require? (e.g. information, tree seedlings, fertiliser, well drilling equipment, marketing facilities). Do you think the government would step in to provide the money? Do you think all villagers would accept yout plan?

9. Man and nature

9.1 Human attitudes towards nature

As described in chapter 6 man's role in the ecosystem used to be not too different from the role of other organisms until quite recently. Several natural factors directly limited man's activities and population size. Emotionally people felt their life to be determined by the powers of nature. Modern development largely consists of an increased ability to manipulate the environment and to master natural limiting factors. 'Everything depends on everything' in the ecosystem and many undesired side effects are the result of man's present activities, as explained in chapter 7. The increased power to manipulate should be accompanied by an increased sense of responsibility for the environment, as the time and space for the 'trial and error' approach is lacking. **'There is only one Earth'**. This expression is a milestone in the thinking about environmental problems. There is only one earth, so we have to be very careful not to destroy nature's potential.

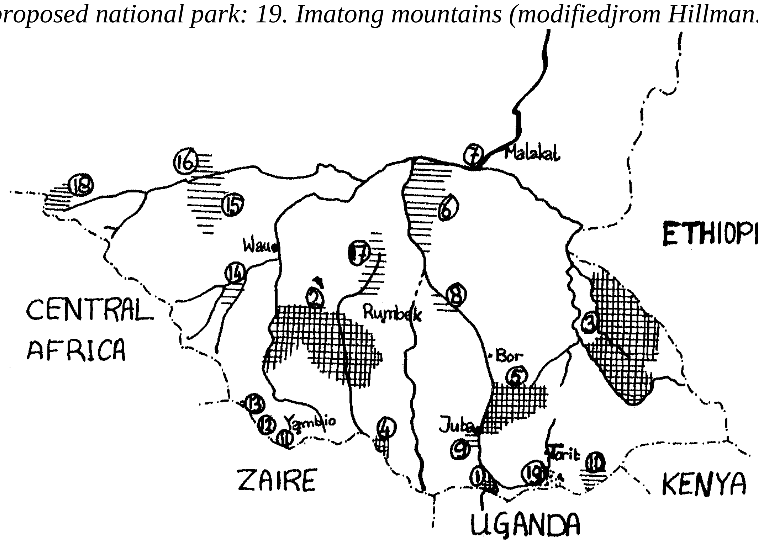
> An increased sense of responsibility for the environment does not evolve spontaneously and not for all members of het society at the same time. In the Western world the first concern about nature arose some hundred years ago. To a small group of people the possibility of extinction of certain plants or animals became obvious and they took action to create nature reserves. After some time, people realised that to conserve an animal or plant species, one has to conserve its habitat and that larger nature reserves or National parks are necessary. In these parks human influence is limited, although usually it cannot be absent because the parks are too small to show the 'balance of ' nature'. In, several East African parks for example, the concentrations of elephants became very high, because natural migration cycles outside the park were cut off. Some form of management of the park is necessary to prevent overgrazing and uprooting of all the trees.

National parks are necessary to maintain the diversity in nature, but they are not isolated from the developments in the environment outside the parks. The recent degradation of Dinder National Park is a clear example in the Sudan.

Over the last ten or fifteen years it has become increasingly clear to a large part of the world's population, that conservation of the environment in a wider sense is necessary. National parks and nature reserves should not become small green islands in the middle of a degraded, ruined and polluted landscape. All the land of this 'only one earth' should be managed so that the long-term survival of man as part of the ecosystem is guaranteed. This lead to the formulation and acceptance by many countries of a 'world conservation strategy'.

Concern about nature reserves seems to be a luxury, only possible for rich people. But by the time a larger part of the population will see the necessity of conservation, not much will be left if no action is taken now by the forerunners of the conservation movement. For many people who have constant problems in ensuring their food for today or tomorrow, the environment is not of prime interest. But their actions of today make their food supply of tomorrow even more dubious. As soon as they would consider their interests on a somewhat longer time-scale, they would see the need for keeping their environment and natural resources in a good shape. It is part of the tragedy of recent developments, that the control nature and tribal rules traditionally had over human activities is lost, before a new mentality and responsibility has gained enough ground. Especially young people should be concerned with these problems, as their lives will be mainly affected.

Figure 9.1 Nature reserves in Southern Sudanese National parks: 1. Nimule, 2. Southern, 3. Boma, 4. Lamtoto, 5. Badingilo; Game reserves: 6. Zeraj, 7. Fanyikang, 8. Shambe, 9. Juba, 10. Kidepo, 11. Mbarizunga, 12. Bire Kpatuos, 13. Bangangai, 14. Numatina, 15. Chelkou, 16. Ashana, 17. Meshra, 18. Boro; proposed national park: 19. Imatong mountains (modifiedjrom Hillman.).



In traditonal tribal societies modesty in relation to nature is often valued. This point may be clarified by a widespread Dinka myth about the introduction of death in the world. The myth exists in several versions which are not essentially different from each other. In the beginning of times God and man were directly connected by a rope. Death did not exist on earth, and one grain of dura was sufficient to feed the people". However, a woman who cultivated this grain decided that she could cultivate more grains that is, more than was necessary to sustain the people. In respons to this greediness, God broke the rope that gave the connection with mankind. In another version the woman was stamping dura when a small bird took away a grain. The woman got angry and killed the bird whereupon it cut the rope with its bill. Both versions of the story suggest that the connection with God was broken because of greediness, or more precisely, because of the lack of modesty in the relation of man to nature.

9.2.B. Maintaining genetic resources

All the plants and animals which have been domesticated in the past, have been derived from natural ancestors. The genetic resource of their wild populations still is important for deriving new traits, necessary for improving the domesticated stock. Many species of plants which are not yet used, probably can become important resources for food or medicine, if enough research work is done. But at the moment the destruction of tropical rain forests on a worldwide scale is such, that many species will become extinct before they have been described scientifically. Maintaining the diversity in nature is of prime importance.

9.2.C. Scientific and educational reasons

'Nature is the teacher of the arts' is an old expression, indicating that many of the (artificial) techniques developed by mankind have a natural basis. Studying the structure and functioning of natural ecosystems is of great value to the understanding of human systems as well, The wider the range of environments available for study, the easier the various processes can be regocnised.

9.2.D. Tourist attraction

For various reasons people from countries where most of nature has been destroyed, are willing to spend money to see nature reserves. This makes national parks into tourist attractions, such as the East African countries have developed. The overall effects of this sort of tourism on a country is considered to be negative by many people, mainly because of the disturbance of social structure by the influx of rich outsiders. On the other

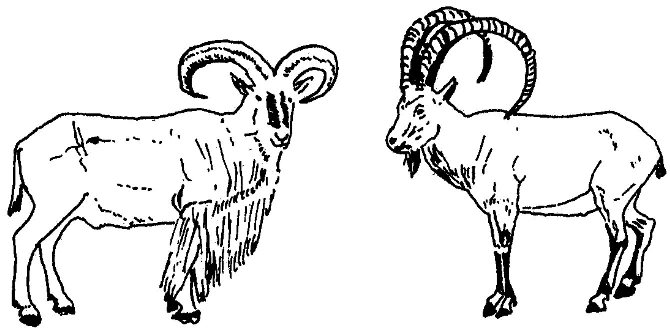


Figure 9.2 Two Sudanese mammals endangered by extinction: Barbary she (left) and Nubian ibex (right) (or.).

9.2 Arguments for conservation of nature and the environment

In Sudan the Wild Animals Ordinance of 1935, amended in 1971, is the basis for wildlife administration. It covers national parks and game sanctuaries in which hunting is prohibited and game reserves in which hunting is restricted. Figure 9.1 shows the national parks and game sanctuaries of Southern Sudan, which form by far the largest part of the protected area. For the rest of Sudan Dinder National Park is the only National park and many of the game reserves and game sanctuaries have deterioriated so much that they are not worth mentioning any more. Several areas have been proposed as National Parks, but no action has been taken so far. Figure 9.2 shows two animals, part of Sudan's national heritage, which need protection urgently: the Nubian Ibex and the Barbar sheep.
Arguments for conservation of nature and the environment can be summarized as:

9.2.A. Maintaining natural resources.

Many of the natural resources on which man is dependent can easily be destroyed. Overhunting and overfishing should of course be avoided, but maintaining breeding grounds and space for the complete migration cycle of the animals is equally important. This often implies maintaining areas in their natural state. Maintaining forests on mountain slopes is necessary to regulate the waterflow of the whole watershed. Natural vegetation often plays an important role in the water cycle and should not be removed without due consideration hand, educational facilities in national parks and nature reserves have to be improved to exploit the didactic value of nature for the country's own people, as mentioned under point C.

9.2.E. Esthetical reasons

The reasons given so far are directly or indirectly economical or related to the survival of mankind. The beauty of nature can be an additional reason for conservation. Especially for people living in urban areas, possibilities for recreation in natural environments are important. .

9.2.F. Ethical reasons

The reasons listed under A till E are man-centered. A nature-centered motivation would consist of ethical reasons for conserving nature for its own sake. Such ethical reasons depend on ones outlook on life. In the Judeo-Christian and Islamic religions the earth has been created for human beings to exploit, but mankind also has the duty to guard and maintain the other creatures on earth. Many African, Asian and American-Indian religions have a much more modest conception of man in relation to nature. Man evolved as and still is a part of nature in their view. There has been life on earth before man appeared and there should be some left for after our, times.

9.3 The tragedy of the commons

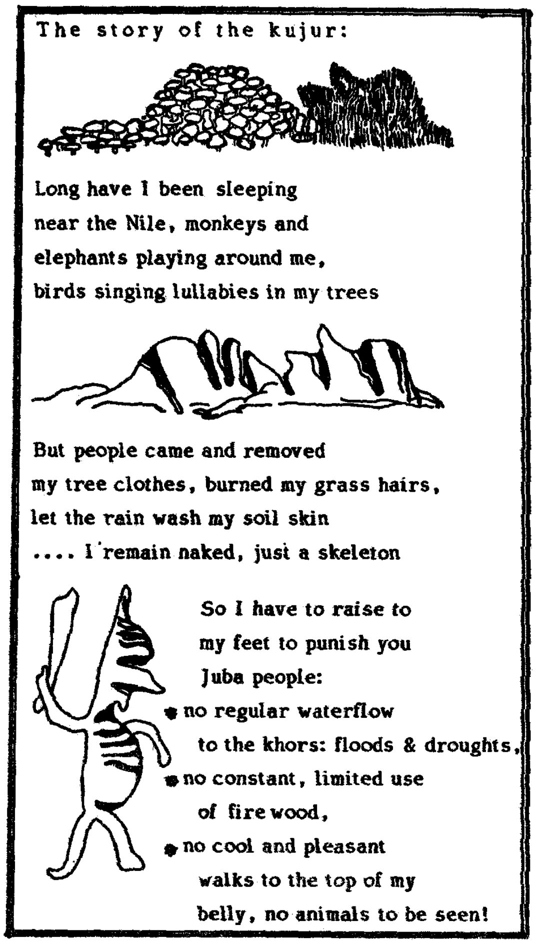
Part of the environmental problems stem from the 'tragedy of the' commons'. Many people benefit from common resources such as forests, grazing land or fish populations, but no one cares to look after them. For many human activities there is a short-term benefit to a few persons, while there is a long-term cost to the environment and thus to the community at large. If one decides to cut trees from a mountain slope, one will gain some profits from the wood, but after some time erosion will remove the soil from the slope. No forest will regrow on that slope and the water flow of the river will no longer be regulated, resulting in floods and droughts. The person who was responsible for this chain of events by cutting the trees will not have to pay for this damage, so for him it will still be profitable to go on cutting (figure 9.3).

> A similar situation arises when a fisherman can use new gear and start to overfish the waters. He will gain a lot in the beginning, while the costs of a reduced fish population will be a problem for all the fishermen.

Every community needs rules and regulations to regulate such things. In traditional tribal societies there were all kinds of rules about land use etc.

Due to the rapid changes during development new rules and regulations are needed, but these often lag behind reality. More important than rules and regulations is the mentality of the people. If every one has learn to understand long term interests of the community at large, there is a larger chance that one's actions will be in agreement with these long-term interests. The tragedy of the commons can only be solved by a stable community with a highly developed sense of responsibility.

Figure 9.3



9.4 Who decides for whom?

Often the community whose environment is affected has no say in the decisions about such activities; this situation is common to almost all cases of colonial exploitation of a country or region by other countries or other parts of the same country. The natural resources as well as the human resources suffer from a cononial exploitation meant to give a quick financial benefit, leaving the costs of environmental destruction to the local population.

> The cutting of tropical rain forests in Asia and Latin-America is presently done by large multinational companies who give a small share of their profits to the government, but leave the burden of erosion and loss of soil productivity to the local population.

Sometimes a national government shares in similar activities. An example of this can be found in Africa, in Zambia in the construction of the Kariba Dam in the Zambesi river.

This dam was mainly constructed to generate hydro-electric energy for the copper mines, but an improved fish potential of the new lake and efficient irrigation farming were promised to the local inhabitants as well.

The following text is a quotation from a critical study on the ecological effects of this dam: "The 'underdeveloped' local population of Tonga struggled with only the help of their bare hands and a naive belief ('Nyaminyami, the river-God will help us') in order that their familiar and balanced environment might survive. Some had to be forced, though others volunteered to abandon the river valley for preselected resettlement areas, which were in general less fertile than their native lands. At the same time the fate of the local population caused less concern than the animal tragedy in the same area -the hopeless' operation Noah'. The complaints of the people were subdued by a grant of a two year government subsidy on essential material needs such as grain, medicins etc.

Some difficulties were alleviated by the enormous fish production of the lake-the diluted nutrients from the flooded terrestrial habitats and the rising lake water brought an explosive reproduction, survival and growth of fish, so this well known natural phenomenon helped in the most critical stages to support the builders promises. Then the lake began to stabilize and the catches decreased. By that time those responsible had long since left the scene. (..….). The Tonga knew their country intimately and utilised a wide range of plants and animals; resettlement changed all this. The majority are farmers, reaping a very low harvest and suffering crop failures, as might be expected in the dry marginal climate of their new settlements, unsuited for conventional agriculture, except on an extensive scale. The promises of

irrigation facilities were never kept. The local people do pot benefit from the electricity either. The electricity gained by the dam is helping to exhaust the copper resources even faster. (.……). There is no cost charged to the developer for destroying a well-balanced, stable ecological system in the area developed, nor for radically transforming all nearby ecosystems."
The local population often has very little political influence to prevent large-scale plans which will affect their environment, with profits mainly for other groups in the society or internationally.
Some positive examples exist however, of cases where the local inhabitants take action against disruption of their environment by outsiders. Recently in Northern India the Chipko-movement started, in protest against multinational companies cutting forests on mountain slopes. Especially the women are protesting because deforestation makes that they have to walk much longer distances for collecting firewood and to fetch water, as the water-balance of the whole valley is changed into a series of floods and droughts, instead of a constant riverflow. By chaining themselves to the trees (Chipko means chaining) the women obstruct the cutting of trees and create a forum for expressing their interests.

9.5 The role of ecological arguments

In discussions about development ecological arguments can play a role at three levels:

a. **To avoid environmental destruction**, like desertification or erosi as side effects to development.
b. **To plead for a small-scale, step-by-step approach**, adapting to the possibilities of the environment instead of the 'green revolution' approach. This approach of gradual change aims at avoiding large scale disasters and at keeping as diverse an environment as possible.

   The biological process of adaptation through evolution can serve as example of stepwise improvement.
c. **To question the material objectives** of the Western type development, as these are unobtainable by more than a small elite internationally and within the country. The typical Western life-style; has only become possible by exploiting natural resources from all over the world, wasting energy and causing large-scale pollution of the land the oceans and the atmosphere (figure 9.4).

   This Western life-style consumes and wastes so much energy a non-renewable resources, that it cannot be maintained much longer a certainly not by the whole earth's population. This being the case, one has to avoid creating false expectations and the urban elite who can afford life-style financially should constrain itself.

The first level of arguments will probably be agreed upon by everyone who has seen the environmental destruction possible after neglecting ecological insights. The second level is probably more debatable already, while the third level will lead to more disagreement, if not in words, certainly in resulting consequences for one's own life-style.

> One often finds confusion about the objectivity of science and the role of scientists, especially if these are 'specialists'. Often science and the 'specialists' are expected to solve all problems and to guide the political decisions. But specialists often lack the overall view necessary to take balanced decisions. The role of specialists should be to show possibilities and consequences, leaving the choice and evaluation of all pros and cons to the politicians and masses they represent. The scientists have their own responsibility like every other citizen. This is especially true for the second and third level of ecological arguments, which are not less scientific than the first. In all cases ecological arguments show that nothing can be gained without cost.

'Do not proclaim easy victories', the adagium of Amilcar Cabral, can also be read as an ecological comment on development plans.

9.6 Towards a philosophy of balance

In the same way as physics has its laws of conservation of matter and energy, ecology has a 'law of conservation of problems'. The solution to one problem often brings about new problems, which will only appear after some time.

> This is clearly demonstrated by the problems the Western world has in getting rid of the radio-active waste-material of its nuclear energy plants. Every solution tried will only displace the problem, e.g. to the oceans, from where the materials can come back via foodchains, or to old mines, from where groundwater can be polluted after movements of the earth crust.

This 'law of conservation of problems' of course does not mean that one should not try to improve the conditions for life. Some form of development is inherent to man as well as to nature. But one's expectations should not be too high and should start from an evaluation of the positive aspects of one's present situation, realising that some of these aspects may be lost by the changes. The picture many people have about the well-being in other, more developed countries is often misleading. The negative aspects are seldom realised, unless one lives in these countries.

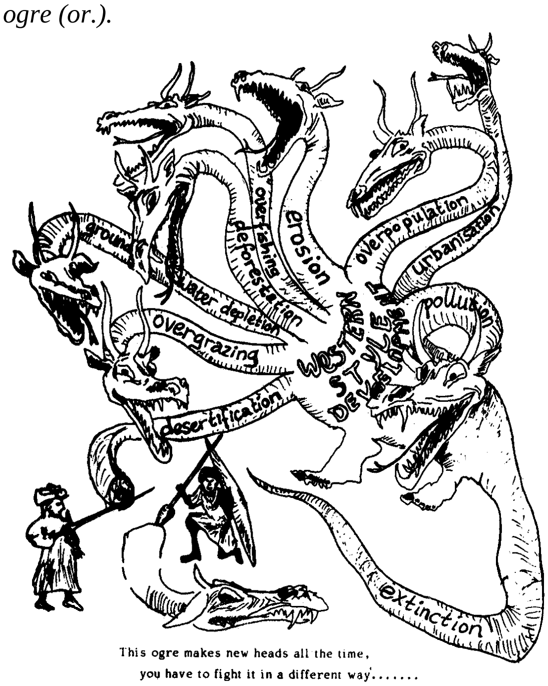
During development the independence of a subsistence economy is replaced by 'interdependence' with the rest of the world in a cash-economy.

But the interdependence is seldom a symbiosis with equal profits to both sides. Underdevelopment on one side is the result of development on the other side. Parasitic economic relations and unequal distribution of political power have brought the world to its present shape, both in international relations and in the internal situation of many countries. The continuation of these inequalities prevents the majority of people from choosing either to maintain their own life-style in their own environment or to change at the rate they want, within the ecological limitations for a long-term-solution. A well-balanced development with due regards to the environment is only possible if these inequalities are solved.
'Do not proclaim easy victories'.
'There is only one Earth'.

9.7 Suggested discussion

1. Discuss figure 9.3: what does the illustrator want to say- do you agree?
2. Discuss figure 9.4: what does the illustrator want to say -do you agree?

Figure 9.4 The development ogre (or.).



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11. Glossary and index of terms

Abiotic factors 7
non-living factors influencing the ecosystem

Abundance.......................... 100
number in which organisms occur

Adaptations 50,52, 69
changes in an organism's structure, physiology or behaviour, which make it better suited to survive in its environment

Adaptive radiation.............. 94
evolution from a common ancestor of different forms, adapted to distinct modes of life

Aestivation 61
surviving the summer or dry season in a resting stage

Afforestation 177
planting trees

Agroforestry..................181,188, 221
land use which combines trees, crops and/or domestic animals

Allelopathy......................... 74
poisoning the environment by a plant for other plants

Amoebic dysentery.............
human disease caused by *Entamoeba*

Annual plant 2, 60
plant which completes its life-cycle within one year

Antibiotics.......................... 72
chemicals inhibiting growth of especially micro-organisms

Aquifer 10
layer of the Earth's crust conducting ground water

Artificial selection 72
human selection, comparable to natural selection, to improve genetic traits of domesticated plants/animals

Autotrophic 84
capable of building up all required food materials from inorganic matter

Arid 32
ecologically dry condition; more specifically, receiving less than 90 mm of rain/year

Bilharzia 6,91, 128
human disease caused by S*chistosoma* worms, which use snails as vectors

Biological control 194
control of pests and diseases by natural means, e,g. by stimulating natural enemies

Biogas 200
methane gas produced by bacteria decomposing waste-materials in an environment without oxygen

Biomass............................. 112
weight of living material, usually expressed as dry matter

Biotic factors 7
living organisms influencing the ecosystem histolytica, associated with frequent passage of bloody stools

Black cotton soil 27
old name for heavy, cracking clay soils of the flood plain

Browsers 78
herbivores eating shrubs, trees, fine herbs etc.

Camouflage 64
deceiving the sense of natural enemies, e.g. by assuming the colour of the environment

Capillary rise 21
water rising from groundwater to higher soil layers through fine pores

Carnivore 64,76,105
animal which eats mainly flesh

Carrying capacity 79,102, 170
the number of individuals that the resources of a habitat can support

12. Index

page numbers in bold print refer to illustrations

12.A. Index of plant names

Lower plants

Herbs and grasses

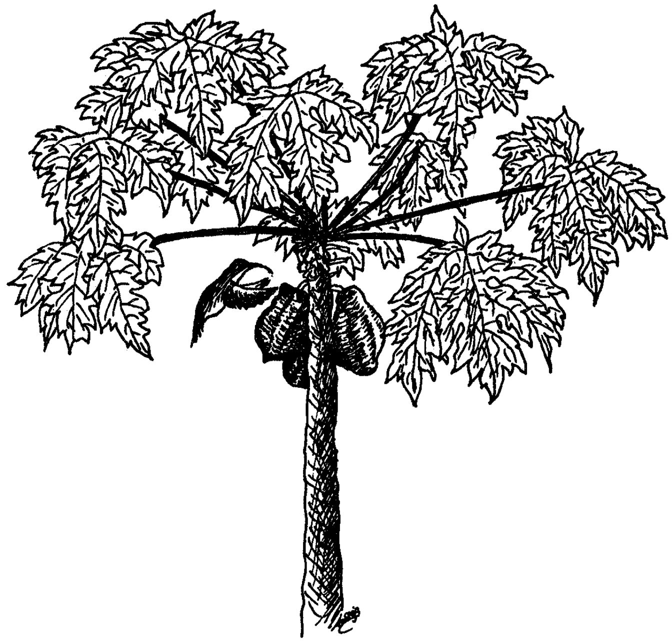
Trees and shrubs

12.B. Index of animal

Insects

Other invertebrates

'12.C. Index-of geographic terms



The joy of observation

illustrations of some common plants and animals of the Sudan

Appendix to: Ecology textbook for the Sudan

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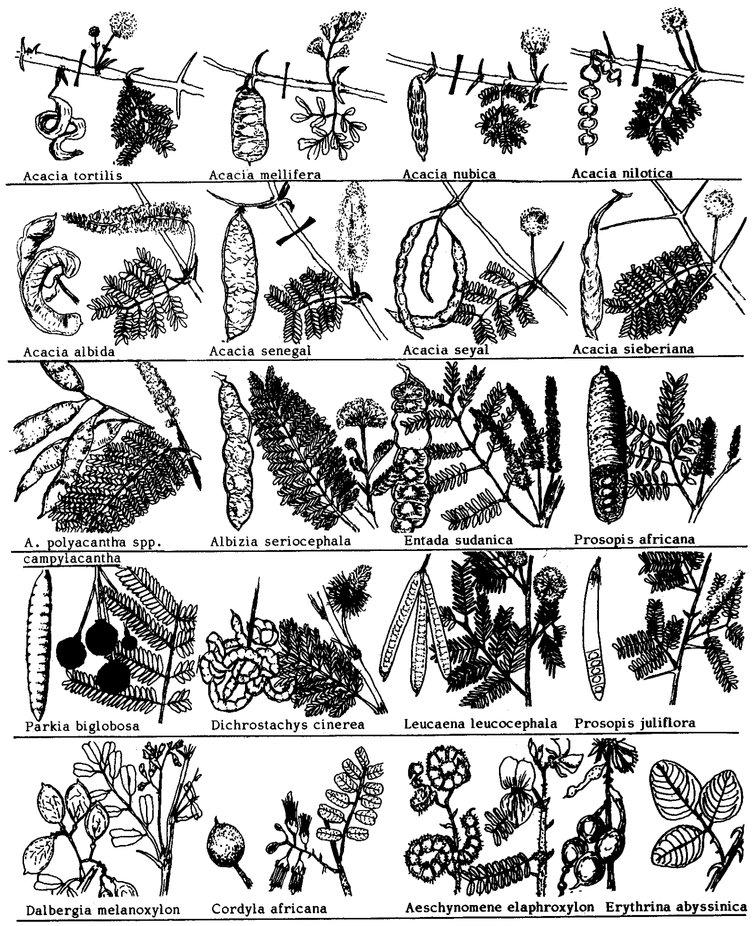
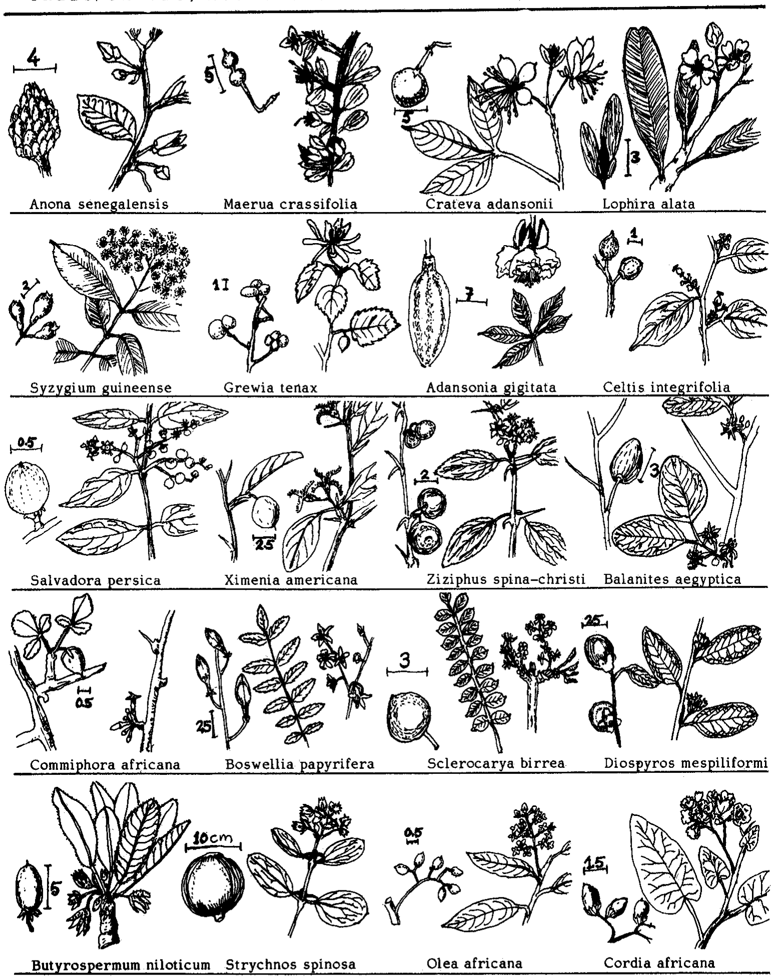
LEGUMINOSE TREES:



TREES/SHRUBS, MOSTLY WITH EDIBLE FRUITS:



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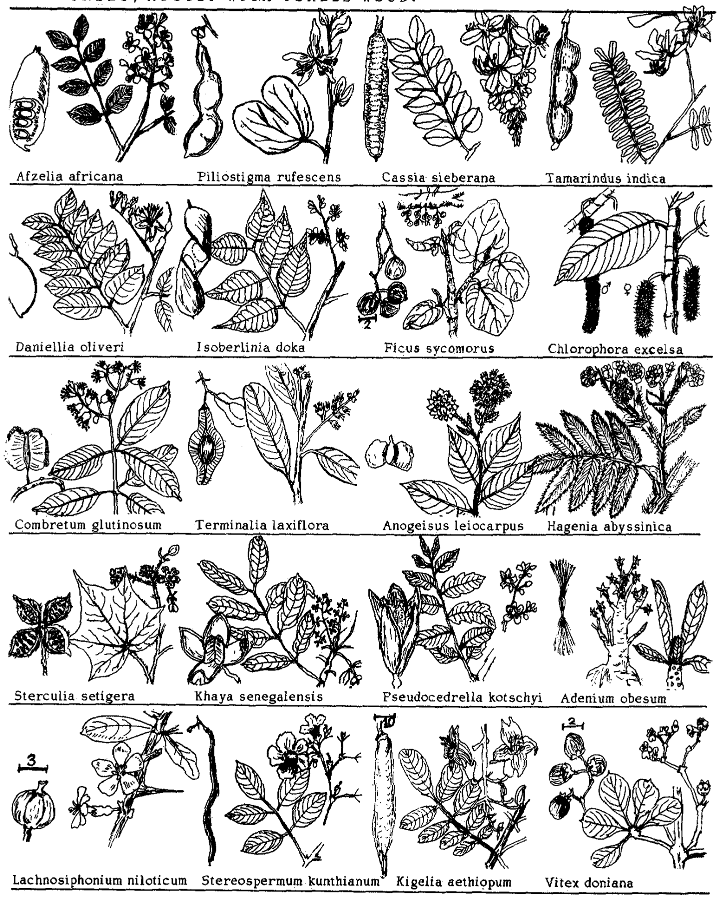
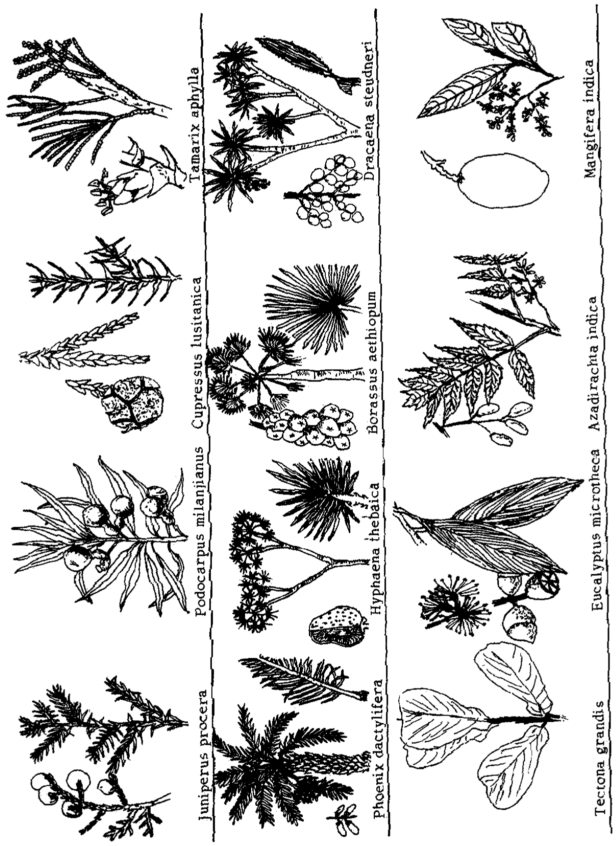
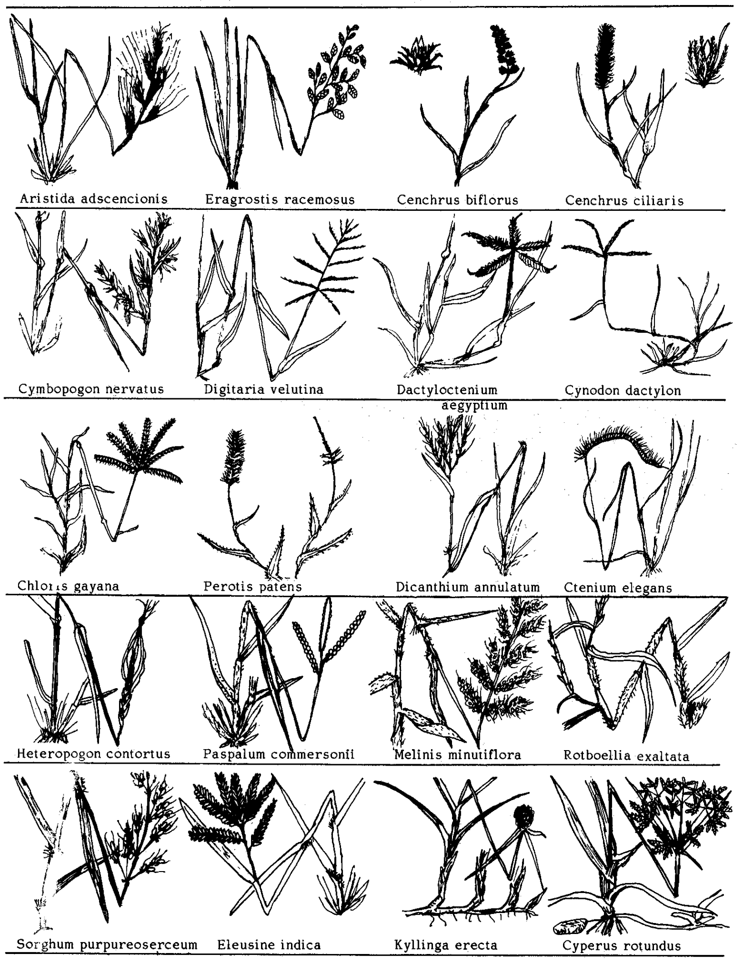
TREES, MOSTLY WITH USABLE WOOD:

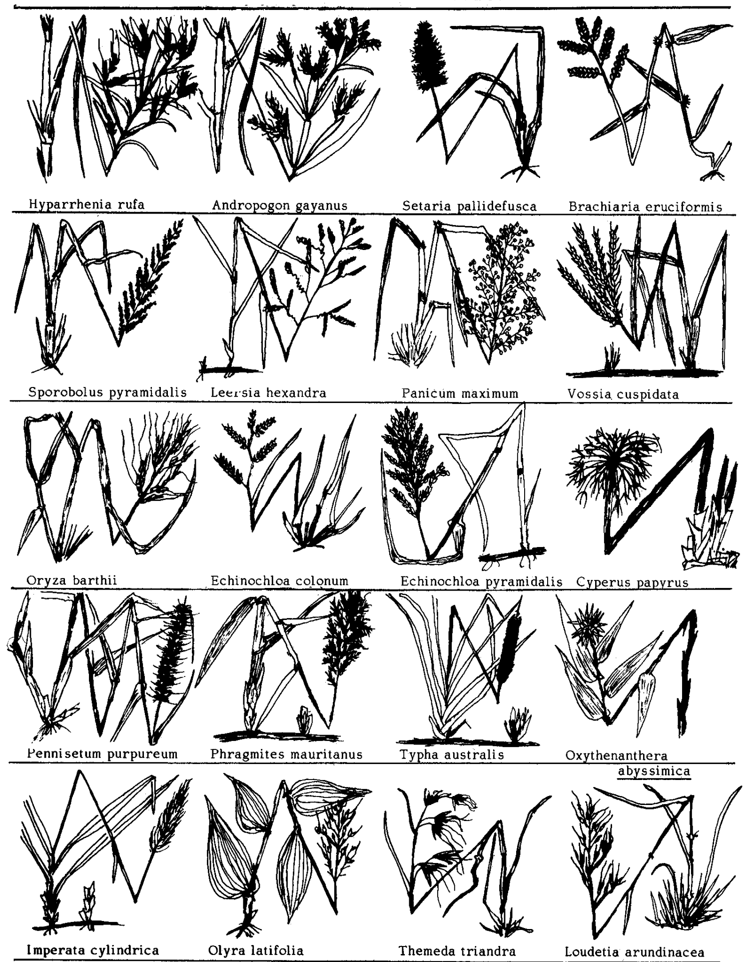



Juniperus procera
Podocarpus milanjianus
Cupressus lusitanica
Tamarix aphylla
Phoenix dactylifera
Hyphaena thebaica
Borassus aethiopum
Dracaena steudneri
Tectona grandis
Eucalyptus microtheca
Azadirachta indica
Mangifera indica

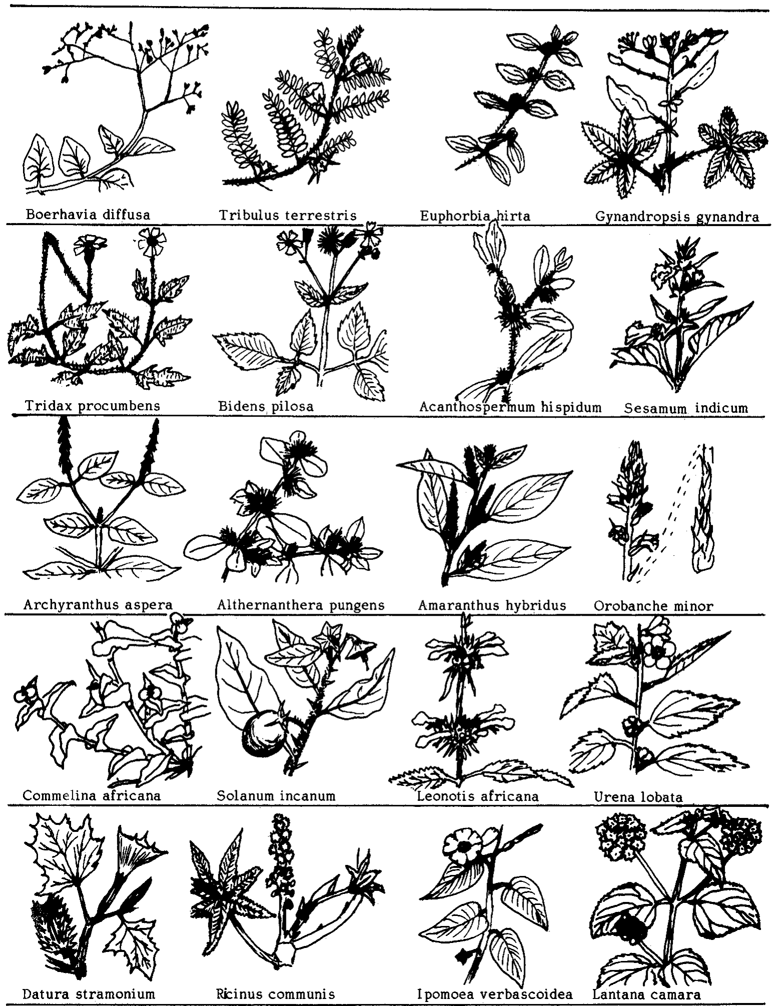
SOME GRASSES AND SEDGES OF DRY PLACES:

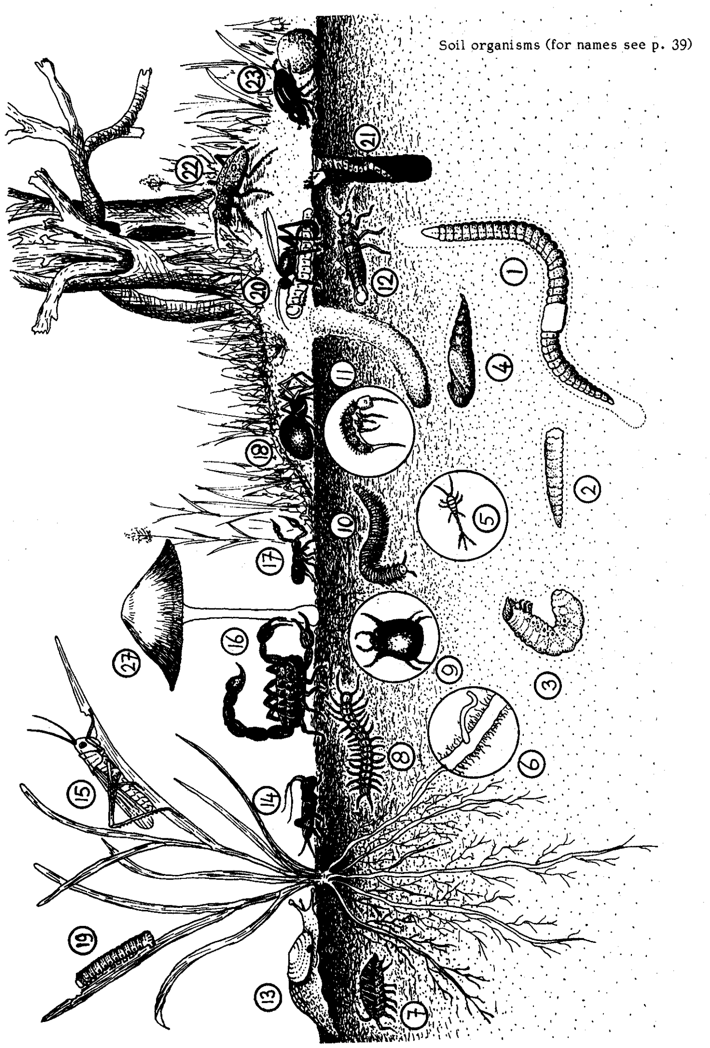


SOME GRASSES AND RELATIVES OF WET PLACES:



SOME COMMON WEEDS:





Soil organisms (for names see p. 39)

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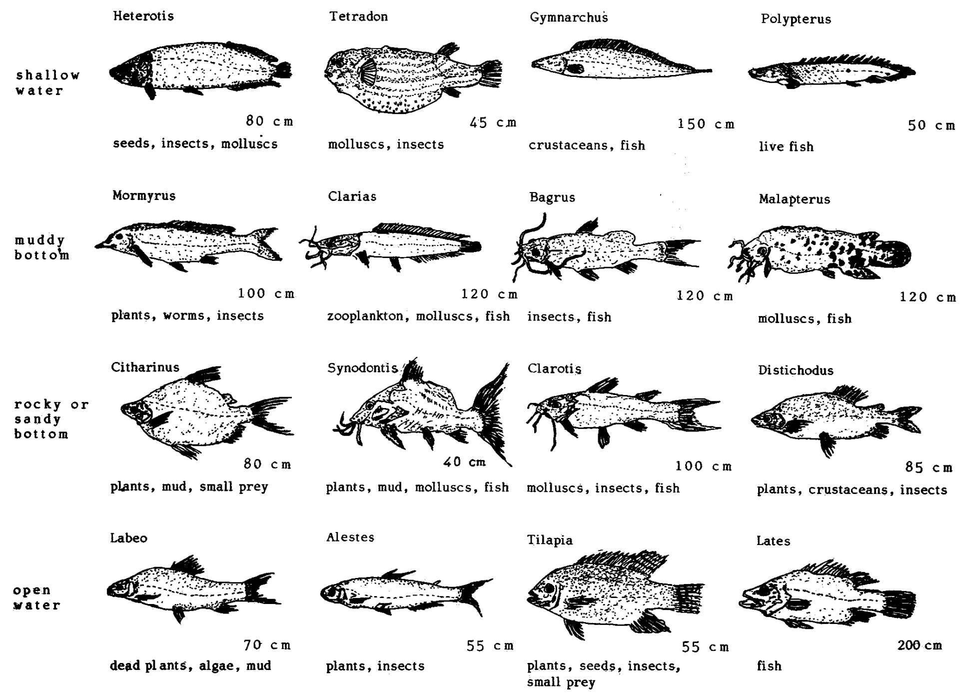
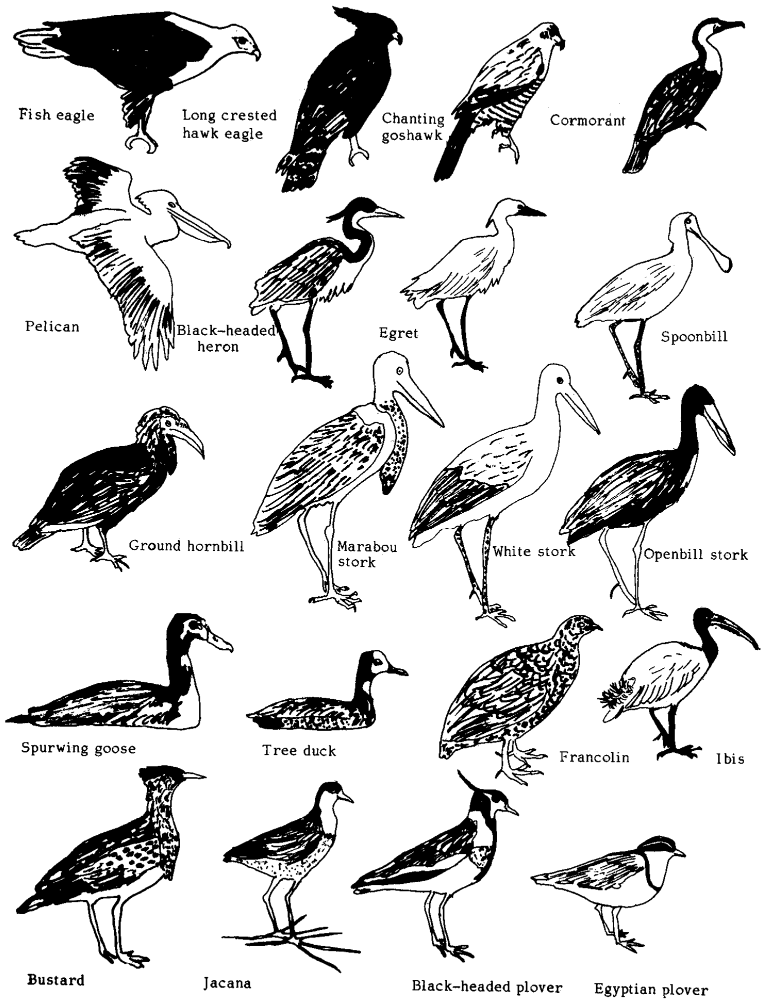
9
Water organisms (for names see p. 40)
274


shallow water
Heterotis
80 cm
seeds, insects, molluscs
Tetradon
45 cm
molluscs, insects
Gymnarchus
150 cm
crustaceans, fish
Polypterus
50 cm
live fish
muddy bottom
Mormyrus
100 cm
plants, worms, insects
Clarias
120 cm
zooplankton, molluscs, fish
Bagrus
120 cm
insects, fish
Malapterus
120 cm
molluscs, fish
rocky or sandy bottom
Citharinus
80 cm
plants, mud, small prey
Synodontis
40 cm
plants, mud, molluscs, fish
Clarotis
100 cm
molluscs, insects, fish
Distichodus
85 cm
plants, crustaceans, insects
open water
Labeo
70 cm
dead plants, algae, mud
Alestes
55 cm
plants, insects
Tilapia
55 cm
plants, seeds, insects, small prey
Lates
200 cm
fish

BIRDS I, MOSTLY OF WET HABITATS:



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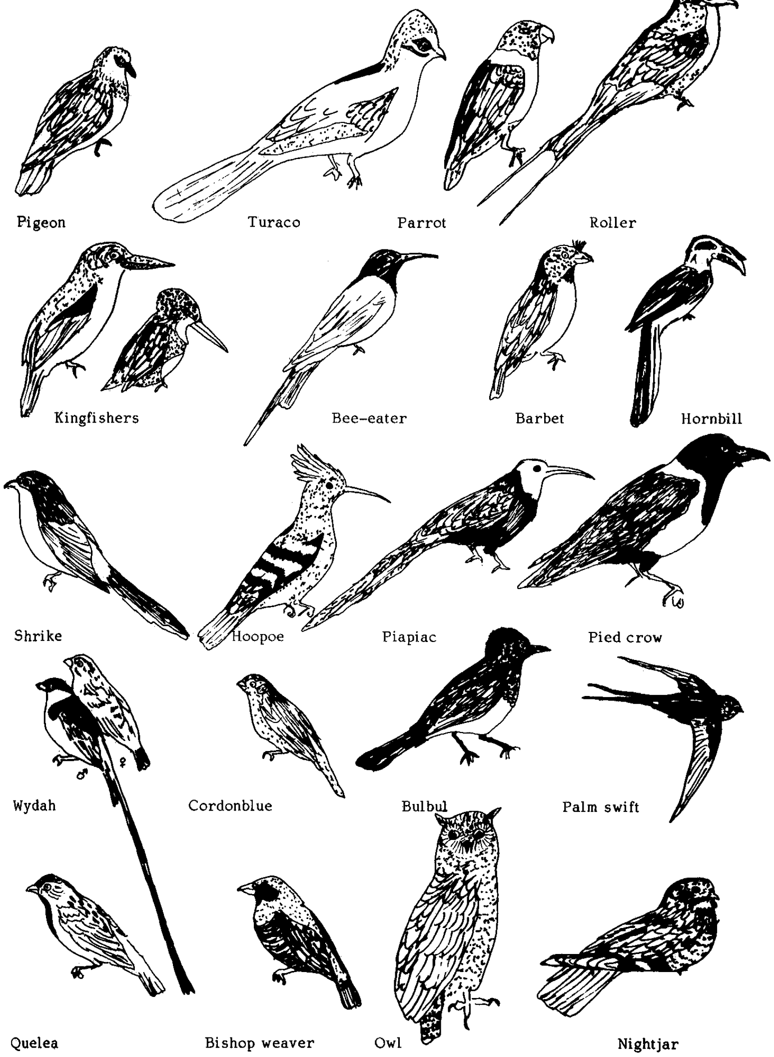
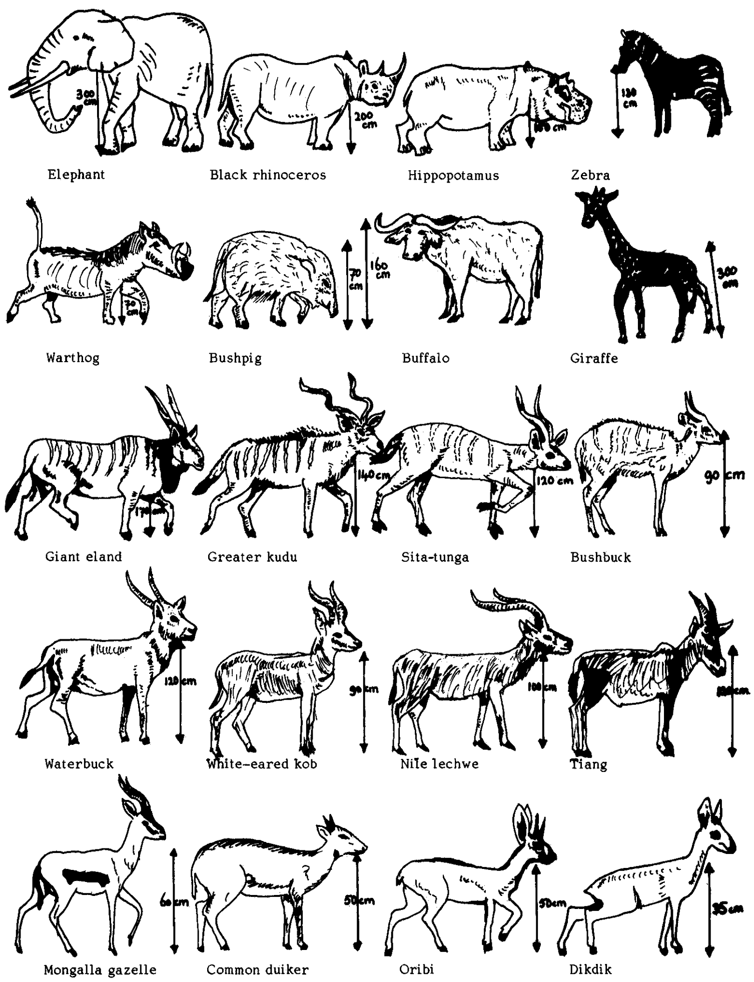
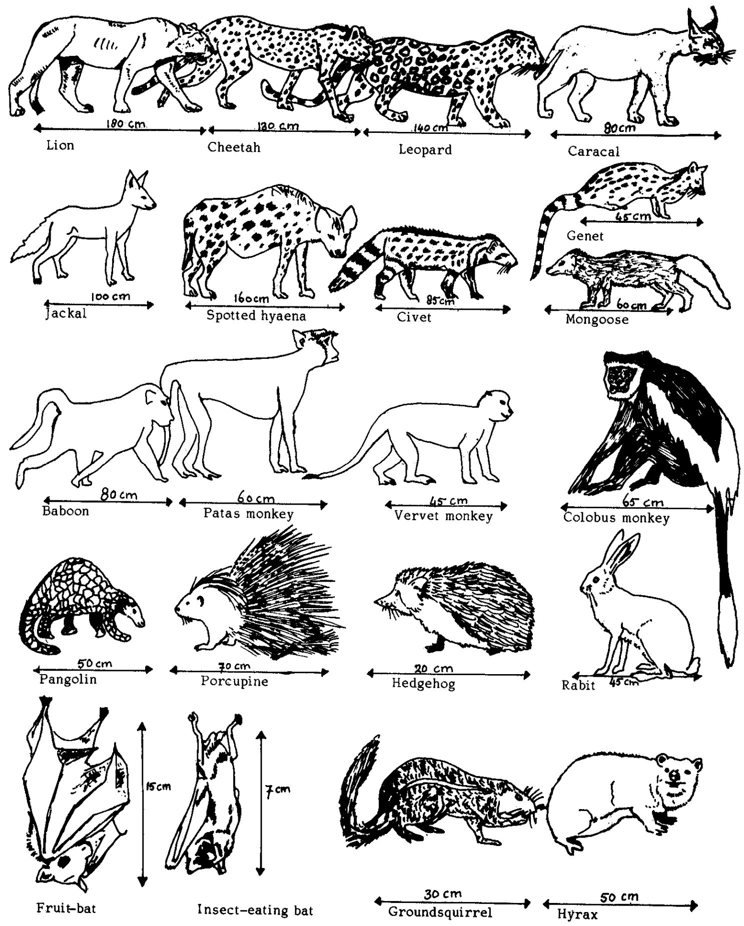
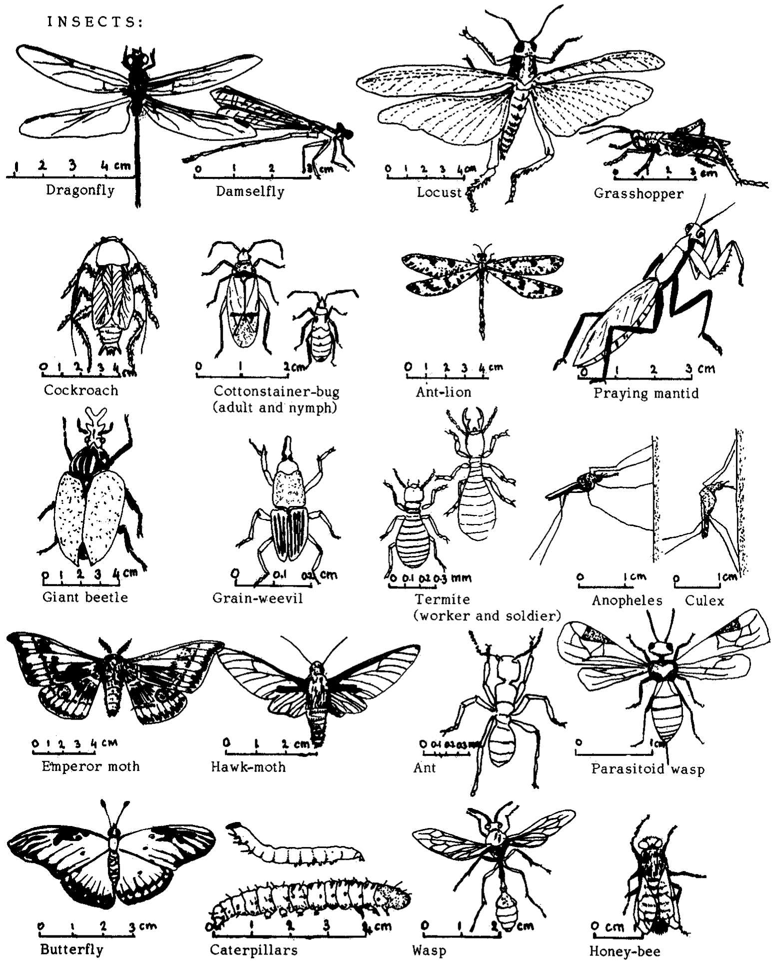
BIRDS II, MOSTLY OF SAVANNA HABITATS:



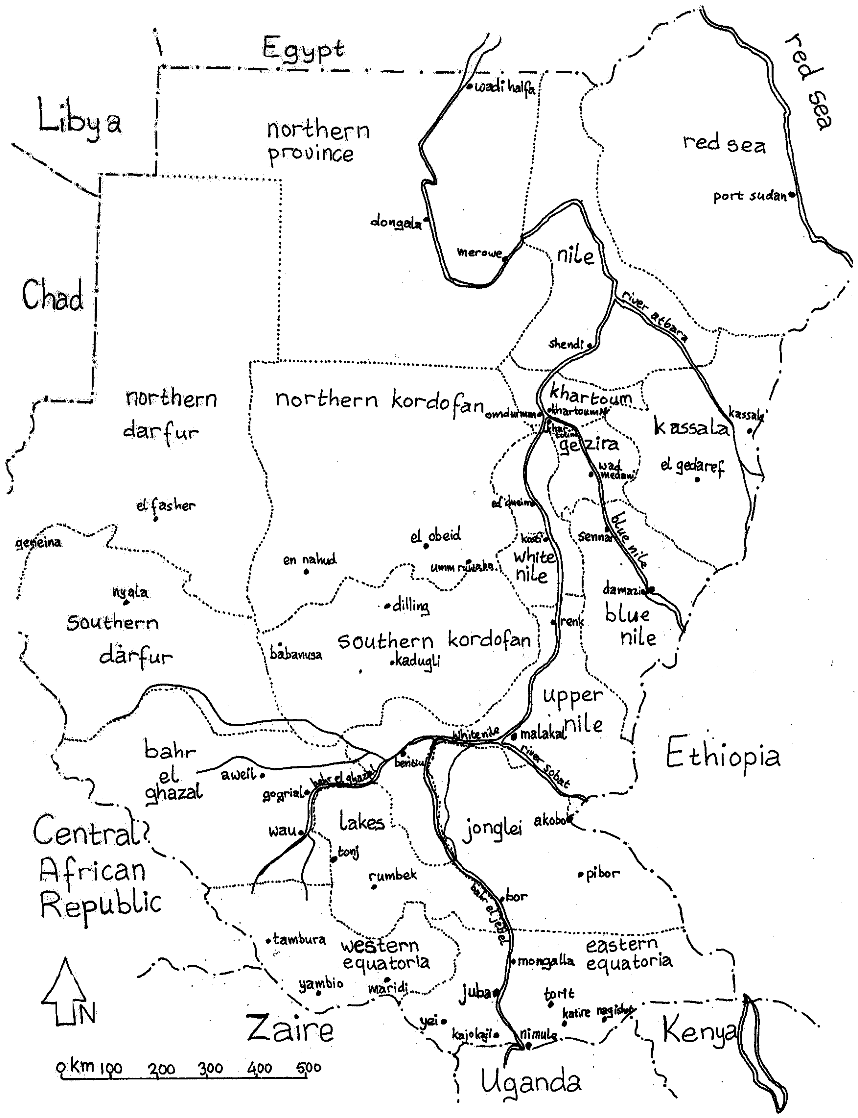

Elephant
Black rhinoceros
Hippopotamus
Zebra
Warthog
Bushpig
Buffalo
Giraffe
Giant eland
Greater kudu
Sita-tunga
Bushbuck
Waterbuck
White-eared kob
Nile lechwe
Tiang
Mongalla gazelle
Common duiker
Oribi
Dikdik


180 cm
Lion
130 cm
Cheetah
140 cm
Leopard
80cm
Caracal
100 cm
Jackal
160cm
Spotted hyaena
85cm
Civet
45cm
Genet
60cm
Mongoose
80cm
Baboon
60cm
Patas monkey
45cm
Vervet monkey
65cm
Colobus monkey
50cm
Pangolin
70cm
Porcupine
20 cm
Hedgehog
Rabit
45cm
15cm
Fruit-bat
7cm
Insect-eating bat
30 cm
Groundsquirrel
50 cm
Hyrax

INSECTS:

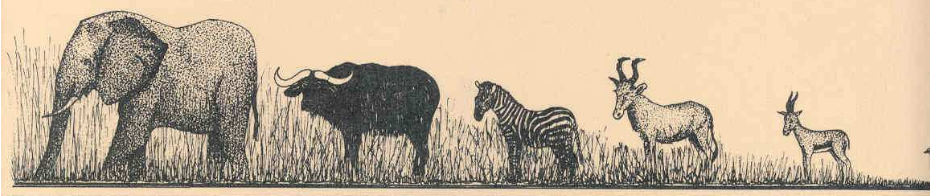


Dragonfly
Damselfly
Locust
Grasshopper
Cockroach
Cottonstainer-bug
(adult and nymph)
Ant-lion
Praying mantid
Giant beetle
Grain-weevil
Termite
(worker and soldier)
Anopheles
Culex
Emperor moth
Hawk-moth
Ant
Parasitoid wasp
Butterfly
Caterpillars
Wasp
Honey-bee


Egypt
Libya
Chad
northern province
red sea
port sudan
wadi halfa
dongala
merowe
nile
river atbara
shendi
khartoum
omdurman
kassala
gezira
wad medani
el gedaref
northern kordofan
northern darfur
el fasher
geneina
el obeid
en nahud
kosti
white nile
sennar
blue nile
damazin
nyala
southern darfur
dilling
southern kordofan
babanusa
kadugli
renk
upper nile
malakal
river sobat
Ethiopia
bahr el ghazal
aweil
gogrial
bentiu
wau
lakes
tonj
rumbek
jonglei
akobo
pibor
bor
Central African Republic
tambura
western equatoria
yambio
maridi
mongalla
eastern equatoria
juba
torit
katire
yei
kajokaji
nimule
Zaire
Kenya
Uganda
N
0 km 100 200 300 400 500

This book gives an introduction to basic principles of ecology in a Sudanese context, using local examples. Much of the material used was sofar available only in a few libraries in the Sudan. Ecology is presented as a way of thinking about and interpreting one's own environment, which can only be learned by practising, by applying these ideas to one's specific situation.
Some people are 'ecologists with their heads', considering ecology to be a purely academic, scientific subject; some are 'ecologists with their hearts', being concerned about the future conditions for life on our planet Earth; others are 'ecologists with their hands', having learned some basic principles of ecology by trial and error in traditional agriculture, fisheries etcetera.

Education of 'ecologists in their mind', combining the positive sides of the three approaches mentioned, can be seen as essential for the future of a country such as the Democratic Republic of the Sudan, with its large environmental potential for positive development, along with great risks of mis-managing the natural resources.



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